A Methodology for Determining Feasibility and Choice of Method for Cellular Manufacturing

by

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(ABSTRACT)

This research addressed two very fundamental issues in cellular manufacturing. These two issues were organizational feasibility for the implementation of cellular manufacturing and the choice of method approach for part-family/machine grouping if feasibility was adjudged, given organizational and manufacturing characteristics. The approach to part-family/machine grouping may follow one of the following options -- a design-oriented approach, a production-oriented approach, or a combination of both. An examination of published literature, in English, on cellular manufacturing indicated the need for this research. A methodology was developed to address the above issues.

A Conceptual Flow Model (CFM) was first developed to structure and rationalize the research problem. The concept of the CFM originated from the basic input-output production model in literature. This model helped the formulation of the research problem by rationalizing that a new manufacturing approach, cellular manufacturing, was feasible for an organization if certain performance measures were weak and if certain criteria regarding the products, available resources, procedures used, and organizational characteristics were met. On the other hand, the model proposed that an organization could remain functionally arranged and improve its existing procedures for better performance if these criteria were not met. This work, however, did not include this latter part of the model as a research issue.

Once feasibility for the implementation of cellular manufacturing was adjudged, the model hypothesized that a part-family/machine grouping approach was necessary for the initial design of the

cells. This approach was to be selected from the design-oriented approach, the production-oriented approach, or a combination of both.

This model formulation enabled the identification of important attributes pertinent to the research problem. The attributes were identified through a comprehensive review of applicable literature in cellular manufacturing. The attributes for the feasibility issue were clustered into four categories. These were the products and processes category, the resources category, the procedures category, and the organizational characteristics category. The attributes pertinent to the choice of method issue were clustered into the product category, the resources category, and the objectives category. The identification of the attributes was followed by an explanation of their relevance.

A set of propositions was developed next to relate the level of an attribute to the feasibility for the implementation of cellular manufacturing and the choice of method issues. The propositions further strengthened the theoretical background of this research through the use of past research and enabled the construction of the rules necessary for resolving the choice of method issue. A complete set of definitions and specifications was then developed for each of the attributes for both issues. The purpose of the specifications was to enable the measurement of the attribute levels through developed measures of each attribute. All the attributes were weighted according to their perceived importance.

A scoring model was developed to determine a score for feasibility for cellular implementation. This score represented a calculated measure of an organization's feasibility for the implementation of cellular manufacturing. A rule-based procedure was developed to determine the choice of method for part-machine grouping.

To verify the relevance of the attributes, their measures and weights, and (indirectly) the propositions, companies engaged in cellular manufacturing were visited and data pertinent to the feasibility analysis and choice of method procedures were collected. Valuable information was gained from these visits, and it was found that some attribute measures will require possible refinement in future research. This field research also indicated the possibility of refinement of the feasibility matrix constructed from the feasibility analysis procedure. Certain attributes pertinent to the choice of method procedure also may require refinement in future research. For comparison purposes, data were also collected from a company with a functional layout and used with the scoring model.

In summary, the objective of developing a framework for determining organizational feasibility for the implementation of cellular manufacturing and the choice of method approach for part-family/machine grouping if feasibility was adjudged, given organizational and manufacturing characteristics, was undertaken. The framework was developed and its components verified through field work.

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I have lost four members of my immediate family in the last two years. My grandmother died two years ago while my grandfather expired about six months ago. I was able to accept their demises. However, I have not been able to accept yet, the tragic death of my uncle and his little daughter, in an automobile accident about two months ago. He was only forty-one years old and my little sister only seven. My uncle loved me very much and was always there when I needed him. To me he was more than an uncle. I will always miss him very much. I dedicate this dissertation to their memories.

I also acknowledge the constant encouragement and company of my friends in Blacksburg, Virginia. They always gave me moral and mental support at various times during my graduate study.

I owe a tremendous amount of gratitude to my parents, my parents-in-law, and all my near relatives. They always believed that I could do it, and had accepted my long absences from home without complaint. They are, and always will be, a source of inspiration to me.

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Chapter I

Introduction

1.1 The Premise

Many manufacturing facilities producing low-volume, high-variety goods are changing their manufacturing methods (Groover and Zimmers 1984). The traditional method of low-volume and high-variety production -- the functional layout or the job-shop method -- is giving way to a new manufacturing philosophy. This philosophy is known as Group Technology (GT) and it seeks to capitalize on similar, recurrent activities in the organization. The recurrence of similar activities -- "the rediscovery of the wheel" -- can occur in various departments of an organization. In the design department, a design engineer may design a part which is very similar to one designed previously. In the process-planning department, the process planner may prepare a process plan for a part which was planned once before. Similarly, the purchasing department may order similar parts or common materials for certain parts at widely different times, perhaps losing volume discounts on purchases. The marketing department may try to introduce products containing special parts without knowing that, by using standard parts with minor modifications in their place, the firm could save substantially in part-drawing alterations, pattern alterations, and tooling alterations (Ranson 1972).

The premise of GT 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 in not having to re-invent the wheel (Durie 1970). GT is a philosophy with broad applicability and is thought to have potential to affect all areas of a manufacturing organization (Groover and Zimmers 1984). The birth of this philosophy can be attributed to three factors -- changing technology, the need for change in overall manufacturing operations for improved productivity, and competition.

Changing technology led to the development of sophisticated production equipment such as numerically controlled machine tools, machining centers, and flexible manufacturing systems. This sophisticated equipment gave manufacturers tremendous opportunities to increase their productivity and quality and also led to greater product variety. Better product quality and variety resulted in increased competition among domestic and international manufacturers and signalled the necessity for a change in the overall manufacturing operations and strategy if such competition was to be successfully met.

This realization of the need for change has brought about a trend toward the restructuring of the operational and managerial aspects of the factory. Old equipment has been replaced and changes in managerial functioning and shop floor control have begun, as well. Reports of European successes in the area of GT prompted domestic manufacturers to explore the avenues of GT and one of its applications, cellular manufacturing, in an attempt to improve productivity (Hyer 1984). Cellular manufacturing (CM) involves processing collections of similar parts (part-families) on dedicated clusters of dissimilar machines or manufacturing processes (cells) such that a part is completed within a cell or with a minimum number of inter-cell transfers. This implies that parts must be grouped into families to be produced by compatible machines. There are various grouping procedures available for both part and machine groupings. These use design-based procedures, such as visual analysis, rule-of-thumb, or classification and coding (CC) procedures (Opitz 1970); or production-oriented procedures, such as production flow analysis (PFA) (Burbidge 1975). However, CM may not be suitable for every company because of product and process characteristics, unavailability of resources required for the implementation of CM, adverse reaction of employees to the implementation of CM, or lack of managerial commitment for implementing a successful CM system. Therefore, a consideration of feasibility for implementation of CM and the determination of the approach to part-machine grouping should be undertaken before the implementation of CM is attempted by any firm interested in the potential benefits of CM.

Current literature in CM fails in this area; it is the area addressed by this research. This research led to the development of a decision tool for determining organizational feasibility for implementing CM and to the choice of method for part-machine grouping if feasibility is indicated, given organizational and manufacturing characteristics.

The consideration of feasibility for implementing CM is important, firstly, because it is imperative to know whether a company's environment or operation is suited to CM. Trying to implement the CM philosophy without resolving its potential applicability may be disastrous. The investment of substantial effort, time, and finances may not result in any operational improvement. Secondly, the result of a feasibility analysis may be helpful in determining problem areas within an organization. For example, a feasibility analysis for a company may indicate excellent CM potential from a technical point of view; however, it may be seen that the personnel within the organization are hostile to change. Thus one outcome of a feasibility analysis may be the identification of problem areas that may inhibit full CM implementation. The knowledge of problem spots prior to starting CM implementation is infinitely more helpful than encountering them during implementation. To determine feasibility, it is necessary to determine the factors that influence it. The first thrust of this research, therefore, was in the determination of these factors to the extent possible, and the synthesis of them into a decision-support framework by considering the entire organization, its characteristics, resources, procedures, objectives, and products.

The same can be said with respect to the choice of approach for part-machine grouping. It is felt, from an examination of the relevant literature, that the choice of method for part-family formation should depend not only on part design and/or manufacturing attributes but also on other factors, such as information requirements, access to skills, and computer support. Therefore it is necessary to identify these factors to the extent possible and, based on these factors, develop guidelines that enable the most appropriate choice for part-machine grouping. This was the second thrust of this research.

1.2 Problem Statement

An examination of current literature indicated that decision aids for addressing (i) company feasibility for the implementation of CM and (ii) the choice of approach for part-machine grouping are currently unavailable. The purpose of this dissertation was to develop a framework and a decision tool for determining (i) organizational feasibility to CM and (ii) the choice of the part-machine grouping approach if applicability is indicated, given the organizational and manufacturing characteristics. Thus, the research problem examined consisted of two parts. The first part was an analysis of feasibility of an organization's implementing CM. The second part investigated the approach to the part-machine grouping procedure if feasibility is established; the approach to be selected from the following options -- the design-oriented approach, the production-oriented approach, or a combination of both. The design-oriented approach includes informal approaches to part-family formation (rule-of-thumb or visual inspection), manual classification and coding, or computerized classification and coding. The production-oriented approach includes manual route sorting of components, a computerized route sorting of components, or a production-based classification and coding system (manual or computerized). A combination of both methods includes the combined use of the design- and production-oriented approaches. A detailed explanation of these approaches is provided in Chapter V.

1.3 The Importance and Contribution of the Work

Much research has been done in the area of GT and CM; the literature survey (presented in Chapter II) corroborates this. However, the dual issues of applicability (or feasibility) and the determination of the part-grouping procedure considering the entire organizational scenario is an unaddressed area in the literature. It is felt that the foremost consideration in implementing CM in an organization is a test for its feasibility. Therefore, it is necessary to conduct a feasibility analysis procedure. If the feasibility analysis indicates suitability for the organization's implementing CM, then part-families and machine cells can be formed via appropriate methods, such as design- or production-oriented methods. It is felt that this research provides exploratory groundwork in CM research by addressing the feasibility and the choice-of-method issues, hitherto unaddressed (Wemmerlov and Hyer 1987c). Both these issues are very fundamental in nature. Results of this research can be used in future research to develop and test specific hypotheses relating to the feasibility for the implementation of CM and the choice of method for part-machine grouping through data collection and comprehensive case studies.

1.4 Research Objective

The research objective was to develop a methodology for determining (i) organizational feasibility for implementing CM and (ii) the selection of the part-family/machine grouping approach if feasibility is adjudged, given organizational characteristics. Three sub-objectives were recognized to be important in the development of the methodology. These sub-objectives are:

1. Theoretical development and model building for a structuring of the research problem and identifying the most important attributes relevant to both issues.
2. Development of a methodology for quantifying the research problem through specification and measurement of the variables.

3. Field work for validation of attributes, attribute measures, and attribute weights, and to exercise the methodology.

1.5 Statement of Work

As a part of the theoretical development, the research problem was structured first. A Conceptual Flow Model (presented in Chapter III) was developed to structure and rationalize the problem. This model led to the identification of the important attributes of the organization. Once these attributes were identified, they were put into distinct categories. The feasibility analysis procedure was modelled next. This modelling procedure considered the attribute categories and the relationship between attribute levels (the value of an attribute on a numeric scale) and feasibility for the implementation of CM. A schematic of this modelling procedure is shown in Chapter III. A similar procedure was also followed in modelling the choice-of-method issue. This modelling procedure postulated that the choice of method is guided by a set of rules for the appropriate method for part-family grouping. Its schematic is also shown in Chapter III.

The development of the methodology started with the definition and specification of all attributes. The attribute definitions were constructed after a review of appropriate GT/CM literature in English. The attributes were specified using scales between 1 and 5 for measurement purposes. Propositions were constructed to link the levels of the variables to feasibility and choice-of-method issues. The level of the attributes were determined by examining attribute data gathered from literature and from field work. The attributes were then weighted with respect to each other according to their perceived importance concerning the feasibility and choice-of-method issues. Weighting of the attributes was done by using information available from literature, by consulting academic participants, and by interviewing organizational members of subject firms engaged in cellular manufacturing. A scoring procedure was developed to generate scores for the feasibility issue. The choice-of-method issue was resolved through the set of propositions and rules that guide the selection procedure by evaluating the levels of the attributes pertinent to this issue. It is felt that the identification of the pertinent attributes and their synthesis into a decision tool for addressing the dual issues constitutes a novel approach in the area of GT/CM research. Furthermore, it is felt that the output from the overall framework (consisting of the Conceptual Flow Model, the scoring procedure, and the rule-based procedure) can be useful in identifying trouble spots in CM implementation for an organization. This framework can also be useful in the future for developing generic frameworks relating the cellular configurations with specific product and process types, and relating the approach for part-family grouping with available resources, procedures and objectives.

The purpose of the field work was to gather organizational data, to verify the relevance of the attributes, and to check for the logic of the propositions. Companies were contacted for their cooperation with this study. Personnel involved with the implementation of cellular manufacturing were interviewed for organizational and manufacturing data. They were also interviewed to verify the relevance of the attributes, attribute measures, and attribute ranks. The participants were presented with lists of attributes, attribute measures, and attribute ranks for examination. Their responses about the validity of the attributes, attribute measures, and attribute ranks were then recorded in spaces provided in the lists. Relevant organizational and manufacturing data, necessary for exercising the scoring procedure for the feasibility issue and the rule-based procedure for the choice-of-method issue, were also recorded in data sheets and specification sheets developed for that purpose. The logic of the propositions was also indirectly tested by determining the score output by the model. The results of the field work indicated that the modification of certain attributes and their measures are necessary. The feasibility scores for the CM facilities indicated a valid scoring procedure.

1.6 Organization of the Dissertation

Chapter II reviews pertinent literature in the area of GT/CM. A brief review and history of GT is first presented. This is followed by a literature survey addressing the applicability of CM to organizations. Literature on simulation studies on CM is reviewed next to determine which operational parameters, if any, should be considered in this study. Research addressing part-family and machine-grouping techniques relevant to this study is also surveyed. A review of industrial applications of GT/CM, the social aspects of CM, and CM frameworks completes the literature review. A summary of the literature and its implication for this work are presented at the end of Chapter II.

Chapter III begins with the formulation of the research model. This chapter also includes the lists of attributes pertinent to the examined research issues and a discussion of their relevance. Chapter IV includes the specifications of the attribute measures, the propositions which establish the levels of the attributes for the feasibility and the choice-of-method issues, and the weighting procedure. Chapter V describes the methodology of the scoring procedure, the rule-based procedure, and field work. Chapter VI presents the results and analyzes them. Chapter VII draws conclusions resulting from this study and also provides recommendations for further research. An extensive bibliography and reference list are also provided.

Chapter II

Literature Review

The literature review presented in this section will begin with a brief review of several types of classical manufacturing systems and introduce the concept of cellular manufacturing. A review and a brief discussion of the history of GT/CM will acquaint the reader with the origin and the underlying ideas of the GT/CM philosophy. A literature review on the applicability of CM, the simulation of CM systems, part-family/machine-grouping techniques, industrial applications of CM, GT frameworks, and the social aspects of CM will delineate current areas of research. A brief review of literature associated with scoring models is also included. A summary of current research will lead to an introduction of the problem investigated in this study.

2.1 A Review of Classical Manufacturing Systems

There are four classical types of manufacturing systems (Black 1983). One of these is the job-shop, in which machines are grouped together by their functions. This is also referred to as a functional layout. The work units for different customer orders follow different paths or sequences through machines. The major characteristics of the job-shop are flexibility, variety, highly skilled labor, much indirect labor, substantial material handling, large work-in-process inventory, and, at times, poor quality and lost orders (Suresh and Meredith 1985).

For production of larger quantities of similar products, the flow-shop system is generally used. In the flow shop, successive units of output undergo the same sequence of operations with specialized equipment and little or no back flow (Hitomi 1985). Volumes are large, runs are long, and changes in product lines are extremely expensive to accommodate. The automated transfer line is one example of a flow shop.

A third kind of system is the fixed-position project shop where very large products are created. All machinery, materials, personnel, and ancillary support are assembled at the project site. The shipbuilding industry is one such example. Here, the time to produce one unit of output is large and very little material movement occurs; this is due to the nature of the product (Black 1983).

The fourth type of manufacturing system is the continuous process. Here, the products (generally gases, liquids, or slurries) flow through a series of directly connected processes or operations that transform raw material into finished product. These systems are designed to produce one particular type of product and their operation is highly complex (Black 1983). The chemical industry is one such example.

The concept of group technology has produced a fifth type of manufacturing system -- the cellular manufacturing system. The cellular system groups processes, people, and machines in some rational manner to treat a specific group of parts. The output from such a cell is typically a complete component. This production system is suited for medium-volume production and provides benefits such as reduced set-ups, reduced material handling and better production control. It is an application of GT in manufacturing.

A review of the CM literature indicates that three major types of cell systems exist. These are GT flow-line cells, GT mixed- flow cells, and GT product cells. GT flow-line cells are those where all components follow a particular machining sequence. However, some components may not require all operations in the sequence. There is no backtracking of parts. The components may be required for single end-products or for product families. Some notable applications of GT flow-line cells are reported by Connolly and Sabberwal (1971), Ranson (1972), and Leonard and Rathmill (1977a). These GT flow-line cells manufacture lightweight components for a relatively low variety of end products.

Examples of GT mixed-flow cells are reported in the works of Middle et. al. (1971), Allen (1973), and Wemmerlov and Hyer (1987b). Here, material movement within the cell does not always follow the same sequence; therefore, there is backtracking of parts. This is due to the nature of the parts and possible changes in the product-mix over time.

The third type of cell is the GT product cell. Here, all components for a particular product type are manufactured. Material flow may be continuous or mixed. Malik et. al (1973), Burbidge (1979), Hyer (1984), and Wemmerlov and Hyer (1987b) provide examples of such applications.

In summary, the above review of the types of manufacturing systems distinguishes the CM system from the other four systems and defines the arena for this study. The following section presents a brief review of the concept and evolution of Group Technology.

2.2 Group Technology -- A Review and Brief History

Group Technology (GT) is a manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their similarities in manufacturing and design (Groover and Zimmers 1984, Hitomi 1985). Similar parts are grouped into families and are processed by machines grouped in cells. This concept originated in Russia in the middle nineteen-fifties and was used extensively for improving productivity by using primarily the single-machine approach for processing a family of parts (Edwards 1971). Here, a family of parts was processed on a single dedicated machine, after which the parts were returned to the existing functional layout for further processing. Productivity was improved by attacking the area of set-up time; and with a family of parts, there was a significant reduction in set-up time for the dedicated machine. Part-families were formed usually by a manual analysis of part drawings.

Reports of substantial improvements in productivity encouraged other manufacturing facilities in Europe to utilize techniques of family grouping. In particular, firms in the United Kingdom, France, and Germany efficiently utilized this concept. The single-machine approach was improved to include multiple dissimilar machines so that a group or cell could produce an entire family of components (Durie 1970).

It was soon realized that, in order to streamline the manual family-grouping procedure, an organized approach was necessary. Classification of parts by design and function seemed a rational approach and the pioneering work of Joseph Gombinski around 1940 (as reported in Hyde 1981) in the area of classification and coding was used by some firms in an attempt to bring control to the tremendous variety of produced components. Gombinski's classification and coding system combined classification methods to establish logical data order with systematic storage, retrieval, and control mechanisms (Hyde 1981). In the late nineteen-sixties and early nineteen-seventies the Opitz classification system was developed (Opitz 1970, Opitz and Wiendahl 1971). Today, many commercial classification and coding packages are available. These include CODE, MICLASS, VUOSO and others (Gallagher and Knight 1971, Houtzeel 1981). A discussion of the basics of classification and coding (CC) systems and their use in design, manufacturing, purchasing, cost estimation, and other areas is provided in a number of articles (Ingram 1982, Wemmerlov and Hyer 1985, Houtzeel 1981, Mills 1985) and textbooks (Hyde 1981, Groover and Zimmers 1984). These articles and textbooks state that classification and coding can either be design-oriented, production-oriented, or a combination of design- and production-oriented methods. A distinction is also made between manual classification methods (where all classification and coding is accomplished manually) and computerized classification procedures where computer assistance is used for the interactive classification and coding of parts (Houtzeel 1981, Groover and Zimmers 1984).

A pioneering effort toward part-family and machine-group formation was made by John Burbidge in the middle and late nineteen-sixties (reported in Burbidge 1975). He developed a manual method of sorting production route cards to determine manufacturing similarity of parts. This method, known as Production Flow Analysis (PFA), has been used widely for machine cell formation (Burbidge 1975, 1979).

With the increased availability of computers, research in GT accelerated. The part-family and machine-grouping techniques were addressed using CC and PFA. MacAuley (1972) was the first researcher to develop a computerized algorithm for the PFA method. El-Essawy and Torrance (1979) developed the Component Flow Analysis method (similar to PFA) for cell formation. Carrie (1973) applied numerical taxonomy in the design for production systems. Tarsuslugil and Bloor (1979) tested various clustering techniques for GT applications to determine the effectiveness of these techniques. Currently, a vast amount of literature on the subject of GT is available. Much research has been done in the areas of part-family and machine cell formation (Carrie 1973, Husain and Leonard 1975, King 1980, Waghodekar and Sahu 1984, Stanfel 1985, Chandrasekharan and Rajagopalan 1986a, 1986b, 1987; Dutta et. al. 1986, Khator and Irani 1986, 1987; Seiffodini and Wolfe 1986, Askin and Subramaniam 1987, Kusiak 1987, and Ballakur and Steudel 1987a, 1987b). These are mostly academic in nature and use computerized algorithms for part-family formation. Also, the majority of the techniques for part-family formation use modifications of the PFA technique. The use of classification and coding as a vehicle for part-family formation is seen less in academic research (Wemmerlov and Hyer 1987c).

Research has also been done in the human and social aspects of GT/CM (Huber and Hyer 1986), effects and implications of GT/CM on management (Bennet and MacConnel 1974), applicability of GT/CM (Rathmill et. al. 1974), and simulation studies on GT/CM (Ang and Willey 1984). The trend is towards using the GT concept more as an overall integrated approach to solving manufacturing problems than in addressing specific areas like reduction in set-up time or improved machine utilization or product standardization through classification and coding. This indicates a significant shift from the earlier understanding of group technology when it was synonymous with classification and coding, or with the single machine approach for processing a group of parts, or with the reduction of a particular parameter like the set-up time to improve production efficiency.

This review of the concept and history of GT tracks the birth and growth of the GT philosophy and delineates some of the past research areas addressed by researchers in GT. The next sections review in detail past research relevant to this study. The literature reviewed is categorized under applicability of CM, simulation studies of CM systems, part-family/machine-cell formation procedures, industry practices of GT, GT frameworks, and social aspects of GT.

2.3 Applicability of CM

This section reviews literature focusing on the applicability of CM. Applicability refers to the feasibility of CM for an organization. Leonard and Koenigsberger (1972) are of the opinion that the entire company environment must be considered before CM is implemented. According to them, some product and industrial attributes make this method of production more amenable to certain organizations than others. In particular, batch sizes, supplier reliability, part similarity, part weight, labor flexibility, and job skill are important. Leonard and Koenigsberger's (1972) work has led to the identification of some of the attributes, such as supplier reliability, occurrence of part-families and machine cells, and weight of components, considered to be important for the implementation of CM systems. The authors, however, do not provide any method of measuring these attributes of for conducting a feasibility analysis for the implementation of CM by using these attributes. The development of a feasibility analysis through the measurement of such attributes is one focus of this study.

In discussing organizational suitability for the implementation of CM, Lewis (1973) specifically stressed the importance of product forecasting reliability. According to him, a cellular production system limits the processing options available because of the stratifications of machines to cells. Therefore, he argued it was necessary to have reliable product forecasts to avoid under-loading or over-loading machines and cells. He also stressed the need for limiting centralized processing requirements of parts as much as possible. Centralized processes are processes such as sand blasting, heat treatment, or painting. According to Lewis (1973), the presence of such processes results in the disruption of the production sequence and is undesirable for CM purposes. From his work, reliability of product forecast and the presence of centralized processes in part routings are seen to be important attributes.

Rathmill et. al. (1974) developed an appraisal procedure for GT suitability in the form of checklists and questions. Questions were asked about various functions of the company, and for each function, quantitative measures of improvement or deterioration were obtained. The company suitability to CM with respect to the status quo was judged from a cost/benefit analysis. This appraisal procedure requires the prediction of benefits once CM is implemented. For example, the decision maker is questioned about the possible savings if a classification and coding system were to be implemented. However, it is felt by this researcher that the decision maker may not be able to predict these benefits a priori. Also, Rathmill et. al. (1974) do not provide guidelines for the prediction of these benefits. The research reported in this dissertation attempts to establish company feasibility for CM based on current company characteristics. It does not require the prediction of any future benefits for a feasibility analysis. The feasibility analysis is based on available information. Thus, the scope of this research is different than the work of Rathmill et. al. (1974).

Leonard and Rathmill (1977a) are of the opinion that an efficiently run and well-managed functional layout achieves the same benefits as does a GT system. In studying the specific characteristics and advantages of GT and functional approaches, their results indicated that certain characteristics like job satisfaction, minimum work-in-progress, and machine utilization may achieve better levels in a functional layout. They also point out important considerations necessary for CM suitability, such as stable product-mix, stable product demand, and medium operator skill level. These considerations are directly relevant to this study. In a later paper (1977b) Leonard and Rathmill again compared GT and functional layout characteristics and stated that GT flowlines may be a viable alternative to GT cells in cases where parts have high manufacturing complexity. They also concluded that, rather than adopting GT cells, companies should improve their control over production if manufacturing conditions such as part complexity, stability of product demand, and product-mix were unfavorable for CM purposes.

Willey and Dale (1979) and Dale (1980) refuted the conclusions of Leonard and Rathmill (1977b) that GT cells are not viable in most cases. The authors carried out a survey of 35 British companies on performance characteristics before and after the application of GT. Regression equations and graphs were constructed from the data collected. The authors claimed that, if performance measures of a company are known, it is possible to predict the performance measures after GT is applied. These performance measures are manufacturing performance measures, such as average number of operations needed to complete a job, average manufacturing lead time, average machining time per component, value of work-in-process inventory, etc. The average number of operations needed to complete a part and the average machining time per component have been used in this research as measures of the complexity of components. However, it is also felt by this researcher that manufacturing performances alone may not be enough to determine organizational feasibility for implementing CM. Therefore, it is essential to determine other characteristics that will enable the determination of organizational suitability for the implementation of CM.

A survey by Hyer (1984) characterized firms employing CM or GT by the batch quantity range, number of end items produced, and layout type (pure GT, hybrid GT, and pure job shop). This survey found that, for the majority of firms, informal procedures (visual inspection, rule of thumb) proved inadequate for part-family grouping. It also concluded that resistance to change was the most serious impediment to CM implementation. Hyer's survey points out the possibility of using informal and formal procedures in part-machine grouping. Levulis (1980) treated the question of applicability by stating that the organizational climate should be assessed in addition to the assessment of economic potential before GT or CM is implemented. He also stressed the importance of understanding the length of time involved in implementing a CM system. In this study, resistance to change, and implementation time are recognized as important variables in determining feasibility for the implementation of CM.

The above literature review points out the state of research regarding CM applicability to an organization. The work of Leonard and Koenigsberger (1972) identified some of the important variables with respect to CM applicability. Rathmill et. al. (1974) considered the cost/benefit picture, while the work of Willey and Dale (1979) and Dale (1980) considered performance measures alone in determining applicability. Hyer's survey (1984) showed that CM is used in quite a few companies. The review of the works of these researchers has enabled the identification of certain attributes important for this study. There is no evidence of any work in attempting to synthesize the attributes pertinent to CM applicability into a decision-making tool.

2.4 Simulation Studies of CM Sytems

This part of the literature review indicates that the thrust of simulation studies of CM systems is toward evaluating cell performance via output measures for given cell configurations and different part input conditions (Athersmith and Crookall 1974; Willey and Ang 1980, 1984; Foo and Wager 1983). The focus of this literature review is not to provide a detailed discussion of CM simulation research, but to identify some attributes relevant to this research. Greene (1980) developed two heuristics for loading jobs to cells for different job and cell characteristics. Job characteristics included the number of operations per job, number of different job types, and job routings. Cell characteristics included number of cells, cell size, remainder cell, and total number of different machine types. The number of operations per job and the number of different machine types are especially important for this research.

Simulation studies of a GT product cell by Dale and Dewhurst (1984) demonstrated that the sequence of processing of jobs is sensitive to changes in batch size, the number of operators (therefore, their flexibility) and machine tools. Their model was developed to aid a company in improving its current scheduling procedures for components in its cells; it indicated that improvements in cell performance could result if flexible labor was available. From this study, flexibility of labor was identified as an important attribute.

Burbidge and Dale (1984) reported the implementation of an actual GT project for a company engaged in the manufacture of gears and shafts. PFA was used in determining part-families and machine cells. Predictions of the likely benefits were carried out by using a statistical model developed by Dale (1980). This work enabled the determination of a measure of component complexity used in this research.

A simulation comparison between a job shop and a CM environment by Flynn and Jacobs (1984) considered pure job shop, hybrid, and pure GT cells. The data for the study were obtained from a manufacturer of dies. Long set-up and operation times, large number of operations per part, and large component weight were characteristics of the data. The simulation indicated that the CM layout was inferior to a job shop in the areas of queue lengths, waiting time, and average work-in-process inventory. However, long set-up and operation times, large numbers of operations per part, and heavy components may not be conducive to a GT environment. These three factors were, therefore, chosen as attributes for this study. It would be interesting to know the effects of shorter set-up times and number of operations per part on the performance measures, but this is left for future research.

This literature review indicated that the feasibility of a CM system has been implicitly assumed. The work of Greene (1980), Flynn and Jacobs (1984), Dale and Dewhurst (1984) and Burbidge and Dale (1984) have helped in identifying some of the important attributes necessary for this study. Specifically, complexity of components, weight of components, and flexibility of labor were the attributes identified. These attributes will be addressed again in the development of the research model in Chapter III.

2.5 Part-Family/Machine-Cell Formation Procedures

This section examines some of the articles in the areas of part-family/machine-cell formation procedures directly related to this research. The two purposes of this review are: (i) to demonstrate that two broad approaches to part-family/machine groupings exist in academic research and (ii) to identify some of the important attributes relevant to this study.

Most part-family/machine-grouping techniques developed through academic research use part routings to determine part-machine groupings. These methods are all modifications of the PFA method. Therefore, they are considered to be production-oriented in their approach to part-machine grouping. Rajagopalan and Batra's (1975) method is one such example. The specific data requirements for the execution of their algorithm are set-up and machining times and routes of components. The authors stress the necessity of an accurate product forecast for their method. The reliability of product forecast and machining times are important for this study as well.

The review of the work of DeBeer et. al. (1976) and DeBeer and deWitte (1978) enabled the development of the concept of using primary and secondary machine utilizations for determining capacity balance in existing layouts. Both of these works used part routings and capacity balance considerations to determine cell configurations. The concepts of capacity balance and of primary and secondary machine utilization have been directly used in this research.

Tilsley and Lewis's (1977) production-oriented cell-formation procedure approached cell design from a flexibility standpoint. According to the authors, a fluctuation in demand pattern can be effectively handled by such a cellular configuration. Their method was based on the analysis of production data and they stressed the stability of product demand and product-mix in the operation of a cell.

Oliva-Lopez and Purcheck's (1979) production-oriented approach to cell formation used linear programming techniques to determine part-machine groupings. The important variables in this study were the number of operations per job, part demand, and workload of cells. The authors showed a case where lengthy part routings (large number of operations per job) resulted in poor cell performance. This finding has been used to develop measures for job complexity in this research. Also, the importance of capacity balance in an existing facility is noted from this work.

King (1980), King and Nakornchai (1982), and Chan and Milner (1982) stated explicitly the computer memory requirements for the execution of their routing-based method for cell formation using matrix rearrangement. The authors mentioned memory requirements for particular problem sizes. This information has been directly used in this research in the specification of the attributes.

The use of mathematical techniques for forming part-families was reported by Gongaware and Ham (1981) and Han and Ham (1986). A clustering procedure was used to determine part-families from part codes. The procedures allowed different user information requirements (from purchasing, tooling, costing, design, etc.) to be accommodated while determining part-families and demonstrated the usefulness of classification and coding in providing information requirements.

The above literature review demonstrates that substantial research has been done in the development of part-family/machine-grouping techniques. This review is important because it indicates that research in GT/CM is directed more toward the development of part-grouping techniques than toward determining feasibility of an organization to CM. This review also has enabled the identification of certain important attributes that merit consideration before attempting to implement a CM system. These attributes are capacity balance, stability of product demand and mix, computer support, and information requirements. It also shows that two major approaches to part grouping exist. One is the design-oriented approach while the other is the production-oriented approach.

2.6 Industry Practices of GT

In this section, a review is done on some industrial applications of GT to reveal some of the important factors regarding the implementation of CM in an organization. The motivation to introduce GT in industry stemmed from the realization that a more efficient production method was necessary in order to keep delivery promises, improve coordination between departments, avoid redundant part designs, eliminate high waiting times and material movements, and improve the scope of production control (Edwards 1971, Ranson 1972).

Serck Audco Valves in the United Kingdom was one of the first successful companies to apply GT (Ranson 1972, 1973). In the middle nineteen-sixties the company found itself immersed in excessive stock, indifferent delivery performance, and many inter-departmental frustrations. To mitigate these problems, it took a totally integrated approach, starting from ensuring improved supplier reliability and planning the work from sales forecast through various departments to final dispatch. Sales, purchasing, accounting, and the production departments were involved in the initial planning activities such as work study, production engineering, cellular grouping of machines, job evaluation, and production control. Management felt the need for a consolidated information system accessible to all departments. Also, variety reduction in design, manufacturing, and purchasing was an important consideration. This led to the implementation of a classification system. All components were classified and coded with a consultant's help and the plant layout changed from functional to cellular. The benefits reported included increases in sales, reductions in stocks, decreases in orders due, and increases in employee wages. This application of classification and coding in the implementation of a CM system demonstrates its importance in the standardization of design and manufacturing procedures. It also shows that information requirements of diverse departments were met by the implementation of this classification and coding system.

Craven (1973) reported benefits derived in a multi-product firm in the U.K. after the application of GT. About 70,000 piece parts were coded, their flow structures analyzed, and cells formed.

Substantial gains resulted and the entire company was reorganized on GT lines. The desire to reduce design redundancy and retrieve similar designs led to the classification of all parts. Craven also discussed the importance of the single cycle type of material control system.

Allen (1973) described the effort at Ferranti Limited, Edinburgh, Scotland, towards the conversion from functional to a cellular layout. Ferranti produces avionic equipment and suffered from long set-up and throughput times resulting in uncertain deliveries and loss of production control. A pilot cell was initially set up and consisted of turning, milling, and drilling machines. It was noticed that substantial reduction in throughput times resulted with simplified work-flow movements. This encouraged the extension of the cell system to the remainder of the shop. PFA was used to obtain part-family and machine-groupings and the entire plant was converted to cellular layout. Coupled with the use of NC machines, the overall operation improved significantly. A classification system was not used here because it was felt that an expensive and sophisticated coding system could not be acquired. Also, the firm did not have the capability to develop a classification system in-house. Therefore, PFA was used to determine the cell configurations. This application establishes the amount of monetary support as an important attribute in determining the approach to cell formation.

Application of GT principles in India originally started with the single-machine approach (Venkitadri and Kemshetti, 1975). The Central Machine Tool Institute (CMTI) promoted GT concepts. The first test-bed was a valve manufacturer. For family formation, a four-digit classification coding system was developed in-house. The reason for implementing a classification system was the desire for identifying component design families for set-up reduction purposes. Variety reduction in design and reduction in the set-up times resulted from this effort. However, it was realized that the single-machine approach did not have much impact on the overall performance of the company. To further the implementation of GT as a systems approach, CMTI undertook consulting for a firm manufacturing aircraft fittings. Based on Component Flow Analysis (a production-oriented approach), cells were designed on the cascading principles of Tilsley and Lewis (1977). Reports of increased machine utilization, process efficiency, elimination of shortages in assembly, and better control encouraged other firms to approach CMTI. No reason was given for implementing a production-oriented approach. In the course of cell design for a variety of companies, CMTI developed simulation programs to consider effects of long-range and short-range fluctuations in product demand and mix on the cell capacity.

A further example of the application of GT principles in India through the application of production-oriented procedures is reported in the work of Hedge et. al. (1979). The application was in a fastener manufacturing company, characterized by a stable demand of 3500 varieties of components which were produced on 120 machines laid out on a functional basis. The problems associated with such a layout were excessive throughput time and material handling, low operator efficiency, and the lack of production control. No reasons were given for the application of the production-oriented approach to determine cell configurations. Computer simulation was used to determine cell stability with fluctuation in product demand.

GT has also been applied to the sheet metal industry (Nagarkar and Fogg, 1979). The procedure used was a modification of the PFA technique. In conjunction with cell design, a method of cyclic ordering of parts (similar to MRP) was introduced. The authors stressed the need for a time-phased part-ordering system (also considered important for this study) and reported benefits in the area of throughput, reduction in set-up time, and better cell control.

The lamp division of The General Electric Company in Cleveland, Ohio, is an example of the application of the GT principles through classification and coding (Schaffer, 1980). The motivation for such a step was to gain better control of the overall operations through better process planning. The process planners in this facility were constantly overloaded. Other reasons for implementing a classification system included standardization of part designs and process plans and better information availability. After appropriate consultation, it was decided to use a process planning and a classification and coding package to aid in the formation of families and to optimize process plans. This indicates the usefulness of a classification system where different departments feel the need for product information and where design and process planning standardization is sought. An immediate benefit to G.E. was in the savings in the process planner's time through the retrieval of existing process plans. Entering the appropriate part code enabled such a retrieval. It was also possible to edit these plans to suit new part requirements. Further benefits were in the overall control, design standardization, and efficient operation.

The reorganization of operations at Deere and Company in Waterloo, Iowa, is another example of the application of GT principles (Dumolien and Santen, 1983). The company developed an in-house computerized classification and coding package to classify and code part data because a manual analysis was not possible for the massive amounts of data involved. This package generates a code that references geometric part features. The system also contains product data such as part operation routings, current and future production requirements, cost amounts, and machine load information. A data analysis yields part families for which production cells are formed using computer programs. Load calculations and machine utilization calculations are then done with cell merging or re-routing if necessary. It is evident from this CM application that computer support is essential for effective CM implementation. The effectiveness of a classification system in satisfying information requirements is also noted.

The desire to reduce product costs and flow times led to institution of GT principles in the fabrication department of the transmission division of Rockwell International in Dallas (Kriegler, 1984). An initial, in-house-developed informal classification and coding package, although suitable for part-family definition, was found incapable of generating operation charts or retrieving existing parts to satisfy new designs. This led to the installation of a commercial process-planning system in conjunction with a commercial computerized classification and coding package. A physical rearrangement of the plant was undertaken and with the part-family approach, waiting times were drastically reduced with a simultaneous improvement in quality. The payback period was less than one year. This CM application highlighted the importance of design retrieval as an objective in the selection of a classification and coding system for cell formation.

Recent reports by Wemmerlov and Hyer (1987a, 1987b) reported the findings of a survey of thirty-two firms in the U.S. involved with cellular manufacturing. The participating companies were medium-to-large in size and predominantly in the metalworking and electronics industries. The most common reasons for establishing cells were to achieve reductions in lead time, work-in-process inventory, set-up times, materials handling, and to improve output quality. The most common problems encountered during implementation were resistance to change and load-balancing of the cells. This finding highlights the need to consider resistance to change and capacity balance while determining CM feasibility. The survey found that several companies created formal part families and dedicated equipment to these families. The techniques used for part grouping included grouping of parts by design, grouping of parts by using the key machine approach, grouping by part/machine rearrangement, and grouping by component route sorting. The authors do not state whether these grouping techniques were manual or computerized. Sixty-two percent of the respondents indicated that they had in place classification and coding schemes for use in conjunction with GT applications although it was not stated whether these schemes were manual or computerized. Identification of similar items, process plan standardization, development of group NC programs, and rationalization of purchasing and sales were cited as reasons for using classification and coding schemes. Several firms used computer support in connection with cell design and evaluation. Machine load and utilization calculations, throughput time estimates, and routing analyses were the types of analysis performed. Most companies reported benefits in the areas of throughput time, WIP inventory, material handling, set-up time, quality improvement, and job satisfaction. A clear message from these firms conveyed that total involvement coupled with extensive training is required to make a GT program successful.

The above literature review demonstrates the use of GT in industry. It also shows that resistance to change, capacity balance, computer support, design and process-planning standardization, information requirements, and managerial support are important attributes in the cell design process. It also shows that the three approaches to part-machine grouping -- the design-oriented approach, the production-oriented approach, or a combination of both -- are used in industry. However, this literature review also reveals the absence of a structured approach in industry in the analysis of feasibility for the implementation of CM or in the choice of method for cell design. This dissertation attempts to develop a framework for structuring the CM implementation procedure and the choice of approach for part-machine grouping from the approaches noted above.

2.7 GT Frameworks

A framework for cell-formation procedures was developed by Wemmerlov and Hyer (1986). Cell formation activities are divided into four distinct categories. This framework identifies the initial approach to the part-family/machine-group identification problem and includes a step for the initial evaluation of the cell. The results of the evaluation are then used as guidelines for further revision of the cell. According to their framework, there are four approaches to the selection of the part-family/machine-grouping problem. The first approach identifies the part families without the help of machine routings. This is the design-oriented approach. Rules-of-thumb, informed judgment, and the use of classification and coding procedures are the methods employed to determine the part-families in this approach. The second approach identifies machine groups with the help of existing routings. As aids to such grouping, the contributions of research using various tools (similarity coefficients, graph theory, production flow synthesis, and production flow analysis) are recognized and their methods discussed. The third approach identifies part families using routings. The authors note that this method of part-family formation is found in only one article. The determination of the similarity between parts followed by clustering of machines is the driving mechanism for cell-formation in this approach. The fourth approach determines part-families and machine routings simultaneously via matrix rearrangement. The second, third, and fourth approaches are production-oriented because they all use part routings in determining part-families. The contribution of Wemmerlov and Hyer's work lies in the analysis of the available literature and the creation of the framework. This framework has also helped identify two major approaches to part-machine grouping and, therefore, is directly related to this research.

Another framework by Vakharia (1986) considered available literature addressing cell formation based on production data and categorized the resulting production cells into a framework. Only academic cell-formation procedures were considered by Vakharia in the construction of his framework. The author hypothesized four types of production cells. In the first type, all components emerge out of the cell as completed units. In the second type, cells share centralized facilities or expensive equipment. In the third type, cells are formed such that component families can be processed within one or more cells. In the fourth type, an assembly line cell system is hypothesized where the output of a preceding cell is the input for the next cell.

In summary, some researchers in GT have categorized published literature of part-machine grouping and have embedded these categories into frameworks for part-machine grouping procedures and GT production cells. The framework by Wemmerlov and Hyer (1986) has resulted in the identification of the choice of method for cell formation as a researchable issue. The review of other frameworks was done to aid in identifying the relevant attributes.

2.8 Social Aspects of GT

Edwards and Fazakerley (1973) were among of the first to recognize the human and social aspects of GT. According to the authors, the cell system is a people-centered system. Therefore, as much importance is due the operator and the organization as the techniques used in the formation of the cells -- a view clearly of importance for this study. They state that the objectives of CM implementation should be clearly specified at the outset and every individual who is involved with CM should be informed of the effects of the change. According to them, opportunities should be provided for social contact and increased interaction between group members. They also feel that management involvement is a must from the very outset and that managers should act as change agents in removing departmental parochialism and in changing resisting attitudes of individuals and trade unions through communication. The authors stressed that in order to have a successful GT installation, appropriate consideration of the human and organizational factors is an absolute necessity. Similar conclusions were drawn by Fazakerley (1976) while investigating the social significance of GT. She concluded that management involvement could help significantly in overcoming resistance to change by allaying fears of job insecurity in the new environment. A survey by Huber and Hyer (1985) found that, although a resistive attitude of employees to changes was a factor in the implementation of CM, such an implementation did not have a negative effect on the workforce.

The above literature review portrays the state of research in the area of human and social aspect of GT. It establishes the importance of the human aspect of CM implementation, and identifies managerial support and resistance to change as important attributes in the implementation of CM.

2.9 A Brief Review of Scoring Models

The objective of this section is to discuss certain scoring models found in literature relevant to the present work. The basic purpose of using a scoring model for alternatives is to generate a score for each alternative such that an evaluation of the alternatives based on the score is possible. The scoring is based on the contribution of common attributes for each alternative toward a common objective. These may be subjective or objective attributes. The alternative that yields the "best" score is chosen.

Brown and Gibson (1972) developed a quantified model for facility site selection. They considered both the objective and subjective factors involved with the selection of a site among alternatives. The objective factors, all measured in monetary units, were converted to dimensionless indices. The subjective factor indices were determined by a series of pairwise comparisons by the decision maker. The sum of the objective and subjective factor measures were totalled to give a score for each alternative.

Huang and Ghandforoush (1984) used Brown and Gibson's model to select a robot from among a feasible set. They considered critical factors, such as budget ceiling and minimum rate of return; objective factors, such as cost of a robot; and subjective factors, such as quality of training for robot operation by vendors, in their evaluation. The procedure required the user to rate the subjective factors on a scale between 1 and 4. The subjective factor weights were then determined by normalizing the scale values. The weights of the objective factors were determined from cost figures. The sum of the subjective and objective measures yielded the score for each alternative.

Canada (1986) discussed a scoring model in the context of evaluating computer integrated manufacturing (CIM) opportunities. An example of an opportunity given by the author is an automated storage and retrieval system. For each alternative of an opportunity, tangible and intangible factors were identified. The tangible factors were evaluated according to their net present value. The intangible factors for each alternative were scored out of 100 and the scores normalized to give an indication of the weights of the factors. The summed weights yielded the score of each alternative.

Another approach for comparing alternatives was developed by Saaty (1980, 1982). In this approach, the problem was broken up into one or more levels of detail and a series of pairwise comparisons between attributes at each level enabled assessment of weights for each attribute with respect to the others. This approach was used later by Arbel and Seidmann (1984) to evaluate alternative FMS systems.

In this research a scoring procedure was used in the development of the feasibility analysis procedure. The scoring procedure used was a modification of Canada's (1986) method. The reasons for doing so are given in Chapter IV.

2.10 Summary of Current Research in CM

The literature review presented above details the contribution in many facets of GT/CM. The GT/CM concept is recognized and its application is widespread. In industry, the implementation of GT/CM is through the use of methods appearing in published literature or via the help of in-house or outside consultants. In academia, research on GT/CM has focused on the development of part-family or machine-grouping techniques; on simulation studies; and, in certain cases, on the construction of frameworks for the methods of cell formation and cell evaluation. Some researchers have also focused on the impact of GT/CM on personnel and the organization.

In summary, the literature reviewed includes the applicability of CM, simulation studies of CM systems, part-family/machine-grouping techniques, industry practices of GT, GT frameworks, and social aspects of GT. But the issue of applicability has not been addressed adequately.

This literature review is comprehensive with respect to the focus of this study and provides the groundwork for the present study. It is felt that the area of GT/CM is rich in its scope of research (Suresh and Meredith 1985; Meredith et. al. 1986; Wemmerlov and Hyer 1987c). Wemmerlov and Hyer (1987c) divided the area of CM research into applicability; justification; design of system structure and operational procedures; and behavioral implications and application strategies. Of interest for this research is the issue of applicability of CM and the issue of the selection of part-family/machine-grouping technique if CM is applicable. It is clear from this literature review that the applicability of CM, taking into account an organizational scenario, has not been addressed previously. Previous studies have tried to determine applicability by considering the benefits that may be achieved if CM is implemented (Rathmill et. al. 1974, Willey and Dale 1979). They have not considered whether organizational conditions are suitable for CM implementation in the first place. That is, given the characteristics of an organization in terms of the products made, resources available, the procedures followed, and the prevailing organizational climate, is CM feasible? The second issue relates to the choice of method for part-machine grouping. It is clear that three distinct approaches to part family and machine grouping exist. One is what will be called "the part-oriented method," the second the "production-oriented method," and the third a combination of both. Within these approaches, a distinction is made between the informal design-oriented approach (rule-of-thumb, visual inspection), a CC-based design-oriented approach, a CC-based production-oriented approach and a production-oriented approach based on a routing analysis of parts. Furthermore, a CC-based design-oriented approach can be manual or computerized. A classification and coding system is manual when parts are coded manually. A computerized classification and coding system is one where coding of parts is done interactively with the computer. With a CC-based production-oriented approach, the stress is on coding production characteristics, such as part routings, operation sequences, set-up times, machine tools required for part processing, fixtures and cutting tools needed, batch sizes, etc. Here, a manual or computerized approach is possible. Finally, a production-oriented routing analysis of parts may be manual or computerized. Manual methods involve a manual route sorting for determining families. A computerized procedure involves the use of programmed algorithms found in literature. The overall structure of the part-family/machine grouping approaches addressed in this research is shown in Figure 1. In this figure, a third approach is also shown. It is a hybrid of the design and production-oriented approaches and consists of a combination of manual and computerized approaches.

It is necessary for an organization to have guidelines suggesting when it is advisable to use a part-characteristics approach, when to use a production-oriented one, or when a combination of both would be most appropriate. Both these issues are fundamental and, to date, have been unaddressed in GT/CM literature. They are clearly of importance to an organization considering cell system implementation.

This study is exploratory in nature because there is is no evidence in literature of an attempt to identify the factors critical to the feasibility for implementation of CM in an organization or the choice of method for part-family grouping, if feasibility is adjudged. Thus, this study is the first of its kind in addressing the feasibility and choice-of-method issues. The variables pertinent to the study were identified and synthesized into a decision aid for resolving both the issues. The focus

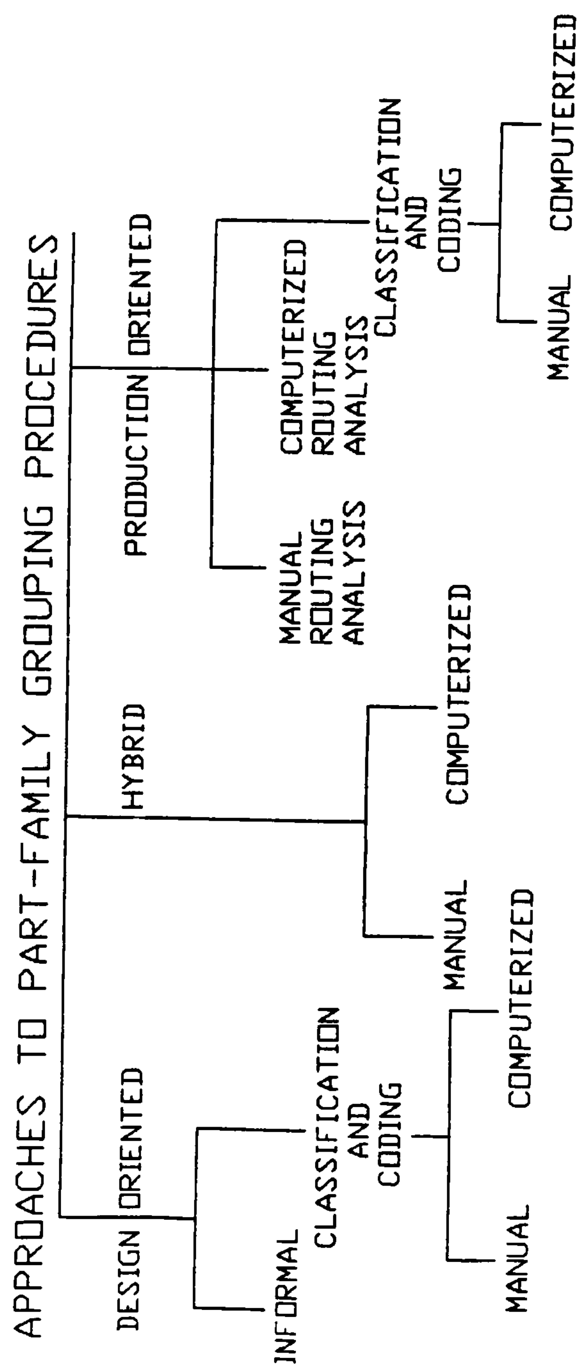

Figure 1. The choice of method

of this study was to develop a decision tool for: (i) determining CM feasibility and (ii) to recommend a part-machine grouping approach if CM is applicable.

This research will be valuable for researchers in the area of GT/CM. The development of the Conceptual Flow Model (discussed in Chapter III) with respect to CM implementation will enable viewing the CM implementation procedure clearly from a macroscopic level and will help formulate a "systems" approach to CM implementation.

There is no evidence of research in the identification and inclusion of attributes important for CM purposes into a decision-making framework for resolving the feasibility for CM implementation and the choice-of-method for part-machine grouping, if feasibility is adjudged. Therefore, the identification of the attributes was the first step of this research. The literature review enabled the identification of the attributes important for CM purposes. However, the literature review in most cases failed to provide any specifications necessary for the measurement of the attributes. The identification of the attributes, the development of a model for addressing the feasibility and choice-of-method issues, the specification of the attributes, the development of a scoring model for determining CM feasibility, and the development of a rule-based procedure for addressing the choice of method issue are all unique in the area of CM research. It is believed that this research will enable other researchers to have a better understanding of the variables involved in the implementation of CM. Such a decision-making framework could also be developed into an interactive decision support system in the future to aid decision makers within a complex industrial environment to make better decisions on CM, subject to the constraints and requirements found in their manufacturing firms.

Chapter III

Model Formulation

This chapter describes the formulation of the research model, identifies the important attributes of the research model, and discusses the relevance of the attributes in relation to this research. The research model is named the "Conceptual Flow Model," (CFM). The development and description of the CFM is discussed first. This is followed by the identification of the attributes pertinent to it. Finally, their relevance is discussed.

3.1 Discussion of the Conceptual Flow Model

The purpose of the CFM is to lend structure to the research problem (stated in Chapter I) and to rationalize the research procedure. Figure 2 shows the schematic of the model. The conception of the CFM originates from the basic production model which can be viewed as an input-transformation-output system (Hitomi 1985); Hitomi's part of the CFM is represented by Blocks A, B and C of the schematic of the model.

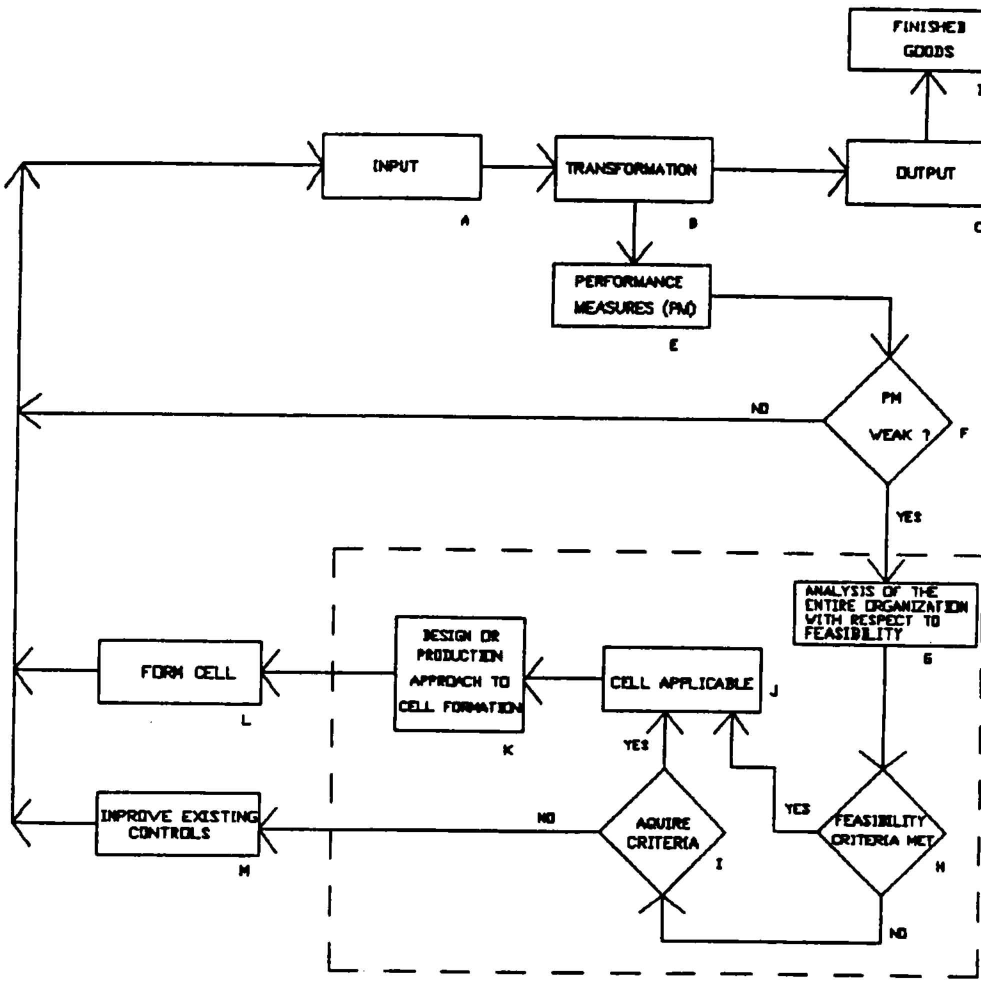

Figure 2. The conceptual flow model

Specifically, Hitomi's model takes into account the inputs to production which consist of land, labor, capital, materials, production means, and production information. The process of conversion of the raw materials into tangible goods or products is represented by Block B in the schematic. Here machines are assumed to be laid out initially in a functional manner. The implementation of CM is concerned mainly with the activities related to this transformation function. As an extension of Hitomi's basic production model, the ideas represented in Blocks B through M of the CFM are the result of this researcher's conception of the mechanism involved in a test of CM feasibility and the choice of method for cell formation if feasibility is adjudged.

The result of the inputs of land, labor, material, production means, and production information is the output of the final product designed to satisfy the customer for a profit. Output Blocks C and D represent the output of finished goods. The transformation process also results in an indirect output -- the performance measures of the system, Block E. By analyzing them, it is possible to determine whether an organization is performing at or below par. Typical performance measures are legion, and include, for example, the number of unfulfilled orders, the level of work-in-process inventory, sales figures, the total time required to produce from order receipt to delivery, and percentage scrap rate. Block F represents the activity of the examination and analysis of the performance measures. If these measures are weak, then the organization in question may not be performing as it should. Therefore it should either improve its control measures while staying in a functional layout or consider a new manufacturing approach (Leonard and Rathmill 1977b). For a job shop with sub-optimal performance, one potential approach to improvement is through cellular manufacturing. This deduction and structuring of the approach to improved productivity through CM is based on literature describing the actual procedures applied by organizations for streamlining their production through a changeover from the traditional functional layout to a cellular one (Durie 1970, Ranson 1971, Burbidge 1979, Willey and Dale 1980, Wemmerlov and Hyer 1987b). The CM approach, however, may not always be possible, nor may it be an improvement; organizational feasibility should therefore be considered prior to implementation. As an aside, it should be noted that CM may also be a viable production alternative even if the performance measures are not weak; however, this consideration is beyond the scope of this work.

Block G of the CFM considers the feasibility of an organization's implementing CM. One main thesis of this research is that, for successful CM implementation, certain attributes must be present or be acquired. These attributes are categorized with respect to the *products and processes* made, the *resources* used to make them, the *procedures* followed, and the *organization* in which they are made. The "products and processes" category consists of attributes that are related to products made in the organization and typify product and process characteristics. In the context of CM, they have received individual attention; yet they have seldom been considered together in determining organizational feasibility for implementing CM. It is felt that certain products are more amenable to CM than others (Leonard and Rathmill 1977). In addition, certain manufacturing processes lend themselves more to CM than others. Therefore, it is important to consider them collectively in the construction of the CM framework. The "resources" category consists of attributes relevant to the resources used in making the products. Since one focus of this study is to determine organizational suitability to CM, the resources required by the organization to process its products should be considered in building the framework. It is felt that the availability or unavailability of resources plays a major role in determining CM feasibility. The attributes pertinent to the procedures followed in making the products are categorized under "procedures." These attributes typify aspects of these organizational procedures that should be investigated in determining CM feasibility. The literature review has shown the importance of the attributes of the "procedures" category with respect to the feasibility for the implementation of CM. Finally, the "organization characteristics" category groups attributes relevant to the organization's environment. These attributes reflect the attitude of management and labor in an organization. In the context of CM implementation, these attributes are extremely important and have received considerable attention in literature (Hyer 1984a, Wemmerlov and Hyer 1987a, 1987b). Therefore, they are incorporated in the decision-making framework.

The above categorization is thought important for two reasons. In the first place, an entire organization can be conceptually viewed as an agglomeration of these four categories. Without any one of these characteristics, the organization is incomplete and ceases to function. Therefore, it is logical to group the entire organizational scenario in terms of these four categories. Secondly, a test for feasibility for the implementation of CM should involve the entire organization and not only parts of it. Ideally, every possible attribute within each category should be identified and included in a test for CM feasibility. However, it may not be possible to identify each and every attribute. Thus, one part of this research was to identify and consider the most important ones.

A schematic of the feasibility analysis procedure is shown separately in Figure 3 and is an expansion of Block G. It is named the "Feasibility Analysis Procedure." The four major attribute categories discussed above are represented by the Blocks shown on the left. Each of the attribute categories consists of a set of attributes. Thus, the initial attempt in the feasibility analysis is the identification of the attribute sets corresponding to each of the categories. Once these attributes are identified, the next step in the analysis procedure is the determination of their levels. The word "level" indicates a value of an attribute on a numeric scale. The directional arrows in the schematic indicate the progression of the analysis. Once the attribute levels are determined, propositions are used to determine feasibility for the given level of the attribute. The purpose of the propositions is to link the level of an attribute to feasibility. This procedure is followed for every attribute, and a final measure for feasibility is determined. The feasibility measure is determined during the analysis. This feasibility analysis procedure is described in Chapter V.

The feasibility issue may also be addressed from the relationship between attribute criticality and feasibility for the implementation of CM. Figure 4 indicates the hypothesized theoretical feasibility possibilities. These hypothetical possibilities are the result of this researcher's perception about the possibility of CM implementation feasibilities. In the diagram, the horizontal axis represents the number and type of attributes that are at levels favorable for CM implementation. The number of attributes refers to the total number of attributes (in all categories) included in the analysis. The types of attributes refers to the critical and non-critical sets of attributes. A critical set is one whose

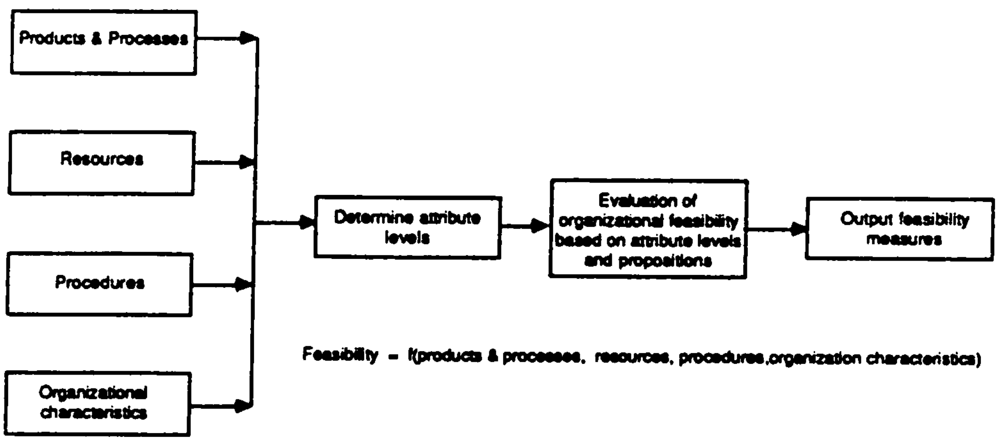

Figure 3. The feasibility analysis procedure

attributes are those which have to be at minimum levels favorable for CM implementation to be feasible. A non-critical set of attributes is one whose levels can be altered to make the implementation of CM feasible even if their initial levels indicate infeasibility for CM implementation. An attribute is favorable for CM implementation if its level indicates suitability for the implementation for CM. An attribute is unfavorable for CM implementation if its level indicates unsuitability for CM purposes.

The horizontal axis is divided into three sectors. The extreme right-hand sector indicates a situation where all attributes, both critical and non-critical, are at levels that are favorable for CM implementation. The middle sector indicates a situation where all critical attributes are at levels favorable for the implementation of CM. Here some non-critical attributes are at levels that are unfavorable for CM implementation. The extreme left-hand sector indicates a situation where all or some critical and non-critical attributes are at levels unfavorable for CM implementation. The vertical axis represents degrees of CM feasibility. The upper-most sector represents the situation where CM implementation is highly feasible. The middle sector represents the situation where the implementation of CM is feasible with improvements of the levels of certain attributes. The lower-most sector represents the situation where CM implementation is infeasible. For each of these sector combinations (considering both axes), an outcome is shown in the figure. These outcomes are indicated by numerals 1 to 9. The first block (marked 1 in the figure) represents an impossible condition, because CM implementation cannot be feasible when some or all critical and non-critical attributes are at levels unfavorable for the implementation of CM. The second block (marked 2 in the figure) also represents an impossible and illogical situation, because CM implementation cannot be feasible if some or all non-critical attributes are at levels unfavorable for CM implementation, even if all critical attributes are at levels favorable for CM implementation. The third block (marked 3 in the figure) is a possibility, because CM implementation is feasible if all attributes (critical and non-critical) are at levels favorable for CM implementation. The fourth block (marked 4 in the figure) represents another impossible condition. CM implementation cannot be feasible if some or all critical and non-critical attributes are at levels unfavorable for CM imple-

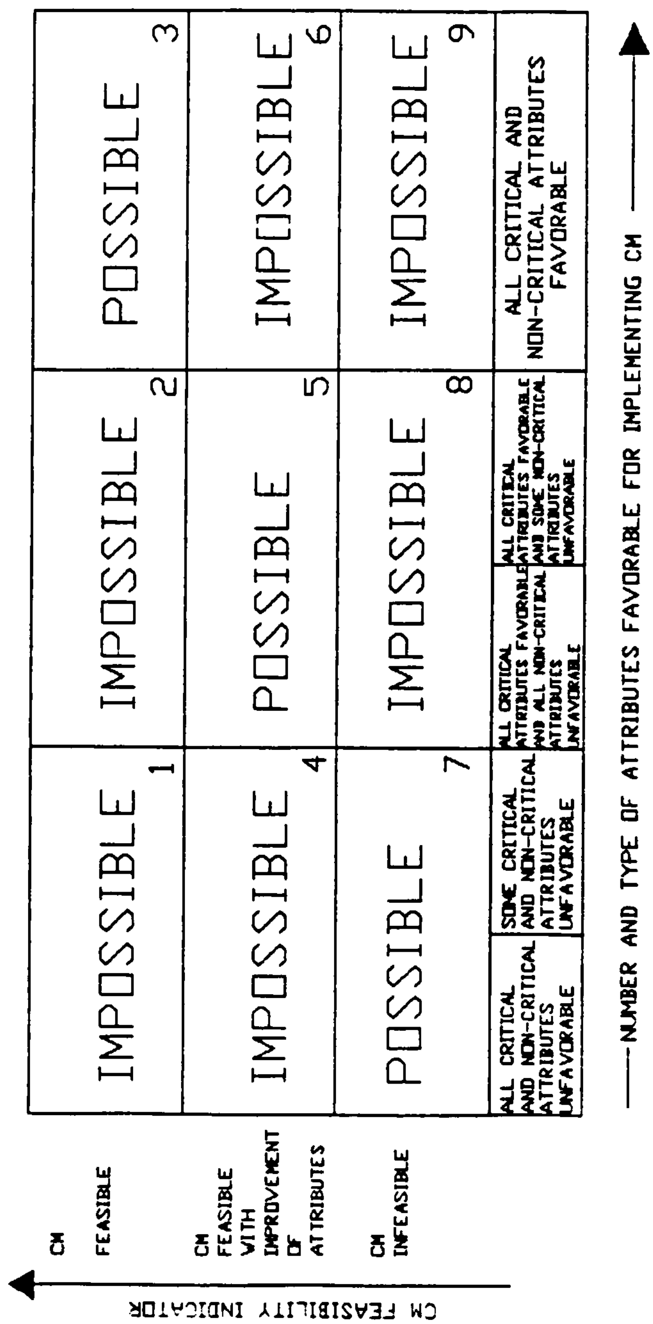

Figure 4. The feasibility matrix

mentation. The assumption still is that critical attributes cannot be improved. The fifth block (marked 5 in the figure) is a possibility, because the implementation of CM is possible if all critical attributes are at levels favorable while some or all non-critical attributes are at levels unfavorable for CM implementation. The levels of these attributes may be improved if feasibility is desired. The sixth block (marked 6 in the figure) represents another impossible situation, because if all attributes, critical and non-critical, are at levels favorable for CM implementation, then CM implementation is highly feasible; obviously attribute improvement is not necessary. The seventh block (marked 7 in the figure) indicates infeasibility for the implementation of CM, because one or more critical and/or non-critical attributes are at levels unfavorable for CM implementation. The eighth block (marked 8 in the figure) indicates another impossible condition. The implementation of CM cannot be infeasible if all critical attributes are at favorable levels, and some or all non-critical attributes are at unfavorable levels. Finally, the ninth block (marked 9 in the figure) shows another impossible condition. If all attributes, both critical and non-critical, are at levels favorable for CM implementation, then the implementation of CM cannot be infeasible.

The matrix diagram indicates nine theoretical possibilities for the feasibility of the implementation of CM. Only three possibilities are important, however, for the reasons stated above. These possibilities are indicated by the blocks marked 3, 5, and 7.

This matrix diagram also provides directions for approaching the feasibility analysis procedure. Firstly, the use of the matrix diagram requires the determination of all critical and non-critical attributes. This indicates that a ranking and weighting scheme is necessary. Secondly, a method is required for determining the favorability for the implementation of CM from the level of an attribute. Therefore, a specification of the attributes is necessary to determine their levels. Also, guidelines are necessary to relate the attribute levels to favorability for the implementation of CM. Thirdly, a quantification of the vertical axis (the feasibility measure) is possible and can indicate overall feasibility Thus, the use of the matrix alone may point to the worst scenario for feasibility, because if one critical attribute is at a level unfavorable for the implementation of CM, then infeasibility for the implementation of CM is indicated by this matrix. The feasibility measure, on the other hand, will yield the best measure possible under the given circumstances. Therefore, it reflects the most optimistic possibility for CM implementation under the existing conditions. Decision making can be better if the best and the worst possibilities are known.

A ranking and weighting scheme of the attributes is presented in Chapter IV. The specification of all attributes is also done in Chapter IV. These specifications help in determining the levels of attributes. Propositions, also developed in Chapter IV, relate the level of an attribute to the feasibility for the implementation of CM. Chapter V presents the scoring procedure for determining the feasibility score.

Block H (of the CFM) is a decision node that questions if feasibility criteria have been met. The matrix diagram relates directly to Blocks I and J of the CFM. The matrix diagram's Blocks 3, 5, and 7 provide answers to this question. If the situation of Block 3 of the matrix diagram is indicated, then the conclusion is that CM implementation is highly feasible. This corresponds to the answer "Yes," emanating from Block H of the CFM. However, if the situation is represented by either blocks marked 5 or 7 of the matrix diagram, then feasibility is met partially or not met at all. This corresponds to the answer "No," emanating from Block H of the CFM. The feasibility criteria are not met at all if all critical attributes and some or all non-critical attributes are at levels unfavorable for CM implementation (represented by Block 7 of the matrix diagram). Here, the critical attributes are at levels unfavorable for the implementation of CM; it is assumed that their levels cannot be improved, at least in the short term. This situation is equivalent to the answer "No," emanating from decision Block I. The indication, therefore, is to retain the existing manufacturing system while improving existing controls (Block M of the CFM).

If the feasibility criteria are not met partially because some non-critical attributes are at levels unfavorable for the implementation of CM (Block 5 of the matrix diagram), then the improvement of the attribute levels will enable CM implementation. For example, capacity imbalances may be offset by acquiring additional machines. Decision Block I of the CFM questions the organization's willingness to acquire or improve the levels of these attributes. If the organization is willing to acquire or improve the attribute levels in question (indicated by "Yes," emanating from Block I of the CFM), then a CM system can be implemented following improvement. In the CFM, this is represented by Block J. The notation "Cell Applicable," means that the implementation of a CM system is feasible. If the organization, however, is unwilling to acquire or improve the attribute levels in question (indicated by "No," emanating from Block I of the CFM), then the implication is to retain the existing manufacturing system, perhaps with other improvements to it.

The contribution of the feasibility analysis procedure is threefold. First, it structures the entire feasibility analysis procedure by considering the entire organization and not only parts of it. Second, this structuring enables the identification of the variables involved in determining organizational feasibility for CM implementation. Third, it points to a methodology for conducting a feasibility analysis.

Once the feasibility analysis is completed and the feasibility is adjudged, then the next step is to address the issue of the approach to cell formation, Block K. The choices available are the design-oriented approach, the production-oriented approach, or a combination of both. The choice-of-method is thought to be a function of the product characteristics, the resources available, and organizational objectives. The basis of this thought is derived from the attributes collected from the literature review. The organizational objective category is included here because the literature review indicated that the approach to cell formation involves consideration of certain objectives, such as design standardization, process planning standardization, information requirements, and value analysis. Therefore, they were considered in the choice-of-method procedure for part-machine grouping and not in the feasibility analysis procedure. The attribute list presented later identifies the categories and the attributes and provides a detailed reasoning for their inclusion.

Figure 5 shows the schematic of the procedure for determining the choice of method and is an expansion of Block K. It has been appropriately named "The Choice of Method Procedure." This research postulates that attribute categories *"products and processes," "resources,"* and *"objectives"* play a role in the choice of method for the reasons stated above. A set of attributes are included in

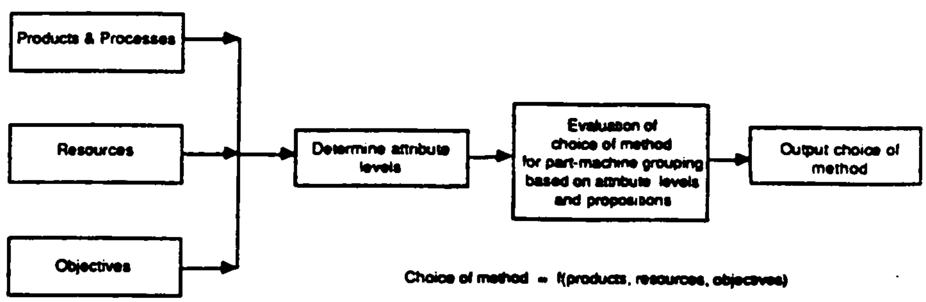

Figure 5. The choice of method procedure

each of these categories. The other categories, used in the feasibility analysis, namely, *"organizational characteristics,"* and *"procedures"* are not considered, since it is felt that they are more appropriate at the initial feasibility level. Further, no support for including them could be found in the literature. The attributes of the *"product and processes"* category typify product characteristics that influence the choice-of-method issue. In the context of the choice-of-method issue, they have received wide attention as a vehicle to part-family formation. The *"resources"* category includes attributes which influence the choice of method. It is felt that the decision to implement an approach to part-machine grouping should consider the availability of resources in an organization. The literature review has further supported this perception. Finally, the *"objectives"* category includes attributes relevant to the choice-of-method category, because they represent objectives which could be met through the choice of method. Thus an awareness of these objectives may help in selecting the right approach to the choice of method. A literature review also indicated the importance of this attribute category. Some of these attributes have been considered individually to be important in determining the approach to part-machine grouping in literature; however, they have not been collectively addressed within the scope of a decision-making framework. Therefore, they are incorporated under these categories in this study.

The next step in the analysis procedure is the determination of the attribute levels. This activity is represented by the next Block in the schematic in Figure 5. The next activity uses attribute levels and propositions to come to a conclusion for the choice of method. The propositions link the attributes to the choice of method based on the level of the attributes. The output of the final result is represented by the rightmost Block. The directional arrows represent the progression of the analysis procedure.

The choice of method procedure provides a structured sequence for determining the approach to part-machine grouping. This procedure also enables the identification of the variables involved and points to a methodology for determining the most appropriate approach to part-machine grouping.

Once the part-machine grouping approach has been determined, the next activity is the actual relocation of machines. Block L in the model represents this activity; once this is accomplished, production can be started in the new environment. However, if the criteria for cell formation cannot be met, the remaining option represented by Block M is to stay functional while improving existing procedures and controls. The scope of the feasibility and implementation of CM in an organization is represented by the dotted boundary and should not be confused with the scope of this dissertation which is stated in Chapter I.

3.2 A Conceptual Cell Matrix

The literature review enabled the identification of three types of cells based on product and process characteristics. These are GT flow-line cells, GT mixed-flow cells for individual components, and GT product cells. However, the literature review did not indicate any formalized approach to the classification of cells by products made or material flow. The only evidence of a formalized approach to such classification is by Vakharia (1986). In his work, Vakharia developed a framework of various cell types based on published cell formation procedures.

The motivation to develop a classification of cells based on products made and the material flow stems from the perception that different cell types may result depending on the type of product manufactured and the material flow. Such a classification will enable the identification of the potential cell type for an organization, if feasibility for the implementation of CM is adjudged, once the product types manufactured and the material flow is known.

Another motivation for developing this classification is a result of this researcher's educated opinion (and after consultation with faculty) that scheduling procedures may be dependent upon the type of product manufactured and the material flow. Thus, it is felt that the scheduling procedures for mixed-flow of material may be different than for straight-line material flow. Also, there may be differences in the scheduling procedures for the different types of products made. It is also felt that scheduling procedures may be dependent upon the manufacturing mode. Therefore, a classification of cell types based on material flow, the type of product manufactured, and the manufacturing mode will not only enable the identification of the potential cell type, but may also indicate the scheduling procedures to be followed.

A conceptual matrix of cell types based on material flow and the products made, shown in Figure 6, was developed during the course of this research. This matrix is the result of this researcher's educated opinion after an extensive review of GT/CM literature, of material flow and product types that can be produced in a manufacturing environment.

Two types of material flow are recognized in the development of this matrix. These flow types are straight-line flow and mixed-flow. In straight-line flow, material flows in a straight line (or in a sequential fashion). Thus, there is no backtracking of material during processing. In other words, material flows successively from one machine to another until it is completely processed. In mixed material flow, material does not flow in a sequential manner; there is backtracking of parts. That is, material may visit machines in any sequence.

The following two categories of products are recognized. The first is a product family. Here, a variety of similar products are manufactured and products can be distinctly clustered into families. Product families may be singular (variety of one product) or multiple (many varieties of many products). Examples of product families are valves or motors in varying sizes. The second category is the single product. Single products are unit entities. Examples of single products are single components made for stock or a particular type of lathe.

The products belonging to a family are similar because they are functionally the same, with size, capacity, or other variations. A product family might be produced by component processing in a cellular environment. That is, all components required for the product families might be manufactured in cells, with assembly done elsewhere. Again, all components required for the product family might be processed and assembled in the same cells. It is also possible to assemble the components into products of the product family. The components are manufactured elsewhere.

The manufacture of single products may involve the processing of individual components in a cellular environment, with component assembly, if necessary, being done elsewhere. Also, all components could be manufactured and assembled in the cells. Again, end components manufactured elsewhere may be assembled in a cell.

Thus it is seen that there can be three manufacturing modes for each category of product. These modes are component processing only, component processing and assembly, and component assembly only. Also, there are two types of material flow in cells -- straight-line and mixed. Also, there are two product types. Therefore, it is conceivable that there will be one cell type for every combination of material flow, manufacturing mode, and product type. With this in view, the following cell matrix in Figure 6 is developed.

In this matrix, the vertical axis represents the flow types -- straight or mixed. The horizontal axis represents the manufacturing mode for each product category. The three manufacturing modes shown are component processing, component processing and assembly, and component assembly. The product categories are single product and product families. In this matrix there are 12 cell types; one for each of the combinations. The first cell type is where components of single products are processed in a sequential mode. The second cell type is where the components of simple products have mixed processing paths. In these cell types there is no assembly. In cell type 3, components of single products are processed and assembled in a sequential fashion. In cell type 4, components of single products are processed and assembled in a mixed flow. Cell type 5 is a straight flow-line cell of the assembly type. Here, the individual components, fabricated at separate locations, are assembled to form a single product. Cell type 6 is a mixed flow cell where individual components are assembled to form a single product.

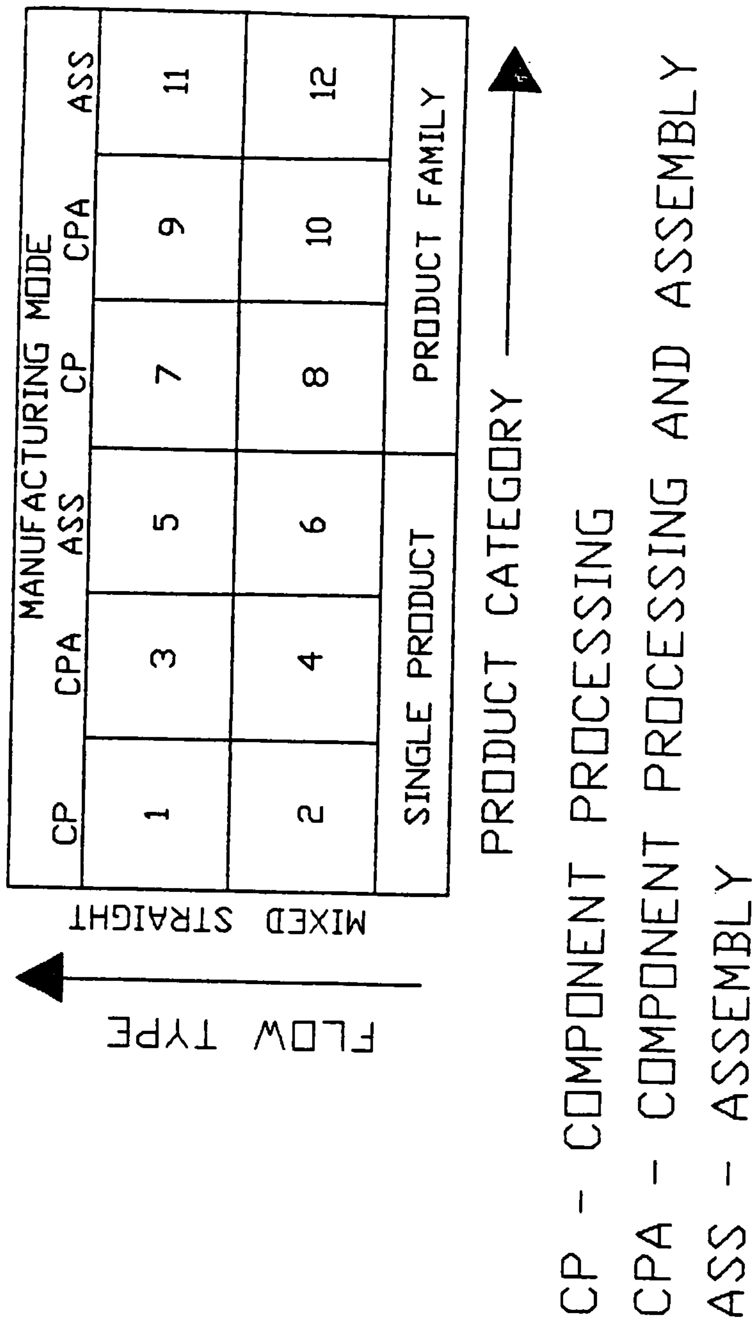

Figure 6. Cell-type matrix

Cell type 7 is a flow-line cell for processing components belonging to a product family. The components are assembled elsewhere into product families. If component processing follows a mixed path, then cell type 8 results. Cell type 9 is a flow-line cell where all components of the product families are processed and assembled. Cell type 10 is a mixed-flow cell for the processing and assembly of components belonging to a product family. Finally, cell types 11 and 12 are straight and mixed-flow cells, respectively, for the assembly of components fabricated elsewhere.

Therefore, it is possible to locate an organization anywhere in this matrix for its product categories and material flows. The three variables that have to be known are the flow types (straight or mixed), the manufacturing mode (processing, assembly, or both), and product category (single product or product family).

This completes the theoretical development pertinent to this research. In summary, a structured approach to the feasibility analysis procedure and the choice-of-method procedure were presented. A cell type matrix based on the products manufactured and the material flow was also developed. The discussion of the assumptions constraining this research follows.

3.3 Assumptions

Assumptions constraining this research are stated below and are thought by this researcher to be the most relevant ones. They are divided into two categories -- environmental and analytical. The environmental category relates to the assumptions concerning the manufacturing environment. The analytical category identifies the assumptions linked with theoretical development and model building.

- Environmental assumptions :
  1. The specification of the attributes and the field work of this study is aimed at the metal-machining segment of manufacturing. Since this study is exploratory in nature, it is felt

that restricting its scope will help in identifying and addressing the important issues and variables better. It is believed by this researcher that this research would become extremely complex if all manufacturing processes were considered. Therefore, the current focus in developing the specification of attributes and conducting the field work is on the metal-machining segment alone.

2. The entire field work analysis is for an existing functional layout. The focus of the dual research issues is on a firm utilizing an existing functional layout alone. The assumptions preclude the consideration of greenfield situations.
3. This study considers existing equipment only. Since the dual research issues are to be evaluated with respect to an existing functional layout, only existing equipment will be considered.

- Analytical assumptions :
  1. Interactions between variables are not considered. This is to keep the model building approach as simple as possible. It is necessary to identify the variables and have a clear understanding of their importance before their interaction can be investigated.
  2. The modeling approach is deterministic only. A stochastic modeling attempt is not considered, because the approach of this study is to determine procedures for a feasibility study only. Also, a stochastic modeling approach is not yet suited for a problem as subjective as this.
  3. The performance measures of existing operations must be known beforehand. This model does not determine any of them.

3.4 Identification of the attributes

Two sets of attributes pertinent to the dual research issues of CM feasibility, and the choice of method if CM is feasible, have been identified. The first set is pertinent to the applicability issue (Table 1). The second is relevant to the choice of method (Table 2). The examination of relevant literature and interviews with faculty have yielded these sets. With respect to the CFM, the two attribute sets are associated with Blocks G and K respectively, that is, the feasibility and the choice-of-method procedures. These sets will be further divided into the following categories: products and processes -- those attributes related to the product or component characteristics; procedures -- those attributes related to the procedural aspects of the organization; resources -- those attributes related to the resources available or necessary for the implementation of CM and determining the approach to part-machine grouping; organizational characteristics -- those attributes describing the organizational characteristics; and objectives -- those attributes describing organizational objectives. Attributes in the "products and processes," "procedures," "resources," and "organizational characteristics" categories are used for the feasibility analysis (Table 3). Attributes in the "products and processes," "resources", and "objectives" categories are used in determining the choice of method for part-machine grouping (Table 4). The reasoning behind these choices was discussed earlier. Some attribute categories are common to both the feasibility analysis procedure and the choice of method. Tables 1 and 2 present the relevant attributes and supporting references. Categorizations of the attributes are shown in Tables 3 and 4. Their relevance is discussed following the tables. This discussion of the relevance of the attributes is done by categories (discussed earlier) for the feasibility and choice-of-method issues.

3.5 The Relevance of the Attributes

This section discusses the relevance of the attributes related to the feasibility and the choice-of-method issues. The relevance of the attributes relating to the feasibility issue are discussed first.

Products and Processes

1. Occurrence of part families and machine cells: This attribute is the cornerstone to the concept of CM. For CM to be feasible, parts have to form families to be machined in cells (Leonard and Koenigsberger 1972). Ideally, part families and machine cells should be distinct; that is,

Table 1. Attributes identified as relating to the feasibility issue

Attributes	References
Occurrence of part families and machine cells	Leonard and Koenigsberger 1972.
Occurrence of indivisible processes	Lewis 1973, Rathmill et. al. 1974.
Capacity balance	Tilsley and Lewis 1977. Oliva-Lopez and Purcheck 1979.
Stability of product demand	Hedge et. al. 1979, Tilsley and Lewis 1977
Stability of product-mix	Venkitadri and Kemshetti 1975.
Complexity of components	Flynn and Jacobs 1984, Burbidge and Dale 1984, Greene 1980.
Flexibility of labor	Burbidge 1979, Dale and Dewhurst 1984.
Managerial support	Hyer 1984a, Suresh and Meredith 1985.
Skill level of operators	Burbidge 1979, Rathmill and Leonard 1977.
Resistance to change	Wemmerlov and Hyer 1987a, 1987b, King 1979,
Availability of computer support	King and Nakornchai 1980, Wemmerlov and Hyer 1987a, 1987b.
Availability of a classification system	Burbidge 1975.
Computer literacy of personnel	Wemmerlov and Hyer 1987a, 1987b.
Reliability of suppliers	Ranson 1972, Leonard and Koenigsberger 1972.
Weight of components	Flynn and Jacobs 1984, Leonard and Koenigsberger 1972.
Material control system	Nagarkar and Fogg 1979, Burbidge 1975.
Workload on process planners	Houtzeel 1981.
Forecasting reliability	Lewis 1973.
Reliability of equipment	Leonard and Rathmill 1977.
Implementation time	Levulis 1980, Burbidge 1975.
Scheduling procedures	Burbidge 1979, Greene 1988.

a part family should be able to be completed within its allocated cell. This is not always possible and intercell transfers of parts often result because of the need to balance machine and

Table 2. Attributes identified as relating to the choice of method issue

Attributes	References
Component design homogeneity	Groover and Zimmers 1984.
Component manufacturing similarity	Groover and Zimmers 1984.
Availability of a CAD system	Bhadra and Fischer 1988, Myklebust 1988.
Interdepartmental information requirements	Ranson 1972, Ingram 1982.
Value analysis	Edwards 1971.
Design standardization and retrieval	Hyde 1981, Wemmerlov and Hyer 1985.
Process plan standardization and retrieval	Ingram 1982.
Monetary support	Allen 1973.
Implementation time	Wemmerlov and Hyer 1985.
Availability of computer support	Wemmerlov 1988.
Computer literacy of personnel	Wemmerlov 1988.
Usage of standards	Bhadra and Fischer 1988.

cell loads and to avoid machine investment through duplication. However, intercell transfers should be low; large intercell transfers increase material movement and result in increased scheduling effort (Willey and Ang 1984). One key to a good CM system is, therefore, the ability of the parts to form part families and machines to form cells.

2. Occurrence of indivisible processes: Indivisible processes are centralized in nature. Examples of such processes are heat treatment, sand blasting, painting, and subcontracted work. If the manufactured parts require a lot of such intermediate processing, then the results are complex material flow, queueing in front of machines, and increased throughput time (Lewis 1973, Rathmill et. al. 1974). This greatly increases the difficulty of forming self-contained groups.

3. Stability of product demand: Once cells are formed, certain machine types are responsible for completing a set of parts required for the final product. Prior to cellularization, parts could be routed to one of many appropriate machines. Thus, with cellularization, unstable product demand will result in severe unbalancing of cell and machine loads, because the parts have a restricted number of machines available for their processing (Tilsley and Lewis 1977, Hedge et. al. 1979).

Table 3. Attribute for the feasibility issue arranged into categories

Attributes	Category
1. Occurrence of part families and machine cells	Products and processes
2. Occurrence of indivisible processes	Products and processes
3. Stability of product demand	Products and processes
4. Stability of product-mix	Products and processes
5. Complexity of components	Products and processes
6. Weight of components	Products and processes
7. Capacity balance	Resources
8. Flexibility of labor	Resources
9. Availability of a computer support	Resources
10. Availability of a classification system	Resources
11. Computer literacy of personnel	Resources
12. Skill level of operators	Resources
13. Forecasting reliability	Resources
14. Reliability of equipment	Resources
15. Implementation time	Resources
16. Reliability of suppliers	Resources
17. Material control system	Procedures
18. Workload on process planners	Procedures
19. Scheduling procedures	Procedures
20. Managerial support	Organizational Characteristics
21. Resistance to change	Organizational Characteristics

4. Stability of product-mix: Stability of product-mix is necessary to enable an even loading of a CM system. Variations in the product-mix are liable to cause underloading or overloading of the machines within the cells in a CM environment; and extreme fluctuations in the product-mix are liable to disrupt the entire production process because of decreased flexibility and machine utilization (Venkitadri and Kemshetti 1975).

5. Complexity of components: Research indicates that CM is suited in situations where the total number of operations per part is low (Leonard and Koenigsberger 1972, Burbidge and Dale 1984, Flynn and Jacobs 1984). This seems intuitively correct because, with increasing numbers of operations per part, there is an increased material flow with longer throughput times.

6. Weight of components: There are distinct advantages to be gained with CM if the manufactured components are light. Heavy components need additional material handling equipment and often handling problems emerge (Leonard and Koenigsberger 1974, Flynn and Jacobs 1984).

Table 4. Attributes for the choice of method arranged into categories

Attributes	Category
1. Component design homogeneity	Products and processes
2. Component manufacturing similarity	Products and processes
3. Availability of a CAD system	Resources
4. Monetary support	Resources
5. Implementation time	Resources
6. Availability of computer support	Resources
7. Computer literacy of personnel	Resources
8. Interdepartmental information requirements	Objectives
9. Value analysis	Objectives
10. Design standardization and retrieval	Objectives
11. Process plan standardization and retrieval	Objectives
12. Usage of standards	Objectives

Resources

7. Capacity balance: The change from a functional to cellular layout should take into account the problem of capacity bottlenecks. There often are a few machine types that are always overloaded. If more than one machine exists for each machine type, the problem is alleviated somewhat. In situations where the majority of the machines are overloaded and there is only one of each kind of machine, a conversion to a cellular layout may create severe load-balancing and capacity problems. A large cell will also result if CM is implemented in such a case. In this situation, the conversion to a CM layout will require the replanning of parts or investment in additional machines to reduce such bottlenecks.

8. Flexibility of labor: In order to operate the machines in the cells, operators should have the capacity to operate multiple machines. According to researchers (Leonard and Koenigsberger 1972, Burbidge 1975, 1979), the number of workers in a cell should be less than the number of machines to increase labor utilization. Therefore, workers should have flexibility.

9. Availability of computer support: The manipulation of massive amounts of data necessitates the use of computer power, both in the form of hardware and software. All current procedures for part-family/machine-group formation, as available in literature, are completely computer dependent. While manual part-machine grouping is possible, reports of current industrial applications of CM also indicate substantial use of computer resources in data analysis (Nagarkar

and Fogg 1979, Dumolien and Santen 1983), in the use of material control systems, in classification procedures, and in operation analysis (Wemmerlov and Hyer 1987a, 1987b).

10. Availability of a classification system: This attribute is not strictly a prerequisite to CM; however its existence greatly enhances the scope of success (Burbidge 1975) by providing a basis for data storage, retrieval, and standardization.

11. Computer literacy of personnel: Computer literacy of implementing personnel is important because some form of computer work is necessary during the implementation procedure. Procedures for part-family/machine grouping will normally require computer skills unless the part spectrum is narrow. Procedures for load analysis also require computer programming ability. Current industry surveys indicate that computer support is used in many companies in their approach to cell design (Wemmerlov and Hyer 1987a, 1987b).

12. Skill level of operators: It has been postulated that CM systems are viable for jobs requiring low levels of worker skills (Leonard and Koenigsberger 1972, Burbidge 1979). Concerns have also been raised about skilled operators performing unskilled jobs in cells (Leonard and Rathmill 1977). It is felt by this researcher that CM is suited for jobs which do not need a high level of skill, because high job skill requirement polarizes operators to machine types and, therefore, reduces the opportunity for labor flexibility. Also, deskilling effects where skilled operators perform low-skill work may reduce employee morale. Thus labor skill is an important attribute in examining CM suitability.

13. Forecasting reliability: The relevance of this attribute is understood from the standpoint of production planning. A good forecast generally assists in accurate production planning. This requirement is more pronounced for CM because the availability of machines and labor is restricted in comparison to a functional layout where inaccuracies in product forecasting can be accommodated through inherent flexibility (Lewis 1973). A good forecast is also necessary from a material control point of view. Single-cycle ordering is based on ordering to a fixed short cycle. Unless it is known what to order, planning will not be possible. Also, the supply of raw material is affected by the lack of good forecasting. Therefore, this attribute is extremely important for CM.

14. Reliability of equipment: When machines are grouped into cells, their breakdowns are likely to result in a complete stoppage of operations. Unlike a functional layout, other machines are not normally available (Leonard and Rathmill 1977a). Thus machines with high breakdown frequencies are not amenable to CM.

15. Implementation time: Implementing a CM system requires a substantial length of time (Burbidge 1975, Levulis 1980, Wolfe 1985). Time is required for planning, thought, equipment acquisition, overcoming resistance, and actual implementation. Therefore, insufficient allocation of time to the entire project may result in its demise.

16. Reliability of suppliers: CM is dependent upon the reliability of suppliers because the premise of reduced throughput time is governed not only by the reduction in the manufacturing time within the shop, but also by the accurate delivery of material by suppliers (Ranson 1972, Leonard and Koenigsberger 1974).

Procedures

17. Material control system: It is believed that a multi-cycle material control system for individual parts (a reorder-point system based on an economic batch quantity of individual parts), is unsuitable in the CM environment (Burbidge 1975). The important deficiencies of this system are as follows:

    a. a high investment in stock is necessary to operate the system,
    b. major losses are possible due to material obsolescence,
    c. unbalanced and unpredictable variations in machine load results from using this system,
    d. unbalanced and unpredictable variations in the stock level may result from using this system, and
    e. the use of this system precludes family processing of parts because orders for parts are generated at random and not by families. Thus, the same set-up and tooling cannot be used in the processing of parts.

The use of single-cycle ordering systems like MRP is advocated as they inject a balanced set of parts into the system (Burbidge 1975, Nagarkar and Fogg 1979). However, all parts in a family may not be on order at the same time. This points to a conflict between part-family processing requirements and the time-phased release of orders by a single-cycle ordering systems. One area of GT research is in the development of algorithms for balancing GT/MRP needs (Wemmerlov and Hyer 1984). However, this is outside the scope of the present study.

18. Workload on process planners: An indicator of CM suitability is the workload on process planners. An overload implies that many different process plans are issued frequently, or that process planners are in short supply. Chances are that many process plans are duplicated unknowingly and, therefore, process planning rationalization is necessary (Houtzeel 1981).

19. Scheduling procedures: It is necessary to study the effects of current scheduling procedures on a future CM system. It is known that, with the implementation of a CM system, the scheduling function changes (Burbidge 1975, Wemmerlov and Hyer 1987a). Scheduling by part families and sequencing according to common tooling is normally followed. This is in contrast to scheduling in a functional layout where scheduling is by process. This attribute focuses not on scheduling algorithms or procedures, per se, but on the current organization of production scheduling. According to Burbidge (1975, 1979), for effective CM scheduling, the scheduling function needs to be decentralized. In a group layout the stress is to complete all the parts within a group and, therefore, scheduling should be accomplished in the proximity of the group rather than in a centralized office. Also, the authority given to the group supervisor to pre-empt or override specified schedules is important in a CM system. This is because the supervisor of a cell can react quickly to events like machine breakdowns or operator absenteeism. Thus, for the purpose of this study it is necessary to consider this attribute with respect to these three aspects: (i) centralization of scheduling, (ii) the extent of scheduling done by group supervisors, and (iii) the authority of group supervisors in overriding schedules as and when necessary.

Organizational characteristics

20. Managerial Support: There is evidence that one of the major obstacles in the successful implementation of CM is managerial and not technical (Hyer 1984a, Suresh and Meredith 1985). Top management support is a must if such a venture is to succeed. Management must champion the cause and nurture the concept among the employees through communication,

coordination, and the allocation of proper resources. Therefore, in determining organizational suitability to CM, one must examine the prevailing managerial attitude and support.

21. Resistance to change: This factor is often the major contributor to the failure of a CM implementation plan (Burbidge 1979, Wemmerlov and Hyer 1987a, 1987b). Employees resist new methods because of fears of job insecurity, loss in power, the necessity of learning new procedures, etc. Therefore it is necessary to know the existing climate and potential for resistance to change in the organization before any effort toward CM implementation is undertaken.

The above discussion underscores the relevance of the attributes related to the *feasibility* for implementing CM. Following is a discussion on the relevance of the attributes pertinent to the *choice of method* for part-machine grouping if feasibility is adjudged.

Products

1. Component design similarity: This attribute merits consideration in deciding between the two approaches to part-family and machine grouping. Parts that are very similar in design should be grouped together (Groover and Zimmers 1984). Thus in determining the approach to part-machine grouping, it is necessary to check for design similarity of parts.
2. Component manufacturing similarity: The focus for this attribute is on manufacturing similarity. Parts may not have enough design similarity to be grouped in design families. Yet their manufacturing sequence may indicate a high manufacturing similarity. In such a case, the choice will more likely be a production-oriented approach.

Resources

3. Availability of a CAD system: A CAD system may be used directly to generate part codes from design (Bhadra and Fischer 1988). From the knowledge of part-design, it is possible to create part codes by a mathematical manipulation of the part-design database. Therefore a design-based part-grouping procedure will assist in design standardization and retrieval. It may also aid in automatic code generation from the product-design data if such software is available.
4. Monetary Support: The choice of method is likely to be dependent on the monetary support available. Manual methods of part-machine grouping do not entail much expenditure; how-

ever, the use of a design- or manufacturing-oriented classification package involves substantial investment (Burbidge 1975). Thus, this attribute needs to be examined with respect to the choice of method.

5. Implementation time: Time required to implement a design- or a production-oriented procedure is an important attribute in the decision-making procedure. A classification-based grouping requires more time to implement than does a visual-analysis procedure or a production-oriented approach (Burbidge 1975). Therefore, it is likely that this attribute will influence the choice of method.
6. Availability of computer support: The choice of method is dependent on the extent of computer power available. Use of classification packages requires the extensive use of computer systems (Hyde 1981). The application of most production-oriented techniques also require the use of computer resources (Rajagopalan and Batra 1975, DeBeer and deWitte 1978, DeBeer 1980). Instances of manual grouping of parts also exist (Wemmerlov and Hyer 1985). It is likely that the extent of available support influences the approach to the choice of method.
7. Computer literacy of personnel: It is likely that the extent of computer literacy of personnel influences the choice of method for part-family/machine grouping. Procedures for part-family/machine grouping will normally require computer skills unless the part spectrum is narrow or if a manual attempt of part grouping is undertaken. This requirement is more pronounced if it is decided to develop an in-house classification software.

Objectives

8. Interdepartmental information requirements: The use of GT has proven valuable to firms that need to construct cost estimates quickly and accurately. To estimate the cost of producing a new item, cost information on similar items is retrieved either from a part-family database or from a process-planning database. This has the effect of reducing the turn-around time for customer price quotes (Wemmerlov and Hyer 1987a). Purchasing is also able to identify similar parts or materials for bulk purchase purposes (Ingram 1982).
9. Value analysis: Value analysis is the process of designing the best product for the least cost. Use of a design-based classification of parts aids in value analysis (Edwards 1971). The tech-

nical side of value analysis is concerned with an examination and subsequent modification of component drawings for least-cost production. Thus, the process of value analysis is simplified when drawings are grouped by design; the value analysis technique can then be applied to all components. This benefits the organization by reducing production costs (Edwards 1971).

10. Design standardization and retrieval: Design standardization is the process of reducing design redundancy by recognizing similarity in product designs. It has been observed that design duplication is a commonplace occurrence (Hyde 1981). This can be reduced via design standardization. For every new order, the existing design files are checked for similar designs. This way design proliferation is reduced. Design retrieval is the process of retrieving similar designs. Design duplication can be avoided if an efficient design retrieval system exists. Design retrieval also has the effect of reducing the design turn-around time.
11. Process plan standardization and retrieval: Traditionally, each part flowing through the factory has been treated as a discrete entity. Thus there will be many parts having similar process plans. These parts could be grouped together by their routing similarity to achieve routing standardization. New part routings can also be checked against existing routings by a retrieval procedure. This results in the reduction of manufacturing time for similar parts (Ingram 1982).
12. Usage of graphics and product standards: Procedures are currently available for generating part codes directly from computerized part designs through the use of graphics standards, such as the Initial Graphics Exchange Specification (IGES) (Bhadra and Fischer 1988). Part design data are stored in a computer database using the formats specified by these standards. These data can then be accessed for generating part codes. Therefore the existence of such facilities needs to be investigated with respect to the choice of part grouping. It must be stressed, however, that this attribute is not of primary importance in the choice of method. Its presence points to the enhancements possible in a design-based choice; its absence does not negate such a choice.

The above discussion presents the relevance of the attributes with regard to both issues. The attributes relevant to the feasibility issue were considered first; the attributes pertinent to the choice-of-method issue were considered second.

In summary, Sections 3.1 and 3.2 of this chapter formulated the research problem. Section 3.3 stated the assumptions constraining this research. Section 3.4 identified the important attributes pertinent to the dual issues of the research problem, and Section 3.5 discussed the relevance of the attributes with respect to the research problem.

3.6 A Brief Review of Operationalization and Scaling of Variables

The variables involved in this study must be operationally defined to be measurable. According to Emory (1985), "an operational definition is one stated in terms of specific testing criteria or operations." The process of operationally defining a variable starts by the identification of the dimensions or characteristics that qualify the variable in question (Sekaran 1984, Emory 1985). This reduces the level of abstraction of the variable. The next step reduces this abstraction further by breaking down these individual characteristics or dimensions such that they can be measured quantitatively by the use of appropriate measuring or scaling techniques. This approach was followed in the treatment of variables for this research. The dimensions/characteristics were identified first by using definitions. The elements describing these dimensions were then determined and quantified via scaling techniques. The concept of scaling and scales for measurement are described next.

Scaling is defined as a procedure for the assignment of numbers or symbols to properties of objects in order to impart some of the characteristics of numbers to the properties in question (Emory 1985). In other words, a scale is a tool or mechanism by which numbers are assigned to the properties of objects to distinguish between objects. In the realm of subjective measurement, scales are primarily used for measuring attitudes or subjective beliefs toward a concept. They can also be made up of simple measures of individual subconcepts which can then yield an overall measure of the concept (Rubin 1983).

To determine differences in the degree of feeling toward an idea, situation, or opinion, one of two types of techniques can be used (Selltiz et. al. 1959). The first is where an individual makes a judgment about some characteristic and places it on a scale defined in terms of that characteristic. Graphic rating scales and itemized rating scales are used in such ratings (Selltiz et. al. 1959, Emory 1985). The second type is known as the ranking scale; the subject compares two or more objects and makes choices between them. Paired comparisons, method of successive intervals, and method of rank order are the approaches used here. The scales used for ranking are the differential scales, summated scales, cumulative scales, and factor scales (Rubin 1983, Emory 1985). Of particular interest for this research is the summated scale, because it is the most frequently used and is well established (Sekaran 1984, Emory 1985).

The summated scale, most often used as a Likert scale, assists in the evaluation of an item by means of a series of statements which expresses either a favorable or unfavorable attitude toward the object of interest. In using the Likert form as a measure of the attitude, the respondent is asked to respond to each statement in terms of five degrees of agreement. The numbers are assigned to indicate the value of each possible answer with 1 indicating the least agreement and 5 the most agreement (Rubin 1983). The summated score is an indicator of the attitude of the respondent. It can then be normalized, if desired, to yield a weight between 0 and 1.

This scale is relevant for this study because the study involves the measurement of several subjective variables. The levels of these variables have to be determined for the organization in question in order to determine a measure for its suitability for CM. Each variable was operationalized first. The responses to these variables were used via the scaling technique to obtain a summated score for each attribute. These summated scores were then used to determine a feasibility score.

3.7 Summary

This chapter formulated the research model and identified the important attributes of the research model. A conceptual cell-type matrix was also developed in this chapter. The relevance of the attributes and the operationalization of variables were also discussed in this chapter. In order to develop completely the decision-making framework, the identified attributes need to be linked with the feasibility and choice-of-method issues. They also need to be defined and specified. The propositions developed next in Chapter IV link the attribute levels to the feasibility and the choice-of-method issues. The attribute definitions and specifications, also developed in Chapter IV, define and specify each attribute. The scoring procedure is also discussed in Chapter IV. It is also necessary to validate the attributes, their measures, and weights and to exercise the methodology. The verification procedures (through field work) of attributes, their measures, and weights are given in Chapter V.

Chapter IV

Model Specification

Introduction

This chapter describes the details of the model specification. It includes the propositions relating the levels of the attributes to the feasibility and the choice-of-method issues, a ranking procedure for the attributes, and the definition and the specification of all attributes. Sections 4.1 and 4.2 discuss the propositions and the ranking procedure, while section 4.3 presents the definitions and the specifications of all attributes.

4.1 Propositions

4.1.1 Introduction

This study develops a theoretical framework for addressing feasibility for the implementation of CM and the choice of method for part-family formation, if feasibility is adjudged. One instrument to such development is the proposition. A proposition is defined as a statement or an assertion about a variable that is to be discussed. This statement or assertion is based on certain theoretical underpinnings. It was not intended in this research to test the propositions through data gathering and analysis. A proposition is different from a hypothesis. A hypothesis is a statement describing a logically conjectured relationship between two or more variables that is testable through data gathering and analysis (Rubin 1973, Sekaran 1984). These relationships are conjectured on the basis of a developed theoretical framework. Therefore, one difference between a hypothesis and a proposition is that a hypothesis is tested with data, while a proposition is necessarily a theoretical developmental tool and is not tested.

In this research, propositions are constructed to link the level of an attribute to an outcome. The outcomes here are (i) the feasibility of a company's implementing CM and (ii) the choice of approach for part-machine grouping, if CM implementation is feasible. The purpose of the propositions is to guide the decision-making procedure to a logical outcome. For each attribute involved with either of the issues, a proposition is constructed. These propositions are supported with arguments based on the literature and/or reasoning. The decision-making process will examine the propositions after the levels of the attributes are determined and will determine the organizational suitability for implementation of CM. The development and use of propositions form the backbone of this decision-making procedure. As of now, this approach to the construction of a decision aid is unique to the area of CM. The propositions are now stated.

4.1.2 Propositions -- Feasibility analysis issue

Occurrence of part families and machine cells

Proposition 1: Organizational feasibility for implementation of CM is enhanced by the occurrence of natural families of parts with similar processing requirements.

The premise of CM is the existence of part-families and corresponding machine cells. In other words, there must exist a group of parts that can be manufactured by a set of machines. These different machines are clustered together to form machine cells. The ideal situation in CM is when a group of parts can be completely manufactured within a cell. In this situation, parts do not cross cell boundaries and maximum benefits of CM are realized. However, this may not always be possible; in such situations, parts are allowed to move from one cell to another. This is due to the unavailability of certain key machines because they are one-of-a-kind machine types, and/or there is a need to balance cell and machine loads.

For the successful implementation of CM, therefore, one requirement is the existence of independent sets of parts that can be manufactured on a set of machines. This requirement mandates the determination of the incidence of such part-families. If an analysis of all the manufactured parts indicates that distinct groupings of parts, based on part routings is possible, then the indication is of a high incidence of part-families with similar processing requirements. Consequently, these part-families can be manufactured in the machine cells with little or no inter-cell movement. Conversely, a low incidence of part-families and corresponding machine cells will indicate that very few parts can be grouped into families for cell manufacture. In such a case, an attempt to design a CM system will result in a large cell size and/or substantial inter-cell movements with the attendant control problems. Thus, in accordance with this proposition the level of this attribute should be high for organizational feasibility for implementation of CM.

Occurrence of indivisible processes

Proposition 2: Organizational feasibility for implementation of CM is increased by the absence of (or by the presence of very few) occurrences of intermediate indivisible processes in part routings.

By definition, indivisible processes are centralized in nature and consist of processes such as heat treatment, sand blasting, painting, and sub-contracted work. Existence of such intermediate processes in part routings makes the creation of self-contained part/machine groups difficult, because parts are required to visit the centralized process, complete the operation there and return back to the group for further processing (Leonard and Rathmill 1977a). Therefore, for effective CM implementation, the incidence of such intermediate visits should be very low. Ideally, the absence of indivisible processes between machine operations is desirable; however, if such processes are absolutely necessary, then cells should be placed in near proximity to these processing departments. Also, if possible, such processing should be done after the end of the machining cycle. Parts can then be transported to these processing departments as a group. Therefore, in accordance with this proposition, the level of this attribute should be low for organizational suitability for implementation of CM.

Stability of product demand

Proposition 3: Organizational suitability for implementation of CM is increased with a stable, long-term product demand.

CM should only be implemented after an intensive survey of product demand and the demand of the corresponding components needed to make these products (Leonard and Rathmill 1977a, 1977b). A stable product demand enables the estimation of capacity requirements fairly accurately. It also translates into stable load conditions on the cells and machines. Conversely, variation in the product demand will result in the starvation of some cells and overloading of others with disastrous consequences. Also, flexibility may be lost when cells are created, due to the restriction on a group of machines to manufacture a group of products. With an unstable product demand, maximum flexibility is desired to cater to the unexpected demand situation. Conversion to a cellular layout in such a case will result in lower production efficiency and consequently, unfulfilled customer demands. It must be remembered that the creation of cells involves high plant relocation costs; thus once cells are developed, their configuration cannot easily be changed. Therefore, it is necessary to consider the stability of product demand before changeover. Examples of CM applications found in the literature show that the organizations implementing CM were in a stable market (Durie 1970, Ranson 1972, Allen 1974, Tilsley and Lewis 1977). The level of this attribute (given by the stability of the product demand) should be high for CM implementation purposes.

Stability of product-mix

Proposition 4: A stable product-mix condition enhances organizational feasibility for implementation of CM.

A stable product-mix implies a predictable demand on production capacities. Therefore, a stable product-mix enables a fairly accurate estimation of capacity requirements. The necessity of accurate capacity requirements is more pronounced for CM purposes in comparison to the functional layout because of reduced machine availability. The distribution of orders also dictates the extent of machine loading. Should the distribution of orders change, "certain cells and machines may be excessively loaded while others may be starved of work," (Rathmill et. al. 1974).

As the variety of product-mix to be produced decreases, the variety of components required to assemble the end products also decreases. This variety reduction can probably enable the grouping of components into specific families; this characteristic can, therefore, be viewed as a move from a "one-of-a-kind" type of manufacture to a "medium-part-variety" and "medium-production-volume" manufacturing situation for which CM is thought ideal (Lewis 1973, Groover and Zimmers 1984). Therefore, a stable product-mix is conducive to an organization's implementation of CM. Industrial case studies reported by researchers indicate a relatively stable product-mix in the long-term (Ranson 1972, Venkitadri and Kemshetti 1975, Burbidge 1979). Thus, the level of this attribute (given by the stability of the product-mix) should be high for effective CM implementation.

Complexity of components

Proposition 5: Organizational feasibility for implementation of CM mandates low complexity of manufactured components.

Complexity of components has been defined for this research in terms of three sub-factors: total number of machines required for the manufacture of a component, the total number of operations per component, and the total machining time per component. The pertinence of the proposition with respect to each of the three factors is discussed below.

The total number of machines required to complete a component reflects the length of the routing and is therefore a measure of its manufacturing complexity. In general, the larger the number of machines required to complete the component, the more complex is the component. Increasing machine requirements imply an increase in the routing and, thus, in probable cell size. Literature on CM does not provide limits on the cell size although an average of six machines is mentioned by some researchers (Greene 1980, Wemmerlov and Hyer 1987c). However, it is felt that increasing cell size will negate the benefits of CM due to increased material flow with its attendant drawbacks, such as increased material handling, job tracking, and resulting increases in throughput time (Oliva-Lopez and Purcheck 1979).

The total number of operations required to complete a component also indicates component complexity. The larger the required number of operations, the more complex the component (Burbidge 1979). It is, therefore, conceivable that inter-operational set-ups incur additional set-up times, thereby increasing total manufacturing times. In a CM situation, such increases result in queueing of part-families awaiting set-ups and processing in front of machines, the number and range of which have already been reduced (Flynn and Jacobs 1984). Another effect of such complexity is the problem of load balancing among machines within the cells if the operations are performed mostly on certain machine types leading to overloading of certain machines and underloading of others (Burbidge and Dale 1984). Therefore, for successful CM operations, the number of operations required to complete a component should be low.

It is felt that the average machining time per component should be low for CM implementation to be feasible. Increased machining times per component will result in increased queueing in front of the machines in a cell (Flynn and Jacobs 1984) because of a restriction on the number of machines available for component processing. Efforts to alleviate such situations may require inter-cell movements. Benefits of CM may thus be nullified to a great extent. Therefore, based on the arguments presented above, it is felt that for successful CM implementations, average machining time per component should be low. Considering the relationships between the sub-factors (defining component complexity) and the feasibility for the implementation of CM presented above, it is seen that component complexity should be low for successful CM implementation.

Weight of components

Proposition 6: Organizational feasibility for implementation of CM is enhanced if the weight of manufactured components is low.

There are distinct advantages when the components manufactured are light. These include ease of transportation, the use of light-duty moving equipment, and the need for less space when compared to bulky components. Heavy components require more moving time and may result in the blockage of machines (Flynn and Jacobs 1984). Side tracking of jobs and additional material handling costs are also cited as notable disadvantages associated with the processing of heavy components under group manufacture (Leonard and Koenigsberger 1972, Rathmill et. al. 1974). Case studies by Burbidge (1979) and Leonard and Rathmill (1977b) demonstrate that CM applications are best suited for the manufacture of light-weight components. Thus, the level of this attribute should be low for successful CM implementation purposes.

Capacity balance

Proposition 7: Organizational feasibility for implementation of CM is improved if there is evidence of capacity balance in equipment of the existing layout.

It has been noted by researchers (Hedge et. al. 1979, Oliva-Lopez and Purcheck 1979) that situations having extremely high utilizations of certain key machine types and low utilizations of the remaining secondary machine types are unsuited for group production. This is due to capacity bottlenecks in the over-utilized machine types and gross under-utilization of the remaining machine types, once these machines are included in the cell. This situation is further aggravated if the over-utilized machines are not duplicated, that is, if there is only one of that kind available. Therefore, current capacity imbalances should be considered in determining organizational feasibility for implementing CM. Ideally, it is preferable to have situations where all machines have high utilizations and are utilized equally. However, this is seldom achieved in practice. Therefore, high to medium utilization of all processing equipment is desirable. This has the effect of providing adequate capacity for all jobs resulting in as close a capacity balance as possible. Thus, the level of this attribute should be high for effective CM implementation.

Flexibility of labor

Proposition 8: Increased labor flexibility enhances organizational feasibility for implementation of CM.

Labor flexibility, that is, the ability of operators to execute various operations and move between workstations within and between cells is often thought to be a prerequisite for an efficient cell system (Burbidge 1979, Wemmerlov and Hyer 1987b). A machine cell will usually have more machines than operators. Therefore, operators should be trained to operate more than one machine type. Labor flexibility is also important when there are a number of underloaded or second operation machines in close proximity, all of which perform operations requiring short operation times. An operator can, in such cases, work at more than one machine while the primary machines are in operation. Labor flexibility is also important when machines are automatic. The operator can then easily handle multiple machines and be engaged in other work when they are running. Intra- and inter-cell labor mobility, either among same machine types or between different machine types, also may act as a buffer against labor absenteeism. According to Burbidge (1979), labor flexibility presents an opportunity for an operator to learn new skills and also adds an element of job satisfaction. Therefore, the level of this attribute should be high for organizational feasibility for implementation of CM.

Availability of computer support

Proposition 9: Organizational feasibility for implementation of CM is enhanced by the availability of computer support.

It is felt that the availability of computer support is essential for successful implementation of CM systems. Analysis of component routings for determining part and machine groupings require the use of computer support; manual handling of such massive amounts of data is not practicable. Instances in literature show evidence of manual analysis of part designs to form part groups, but they are very uncommon (Wemmerlov and Hyer 1985). Almost all academic research in the area of part-machine grouping uses computer support for data analysis. Computer use for the design of CM systems is also prevalent in industry. Burbidge (1975) predicted that "in the future, most computer companies will have application programs for the technique, and that any company with route cards will be able to use one of these package programs to find its families and groups." This has not occurred and could be due to a lack of knowledge in GT/CM or due to a lack of interest in it. However, the literature review indicated the importance of computer support in implementing GT/CM.

Also, a classification-based grouping procedure will require computer support for data manipulation; the computer storage requirement goes up with the sophistication of the classification system. Load computations for the analyzed part-machine groupings also require computer assistance. In addition, if simulation analysis of cell performance is to be done or if computer-assisted scheduling procedures are desired, then computer support is absolutely necessary. The use of in-house or commercial inventory control packages (MRP or MRP II, for example) also need computer support.

Limited information is available on the amount of secondary computer memory required to execute computer programs for determining part-families and machine loads, for executing a GT/CM simulation system, or for running a computer-based classification and coding package. A search has yielded the following regarding computer memory requirements for running certain GT application programs.

King's work (1980) in the area of part-family formation required 120Kb of virtual memory storage for a problem with 50 rows (machines) and 2000 columns (components). A refinement of King's computation technique was by King and Nakornchai (1982). Their solution to a 36 row and 90 column problem required 20Kb of memory. King and Nakornchai did not state memory requirements for the solution of the problem used by King (1979). Thus, a comparison in terms of memory requirement of the two algorithms is not possible. The method for cell formation by Rajagopalan and Batra (1975) was run on an IBM 7044. The authors reported a problem size of 1000 components and 40 machines. Chan and Milner's (1982) method for cell formation via matrix rearrangement required 82Kb of virtual memory for a problem size of 500 rows and 50 columns. The matrix rearrangement procedure by Waghodekar and Sahu (1984) was run on a mainframe computer and their reported problem size was between 5 rows and 7 columns to 36 rows and 90 columns. A CM scheduling simulator by Dale and Dewhurst (1984) was programmed in BASIC to be run on a microcomputer. The authors did not mention the memory required for the execution of the simulator. Han and Ham's (1986) computerized optimization of a classified and coded database was designed to run on an IBM PC/XT computer. From what has been reported by them, it appears that an in-house classification and coding system database was created using the same computer facilities. Chandrasekharan and Rajagopalan (1987a, 1987b) reported the use of an IBM 370 for the execution of a part-machine grouping program while Askin and Subramaniam (1987) used a PRIME 350 computer to run their cost-based GT configuring heuristic.

From the literature search, it is evident that there is a lack of information about specific memory requirements of GT software. When one considers the extent of research done in the area of cell formation and cell simulation, it is surprising that researchers do not mention the specifications of the computer systems that are necessary to execute the software. Also, the literature review presented above does not indicate storage requirements necessary if the problem size increases -- a reality in actual industrial settings. It is clear, however, that computer support is used extensively in GT research.

It is felt by this researcher that computer support in excess of 256Kb of memory is necessary as a minimum. However, this requirement will increase with user requirements. For example, the use of simulation programs, commercial classification packages, or the use of a CAD system will require substantially more memory. Therefore, the level of this attribute should be at high values to favor feasibility for CM implementation.

Availability of a classification and coding scheme

> Proposition 10: The availability of a classification and coding scheme increases organizational feasibility for implementing CM.

It must be stressed here that the availability and use of a classification and coding system is not a prerequisite to the implementation of CM. However, its availability greatly improves chances of successful CM implementation by creating an organized database of parts. Early concepts in GT/CM were thought to be synonymous with classification and coding; the development of PFA (Production Flow Analysis) by Burbidge (1975) presented a new methodology in CM. Many successful CM implementations in Europe have used classification and coding techniques as a vehicle for CM implementation (Durie 1970, Opitz 1971, Ranson 1972, Burbidge 1979). Recent surveys and case studies of U.S. industries report the widespread use of classification and coding systems in the context of CM (Schaeffer 1980, Hyer 1984, Kriegler 1984, Tulkoff 1984, Wolfe 1985, Wemmerlov and Hyer 1987a, 1987b).

The great virtue of classification and coding is its integrity of data preservation. Thus accurate and timely data are available. An organization with an installed classification and coding system can use it effectively prior to and during CM implementation. Classified part data can be used to determine part families, to identify material types, and assess stockholding. Advantages also lie in design engineering (retrieval of existing designs), manufacturing engineering (standardization of process plans), sales (better cost estimation), and purchasing (volume discounts on group purchases). Thus, the availability of a classification and coding system greatly facilitates the initial planning and subsequent implementation of a CM system. However, as mentioned before, its unavailability does not necessarily undermine CM implementation possibilities. Thus high levels of this attribute will be indicative of feasibility for CM implementation, whereas low levels of this attribute will not indicate that CM might be infeasible and, therefore, should not be considered in the decision-making procedure.

Computer literacy of personnel

> Proposition 11: Organizational feasibility for implementation of CM is enhanced by high levels of computer literacy of middle-level personnel.

It has been proposed in a previous proposition that the implementation of a CM system requires the use of computers because of the need for the analysis of bulk data. This need is further intensified if in-house software development is desired. Therefore, the CM implementing personnel need to be fairly conversant with computer systems, packaged software, and/or computer programming in order to code or execute computer programs or analyze output data. As commercial application programs for part-family formation are not currently widely available, it is believed that company personnel will have to develop their own application programs or seek academic help to do so. In the former case, company personnel responsible for such development will have to be proficient in computer programming. Also, recent surveys (Wemmerlov and Hyer 1987a, 1987b) have shown that computer-based material control systems, CAD and CAPP systems, and extensive NC part-programming systems are in use in the facilities engaged in CM. These surveys also indicate the use of computer support in the following types of analyses: load/utilization calculations, work center where-used queries, estimations of throughput time, and routing analyses. Spreadsheet program and projection models were also used in some of the companies surveyed to determine performance measures. Several respondents of the survey claimed the development of in-house programs for the analysis of CM systems.

Based on the evidence above, it is likely that organizations interested in implementing CM will be required to utilize computer services. Therefore, computer literacy of personnel involved is highly desired and thus, the level of this attribute should be high for organizational feasibility for implementation of CM.

Skill level of operators

Proposition 12: Organizational feasibility for implementing CM is enhanced in situations where the majority of the machine operators are semi-skilled.

One characteristic of CM is that the number of machine operators is normally less than the number of machines in the cell. In such cases, operators run multiple machine types. Therefore, highly skilled operators of particular machine types may feel the deskilling effects when they are required to produce simple parts or a restricted range of similar parts with a restricted range of operations and machines as is often prevalent in a CM environment (Leonard and Rathmill 1977a). The highly skilled worker is proud of his/her skills and may feel a loss of status if required to perform semi-skilled duties. Fazakerley (1976) noted the resistance from unions when skilled operators were required to perform semi-skilled or unskilled jobs. This proposition can also be viewed favorably from the viewpoint of operator training for gaining flexibility. Moderately skilled operators can be trained, if necessary, to operate other machine tools. It is believed that retraining of highly skilled operators of a particular machine type for the operation of another machine type may be difficult.

In view of the above, it is proposed that the majority of the operators should be semi-skilled in a CM environment. The level of this attribute (in terms of skill) should, therefore, be low for successful CM implementation.

Forecasting reliability

Proposition 13: A reliable product demand forecast greatly enhances the feasibility of the implementation of a CM system.

In a functional layout, deviations in the product demand forecast can be handled by the inherent flexibility of the system (Lewis 1973). This is not possible in a GT cell; inaccurate product demand forecasts may have the effect of either overloading or underloading the cells because of the allocation of machines to cells. Overloading occurs when the demand is higher than the forecast; underloading occurs when the demand is lower than the forecast. Such a situation will result in unfilled customer orders in the first case and a state of machine idleness in the second. Therefore, inaccurate product demand forecasts can seriously damage the reliable operation of a CM system.

The inaccuracy in product demand forecast also affects the procurement of materials from suppliers. If the forecast is inaccurate, the predicted amount of raw material and the time of its delivery is also inaccurate. Thus, irregularity in supply may result in the breakdown of cell performance.

Advocates of GT/CM propose the use of a short single cycle for the manufacture of parts or for ordering of materials (Burbidge 1975, Nagarkar and Fogg 1979). With short ordering cycles, it is absolutely essential to predict accurately production or ordering requirements. It is not possible to manufacture parts or order material when it is not known what to produce or order. From the argument above, it is therefore suggested that a reliable product demand forecast greatly assists in the successful implementation and operation of a CM system. Therefore, the level of this attribute should be high for successful CM implementation.

Reliability of equipment

Proposition 14: Organizational feasibility for implementation of CM is improved by increased reliability of the processing equipment.

The reorganization to a cellular layout involves the grouping of dissimilar machine types to process a set of parts. Often, each cell contains only one (in number) of certain key machine types. Certain secondary machine types may be duplicated within cells. Therefore, the availability of machines in a cellular layout is more restricted than in a functional layout. Thus, in the event of a breakdown of a certain machine type, the entire processing activity stops; job reallocation is not possible then. This contrasts directly with a functional layout where the job may be directed to one of many available machines of the same type. Further, the reliability of key machine types is more important than that of the secondary machine types.

Industrial case studies also point to the hindrance of production in a cellular environment due to machine breakdowns (Hyde 1981, Wemmerlov and Hyer 1987b). Acquisition of new machine tools was cited in one case as a way of solving the problem. Therefore, the effective operation of a CM system requires that the machine tools be reliable. The level of this attribute should, therefore, be high for effective CM implementation.

Implementation time

Proposition 15: Organization feasibility for implementation of CM is improved with sufficient implementation time.

The effort to reorganize a functional production facility along the lines of a successful CM facility requires a considerable amount of time. Since the conversion requires a total reorganization (both in layout and administration), management must be willing to allocate the time necessary to implement the concept. The initial effort is mostly given to determining the component families and machine groups. Although a rough analysis may be done in a short period of time, a refinement of the established cell evolves over a period of time (Wemmerlov and Hyer 1987b). A detailed classification and coding procedure, if desired, can also take as long as two to three years (Ranson 1972). Plant relocation also requires time, especially if heavy machinery is required to be moved. Foundations have to be built; electrical connections, water lines, and compressed air ducts installed; and gangways have to be constructed. Also, the installation and operation of a different material control system will require time. Furthermore, substantial time will have to be invested in management and worker education and training in GT/CM principles.

Industrial implementers of CM systems have stressed the need for progressing slowly and not under-estimating the time requirement for CM implementation (Burbidge 1975, Levulis 1980, Wemmerlov and Hyer 1987b). Available estimates in CM literature indicate that actual CM implementation can take a year or more (Burbidge 1979), and changes are evolutionary. Therefore, insufficient allocation of implementation time will increase the likelihood of failure in implementing a CM system. Therefore, the level of this attribute should be high for successful CM implementation.

Reliability of suppliers

Proposition 16: Organizational feasibility for implementation of CM is enhanced by high supplier reliability in the delivery of all raw materials.

One of the claimed benefits of CM is reduced throughput time. This reduction in throughput time is dependent not only on faster movement of material within the facility but also on timely and defect-free materials from the supplier. According to Leonard and Koenigsberger (1972, p.136), "when attempting to meet customer demands it is of little value to have a group line with a production time of two days, if a six-week delay in the delivery of raw materials exists." Thus, the short-cycle operation of a CM system requires quick response from material suppliers. The quality of supplied material also has an impact on production performance. Since a CM environment operates on the basis of short order cycles, inferior material supply will delay group production more than it will a functional production schedule.

Burbidge's (1979) case studies on CM facilities found that the main difficulty in production control in a number of companies was caused by unreliable deliveries of materials and finished parts from suppliers. According to him, the problem of unreliable material supply should be tackled before attempting the introduction of GT/CM. Therefore, supplier reliability in the delivery of raw materials is important from the implementation point of view. Thus, the level of this attribute should be high in order to support CM implementation.

Material control system

Proposition 17: Organizational feasibility for implementation of CM is enhanced if a single-cycle ordering system based on short cycles is in effect.

It is believed that a reorder-point system based on economic batch quantity of individual parts is unsuitable for group production (Burbidge 1975). A reorder-point system is based on the ordering of individual parts at varying intervals of time. This random ordering of parts precludes the use of part-family processing. Also, the triggering of order releases based on the actual inventory levels disables any control over the variability of periodic load input (New 1977). It is also impossible to plan the sequencing of components if individual orders are controlled independently. Advocates of GT therefore suggest the use of a single-cycle, short-term ordering system like MRP (Burbidge 1975, New 1977, Wemmerlov and Hyer 1982). They claim that the explosion of the product structure based on short-term product demand enables a part-family approach to ordering for production. Product forecasts are generally more accurate because of a shorter forecasting period. The production system is also more flexible to change in market demands. Researchers (New 1977, Sata et. al. 1978, Wemmerlov and Hyer 1982) have also found that the use of a combined GT and MRP system provides a manufacturing environment with the advantages of both the systems. The input end of MRP allows a specific identification of the product demand. The GT system provides an efficient scheduling of the product demand in the short-term. When GT is used by itself, the time-phased aspects of part production are not considered (Sata et. al. 1978); that is, it assumes that all parts are available for production at the beginning of the time period. This is not always true; therefore, there is a possibility that wrong components are produced. MRP, specifically, handles this issue. Therefore, it is felt that if an MRP system (or a similar system) is in use in a functional production facility and will be used after reorganization, the transition to a GT system will be much smoother. The use of a single-cycle, short-phase material control system, therefore, will lead to better control over production and, consequently, successful CM implementation.

Workload on process planners

Proposition 18: Organizational feasibility for implementation of CM is indicated by high workload on process planners.

The incidence of high workloads on process planners stems from the absence of a design or process planning standardization procedure in a typical functional system. Typically, with an absence of standardization procedures, the design office will send multiple drawings with references for the part orders received. This necessitates the preparation of process plans and tooling. When many orders of different parts are received, many different process plans will be required. Therefore, without GT in design or manufacturing, there is a distinct possibility that part similarities in design and/or manufacturing will be frequently overlooked. Thus, unnecessary process plans will be created and with many such demands, process planners will be constantly overworked.

Recognition of this factor has led in certain instances to the standardization of process plans after CM implementation. Schaeffer (1980) reported the case of the GE facility in Cleveland, Ohio, where the overload on the process planners led to the standardization of process planning and, finally, to the establishment of manufacturing cells. Houtzeel (1981) also described how computer-aided process planning via GT can help in reducing the planner's labor and, therefore, planning costs. However, a low process planning workload does not automatically imply infeasibility for the implementation of CM. Thus, high levels of this attribute will be indicative of feasibility for CM implementation. However, its low levels will not indicate otherwise; and if such is the case, then, this attribute should not be considered in the decision making procedure.

Scheduling procedures

Proposition 19: Organizational feasibility for implementation of CM is enhanced if there is currently a decentralization of scheduling and if much scheduling is done by first-line supervisors.

A change to a cellular layout almost always results in scheduling of jobs by the first-line cell supervisors (Burbidge 1975, 1979). This is in contrast to the functional environment where jobs travel to different departments and therefore, require centralized control. One effect of centralized scheduling is that it tends to isolate the scheduler from the shop. With a GT/CM system, centralized scheduling acts to the disadvantage of the production system. A cell supervisor will have a better idea of current situations, such as machine breakdowns, labor absenteeism, tooling requirements, etc., and will be able to react better to emergencies through proximity to the cell. Also, the feeling of responsibility is enhanced, which is thought by researchers to contribute to the success of a CM system (Fazakerley 1976). Burbidge's (1979) case studies found one situation in a company where centralized scheduling after CM implementation was a major cause for production inefficiencies.

A survey of manufacturing cells in the U.K. by Pullen (1976) found that operators did not have any authority for any production sequencing or output target setting. These decisions were mostly made by management. As a result, the author claims, cell efficiency suffered. Thus, it is felt that decentralization of production scheduling (where the functional first-line supervisor is directly involved with scheduling procedures) will enhance an organization's feasibility for the implementation of CM. Therefore, the level of this attribute should be high for successful CM implementation.

Managerial support

Proposition 20: Organizational feasibility for implementation of CM is enhanced by the presence of top management support.

Literature in the area of GT/CM has frequently cited managerial support as one key ingredient for the promotion of CM. Grayson's (1981) article on the evolution of GT in the USSR reported the official support given to this production philosophy and ascribed the growth of GT to such official backing. Other reports of industrial surveys and case studies of CM applications also point to the presence of a committed and supportive management for successful CM installation (Burbidge 1979, Hyer 1984, Wemmerlov and Hyer 1987a, 1987b). On the other hand, there is evidence that indicates that management indifference and lack of commitment has resulted in failures in implementing CM (Burbidge 1979).

Implementing CM requires long-term planning because of the length of time and costs involved. Therefore, top management should have a future-oriented perspective if CM implementation is to be successful. A short-term payback orientation is unacceptable for such a scheme. Incidences in literature illustrate situations where a CM implementation was abandoned due to a change in managerial perspectives (Burbidge 1979, Wemmerlov and Hyer 1987a). Also, implementing a CM system requires resources in the form of labor, materials, and money. Management must be committed to provide them as and when needed. Furthermore, managers should be willing to educate themselves and lower-level employees about the new philosophy.

Therefore, in light of the evidence above, it is felt that top management support is critical for the implementation of CM systems. In particular, long-term thinking, allocation of resources, and leadership capabilities on the part of management are essential for successful CM implementation. Thus the level of this attribute should be high for successful CM implementation.

Resistance to change

> Proposition 21: Organization feasibility for implementation of CM is enhanced by low employee resistance to change.

Resistance to change is frequently encountered in the context of implementing a CM system. One reason for resistance stems from concerns over job security. Many employees fear that the implementation of a new production technology will result in their displacement (Hyer 1984). The requirement of retraining in GT/CM has often led to open hostility and unionized resistance; people tend to adhere to the belief that theirs is the "one best way of doing things." Resistance to change in the context of CM has also taken the form of inter-departmental non-cooperation and non-cooperation among personnel within departments toward guidelines set by management to facilitate the implementation procedure (Wemmerlov and Hyer 1987a). Examples are found of design engineers refusing to use the part-coding systems in design retrieval because they felt that it would curb their creativity; and the unwillingness of diverse departments to work together in the installation of a classification system. Burbidge (1979) cites an example of a failure in GT due to the impossibility of reaching an agreement with the labor force regarding payment systems in the CM environment.

Based on the arguments above, it can be deduced that if a company's history shows high incidence of strikes, labor turnover, or supervisors intransigent to changes, chances are that the proposal of implementation of CM will incur large-scale resistance. It is then the responsibility of the management to overcome such resistance by communication and involvement. Conversely, lack of such resistance will facilitate a smoother transition to CM. Therefore, the level of this attribute should be low for effective CM implementation.

In summary, the propositions above have linked the level of an attribute to the feasibility for implementation of CM. The theoretical underpinnings of these propositions are largely in the literature. The next section constructs the propositions relating the levels of the attributes of the choice-of-method issue with the approach to part-family formation.

4.1.2 Propositions -- Choice-of-method issue

Component design similarity

Proposition 1: A high component design similarity favors a design-oriented approach.

Design similarity of components takes into account similarity based on component shape and size. This attribute in fact has been used to form component families and associated groups in many GT applications (Hyde 1981). If components have closely similar geometric configurations and similar features, then it is evident that they can be thought similar from a design point of view. This similarity can, therefore, be used to group them together. This may also result in standardization of component designs, avoidance of component redesign by eliminating design duplication, and quick and efficient component design retrieval. These are benefits arising from the use of design similarity and have been much reported in GT literature.

High component design similarity, used in conjunction with manufacturing similarity, may be used in sequencing parts for manufacture using the composite part concept, thus resulting in savings in set-up times and correct component sequencing (Burbidge 1975). The composite part is a hypothetical part that represents all of the design and corresponding manufacturing attributes possessed by the various individuals of the part-family. However, it must be remembered that the composite concept in manufacturing holds only if there is sufficient manufacturing similarity. While it is expected that components similar in design attributes will have similar manufacturing attributes, this may not always be the case.

Case studies of GT applications in literature illustrate the use of a design-oriented grouping procedure in the cell design process (Hyde 1981, Wemmerlov and Hyer 1986, Wemmerlov and Hyer 1987a, 1987b). Based on the discussion above, it is felt that high component design similarity favors a design-oriented approach.

Component manufacturing similarity

Proposition 2: A high component manufacturing similarity favors a production-oriented approach.

Manufacturing similarity among components takes into account the similarity of their manufacturing processes. This similarity is determined by analyzing the routings of components. The use of the production-oriented procedure for the purpose of designing cells was first introduced by Burbidge (1975). The rationale of this approach is that components may not be geometrically similar for grouping, yet they might possess significant process similarities to be amenable for group production. Therefore, if components possess significant manufacturing similarity, then a grouping procedure based on the routing analysis is possible. Also, such an analysis enables the standardization of process routes. It does so by identifying infrequent or irregular process routes and rationalizing them. Thus a manufacturing-based grouping technique is preferable when high manufacturing similarity exists among components.

Availability of a CAD system

Proposition 3: The availability of a CAD system enhances the use of a design-oriented approach.

A computer-aided-design system is one that enables the development, analysis, or modification of an engineering design with the help of a computer and computer graphics (Groover and Zimmers 1984). It also helps in creating a design and manufacturing database for product design that includes part geometry data, bill of materials, material specification, etc. Part designs stored in the database can also be used in process planning, numerical control programming, tool and fixture design, and production planning. The benefits of CAD are also noted in the area of GT where the design database can be used effectively for developing an interactive parts classification and coding system and for developing a family-of-parts NC program (Houtzeel and Schilperoot 1975, Houtzeel 1981, Bhadra and Fisher 1988). A part code can also be used to check a design database for existing part similarity. This eliminates design redundancy.

Research has been done in the development of algorithms for the generation of part codes directly from a drawing database (Nnaji and Vishnu 1986, Bhadra and Fischer 1988). However, these algorithms cater to a restricted range of components (for example, rotational parts alone) and have not been applied in industry. Thus, it is unlikely that small to medium manufacturing concerns will use the algorithms in the near future. However, a CAD system can be efficient in retrieving similar designs if it is interfaced with a GT code input scheme (Houtzeel 1981). A recent survey of GT applications by Wemmerlov and Hyer (1987a) found that 4 out of 52 respondents had integrated CAD systems with a GT coding and classification scheme. Thus the presence of a CAD system with its efficient design procedure and quick retrieval system would seem to enhance a design-oriented approach. It would not be a critical factor in the approach for part-machine grouping, however.

Monetary Support

Proposition 4: a) A formal design-oriented procedure requires extensive monetary investment; b) a formal production-oriented procedure requires low to moderate monetary investment.

A formal design-oriented procedure is defined as one using a comprehensive classification and coding scheme for the design-based coding of parts. This procedure may be computerized or manual. This procedure is distinguished from informal design-oriented procedures, like visual inspection or rule-of-thumb approaches where some families of components may be self-evident. However, these methods do not provide necessarily the best groups if large numbers of components are involved (Abou-Zeid 1975, McManus 1980). Also, data about components are not recorded when the groups are formed by using these informal procedures; that is, the utility of these procedures terminates with the formation of groups. Component shape classification, on the other hand, provides an organization with integrated data that can readily be accessed.

However, the implementation of a formal classification and coding scheme requires substantial financial investment. Three options are available: (i) to develop the system in-house without consultant help, (ii) to seek consultant help in developing a tailor-made system, and (iii) outright purchase of a commercial package. The first option requires investment in talent and training, both of which cost money. The second and the third options are the most expensive because of high consultant fees over extended periods of time; commercial classification packages are known to be expensive.

The production-oriented approach, on the other hand, involves little expense because the basis of part-family grouping involves an examination of the component route cards. A manual or computerized analysis of the route cards can then yield part-families. This can mostly be accomplished in-house.

However, if the component range is small and visual inspection of parts or part-routing knowledge enables the identification of similar part designs and/or identical process routes, then it is felt that either approach is not expensive. This, therefore, leads to the following corollary proposition:

> Proposition 4: c) an informal design-oriented or a manual production-oriented approach requires low monetary investment.

In summary, monetary investment is needed more for the formal design-oriented approach than for the informal design-oriented or production-oriented approaches.

Implementation time

> Proposition 5: a) A formal design-oriented procedure requires extensive implementation time. b) a formal production-oriented approach requires lower implementation time.

A formal design-based classification and coding system requires a substantial amount of time whether it is developed in-house or acquired externally. If it is developed in-house, the time required comprises the time taken by personnel to get acquainted with the principles of classification and coding, the time taken to develop the coding system, and the time taken to implement the system. If the system is acquired outright as a software package, or if consultant help is sought, then the time required is slightly less as the system is not required to be developed. Published accounts of the time required to implement a classification and coding system estimate times of one to two years (Ranson 1972, Levulis 1980).

A production-oriented procedure, on the other hand, is not as lengthy to implement as a formal design-oriented procedure. Analysis of part routings do not involve the large time delays, because only the routings need to be analyzed instead of a comprehensive analysis of part-geometry and other relevant part information. The only time required is for the collection of the already existing data and for the development of computer software for the data analysis. Academic publications of developed software for such purposes do not specifically state the time required for the development of the software. However, as the underlying logic of the part/machine grouping is not very complex, it is felt that the time requirement is not extensive.

However, if the component range is small, it is felt that there is not an appreciable time differential in implementing an informal design-oriented approach or a manual production-oriented approach. This leads to the following proposition:

> c) An informal design-oriented approach or a manual production-oriented approach requires lower implementation time.

Thus, the formal design-oriented procedure requires more implementation time than informal design- or production-oriented procedures.

Availability of computer support

> Proposition 6: a) a formal interactive design-oriented approach to part-family formation requires extensive computer-support; b) a formal manual design-oriented approach to part-family formation requires no computer support; c) a formal production-oriented approach requires low computer support.

The manipulation of numerous part data in a formal design-oriented system necessitates extensive computer support. It is difficult to implement a classification system without computer support because of the amount of information stored in the part codes, the length of which vary. In the Opitz coding system, the code length is a minimum of 9 digits; whereas, in the MICLASS coding system the code length may be as high as 32. Therefore, if a multitude of components is to be sorted by code comparison for family formation purposes, then computer support is inevitable. The available commercial code systems all have computer capability, and some, like MICLASS, interactively assign codes to parts. In addition, computer support requirements increase with supporting computer software (CAD, MRP, etc.). However, manual coding systems are also available and lead to the construction of proposition 6b.

In comparison, it is felt that production-oriented procedures for group formation do not require as much computer power. Available algorithms for developing part-family/machine groups are reported to require from 20Kb (King 1980) to 82Kb (Chan and Milner 1982) for the execution of small- to medium-sized data sets. Therefore, for increased problem size, it is conjectured that the memory requirements for executing the problems will not be as large as those required by formal computerized classification and coding schemes. Also, storage requirements depend on the quantity of data stored. For a production-oriented method, manufacturing data such as component routings, set-up time, lot size, etc., are stored. Information on part-shape characteristics are not required. Conversely, a design-based classification system will store part design information and additionally, part routing information and other company-specific information. Therefore, computer storage requirements for a design-oriented approach is much higher than its production-oriented counterpart.

There is a lack of comparison studies regarding the requirement of computer support associated with either method. However, considering the breadth of part data that is usually addressed by a classification system, it is felt that substantially more computer capabilities are required for the operation of a an interactive design-oriented approach than a production-oriented approach.

The following proposition is also presented:

> Proposition 6 d): An informal, design-oriented approach or a manual production-oriented approach, require little or no computer support.

It is obvious that, if part quantities are limited, a visual grouping approach may be followed or a manual route-card sorting procedure may be performed for the grouping of parts and machines. The visual part analysis approach has been applied in industry (Wemmerlov and Hyer 1985). It is possible that the use of this approach stemmed from a knowledge of part shapes and from the inability to afford the high-priced classification packages. Regarding manual analysis of route cards, it is felt that a limited numbers of cards might enable the operation of this method. Burbidge (1975) mentioned a limit of 2,000 cards. However, it is difficult to imagine a manual grouping analysis for such a large number of cards. Therefore, it is felt that the part population should be considerably smaller if manual methods are to be applied.

Computer literacy of personnel

> Proposition 7: a) A formal interactive design-oriented approach requires high computer literacy of implementing personnel; b) a formal production-oriented approach requires high computer literacy of implementing personnel.

It has been mentioned before that a formal interactive design-oriented procedure requires extensive computer support. It is logical to deduce, therefore, that extensive computer support, in turn, implies high computer literacy of the personnel involved. If a coding scheme is developed in-house, then its computerization will require computer programming. Industrial examples of in-house coding development (Ingram 1982, Dumolien and Santen 1983), corroborate this statement. Purchased software may have to be modified or interfaced with user-written application software (Wemmerlov and Hyer 1987a). Therefore, computer literacy of implementing personnel is a requirement if a formal design-oriented approach is to be applied.

The production-oriented procedures have evolved through academic research. These procedures have also been applied in industry (Burbidge 1975, 1979, DeBeer and deWitte 1978, Nagarkar and Fogg 1979, Wemmerlov and Hyer 1987b). The computerization of these procedures must be done internally if software cannot be acquired (from academicians or elsewhere). The development of software requires the ability to program the algorithms. If software is acquired externally, computer literacy is needed for its execution or modification. Therefore, it is logical to conclude that computer literacy of implementing personnel is essential for applying a production-oriented approach.

It is obvious that if the component range is small enough or is not varied, informal design-oriented procedures or manual production-oriented procedures may be used. In such cases computer skills may not be necessary. This may also be the case if a formal manual design-oriented approach is used. This leads to the following proposition:

Proposition: 7c) Informal design-oriented procedures or formal manual design-oriented procedures and manual production-oriented procedures require little or no computer literacy of implementing personnel.

Inter-departmental information requirements

Proposition 9: High inter-departmental information requirements favor a formal design-oriented approach.

One criticism leveled against the production-oriented technique is that it ignores the information requirements of different departments. The main focus of this technique is to form part-families and machine groups to serve the manufacturing departments. Thus, the wider information requirements of other departments are frequently overlooked. It is felt that if various organizational functional areas require information for various purposes (cost estimation, purchasing, sales) a formal design-oriented approach would be ideal. The central parts database can then be accessed by the different departments.

A very interesting study by Koenig et. al. (1981) compared part-families formed via PFA with those formed using classification and coding for an industry. Not much difference was noticed between the families formed using either approach. Management, however, decided to install a classification and coding system because of the need felt for a company-wide database for all departments. Reports of current industrial uses of such a procedure by diverse organizational departments such as purchasing and sales and also by satellite facilities located at diverse geographical locations (Wemmerlov and Hyer 1987a) further reinforces the belief that inter-departmental information requirements favor a formal design-oriented approach.

Value analysis

Proposition 10: The desire to use value analysis techniques necessitates the use of a design-oriented approach.

The value analysis (VA) concept assumes that many of the components and products are manufactured at costs above what they actually should be. The reason lies in poor design practices (Edwards 1971). The VA technique examines component costs to determine if components can be produced at lower costs while retaining functionality. Therefore, this technique is essentially a design function.

The technical aspect of VA involves the examination of component drawings. This analysis may be repeated for many drawings without realizing that component drawing similarities could be exploited. This is where the value of a design standardization system is appreciated. With the availability of such a system, it is obvious that the scope of the VA technique is enlarged with respect to the components handled. Edwards (1971) identified the usefulness of the combination of VA technique and a design standardization system and claimed that they mostly worked in isolation in industries. They probably still do; literature does not indicate that these two techniques are in widespread use together. However, for an integrated approach in CM these two techniques should be considered together as they are closely related. It is, therefore, felt that the desire to use VA techniques in the context of CM favors a design-oriented approach.

Design standardization and retrieval

Proposition 10: Design standardization and retrieval is aided by a design-oriented approach.

The ability of a design-oriented system to standardize and retrieve existing designs in the context of GT is well known (Beeby and Thompson 1979, Hyde 1981). This is due to the selective grouping of parts based on their geometric similarities. Standardization of designs results from better visibility of redundant designs and of excessive variety upon implementing a design-based approach. Retrieval of designs are possible because of the order brought about by the creation of part-families. This procedure is made infinitely more efficient if a well-designed classification and coding system is in place. GT literature is replete with instances of the use of the design-oriented approach for design standardization and retrieval. The very successful GT installations in the U.K. at Ferranti (Durie 1970) and Serck-Audco (Ranson 1972) used classification and coding of parts to gain the advantages of design standardization and retrieval. Notable examples in the U.S. include the Boeing Company (Beeby and Thompson 1979) and John Deere and Company (Dumolien and Santen 1983). A recent survey of GT applications in the U.S. found the majority of firms using GT in design standardization and retrieval with or without the use of formal classification and coding (Wemmerlov and Hyer 1987a). Therefore, it is felt that, if a firm contemplates using standardization and retrieval of existing drawings, it is better served by following a design-oriented approach.

Process planning and retrieval

Proposition 11: Process planning standardization and retrieval is aided by a production-oriented approach.

Process planning involves the determination of part routes through machines, an estimation of their set-up and machining times, and a description of the machining parameters. If part groups are formed based on production sequences resulting in standard process plans for families, then it is conceivable that the process planning of new parts will take into account the existing standard process plan for the family to which the part belongs. Such standard part-family process plans, therefore, help in the standardization of process plans and reduce process planning times for new parts. Thus, if a company contemplates using standardization of process planning, then it is better served by utilizing a production-oriented approach.

Usage of graphics standards

Proposition 12: The use of graphics and product standards for product design and development enhances the use of a formal design-oriented approach.

The use of graphics and product standards imply an effort towards database integration. A formal design-oriented procedure provides such an opportunity because it preserves part design databases. There is very little industrial evidence of the use of such standards, except in large corporations. It is unlikely that small- to medium-sized companies will be attracted to the use of such standards, primarily because these standards are still in the developmental phase and also, once developed, the costs for implementation may be high. Therefore, it is noted that the use of graphics and product standards may be an enhancement to a design-oriented approach and not a determinant of the approach to part-machine grouping.

The above propositions have been developed in an attempt to establish the theoretical framework necessary to relate the two candidate approaches for the initial cell-forming processes with the level of the attributes. These propositions are largely based on knowledge gathered from literature and will be used to develop the rule-based procedure for determining an appropriate choice of method for part-family grouping.

4.2 Weighting of attributes

This section describes the rationale behind the chosen weights of the attributes. The attributes pertaining to the feasibility for the implementation of CM were weighted first. The attributes involving the choice of method were weighted next. The attribute lists for both the issues were rank ordered by this researcher according to the perceived importance of attributes with respect to each other. Thus the attribute deemed most important was ranked first, followed by the next, and so on, until the attribute list was exhausted. Available literature on GT/CM does not indicate such a ranking scheme. The importance of such a ranking scheme lies in (i) determining the relative perceived importance of the attributes and (ii) in lending structure and quantification to a subjective issue.

It is pertinent to mention here that this ranking scheme is based totally on the educated opinions of this researcher of the relative importance of the attributes. The attributes were ranked following a two-year study of most of the literature on GT/CM available in English. Still such a ranking procedure is the first of its kind in the area of GT/CM, and the subjectivity of the rankings may be open to question. Continuing research with regard to the assigned ranks will be extremely useful in refining the rankings and is left for future research.

Weighting of attributes -- feasibility issue: The ranking scheme has yielded four rank categories. Categories I and II are believed to be extremely critical with respect to the implementation of CM in an organization. Category III comes next and last in importance is Category IV. Within the rank categories, all the attributes are perceived to be equally important, or with so little difference that further division would be difficult or impossible.

The feasibility analysis procedure in the context of CM implementation identified four attribute categories. These were the products and processes, resources, procedures, and organizational characteristics categories. The ranking scheme took into account the attributes within each of these categories and established a ranking based on the perceived importance of the attributes with respect to each other. The perceived order of importance ranked the product category attributes first, followed by the attributes of the organizational characteristics. Then followed the attributes of the resource and the procedure categories. After all, if part-families and machine cells (attributes of the product category), do not occur naturally, then no amount of managerial support or the presence of other resources will make CM viable. Also, if managers and workers do not perceive CM favorably (or large-scale projects in general), then a stable product demand, simple components, high labor flexibility, or the use of MRP II systems will not be able to put a CM system in place. The justification of the ranking procedure follows.

This rationale is largely followed in the ranking of most of the attributes. For some attributes, however, this rationale cannot be followed as these attributes are perceived to be equally (or less) important than the attributes in the other categories.

It is believed that the prime purpose of a manufacturing organization is the manufacture of products to make a profit. Thus, the product line is the central focus in the manufacturing environment and largely determines the manufacturing methods. To support the manufacturing activity and to reach the profit-making objective, a support structure consisting of individuals, equipment, facilities, responsibilities, and authorities -- an organization -- is built. Any change in the manufacturing methods is liable to disturb the equilibrium of the manufacturing support structure. Since the primary objective is the manufacture of the products, the acceptability of the change (to new manufacturing methods) should, therefore, be considered first before attempting to induce the change. The implementation of CM in an organization implies a change in manufacturing methods. Therefore, it is necessary first to examine whether the product and process attributes will accommodate such a change. Also, even with changes in manufacturing methods, although the products made often remain the same, the organizational characteristics and the supporting procedures encounter changes. These changes in turn reflect increased needs in the resources used or required. Therefore, when analyzing for CM feasibility, the importance should first be given to the product attributes. If these attributes suggest potential for the new manufacturing approach, then a change could be worthwhile.

The change to CM also involves certain attributes within the organizational structure which are responsible for accommodating (or sabotaging) the change. With respect to the feasibility analysis procedure, these are the organizational characteristics -- managerial support and resistance to change. The levels of these attributes largely determine whether the change will be successfully implemented. Therefore, it is felt that a consideration of the attributes of the organizational characteristics category should follow those of the product category in the weighting procedure.

If the attributes of the product line indicate potential for change to a new manufacturing approach and the organizational characteristics indicate acceptance of such a change, then procedural changes and resource acquisition and allocation can follow. Thus, the attributes of the organizational characteristics category are thought to be more important than those of the resource and the procedure categories.

In the first category the attribute "occurrence of part families and machine cells," is felt to be the most important attribute for the feasibility of implementing CM in an organization. If the level of this attribute is at a low level, then the implementation of CM is out of the question. The second category comprises the following attributes -- stability of component demand, stability of component-mix, complexity of components, occurrence of indivisible processes, weight of components, managerial support, resistance to change, and implementation time. In this category, all the attributes with the exception of "managerial support," "resistance to change," and "implementation time" belong to the product category and are thought to be equally important. The attributes of the product category are important because they affect the cell design process. The attributes "managerial support" and "resistance to change" are thought to be equally important to the attributes of the product category because they largely determine CM success. The attribute "implementation time" belongs to the resource category. It is the only one from this category thought to be equally important to the others because successful CM implementation takes a long time and the organization must be willing to commit to it, or show a history of successful implementations of similar large-scale projects.

Category III comprises the following attributes: availability of computer resources, computer literacy of personnel, material control system, capacity balance, reliability of equipment, flexibility of labor, skill level of operators, reliability of suppliers, and scheduling procedures. The importance of these attributes are lower than those in Category II because these attributes come into play only when the attributes relating to the product and organizational characteristics categories reflect favorably for the implementation of CM. Also, the levels of the attributes belonging to the resource category can be increased by resource acquisition and allocation. The levels of the attributes belonging to the procedure category may also be changed to improve CM feasibility. Thus, if flexibility of labor is low, labor retraining may be applied. Capacity imbalance may be alleviated by machine tool purchase. Computer literacy may also be improved and scheduling procedures changed. Therefore, in a sense, these attributes can be "controlled" by management in contrast to a majority of the attributes in the previous categories over which management has very little control, at least in the short- to medium-term. Finally, Category IV includes the attributes "workload on process planners" and "availability of a classification and coding system." The attribute "workload on the process planners" does not influence the cell formation procedure, cell stability, or the operation procedure as those in the previous categories do. It indicates the extent of duplication in process planning and acts as an indicator (not a determinant) for CM feasibility; its priority in ranking is, therefore, lower. The attribute "availability of a classification and coding system" is not a prerequisite for determining organizational feasibility to the implementation of CM. Therefore, it is not as important as others. But both of these are included because the former attribute indicates that rationalization of process planning is necessary, thereby indicating CM possibilities. The latter attribute assists tremendously in data visibility and design rationalization and is, therefore, considered helpful for CM purposes.

The weights of these attributes were obtained by assigning scores to each of them in accordance with their importance. The permissible range of scores assignable to each category and the scores given to each attribute is shown in Table 5.

The most important category is given a score range between 90 and 100. The second most important category is given a score range between 75 and 89. The third most important category is given a score range between 60 and 74. The last category is given a score range between 45 and 59. These scores are used to determine the individual attribute weights by dividing attribute scores by the total sum of all scores for all attributes. The individual attributes are used to determine a total feasibility (explained in Section 5.1 of Chapter V).

Weighting of attribute -- choice-of-method issue: The choice-of-method procedure identified three attribute categories. These were the product category, the resource category, and the objectives category. The ranking scheme took into account the attributes of each of these categories and established rankings based on their perceived importance. Thus, in a similar process as for feasibility analysis, the attribute deemed most important was ranked first, followed by the next, and so on, until the list was exhausted. The product characteristics were thought to be most important in determining the choice of method for determining part/machine grouping. In fact, the whole premise of GT/CM is based on the grouping of parts utilizing their design and/or manufacturing similarities.

Table 5. Weighted attributes of the feasibility issue

Category	Attribute	Suggested Score range
I	1. Occurrence of part families and machine cells	90-100
II	2. Stability of product demand	75-89
	3. Stability of product-mix	
	4. Complexity of components	
	5. Occurrence of indivisible processes	
	6. Weight of components	
	7. Managerial support	
	8. Resistance to change	
	9. Implementation time	
III	10. Availability of computer support	60-74
	11. Computer literacy of personnel	
	12. Material control system	
	13. Capacity balance	
	14. Reliability of equipment	
	15. Flexibility of labor	
	16. Skill level of operators	
	17. Reliability of suppliers	
	18. Forecasting reliability	
	19. Scheduling procedures	
IV	20. Workload on process planners	45-59
	21. Availability of a classification and coding system	

Thus attributes pertaining to the product category are ranked in Category I. These attributes are "component design similarity" and "component manufacturing similarity." Both these attributes are perceived to be equally important.

However, it is also believed that secondary considerations also affect the choice. The attributes in the resource and objectives categories are, therefore, considered next. The resource and the objectives category are thought to be complementary to each other with respect to the choice of method. The levels of the attributes in one category in conjunction with the levels of the attributes in the other categories are instrumental in determining the choice. Thus, insufficiency of computer support and little desire for design standardization and retrieval, coupled with high design similarity, would seem to suggest one approach; sufficient computer support and desire for design standardization and retrieval with design similarity, another. Therefore, it cannot be said that the resource category is more important than the objectives category or vice-versa; or that within categories, certain attributes override one another. With this in view, the attributes belonging to the resource and objectives categories are ranked the same and are placed in Category II.

The third category consists of only two attributes: availability of a CAD system and the usage of standards. Products and graphics standards are largely in the developmental stage. Thus it is very unlikely that the small-to-medium sized company will use such standards in the near future. Many may not be cognizant of the existence and the utility of such standards. Also, there is very little evidence yet of the widespread integration of CAD systems with GT coding systems (Wemmerlov and Hyer 1987a). Mostly, CAD systems are likely to be used as enhancements to a CM system and not as a determinant of part-machine grouping. The same reasoning holds for the attribute "usage of standards." Therefore, these two attributes are ranked last in the ranking scheme. The weights of the attributes are not necessary here because a scoring procedure will not be used to determine the choice of method. However, a ranking is useful in showing the relative importance of the attributes. Table 6 shows the ranking scheme of the attributes.

In summary, a weighting scheme of the attributes for the feasibility and choice of method issues was developed. The next section presents the complete set of specifications of all attributes used in this research.

Table 6. Ranked attributes of the choice-of-method issue

Category	Attribute
I	1. Component design similarity
	2. Component manufacturing similarity
II	3. Monetary support
	4. Implementation time
	5. Availability of computer support
	6. Computer literacy of personnel
	7. Inter-departmental information requirements
	8. Value analysis
	9. Design standardization and retrieval
	10. Process plan standardization and retrieval
III	11. Availability of a CAD system
	12. Usage of standards

4.3 Specification of attributes

In order to develop a framework for this study, the attributes chosen were further defined and specified in enough detail to enable their accurate measurement. In this section, details of the attribute measures are presented. Although enough detail is provided in the specification of the measures, the specifications may themselves be somewhat less sophisticated. This is because this model has not been formulated or tested prior to this research. The stress of this study was more toward understanding the basics of the research issues which are (i) organizational feasibility for the implementation of CM and (ii) the choice of method for part-machine grouping if feasibility is adjudged. This warranted a simple model and simple specifications. It is believed that constructing simple measures first and interpreting the results aids in a more thorough understanding of the issues and will enable the construction of more complex measures, if appropriate, in the future. In all specifications, the words "low," and "high," (when addressing attribute levels) imply perceived low and high values because of the relative nature of these terms. The specifications of the attributes of the feasibility issue are done first; those of the choice-of-method issue are done later. In each of the following, a definition is first given and then a scale from 1 to 5 with a specification for each is given. Where two or more measures are used for attribute level measurement, an average value of the measures is used.

Feasibility issue

1. Occurrence of part families and machine cells: This attribute is defined as the existence of parts that can be grouped together because of similar processing requirements. This attribute is specified in terms of component manufacturing similarity.

   • Component manufacturing similarity:

   1 - Of all the components made, very few can be distinctly grouped into separate groups because of common machining requirements.

   2 - Of all the components made, few can be distinctly grouped into separate groups because of common machining requirements.

   3 - Of all the components made, some can be distinctly grouped into separate groups because of common machining requirements.

   4 - Of all the components made, many can be distinctly grouped into separate groups because of common machining requirements.

   5 - Of all the components made, almost all can be distinctly grouped into separate groups because of common machining requirements.

The logic of this specification is derived directly from the mathematical definition of component manufacturing similarity which is defined as the ratio of the number of common machines required for the processing of a pair of parts to the total number of machines required for their processing (MacAuley 1972, Rajagopalan and Batra 1975). This computed measure ranges from 0 to 1 and can be divided into equal ranges of 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8 and 0.8-1.00.

A value between 0 and 0.2 for a component pair indicates a very low level of processing commonality. A value between 0.8 and 1.00 indicates a very high level of machining commonality. This procedure can be extended to include all parts and not part pairs alone. If the average similarity lies between 0.8 and 1.00 for all components then it can be concluded that they have very similar processing requirements. In the specification above, the values 1, 2, 3, 4, 5 represent the ranges 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8-1.00 respectively. It is felt by this researcher that such a specification will enable a quick estimate of this attribute; a detailed analysis of part routing to develop a part similarity matrix is then unnecessary or can be done once the initial feasibility analysis is completed, if necessary. In the context of this study, the scale values 1, 2, and 3 on the specification indicates a low value of this attribute. Values 4 and 5 are specified as high.

2. Occurrence of indivisible processes: The occurrence of indivisible processes is operationally defined as the presence of centralized processes in the component routings. Examples of centralized processes are painting, shot blasting, heat treatment, and sub-contracted work. For effective CM systems, the level of this attribute should be very low (Leonard and Koenigsberger 1972). This is because the existence of such processes in part routings disrupts the normal sequence of operations. For this study, the specification of this attribute is done in terms of intermediate visits by parts to centralized processes. A low level of this attribute representing few visits to centralized processes corresponds to the scale values 4 and 5. A high level of this attribute is given by scale values 1, 2 and 3.

- Extent of intermediate visits to centralized processes

  1 - Almost all or all components require intermediate visits to centralized processes.

  2 - Many components require intermediate visits to centralized processes.

  3 - Some components require intermediate visits to centralized processes.

  4 - Few components require intermediate visits to centralized processes.

  5 - Very few or no components require intermediate visits to centralized processes.

3. Stability of product demand: This attribute is defined as the lack of fluctuation of the long-term product demand imposed on production. For effective CM purposes, the importance of the stability of product demand has been shown by researchers in CM (Tilsley and Lewis 1977). The specification is shown below.

   • Fluctuation in long-term product demand:

   1 - Extreme fluctuation in long-term product demand for all products.
   2 - Large fluctuation in long-term product demand for all products.
   3 - Some fluctuation in long-term product demand for all products.
   4 - Little fluctuation in long-term product demand for all products.
   5 - Very little fluctuation in long-term product demand for all products.

   A high level of this attribute corresponds to the scale values 4 and 5. A low level corresponds to the values 1, 2 and 3.

4. Stability of product-mix: This attribute is defined as the lack of fluctuation of the long-term product-mix. The importance of the stability of product-mix for CM purposes is shown in the works of Ranson (1972), Rathmill et. al. 1974, and Burbidge (1979).

   • Fluctuation in long-term product-mix:

   1 - Extreme fluctuation in long-term product-mix.
   2 - Large fluctuation in long-term product-mix.
   3 - Some fluctuation in long-term product-mix.
   4 - Little fluctuation in long-term product-mix.
   5 - Very little fluctuation in long-term product-mix.

   A high level of this attribute corresponds to scale values 4 and 5. A low level of this attribute corresponds to the values 1, 2 and 3.

5. Complexity of components: Complexity of a component is defined in terms of three sub-factors: total number of machines required for the manufacture of a component, the total number of operations per component, and the total machining time per component. The range of permissible values for each of the three categories is shown below.

• Average number of machines needed to complete a component:

1 - more than 40.

2 - between 20 and 39.

3 - between 10 and 19.

4 - between 5 and 9.

5 - fewer than 5.

Burbidge and Dale (1984) conducted a study on the redesign of a factory from functional to a cellular layout and found that machine requirement of parts ranged from 8 to 29. The authors conceded that the upper limit of 29 is high for CM purposes. In establishing the range for the number of machines above, the work or Burbidge and Dale (1984) is used as a guideline. It is appropriate to mention here that the larger the number of machines required to complete a component the more complex is the component. Thus, cell size increases with an increase in the number of machines required for part processing and negates benefits of CM due to increased material flow (Oliva-Lopez and Purcheck 1979).

• Average number of operations required to complete a component:

1 - more than 40.

2 - between 20 and 39.

3 - between 10 and 19.

4 - between 5 and 9.

5 - fewer than 5.

The works of Willey and Dale (1979), Dale (1980), Burbidge and Dale (1984) and Flynn and Jacobs (1986) are used as guidelines in the construction of the range for the total number of operations per part. The study by Flynn and Jacobs (1984) on a die manufacturing plant found the average number of operations needed to complete a part to be 79.6. The corresponding figure in the works of Willey and Dale (1979) and Dale (1980) is 8.2. Burbidge and Dale's (1984) study found the figure to be 24. It is appropriate to mention here that, with an increase in the total number of operations per part, total part manufacturing time increases. This leads to queueing of parts in front of machines in a cell (Flynn and Jacobs 1984).

- Average machining time per component:

  1 - more than 10 hours.

  2 - between 5 and 10 hours.

  3 - between 2 and 5 hours.

  4 - between 1/2 and 2 hours.

  5 - less than 1/2 hour.

The only available guides for this measure are the studies of Willey and Dale (1979) and Dale (1980). The authors found the average machining time per component to be 35.5 hours per batch. Per component machining time, therefore, should be much lower. Increased machining times per component result in queueing in front of machines in a cell and also creates problems of load balancing among machines within the cells (Burbidge and Dale 1984, Flynn and Jacobs 1984).

For this study, the average of the summed scale values for these three factors will be used as a measure of this attribute. Average values greater than or equal to 4 will indicate low part complexity. Average values less than 4 will indicate high part complexity.

6. Weight of components: This attribute is defined as the heaviness of the individual components. It is also defined in this research in terms of the material handling equipment needed for their transport.

It is appropriate to mention here that heavy components require more moving time and may result in blockage of machines (Flynn and Jacobs 1984). Other disadvantages associated with the processing of heavy components in a CM environment is shown in the works of Leonard and Koenigsberger (1972), and Burbidge (1979).

- Equipment needed to transport components:

  1 - Almost all components need heavy moving equipment (overhead cranes).

2 - Most components need moderate moving equipment (tow trucks), the rest need heavy equipment.

3 - Some components need moderate moving equipment, the rest need light mechanized equipment (tow carts, light conveyors).

4 - Some components need light mechanized equipment, the rest are handled manually.

5 - Almost all components can be moved manually.

Low component weights are indicated by scale values 4 and 5. The values 1, 2 and 3 indicate high component weights of varying degree.

7. Capacity balance: Capacity balance is defined in terms of machine utilization of all machines -- primary or secondary -- on account of parts processed on them. Primary machines types are one-of-a-kind machines and are available in limited quantities. If there is more than one machine of a certain primary machine type available, then it is considered to be a primary machine type with duplication. For secondary machine types, several machines of each type exist.

- Extent of machine duplication:

1 - Extremely high utilization of unduplicated primary machines; extremely low utilization of secondary machines.

2 - Extremely high utilization of unduplicated primary machines; low utilization of secondary machines.

3 - Low to moderate utilization of unduplicated primary machines; low to moderate utilization of secondary machines.

4 - High to medium utilization of duplicated primary machines; low to moderate utilization of secondary machines.

5 - High to medium utilization of duplicated primary machines; high to moderate utilization of secondary machines.

The first level (1) indicates that there are a few one-of-a-kind machines which are used by almost all components. It also indicates that the secondary machines are not used very much.

Another interpretation of this could be process planning inconsistency -- process planners do not take into account the capacity of the machines in loading jobs on them. Such a situation would present severe loading and capacity imbalance in a cellular environment unless processes were replanned or additional capacity acquired. The importance of this specification lies in pointing out the capacity imbalance problem. The last level (5) indicates a condition where more than one machine in each primary machine category is available and where secondary machines also carry a sufficient load. This condition is close to ideal for CM because capacity problems will not be likely to occur if such conditions exist in a functional layout (DeBeer et. al. 1976, DeBeer and deWitte 1978). The intermediate specifications represent the varying capacity conditions. The scale values 4 and 5 represent a high level of this attribute; the values 1, 2 and 3 represent its low level.

8. Flexibility of labor: This attribute is defined as the ability of labor to operate multiple machine types. The importance of this attribute has been seen in the works of Burbidge (1979) and Wemmerlov and Hyer (1987b).

   - Ability of operators to operate multiple machine types:

     1 - None - one operator can operate only one machine type.

     2 - Few - very few operators can operate multiple machine types.

     3 - Some - some operators can operate multiple machine types.

     4 - Most - most operators can operate multiple machine types.

     5 - All - all operators can operate multiple machine types.

   The scale values 1, 2 and 3 represent a low level of this attribute. The scale values 4 and 5 indicate a high level of this attribute.

9. Availability of computer support: This attribute is defined as the availability and access to computer support. The availability of this resource will be indicated in terms of virtual computer memory available on each computer. The minimum level of virtual computer memory required for running part-family forming procedures was determined by examining the litera-

ture and from field work. In accordance with the propositions developed for this attribute, values greater than or equal to 2 will indicate a high level for this attribute.

- Available computer resource in terms of memory of a single computer:

  1 - Greater than 0Kb and less than or equal to 256Kb.

  2 - Greater than 256Kb and less than or equal to 640Kb.

  3 - Greater than 640Kb and less than or equal to 2000Kb.

  4 - Greater than 2000Kb and less than or equal to 10000Kb.

  5 - Over 10000Kb.

10. Availability of a classification and a coding scheme: This attribute is defined as the access to or the availability of a classification and coding package. It must be mentioned here that the availability and use of a classification and coding package is not a prerequisite to the implementation of CM. However, many successful CM implementations have used classification and coding techniques (Durie 1970, Ranson 1972, Burbidge 1979, Wemmerlov and Hyer 1987a, 1987b).

- Availability of and access to a classification package:

  1 - No access to a classification and coding system.

  2 - Limited access to a classification and coding system.

  3 - Some access to a classification and coding package.

  4 - Adequate access to a classification and coding package.

  5 - Sufficient access to a classification and coding package.

Values greater than or equal to 4 are regarded as a high level of this attribute. Values less than 4 indicate insufficient availability of this resource. In such a case, this attribute is not considered in the decision making process for reasons explained in the section on propositions.

11. Computer literacy of personnel: This attribute is defined as the extent of computer orientation of middle-level management. The measures of computer literacy of personnel consider the ability of middle level management (since they are the ones who are mainly responsible for implementing CM (Wemmerlov and Hyer 1987a, 1987b)) in terms of their familiarity with

computers, their ability to use commercial spreadsheet packages (since middle level managers are often required to use them), and their familiarity with programming languages and seminars. In this study, the average of the sum of the measures will be used to determine the level of this attribute. Averages greater than or equal to 4 will indicate a high level of this attribute. Values less than 4 will be indicative of its low level. The operationalized measures, (adapted from Napoliello (1987)), are shown below.

- The frequency of direct use of computer at work:

  1 - Never.

  2 - Seldom.

  3 - Some.

  4 - Quite frequent.

  5 - Very frequent.

- The frequency of use of spreadsheet analysis on computer:

  1 - Never.

  2 - Seldom.

  3 - Some.

  4 - Quite frequent.

  5 - Very frequent.

- The frequency of programming, using procedural (e.g. Fortran), simulation (e.g. GPSS), and/or symbolic languages (e.g. APL):

  1 - Never.

  2 - Seldom.

  3 - Some.

  4 - Quite frequent.

  5 - Very frequent.

- Of all the time spent in attending workshops and/or seminars, the percentage spent in attending workshops and/or seminars directly related to computer education:

  1 - Between 0% and 20%.

2 - Between 20% and 40%.

3 - Between 40% and 60%.

4 - Between 60 % and 80%.

5 - Between 80% and 100%.

12. Skill level of operators: This attribute is defined as the labor skills available according to the following categories: (i) tool and die maker (ii) class A machinist (iii) class B machinist. A tool and die-maker can operate all machining equipment and can make a part from a sketch; can set the required speeds, feeds, and depth of cuts for any machining operation; can also develop tools and jigs and fixtures. The class A machinist requires a blue print to make a part and can operate the basic machines; can set the feeds, speeds, and depths of cut for these machines; and is less experienced than a tool and die maker. The class B machinist is an operator for a specific machine or more than one machine; requires a blue print and a detailed process plan for manufacturing a part; and has very little knowledge about feeds, speeds, and depths of cut and cannot set-up a machine. This definition is based on interviews with machine shop personnel and the production manager of an industrial contact. It is pertinent to mention here that researchers in GT/CM have felt that a CM environment may result in skilled operators feeling deskilling effects (Leonard and Rathmill 1977a) leading to operator resistance (Fazakerley 1976).

• Skill level of operators:

1 - Almost all machinists are tool and die makers; very few are class A.

2 - Some machinists are tool and die makers; majority class A, rest B.

3 - Some tool and die makers, some class A, some class B.

4 - Majority class B, some class A, very few tool and die makers.

5 - Almost all class B, very few class A or tool and die makers.

The values 4 and 5 on the specification scale indicate a high level of this attribute. Values 1, 2 and 3 indicates its low level.

13. Forecasting reliability: This attribute refers to the reliability of forecast of product demand and is defined as the lack of deviation of the product demand forecast from the actual demand. For effective CM purposes, the deviation of the product demand from the forecast should be low (Lewis 1973). The specification of this attribute is shown below.

- Deviation of product demand forecast from the actual:

  1 - Very large deviations; extremely inaccurate forecasts.

  2 - Large deviations; quite inaccurate forecasts.

  3 - No large deviations; some accuracy in forecasting.

  4- Small deviations; fairly accurate forecasts.

  5 - Very small deviations; extremely accurate forecasts.

The scale values 4 and 5 indicate high values of this attribute. Values 1, 2 and 3 indicate its low levels.

14. Reliability of equipment: This attribute is defined as the lack of machine breakdowns in producing the components. It is appropriate to mention here that reliability of equipment is of utmost importance because the breakdown of one machine results in the complete cessation of production. The specification of this attribute is with respect to the frequency of the machine breakdowns.

- Frequency of machine breakdowns:

  1 - Frequent breakdown of all equipment.

  2 - Frequent breakdown of key machines with occasional breakdown of secondary operation machines.

  3 - Occasional breakdown of key and secondary operation machines.

  4 - Infrequent breakdown of key machines and occasional breakdown of secondary operation machines.

  5 - Infrequent breakdown of key and secondary operation machines.

The values 4 and 5 on the specification scale imply high values of the level of this attribute. Values 1, 2 and 3 indicate its low values.

15. Implementation time: This attribute can be defined as the time required to implement a CM system from conception to implementation, either partially or wholly. Since it is not possible to predict the exact time that will be required to implement the CM system, two sub-factors will be used to indicate the level of this attribute. These sub-factors are (i) the planning horizon in the company and (ii) the success in implementing previous projects. It is relevant to mention here that the implementation of CM requires long-term planning (Ranson 1972, Wemmerlov and Hyer 1987b) and time (Levulis 1980). The specifications are shown below.

- Planning is on:

  1 - An extremely short-term view.

  2 - Short-term view.

  3 - Neither short-term nor long-term view.

  4 - Long-term view.

  5 - Extremely long-term view.

- Implementation history of past projects was:

  1 - Totally unsuccessful.

  2 - Mostly unsuccessful.

  3 - Partially successful.

  4 - Successful with minor set-backs.

  5 - Completely successful.

The average value of the two measures is used as an overall measure of this attribute. Values greater than or equal to 4 will be considered high. Values less than 4 represent a low level of this attribute.

16. Reliability of suppliers: This attribute is defined as the timely supply of defect-free material necessary for production. The reliability of suppliers will be measured in terms of the extent of on-time delivery and the frequency of the time that material is delivered free of defects. The importance of this attribute for effective CM purposes is seen in the works of Leonard and Koenigsberger (1972) and Burbidge (1979). The specifications are given below.

- The extent of on-time delivery in the supply of all raw material:

  1 - None.

  2 - Little.

  3 - Some.

  4 - Quite a lot.

  5 - A great extent.

- The frequency of the time that material is delivered free of defect:

  1 - Never.

  2 - Seldom.

  3 - Some of the time.

  4 - Frequently.

  5 - Very frequently.

The average of the sub-measures is used as a measure of this attribute. Average values greater than or equal to 4 indicate a high level of this attribute. Average values less than 4 indicate a low level of this attribute.

17. Material control system: This attribute is defined as the type of material control system (MCS) currently in use. The importance of this attribute is seen in the works of Burbidge (1975, 1979), New (1977), Sata et. al. (1978), and Wemmerlov and Hyer (1982). The specification of this attribute is shown below.

- Type of material control system currently in use:

  1 - No MCS in use.

  2 - A multi-cycle reorder point MCS for individual components in use.

  3 - A single-cycle reorder point MCS for individual components in use.

  4 - A single-cycle MCS based on end product demand; developed in-house.

  5 - A commercial MRP or MRP II or similar type of MCS.

The values 4 and 5 on the specification scale indicate a high level of this attribute. Values 1, 2 and 3 indicate its low level.

18. Workload on process planners: This attribute is defined as the degree to which process planners are occupied daily in the development of process plans. The workload on process planners will be measured with respect to two factors: extent of process planner overtime, and on the extent to which process plans for similar parts are created over again, that is, the extent of duplication in the process planning.

- The extent to which process planners work overtime:

  1 - None.

  2 - Little.

  3 - Some.

  4 - Quite a lot.

  5 - A great extent.

- The extent of duplication in process planning.

  1 - None.

  2 - Little.

  3 - Some.

  4 - Quite a lot.

  5 - A great extent.

The average of the measures is used in determining the level of this attribute. Values greater than 4 indicate a high level of this attribute. Values less than 4 are considered low. The fifth level (5) for both the specifications indicates potential for cellular manufacture.

19. Scheduling procedures: This attribute is defined as the extent of centralization or decentralization of control for scheduling in the manufacturing facility. In particular, the aspects of interest here are: (i) centralization of scheduling and (ii) the authority of first-line supervisors to override schedules as and when necessary. Thus, this attribute focuses not on the scheduling procedures, per se, but the current organization of production scheduling. The level of this attribute is measured by an average of the above two sub-measures.

- Centralization of scheduling:

1 - All shop-floor scheduling done in a central office.

2 - Most shop-floor scheduling done in a central office.

3 - Some shop-floor scheduling done in central office; rest done by first-line supervisors.

4 - Most shop-floor scheduling done by first-line supervisors.

5 - Almost all shop-floor scheduling done by first-line supervisors.

- Authority of first-line supervisors to override schedules:

1 - No authority of first-line supervisors to override shop-floor schedules.

2 - First-line supervisors are seldom allowed to override shop-floor schedules; management permission is necessary.

3 - First-line supervisors are sometimes allowed to override shop-floor schedules with management permission.

4 - First-line supervisors have limited authority to override shop-floor schedules without management permission.

5 - First-line supervisors have complete authority to override schedules as and when necessary.

The average of these two sub-measures is used as an indicator of the level of this attribute. Average values between 4 and 5 indicate a high level of this attribute; average values between 1, 2, and 3 indicate a low level of this attribute.

20. Managerial support: In the context of this research, managerial support is defined as an intangible management attribute manifested through actions that promote organization welfare and contribute to its objectives. For this study, the attribute will be operationalized and measured on a 1 to 5 scale, with 1 indicating least support and 5 indicating most support.

Four dimensions of this attribute will be used. These are: (i) future orientation as opposed to short-term thinking; (ii) attitude toward subordinates; (iii) allocation of resources to projects; and (iv) leadership capabilities. Future orientation or long-term thinking is important in the

CM context because short-term thinking limits the scope and acceptance of the project (Wemmerlov and Hyer 1987a). Research in managing organizational change suggests a tolerant, supportive, and helpful management (Marrow et. al. 1967; Lawrence 1969). Implementing CM also implies a change in the organization; thus a tolerant and helpful attitude toward subordinates is a critical dimension of managerial support. Implementing CM requires the allocation of finances because cost is involved in the relocation of the machines, compensation of personnel engaged in the program, acquiring of computer support and equipment, management education, and worker training (Levulis 1980, Hyer 1984a). As resource allocation is directed by top management, it is included as one dimension of this attribute. Finally, it has been noted that the failure to implement CM systems has often resulted from a lack of a determined individual within the company pushing the implementation (Burbidge 1979). Therefore, one appropriate dimension of managerial support is the leadership capability of personnel. The operationalized measures are shown below.

- Long-term thinking (measure from Pheysey and Payne 1971)

  The extent of management to plan ahead:

  1 - None.

  2 - Little.

  3 - Some.

  4 - Quite a lot.

  5 - Great extent.

- Attitude toward subordinates (measure from Levinson 1968)

  The extent to which senior personnel will go out of their way to help subordinates:

  1 - None.

  2 - Little.

  3 - Some.

  4 - Quite a lot.

  5 - Great extent.

- Allocation of resources (measure from Ein-Dor and Segev 1981)

The length of time taken to get capital allocation through:

1 - Greater than or equal to 6 months.

2 - Greater than or equal to 4 months and less than 6 months.

3 - Greater than or equal to 2 months and less than 4 months.

4 - Greater than or equal to 1 month and less than 2 months.

5 - Less than one month.

The extent of yearly increase in total company budget:

1 - None.

2 - Little.

3 - Some.

4 - Quite a lot.

5 - Great extent.

- Leadership capabilities

There is at least one individual in the management level who can take charge and get things done:

1 - Strongly disagree.

2 - Disagree.

3 - Neutral.

4 - Agree.

5 - Strongly agree.

The average of these measures is used as indicator of the level of this attribute. Values greater than 4 indicate a high level of this attribute. Values less than 4 indicate a low level.

21. Resistance to change: This attribute can be defined as the propensity by personnel in the organization to oppose changes brought about by changes in the manufacturing environment. The operationalized dimension of this attribute will be measured on a scale of 1 to 5; 1 will indicate the most resistance and 5 the least.

According to Coch and French (1952) and Lawrence (1969), employee turnover and strikes are very good indicators of resistance to change. Preston (1979) categorizes resistors of change into three categories. These are: (i) people who rely heavily on personal experience, (ii) people who prefer "one best way" of doing things, and (iii) people who have little propensity to take risks. A study by Wemmerlov and Hyer (1987a) found that typical resistors to CM projects were people in the second category. Therefore, for the purpose of this study, employee turnover, strikes and the propensity of doing things the "old way" will be used as operationalized measures of this attribute.

- The extent to which supervisors stick to old ways of doing things:

  1 - Great extent.
  2 - Quite a bit.
  3 - Some.
  4 - Little.
  5 - None.

- The extent of employee turnover in manufacturing:

  1 - Great extent.
  2 - Quite a bit.
  3 - Some.
  4 - Little.
  5 - None.

- The frequency of strikes:

  1 - Very high.
  2 - High.
  3 - Occasional.
  4 - Low.
  5 - Very low.

The average of the measures is used to determine the level of this attribute. Values between 4 and 5 indicate high level of this attribute. Values between 1, 2, and 3 indicate a low level.

The definition and specification of the attributes pertinent to the feasibility issue has been completed. The definition and specification of the attributes relating to the choice of method issue will be done next.

Choice-of-method issue: The definition and specification of the attributes relating to the choice-of-method issue is also done using a five-point specification scale. The specification of the attributes of the "product and processes" category is done first. The specifications of the attributes of the "resources" category is done next. Finally, the specifications of the attributes of the "objectives" are constructed.

1. Component design similarity: This attribute is defined as the similarity of components with respect to their shape and size. The specification of this attribute is based on the classification scheme by Opitz (1970). The table below shows the scheme to be used in this study. This scheme was also used by Husain and Leonard (1975) in their study of part grouping.

Classification of rotational and non-rotational components

Rotational Components	1. No bore 2. Blind hole 3. Through hole 4. Geared with no bore or blind hole 5. Gear with through hole 6. Company specific components
Non-rotational Components	1. Flat and irregular 2. Box-like 3. Company specific components

Initially, each component is classified into a rotational or non-rotational category. Components within the rotational category are further divided into those that do not have any central bores, those having blind holes, those having through holes, those that are geared, and those components that are company specific. The non-rotational components are divided into those that are flat and irregular in shape, those that are box-like, and those that are company specific.

This procedure is a quick and easy way of determining part design similarity and will be used in this study. It is also possible to determine design similarity by coding of parts (Han and Ham 1986). However, coding of parts requires the use of a coding package, access to part data, and a substantial amount of time. Thus, if the number of parts manufactured by a company is large, the coding effort will be proportionally larger with increasing number of parts. Also, the focus of this study is not to use a classification package to determine part design similarity but to determine if such a package is necessary. Therefore, it is felt that questioning the decision maker on component design similarity will be more efficient. It is assumed that he/she will have a fair knowledge of the range of component shapes and sizes manufactured in the plant. Based on the above discussion the specification of this attribute is given below.

- Component design similarity measure:

1 - Very few components can be grouped into any one or more of the above categories.

2 - Few components can be grouped into any one or more of the above categories.

3 - Some components can be grouped into any one or more of the above categories.

4 - Many components can be grouped into any one or more of the above categories.

5 - Almost all components can be grouped into any one or more of the above categories.

The scale values 4 and 5 indicate a high level of this attribute. Values 1, 2 and 3 indicate its low level.

2. Component manufacturing similarity: This attribute is defined as the measure of the similarity of components because they possess very similar processing requirements. For this study, the measure of this attribute will be according to the specification given below.

- Component manufacturing similarity:

1 - Of all the components made, very few can be distinctly grouped into separate groups because of common machining requirements.

2 - Of all the components made, few can be distinctly grouped into separate groups because of common machining requirements.

3 - Of all the components made, some can be distinctly grouped into separate groups because of common machining requirements.

4 - Of all the components made, many can be distinctly grouped into separate groups because of common machining requirements.

5 - Of all the components made, almost all can be distinctly grouped into separate groups because of common machining requirements.

The basis of this specification has been discussed before (see discussion of Attribute 1, feasibility issue), and therefore, will not be discussed again.

3. Availability of a CAD system: Availability of a computer-aided-design system is defined as the extent to which a CAD system is easily accessed (not necessary owned, if accessible). The specification of this attribute is given below.

• Availability/accessibility of a CAD system:

1 - No availability or access to a CAD system.

2 - Limited availability or access to a CAD system.

3 - Some availability or access to a CAD system.

4 - Adequate availability or access to a CAD system.

5 - Sufficient availability or access to a CAD system.

Values 4 and 5 indicate a high level of this attribute. Values 1, 2 and 3 indicate its low level.

4. Monetary support: This attribute is defined as the availability of financial resources for implementing either approach. In establishing the level of this attribute commercial classification and coding vendors were contacted for cost estimates. There is very little cost information available on the implementation cost (at present) of either the design-oriented method or the production oriented method. In view of this, the bases of this specification are the cost estimates and some application literature provided by the vendors and simple cost estimates constructed by this researcher. These are discussed below.

The cost (at present) of the DCLASS decision tree processor is $5,000 for the PC version of the software and a continuing licensing fee of $1, 200 per year. The mainframe version of the same software costs $45,000 and also involves a continuing licensing fee of $9,000 per year. The cost of implementing a Brisch system is variable and depend on company needs and number of component coded. Recent cost of implementing the Brisch system varied from

$30,000 to several hundred thousand dollars. This cost included the cost of component coding and the cost of the software. The cost of the software alone is $30,000. Travelling and living expenses of company personnel at the consultant headquarters is not included in this estimate. The average cost of a MICLASS/MULTICLASS package is around $100,000. Thus it is seen that the cost of commercial packages is substantial.

The application of the DCLASS package for classification purposes requires the user to enter the logic. A brochure supplied by the vendor provided time estimates for a few applications. About 600 hours (approximately 4 months computed at the rate of 8 hours per day and 20 days per month) were required by engineers at the Eaton Corporation to design the tree logic. At a conservatively estimated personnel salary of $30,000 per year, the cost of entering the logic alone is approximately $10,000. This cost does not consider the training costs. The company required another 3 months to implement and test the system. Thus, a rough estimate of the total cost (including software purchase for mainframe application) could easily be close to $70,000.

Coding costs can also be significant when using interactive part coding systems. It has been reported that an average coding time per part varies between 4 and 10 minutes (Wemmerlov and Hyer 1985, 1987a). Thus the cost to code 10,000 components at 480 minutes per day and at a salary of $30,000 per year is about $42,000. This cost does not include the consultant or maintenance fees. Tailor-making a coding system could be still higher. On the other hand, the production-oriented approach (routing analysis) algorithms available in literature are not complex to program. As a rough estimate, about two months will be required to program and run these algorithms to determine initial part-families. This is one cost aspect. The other cost aspect is the data enter cost. For the same number of components (10,000) with an average route input time of 7 minutes (same as coding), a rough cost estimate is $16,000. It is believed that the time to enter part routes will be significantly less than the estimate provided. In fact, Burbidge (1975) claimed the cost reduction of the PFA method to be an advantage of this technique. The above logic is used in constructing the specification of this attribute.

• Availability of funds:

1 - Less than or equal to $5,000.

2 - Greater than $5,000 and less than or equal to $20,000.

3 - Greater than $20,000 and less than or equal to $40,000.

4 - Greater than $40,000 and less than or equal to $60,000.

5 - Greater than $60,000.

Values 4 and 5 indicate a high level of this attribute. Values 1, 2 and 3 indicate its low level.

5. Implementation time: This attribute is defined as the time allocated for the implementation of a design- or production-oriented approach. This time comprises the time to develop and implement the system. As exact implementation times are unknown, estimates of time will be used. It is estimated that the implementation of a classification package requires a year or more to implement (Hyde 1981). The corresponding estimates for implementing a production-oriented approach is 6 months or less. The specification is given below.

• Amount of time allocated for implementation:

1 - Less than 6 months.

2 - Greater than 6 months but less than or equal to 9 months.

3 - Greater than 9 months but less than or equal to 12 months.

4 - Greater than 12 months but less than or equal to 18 months.

5 - More than 18 months.

Values 4 and 5 indicate a high level of this attribute. Values 1, 2, and 3 indicate a low level.

6. Availability of computer support: This attribute is defined as the access to and the availability of computer support. The availability of this resource is indicated in terms of the memory available. The minimum level of computer memory required for either approach was determined from field work and by examining the literature. The specification for this attribute has been stated before and will not be repeated here (see Attribute 9 in the feasibility section).

7. Computer literacy of personnel: This attribute is defined as the extent of computer orientation of middle level management. The specification of this attribute has been given before and will not be discussed again (see attribute 11 in the feasibility section).

8. Inter-departmental information requirements: Interdepartmental information requirement is defined in terms of these two sub-factors: the objective of the sales department to access standard product cost data for estimating product costs accurately; and the objective of the purchasing department to access product data for purchasing similar items for bulk purchases. The importance of this attribute is recognized by GT/CM researchers (Koenig et .al. 1981, Wemmerlov and Hyer 1987a). The specification of this attribute is given below.

   - The importance of the objective of accurate product costing for the firm:

     1 - Product costing is not one of our important objectives.

     2 - Product costing is one of our slightly important objectives.

     3 - Product costing is one of our somewhat important objectives.

     4 - Product costing is one of our important objectives.

     5 - Product costing is one of our most important objectives.

   - The importance of the objective of identifying similar parts or materials for bulk purchases:

     1 - The identification of similar materials for bulk purchases is not one of our important objectives.

     2 - The identification of similar materials for bulk purchases is one of our slightly important objectives.

     3 - The identification of similar materials for bulk purchases is one of our somewhat important objectives.

     4 - The identification of similar materials for bulk purchases is one of our important objectives.

     5 - The identification of similar materials for bulk purchases is one of our most important objectives.

The average of these two sub-measures is used as a measure of this attribute. Values between 4 and 5 indicate a high level of this attribute. Values between 1, 2, and 3 indicate a low level.

9. Value analysis: This attribute is defined as the objective of the use of value analysis techniques for product design in the organization. The importance of this attribute is noted by GT/CM researchers (Edwards 1971). The specification is as follows.

   • Desire to use VA for designing for least cost:

   1 - The use of VA techniques is not one of our important objectives.
   2 - The use of VA techniques is one of our slightly important objectives.
   3 - The use of VA techniques is one of our somewhat important objectives.
   4 - The use of VA techniques is one of our important objectives.
   5 - The use of VA techniques is one of our most important objective.

   Values 4 and 5 indicate a high level of this attribute. Values 1, 2 and 3 indicate a low level.

10. Design standardization and retrieval (DSR): This attribute is defined as the objective of standardizing and retrieving similar component designs. The importance of this attribute is noted in the works of numerous researchers in GT/CM (Durie 1970, Ranson 1972, Beeby and Thompson 1979). The specification of this attribute is given below.

    • The importance of DSR as an objective

    1 - DSR is not one of our important objectives
    2 - DSR is one of our slightly important objectives
    3 - DSR is one of our somewhat important objectives
    4 - DSR is one of our important objectives
    5 - DSR is one of our most important objective

    Values 4 and 5 indicate a high level of this attribute. Values 1, 2 and 3 indicate its low level.

11. Process plan standardization and retrieval (PPSR): This attribute can be defined as the objective of reducing process plan redundancy. The importance of this attribute is noted by Burbidge (1975, 1979) and Ingram (1982). The specification of this attribute follows.

    • The importance of PPSR as an objective:

1 - PPSR is not one of our important objectives.

2 - PPSR is one of our slightly important objectives.

3 - PPSR is one of our somewhat important objectives.

4 - PPSR is one of our important objectives.

5 - PPSR is one of our most important objectives.

Values 4 and 5 indicate a high level of this attribute. Values 1, 2 and 3 indicate its low level.

12. Usage of standards: This attribute is defined as the objective of the use of graphics standards, such as Initial Graphics Exchange Specification (IGES) or Product Design and Development Standards (PDDS). The specification of this attribute is given below.

- The importance of the use of standards as an objective:

1 - The use of standards is not one of our important objectives.

2 - The use of standards is one of our slightly important objectives.

3 - The use of standards is one of our somewhat important objectives.

4 - The use of standard is one of our important objectives.

5 - The use of standards is one of our most important objective.

Values 4 and 5 indicate a high level of this attribute. Values 1, 2 and 3 indicate its low level.

This completes the discussion of the specification of all attributes used in this research. They are all specified on a scale between 1 and 5. In all specifications, perceived low and high scale values have been indicated. The specifications of the attributes of the feasibility issue have been done first; those of the choice of method issue have been done second. These specifications are used directly in the methodology; in particular, they are used in the scoring procedure for the feasibility analysis and in the rule-based procedure for the choice-of-method approach.

Chapter V

Methodology

This chapter discusses the methodology for this research. In particular, the discussions will focus on the scoring procedure for the feasibility analysis, the rule-based procedure for the choice-of-method approach to part-machine grouping, and the field work methodology.

5.1 The Scoring Model for Feasibility Analysis

The literature review discussed several different scoring procedures developed to aid the selection among alternatives. The scoring procedures reviewed included those by Brown and Gibson (1972), Saaty (1980, 1982), Huang and Ghandforoush (1984), and Canada (1986). It was intended to keep the scoring model for this research a simple one. Brown and Gibson's (1972) method could not be used because objective values in monetary units are unavailable for the attributes in question. The approach of Huang and Ghandforoush (1984) was eliminated for similar reasons. Saaty's (1980, 1982) procedures for comparing alternatives requires breaking-up the problems into different levels such that a hierarchy can be constructed. For the present study, the hierarchy was not appropriate. Thus a procedure similar to Canada's (1986) seemed most appropriate, because it enables the addition of all normalized weights to give a simple score.

It was realized from the theoretical development that a three-stage process was necessary for the scoring procedure. In the first stage, the propositions were used to link each attribute to the feasibility for implementation of CM. The literature was used extensively to construct these propositions. For example, the proposition for the attribute "occurrence of indivisible processes," establishes feasibility for the implementation of CM for this attribute if its level is low. To determine the score it is, therefore, necessary to determine the level of this attribute. This is done in the second stage. In this stage, the attribute levels are determined from the attribute specifications. For example, the attribute "occurrence of indivisible processes," is measured by the "extent of intermediate visits to centralized processes." The measurement, on a 1 to 5 scale, is accomplished through the use of the specifications (see Chapter IV). The attribute specifications also specify the high and low range of the scale for each attribute. Therefore, if the "extent of intermediate visits to centralized processes," is given a scale value of 5 by the decision maker, then using the attribute specification, it can be determined that the level of this attribute is low. For attributes having multiple measures, an average of the scale values is computed. Since the level of this attribute in this example is actually low (because it is given a scale value 5), feasibility for the implementation of CM is adjudged with respect to this attribute. This process is repeated for every attribute. Therefore, in the second stage, the attribute levels in conjunction with the propositions establish feasibility for the implementation of CM for each attribute.

The third stage uses the results from the second stage in computing a total feasibility score. In the above example, the attribute "occurrence of indivisible processes," has a low level and contributes to feasibility by the proposition. Thus its weight, determined from the weighting procedure, is added to the feasibility score. This process is repeated for all attributes which meet the feasibility criteria. Therefore, at the end of the scoring procedure, a total feasibility score between 0 and 1 is computed.

To enable the addition of attribute weights it is necessary to specify the relationship between attributes and their levels required for feasibility for the implementation of CM. Although this has been formally done through the propositions and the specifications, it is felt that a tabular representation of the relationship will enable a better understanding of the scoring procedure. Table 7 illustrates the relationships between attribute levels and feasibility of CM.

In Table 7, the first column lists the attributes relevant to the feasibility issue. The second column lists the attribute levels required for feasibility for the implementation of CM. These levels are derived directly from the propositions. The third column is for recording the actual level of the attributes for a firm. In the fourth and the fifth columns, the weights of the attributes contributing to feasibility or infeasibility are recorded. The last three columns are for scoring purposes. The weights are then summed to yield a score for feasibility. An example will further clarify the scoring procedure. Suppose for a company, the measure of the attribute "occurrence of part-families and machine cells," is determined to be high from the attribute specifications. From the above table, it is observed that this attribute contributes to the feasibility for implementation of CM for this company. Therefore, the weight is added to the feasibility score. Similarly, the level of the attribute "stability of product demand," is determined to be high. Therefore, its weight is also added to the feasibility column. The feasibility score at this point is the sum of the weights of the two attributes. Proceeding in a similar fashion, the total feasibility score is computed after all attributes are considered. This score will lie between 0 and 1, since the sum of all weights equals 1.

This scoring procedure can accommodate the addition or redundancy of attributes if circumstances so require. In such cases, the weights can be determined afresh by recomputing them according to the procedure explained in Chapter IV.

A feasibility matrix, Figure 7, is used in conjunction with the score for decision making. The feasibility matrix is a graphical representation of the feasibility possibility, given the attribute levels. It will point out where an organization lies, given the attribute levels. The score will indicate overall

Table 7. Attribute level and feasibility relationship

Attribute	Attribute level required for CM feasibility	Actual level of attribute	Weight allocation based on actual level of attribute Feasibility Infeasibility
1. Occurrence of part-families and machine cells	High		
2. Stability of product demand	High		
3. Stability of product-mix	High		
4. Complexity of components	Low		
5. Occurrence of indivisible processes	Low		
6. Weight of components	Low		
7. Managerial support	High		
8. Resistance to change	Low		
9. Implementation time	High		
10. Availability of computer support	High		
11. Computer literacy of personnel	High		
12. Material control system	High		
13. Capacity balance	High		
14. Reliability of equipment	High		
15. Flexibility of labor	High		
16. Skill level of operators	Low		
17. Reliability of suppliers	High		
18. Forecasting reliability	High		
19. Scheduling procedures	High		
20. Workload on process planners	High		
21. Availability of classification and coding scheme	High		

feasibility possibility, whereas the feasibility matrix represents graphically the feasibility possibility. The feasibility matrix is shown in Figure 7.

Finally, the cell-type matrix is used to determine what type of cell will be suitable for the organization if feasibility is adjudged. The cell-type matrix shows the likely cell type based on the products made and the material flow. The cell-type matrix is shown in Figure 8.

This completes the discussion of the concept behind the scoring procedure for feasibility analysis. The instruments for conducting the feasibility analysis were presented in this section. The following section discusses the rule-based procedure for resolving the choice-of-method issue.

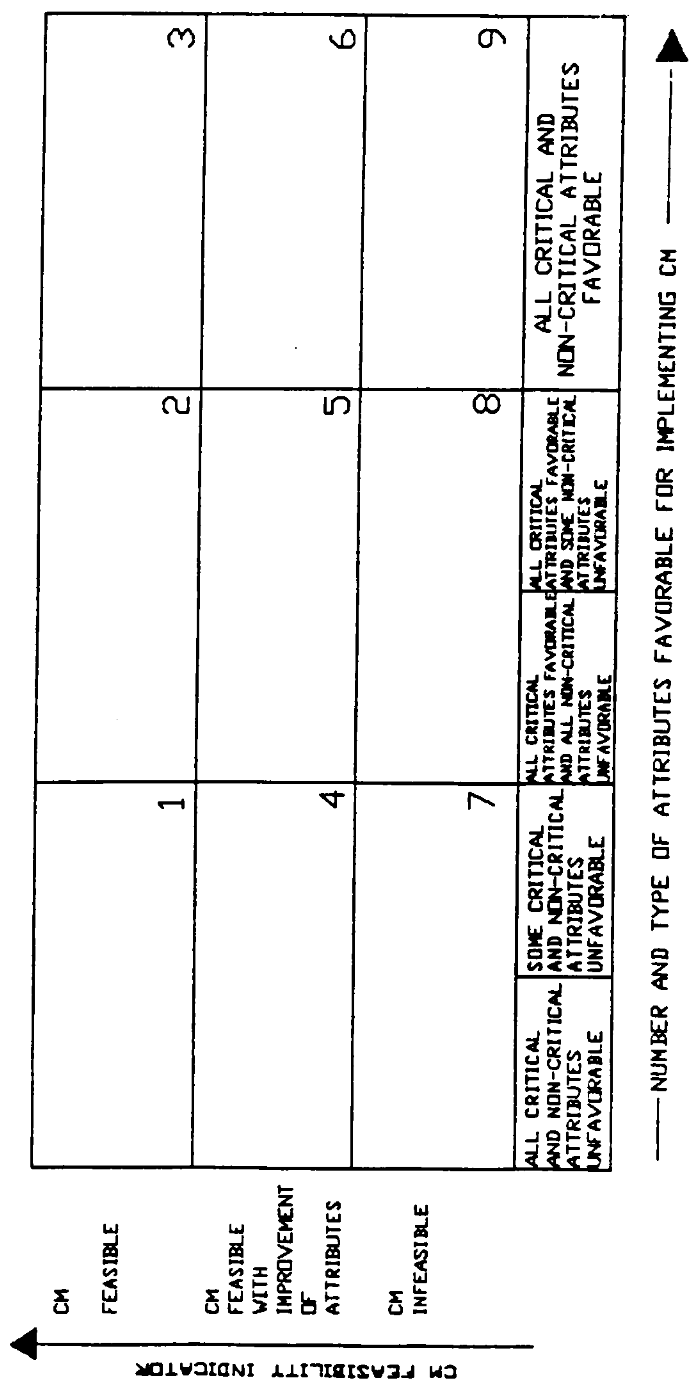

Figure 7. The feasibility matrix

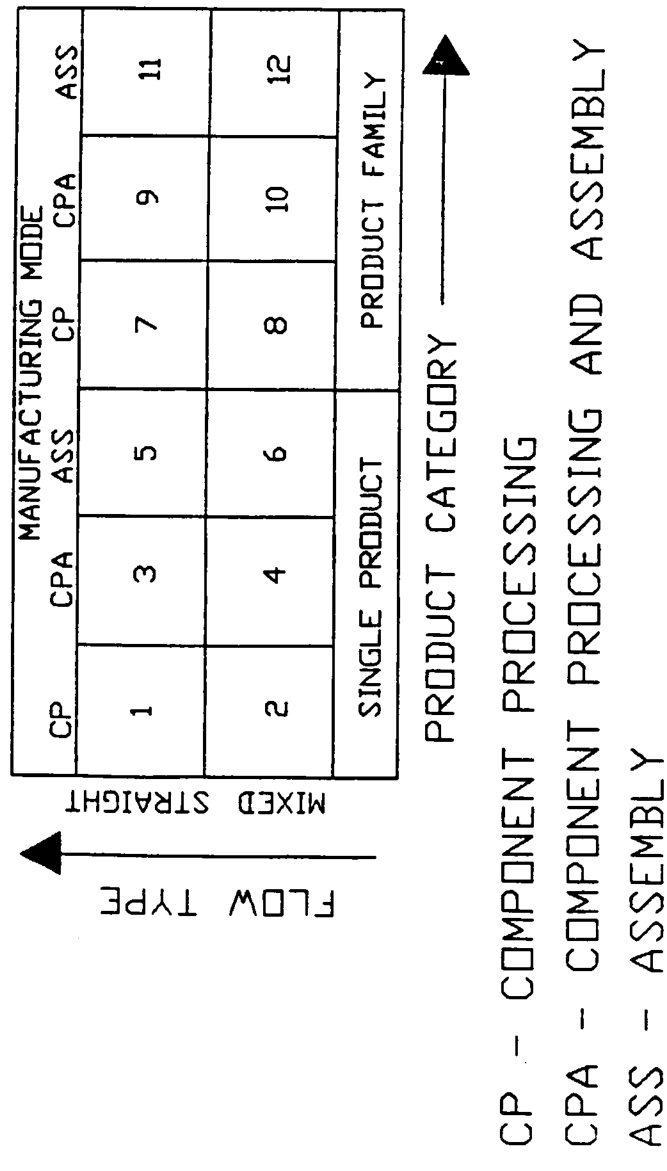

Figure 8. The cell-type matrix

5.2 Rule-based procedure for choice-of-method approach

A rule-based procedure was used to determine the approach to part-machine grouping. The scoring model approach used in the feasibility analysis procedure was not appropriate here because all attributes for the choice of method do not always indicate affiliation one way or another to a particular approach, given their levels. Therefore, an addition of weights might be an erroneous indicator of the choice of method. For example, if value analysis and design standardization are two objectives of the firm, then a design-oriented approach is preferred. However, if these are not objectives, then one does not automatically assume a production-oriented approach. Similarly, if it is desired to retrieve process plans, a production-oriented approach is better suited. However, if this is not desired, then one cannot automatically assume that a design-oriented approach would be better. Thus, attribute levels do not necessarily indicate affiliation one way or another. Therefore, rules were developed to provide guidelines for arriving at a "best" conclusion given the prevailing circumstances. The overall concept for determining the method for part-machine grouping is shown graphically in Figure 9.

In this figure, the attributes involved in the selection procedure are represented by the block labelled "Attributes." All attributes levels are determined next. This activity is represented by the next block. The next step in the determination of the choice for part-machine grouping is the determination of the appropriate rule that considers the attribute levels. This process is indicated by the next block. Finally, the appropriate method is determined. The three available choices are shown at the top of the figure. The choices shown here are the design-oriented approach, the production-oriented approach, and a combination of both, a hybrid approach. The design-oriented approach consists of informal methods to part-machine grouping (such as rule-of-thumb or visual inspection) and manual or interactive classification and coding. An interactive classification and coding system uses a computer interactively to classify and code parts. In this approach, parts are grouped by shape and routings are assigned once these families are known. The production-oriented approach consists of a manual route sort, the use of computerized algorithmic procedures, or production-based clas-

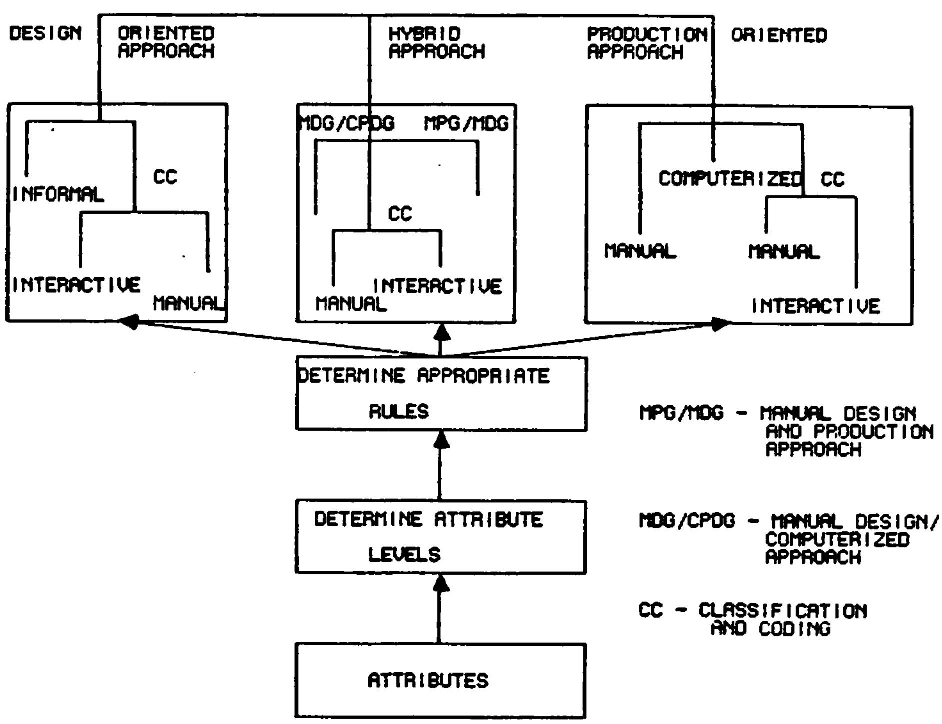

Figure 9. Procedures for part-family grouping in cellular manufacturing

sification and coding -- manual or interactive. In this approach, families are formed based on routing commonality; part shapes are not considered. The hybrid approach consists of the use of design- and production-based classification and coding, or manual route sort in conjunction with the consideration of part shape. An extensive review of applicable GT/CM literature yielded the above three approaches for part-machine grouping. The procedure for developing the rules is explained now.

The first step in the development of the rules was the specification of the attribute levels. The propositions were then used to construct the rules. For CM purposes, it is absolutely essential to have a high level of manufacturing similarity among components. Therefore, low manufacturing similarity (according to the specification) is not considered. Thus, two possibilities arise when component design and component manufacturing similarities are considered. One is when both have high levels. The other is where component manufacturing similarity is high, but component design similarity is low (for example, in the machining of various types of castings). The first possibility is common in metal machining. The second possibility although infrequent in metal machining, is a possibility nonetheless (Groover and Zimmers 1984). For each of these possibilities, the levels of the attributes belonging to the Resources and the Objectives category were considered. The levels of these attributes are high or low according to the specifications developed (see Chapter IV). This is because of the binary nature of the attributes perceived by this researcher. For example, a company will either have sufficient computer support to run a classification system, or it will not. Also, the desire to standardize product designs will either be one of the most important objectives or it will not. Similar reasoning holds for other attributes. An implicit assumption here is that all attributes of the Objectives category simultaneously cannot attain low levels; the implementation of CM always involves the attainment of some or all of these objectives. This is evident from the literature review of CM applications.

The attributes "availability of CAD system" and the "usage of standards" were not considered in the construction of the rules. This is because these two attributes do not directly influence the choice of method. The review of literature also did not reveal any incidence of the use of these two attributes in the choice of method. However, the importance of these attributes for enhancements to the formal design-oriented procedure is noted.

The next step in the rule formation procedure determined the number of possible combinations for the eight attributes remaining by recognizing that each of these attributes has only two levels -- high or low. Thus, for all attributes in the Resources category, there are 16 combinations. There are four attributes (monetary support, implementation time, computer support, and computer literacy of personnel) and two levels of each. Similarly, 16 combinations resulted for the Objectives category. Thus there were 256 (16 times 16) combinations in all for the case of high component design and manufacturing similarity.

The other case is where component manufacturing similarity is high yet design similarity is low. Here, the objectives of design standardization and retrieval and value analysis become secondary in importance because these objectives are associated with the design function and with low component design similarity. This case is noted by researchers (Allen 1973, Gallagher and Knight 1973). The total number of attributes in the Objectives category are, therefore, information requirements and process planning standardization and retrieval. Each has two levels. Thus, the total number of combinations, considering the four attributes of the Resource category, each with two levels, is 64. Thus, there were a total of (256 + 64) = 320 distinct combinations for the two cases of high component design and manufacturing similarity and high component manufacturing similarity and low component design similarity.

For each of these combinations, a particular rule resulted. For example, if the levels of all resources and objectives were high, then the conclusion was that the use of a design and production-based classification and coding system was appropriate. It was noticed that certain combinations produced the same choice. For example, consider the situation with the following attribute levels with high component design and manufacturing similarity. Monetary support -- high; Implementation time -- high; Computer support -- low; Computer literacy -- low; Information requirement -- high; Desire for VA -- high; Desire for design standardization -- high; and Desire for process planning standardization -- high. The choice is a manual classification and coding system, because there is insufficient computer support and literacy to implement an interactive classification and coding system. High monetary support, implementation time, and high levels of the attributes of the Objectives category result in this choice. Also, for example, consider another situation where all the attribute levels remain the same as above except the desire for value analysis has a low value. The consideration of all attribute levels still imply a manual classification and coding system; especially so with the objectives. Thus, these two combinations yield identical results and, therefore, can be combined. All combinations were examined in a similar fashion to check for the commonality of results. This enabled the consolidation of the entire initial set of rules to a total of 22 rules. These rules are given and explained now. The first sixteen rules are for the case of high component design and manufacturing similarity. The next six rules are for the case of high component manufacturing similarity and low component design similarity.

1. IF Monetary support = High And
Implementation time = High And
Computer support = High And
Computer literacy = High And
Information requirement = High And
(Desire for design standardization = High Or
Desire for value analysis = High) And
Desire for process planning standardization = High
THEN Choice = Interactive hybrid (design and production based)
classification system.

Explanation: The levels of all attributes in the resources category are high. That is, there is ample monetary support, computer literacy, and computer support, and implementation time is sufficient. The levels of attributes in the Objectives category are also high. Therefore, the objectives of design and manufacturing (design standardization and retrieval, value analysis, process planning standardization and retrieval) are important. Also, information requirement is high. There is also sufficient computer support and literacy. An interactive classification and coding system addressing both design and manufacturing needs is, therefore, appropriate. Examples of the use of such classification and coding system is provided by Peters et. al. (1974) and Houtzeel and Schilperoot (1975).

2. IF Monetary support = High And
Implementation time = High And
Computer support = High And
Computer literacy = High And
Information requirement = High And
Desire for design standardization = Low And
Desire for value analysis = Low And
Desire for process planning standardization = High
THEN Choice = Interactive production-oriented classification system.

Explanation: In this rule, all attributes of the Resources category (monetary support, implementation time, computer support, and computer literacy) are at high levels. The objectives, information requirements and process planning standardization, are at high levels, while the objectives -- value analysis and desire for design standardization -- are at low levels. Thus an interactive production-based classification and coding system is appropriate here. It will satisfy the high information requirements and process planning standardization. The use of such systems for manufacturing purposes is recognized in GT research (Groover and Zimmers 1984).

3. IF Monetary support = High And
Implementation time = High And
Computer support = High And
Computer literacy = High And
Information requirement = High And
(Desire for design standardization = High OR
Desire for value analysis = High) And
Desire for process planning standardization = Low

THEN Choice = Interactive design-oriented classification and coding system.

Explanation: All attribute levels of the Resources category (monetary support, implementation time, computer support, and computer literacy) are high here. High information requirements in conjunction with the requirements of the design function -- design standardization and retrieval or value analysis -- suggest the use of an interactive design-based classification and coding system. The applications of such systems are reported by Beeby and Thompson (1977) and Kriegler (1984).

4. IF Monetary support = Low And
(Implementation time = High Or
Implementation time = Low) And
(Computer support = High Or
Computer support = Low) And
Computer literacy = Low And
(Information requirement = High Or
Information requirement = Low) And
(Desire for design standardization = High Or
Desire for value analysis = High) AND
Desire for process plan standardization = High

THEN Choice = Manual hybrid (design and production-based) approach.

Explanation: In this rule the low level of the attribute "monetary support" in conjunction with that of "computer literacy" indicates the inability of implementing an interactive classification and coding system or a computerized production-oriented approach. Thus, the levels of the other attributes of the Resources category do not affect the choice. Therefore, high information requirements cannot be met because resources are unavailable to provide such needs. Also, the objectives of design standardization and retrieval, value analysis, and process planning standardization and retrieval reflects the use of the only other option -- a hybrid manual (design and production-oriented) approach. If the components are high in both design and manufacturing similarity, then this rule seems appropriate.

5. IF Monetary support = Low And
(Implementation time = High Or
Implementation time = Low) And
(Computer support = High Or
Computer support = Low) And
Computer literacy = Low And
(Information requirement = High Or
Information requirement = Low) And
(Desire for design standardization = High Or
Desire for value analysis = High) And
Desire for process planning standardization = Low
THEN Choice = Manual design-based approach.

Explanation: The levels of the attributes of the Resources category are identical to those of Rule 4. Also, the objective of information requirement is not applicable here because the resources are unavailable to provide such needs. If the design objectives (design standardization and retrieval and value analysis) are more important than manufacturing objectives, then a manual design-oriented approach seems appropriate by this rule. Quite a few examples of the application of this method are available in GT literature (Edwards 1971, Hyde 1981, Wemmerlov and Hyer 1985).

6. IF Monetary support = Low And
(Implementation time = High Or
Implementation time = Low) And
(Computer support = High Or
Computer support = Low) And
Computer literacy = Low And
(Information requirement = High Or

Information requirement = Low) And

Desire for design standardization = Low And

Desire for value analysis = Low And

Desire for process planning standardization = High

THEN Choice = Manual production-oriented approach.

Explanation: The levels of the attributes of the Resources category are identical to those of Rules 4 and 5. A classification and coding system cannot be implemented here. Since computer support and literacy are both at low levels, computerized approaches to the production-oriented approach cannot be considered. Also, the objective of information requirement cannot be met because the resources are unavailable to provide such needs. A manual production-oriented approach (manual route sort) seems most appropriate because of the importance given to the manufacturing objectives as compared to the design objectives.

7. IF Monetary support = Low And

(Implementation time = High Or

Implementation time = Low) And

(Computer support = High Or

Computer support = Low) And

Computer literacy = High And

(Information requirement = High Or

Information requirement = Low) And

(Desire for value analysis = High Or

Desire for design standardization = High) And

Desire for process planning standardization = High

THEN Choice = Hybrid (computerized production-oriented and manual design-oriented) approach.

Explanation: In this rule, the attribute "monetary support" is at a low level. Therefore, a classification system cannot be implemented. Thus the objective information requirement cannot be met because of inadequate resources. The attribute "computer literacy" is, however, at a high level. Thus, the manufacturing and design objective considerations suggest the use of a computerized production-oriented approach as the main grouping approach with secondary design-based grouping of parts to make the best use of the available resources. The use of a computerized production approach will better use the available resources.

8. IF Monetary support = Low And
(Implementation time = High Or
Implementation time = Low) And
(Computer support = High Or
Computer support = Low) And
Computer literacy = High And
(Information requirement = High Or
Information requirement = Low) And
Desire for design standardization = Low And
Desire for value analysis = Low And
Desire for process planning standardization = High
THEN Choice = Computerized production-oriented approach

Explanation: In this rule, the attribute "monetary support" is at a low level while the attribute "computer literacy" is at a high level. Thus, high information requirements cannot be met because resources are unavailable to provide such needs. Therefore, a computerized production-oriented approach seems to be the best choice. Most part-family/machine-grouping algorithms in literature fall under this category.

9. IF Monetary support = High And
Implementation time = High And
(Computer support = High Or
Computer support = Low) And
Computer literacy = Low And

Information requirement = High And

(Desire for design standardization = High Or

Desire for value analysis = High) And

Desire for process planning standardization = High

THEN Choice = Manual hybrid (design and production-oriented) classification approach

Explanation: This rule points to the use of a manual design and production-oriented classification and coding approach. Here the attributes, "monetary support" and "implementation time" are at high levels while the attributes "computer support" and "computer literacy" are at low levels. High information requirements and the objectives of the design and production departments point to the requirement of a manual classification and coding approach.

10. IF Monetary support = High And

Implementation time = High And

(Computer support = High Or

Computer support = Low) And

Computer literacy = Low And

Information requirement = High And

Desire for design standardization = Low And

Desire for value analysis = Low

Desire for process planning standardization = High And

THEN Choice = Manual production-oriented classification and coding.

Explanation: In this rule, the attributes "monetary support" and "implementation time," are high while "computer literacy" is low. The information requirement level is high as is the objective of process planning standardization. The objectives of design standardization and value analysis are at low levels. Considering the attribute levels, a manual production-oriented approach seems to be the best approach.

11. IF Monetary support = High And

Implementation time = High And

(Computer support = High Or

Computer support = Low) And

Computer literacy = Low And

Information requirement = High And

(Desire for design standardization = High Or

Desire for value analysis = High) And

Desire for process planning standardization = Low

THEN Choice = Manual design-oriented classification and coding.

Explanation: Rule 11 has the attribute "computer literacy" of the Resources category at a low level. Thus computerized classification systems cannot be implemented; algorithmic approaches are also excluded because of low computer literacy. Since the objectives of information requirements and design standardization or value analysis are at high levels, a manual design-oriented classification approach is best suited. Examples of such applications are in case studies by Edwards (1971) and Burbidge (1979).

12. IF (Monetary support = High Or

Monetary support = Low) And

Implementation time = Low And

(Computer support = High Or

Computer support = Low) And

Computer literacy = Low And

(Information requirement = High Or

Information requirement = Low) And

(Desire for design standardization = High Or

Desire for value analysis = High) And

Desire for process plan standardization = High

THEN Choice = Manual hybrid (design and production-based) approach.

Explanation: In this rule the low level of the attribute "implementation time" in conjunction with "computer literacy" indicates the inability of implementing an interactive classification and coding system or a computerized production-oriented approach. Thus, the levels of the other attributes of the Resources category do not affect the choice. Therefore, high information requirements cannot be met because resources are unavailable to provide such needs. Also, the objectives of design standardization and retrieval, value analysis, and process planning standardization and retrieval reflects the use of the only other option -- a hybrid manual (design and production-oriented) approach. If the components are high in both design and manufacturing similarity, then this rule seems appropriate.

13. IF (Monetary support = High Or
Monetary support = Low) And
Implementation time = Low And
(Computer support = High Or
Computer support = Low) And
Computer literacy = Low And
(Information requirement = High Or
Information requirement = Low) And
(Desire for design standardization = High Or
Desire for value analysis = High) And
Desire for process planning standardization = Low
THEN Choice = Manual design-based approach.

Explanation: The levels of the attributes of the Resources category are identical to those of Rule 12. Also, the objective of information requirement is not applicable here because the resources are unavailable to provide such needs. If the design objectives (design standardization and retrieval and value analysis) are more important than manufacturing objectives, then a manual design-oriented approach seems appropriate by this rule. Quite a few examples of the application of this method is available in GT literature (Edwards 1971, Hyde 1981, Wemmerlov and Hyer 1985).

14. IF (Monetary support = High Or
Monetary support = Low) And
Implementation time = Low And
(Computer support = High Or
Computer support = Low) And
Computer literacy = Low And
(Information requirement = High Or
Information requirement = Low) And
Desire for design standardization = Low And
Desire for value analysis = Low And
Desire for process planning standardization = High
THEN Choice = Manual production-oriented approach.

Explanation: The levels of the attributes of the Resources category are identical to those of Rules 12 and 13. A classification and coding system cannot be implemented here. Since computer support and literacy are both at low levels, computerized approaches to the production-oriented approach cannot be considered. Also, the objective of information requirement cannot be met because the resources are unavailable to provide such needs. A manual production-oriented approach (manual route sort) seems most appropriate because of the importance given to the manufacturing objectives as compared to the design objectives.

15. IF (Monetary support = High Or
Monetary support = Low) And
Implementation time = Low And
(Computer support = High Or
Computer support = Low) And
Computer literacy = High And
(Information requirement = High Or
Information requirement = Low) And

(Desire for value analysis = High Or

Desire for design standardization = High) And

Desire for process planning standardization = High

THEN Choice = Hybrid (computerized production-oriented and manual-design oriented) approach.

Explanation: In this rule, the attribute "implementation time" is at a low level. Therefore, a classification system cannot be implemented. Thus the objective information requirement cannot be met because of inadequate resources. The attribute "computer literacy" is, however, at a high level. Thus, the manufacturing and design objective considerations suggest the use of a computerized production-oriented approach as the main grouping approach with secondary design-based grouping of parts to make the best use of the available resources. The use of a computerized production approach will better use the available resources.

16. IF (Monetary support = Low Or

Monetary support = High) And

Implementation time = Low And

(Computer support = High Or

Computer support = Low) And

Computer literacy = High And

(Information requirement = High Or

Information requirement = Low) And

Desire for design standardization = Low And

Desire for value analysis = Low And

Desire for process planning standardization = High

THEN Choice = Computerized production-oriented approach

Explanation: In this rule, the attribute "implementation time" is at a low level while the attribute "computer literacy" is at a high level. Thus, high information requirements cannot be met because resources are unavailable to provide such needs. Therefore, a computerized production-oriented approach seems to be the best choice. Most part-family/machine-grouping algorithms in literature fall under this category.

The above sixteen rules are for the case of high component manufacturing similarity and low design similarity. The next six rules are for the case of high component manufacturing similarity and low component design similarity. With low component design similarity, the objectives of design standardization and value analysis are inappropriate. Therefore, they are not considered in the construction of the rules.

17. IF Monetary support = High And
Implementation time = High And
Computer support = High And
Computer literacy = High And
Information requirement = High And
Desire for process planning standardization = High
THEN Choice = Interactive production-oriented classification system

Explanation: This rule results because all attributes of the Resources category are at high levels. High information requirement is provided with a production-based classification system. It is noted here that a low component design similarity results in the objectives design standardization and "value analysis" (as defined here) being inappropriate.

18. IF Monetary support = Low And
(Implementation time = Low Or
Implementation time = High) And
Computer literacy = Low And
(Computer support = High Or
Computer support = Low) And
(Information requirement = High Or
Information requirement = Low) And
Desire for process planning standardization = High

THEN Choice = Manual production-oriented approach

Explanation: This rule suggests the suitability of using a manual production-oriented approach if there is limited monetary support and computer literacy. High information requirement cannot be met here because the resources are unavailable to provide such needs. Since the resources noted above are at low levels, this is the only option left.

19. IF (Monetary support = Low Or
Monetary support = High) And
Implementation time = Low And
(Computer support = High Or
Computer support = Low) And
Computer literacy = High And
(Information requirement = High Or
Information requirement = Low) And
Desire for process planning standardization = High
THEN Choice = Computerized production-oriented approach.

Explanation: Since the attribute "implementation time" of the Resources category is at a low level, a classification system cannot be implemented. High information requirement cannot be met here because the resources are unavailable to provide such needs. However, as the attribute "computer literacy" is at a high level, a computerized production approach is preferred.

20. IF Monetary support = High And
Implementation time = High And
Computer support = Low And
(Computer literacy = High Or
Computer literacy = Low) And
Information requirement = High And
Desire for process planning standardization = High
THEN Choice = Manual production-oriented classification system

Explanation: In this rule, the attributes "monetary support" and "implementation time" are at high levels. The objective of high information requirement can be provided with a manual classification system; the low level of the attribute "computer support" indicates that an interactive classification system is not possible. Thus, a manual classification is preferred.

21. IF (Monetary support = High Or
Monetary support = Low) And
Implementation time = Low And
Computer literacy = Low And
(Computer support = High Or
Computer support = Low) And
(Information requirement = High Or
Information requirement = Low) And
Desire for process planning standardization = High
THEN Choice = Manual production-oriented approach

Explanation: This rule suggests the suitability of using a manual production-oriented approach if there is insufficient implementation time and computer literacy. High information requirement cannot be met here because the resources are unavailable to provide such needs. Since the resources noted above are at low levels, this is the only option left.

22. IF Monetary support = Low And
(Implementation support = High Or
Implementation time = Low) And
(Computer support = High Or
Computer support = Low) And
Computer literacy = High And
(Information requirement = High Or
Information requirement = Low) And
Desire for process planning standardization = High

THEN Choice = Computerized production-oriented approach.

Explanation: Since the attribute "monetary support" of the Resources category is at a low level, a classification system cannot be implemented. High information requirement cannot be met here because the resources are unavailable to provide such needs. However, as the attribute "computer literacy" is at a high level, a computerized production approach is preferred.

This completes the discussion of the rules for resolving the choice-of-method issue. The rules were constructed for (i) high component design similarity and high component manufacturing similarity and (ii) low component design similarity and high component manufacturing similarity. The following section discusses the methodology employed in the field work. The field sites are briefly described first. This is followed by a discussion of the instruments employed in the field work and the field work interviews.

5.3 Field Work

5.3.1 Introduction

A part of this research involved field work in four companies, of which three are actively engaged in CM. Of these three companies, two are involved in metal machining while the third is involved in assembly. The fourth company has a functional layout and is involved in metal machining. The purpose of the field work was two-fold. The first purpose was to check for the relevance of the attributes and their rankings determined in this research. It was felt that company personnel could verify the relevance of the attributes and their importance, having implemented CM. The second purpose of the field work was to check the correctness of the logic used in the construction of the propositions by (i) determining the score for CM feasibility for the subject companies and (ii) determining the choice-of-method approach for part-machine grouping. That is, if the score indicated feasibility for CM implementation for organizations actually engaged in CM and the rules indicated the choice of method currently followed by them, then the logic of the propositions and the relevance of the attributes would be supported. Other purposes of the field work were also recognized. These were the possibility of adding any attributes not identified by this researcher and the verification of the attribute measures.

5.3.2 The companies visited

For this investigation, four companies were contacted and visited. Company A manufactures drilling equipment and has an operational CM facility. Company B manufactures bearings of various sizes and has a CM flowline layout for their medium-volume production line. Company C has a partial cellular layout and produces electronic components, and Company D has a functional layout and manufactures high-precision electro-mechanical devices for avionic, and other uses. Since companies A, B, and C had CM layouts, they were chosen for validation purposes as stated earlier. Company D had a functional layout and provided a good comparison for CM versus functional layouts. The details of the companies in terms of their production descriptions, CM set-ups, personnel interviewed and other company demographics are provided under the discussion of results of the field work in the next chapter. The names and products of the companies have been altered to provide anonymity for them as well.

5.3.3 The instruments employed

The instruments employed for conducting the field work consisted of a data sheet for recording company demographics, Appendix 1; a specification sheet for obtaining attribute levels, Appendix 2; attribute and measure verification sheets for the feasibility and choice-of-method issues, Appendix 3 and Appendix 4; and attribute rank verification sheets for feasibility and choice-of-method issues, Appendix 5. The purpose of the data sheet was to collect specific company data and data with regard to CM. Typical information requested in the data sheet included company name and location, the name and position of the interviewees, the number of employees, the product line, production description, the number of cells currently in operation, if any, and the number planned in the future. Information was also requested on the motives for introducing CM, the part-family approach chosen for forming cells and the fraction of all production done by cells and the fraction planned eventually. Information on cell characteristics was also requested. This information included descriptions of the products made in each cell, the number of machines in each cell, the number of operators in each cell, the types of machines in each cell, and the type of material handling equipment used in each cell.

The attribute and measure verification sheet listed all attributes with their measures for both the feasibility and choice-of-method issues. Spaces were provided to indicate agreement, disagreement, or unawareness about the validity of the attributes and their measures. Space was also kept for respondent's comments.

The attribute rank verification sheet consisted of a tabulation of the rank-ordered attributes. The suggested score ranges of each category (to be used for weighting purposes), the scores allocated to each category, and the attribute weights were shown in this sheet. Spaces were provided on the sheet to indicate agreement, disagreement, or unawareness regarding the rank ordering of the attributes and preferred rank order.

5.3.4 Field work interviews

Appointments were made for one to two hours with each contact (discussed later) in all four companies. The scope of the study was explained to the interviewees. They were first told that this study aimed at developing a decision tool for determining (i) the feasibility for implementing CM in an organization and (ii) the choice of method for part-machine grouping if feasibility was adjudged. They were also told that a list of factors critical to CM had been identified through a review of technical journals and academic publications and had been rank ordered. They were then asked to review the attribute lists, the attribute measures, and the attribute rank orders and to present their views on the validity of the attributes, their measures, and ranks. Finally, they were also asked to provide data for company demographics and indicate the levels of the attributes with respect to their operations on the specification sheet. The interviews were tape recorded with each interviewee's permission.

The interview started with the collection of company demographic data. Once the necessary demographic data were collected, the verification of the relevance of the attributes and their measures followed. For each attribute and its measure, respondent views were noted. Every attempt was made not to influence the participants by allowing them to express their views without interruption. The levels of the attributes were also determined by questioning the participants while their validity was being verified. Once this process was completed for both the feasibility and the choice-of-method issues, the verification of the relevance of the attribute ranks was done. Finally, the respondents were asked to review the attribute list for its completeness and provide any additional attributes that they thought were not included in the list.

5.3.5 Summary

This chapter described the methodology of the research. The scoring procedure for the feasibility issue was presented and explained first. The rules for the choice-of-method issue were constructed and discussed next. Finally, information relevant to the field work was presented. The next chapter discusses the results of the field work and analyses of the results.

Chapter VI

Results

6.1 Discussion of the field work

This section describes the results of the in-depth field work conducted at the four subject firms. As stated in the previous chapter, the objectives of the field work conducted in firms engaged in CM were: (i) to verify the relevance of the attributes and their measures; (ii) to verify the ranking of the attribute categories; and (iii) to gather data to determine scores for subject firms with respect to the feasibility issue, and resolve the choice of method for the part-machine grouping approach. The first three cases report the field work in firms engaged in CM. The last case is for comparison purposes, and is of a firm manufacturing components using a functional layout.

The presentation of the results of the field work is as follows. For each company, company demographics are presented first. This is followed by a discussion of the interview and a distillation of necessary information to establish the relevance of the attributes and their measures for both issues. Verification of the attribute rankings is discussed next. Finally, the scores determined via gathered data are presented and their implications discussed.

6.2 Case 1 - Company A

6.2.1 The plant and the product line

The first company included in the field work was Company A, employing about 700 people, located in the Southeastern United States. The visit was conducted in November, 1988. The interview time was approximately two hours. The engineering manager was the chief contact; three other company personnel were also present for half the length of the interview. They were a first-line supervisor, a process technician, and the plant superintendent.

The company manufactures a wide range of bearing types for a number of clients. Current clients include Caterpillar Corporation, General Motors Corporation, and Chrysler Corporation. Typically, a manufactured bearing is semi-circular, has a groove running along the inner surface and lips on either end. There are three diameter ranges of bearings made in the cells. These are: 3.50 - 4.25 inches; 2.00 - 3.50 inches; and 2.00 - 3.875 inches. The cellular manufacturing system is utilized for the manufacture of the medium-volume product line for which there are high and low demand values. The high-volume production system is a continuous line; the low-volume production system is for individual operations and is functionally oriented. The company controls about 65% of the original equipment market and about 90% of the service bearing market. About 45,000 units are produced per day in the high-volume line. The corresponding figures for the medium-volume and low-volume lines are 25,000 and 8,500 units per day respectively.

6.2.2 Production description

The production sequence for manufacturing the bearings consists of the following operations (when operations are manual): cornering, grooving, hole making, deburring, counter-sinking, height broaching, and wall-broaching. For automatic operations, the production sequence is: cornering, grooving, hole making, counter-sinking, height-broaching, counter-sinking, deburring, and wall-broaching. After all operations are completed, the individual pieces are stacked in wire baskets and transported for quality control checks.

6.2.3 Cell characteristics

The definition of cellular manufacturing, provided by the engineering manager, is: a combination of individual machine centers with automatic material handling between them. The cell system in this company is configured along GT flowlines. That is, the raw material passes progressively through a set of dissimilar machines until all operations are completed; there is no backtracking at any stage of the manufacturing sequence. The first cell has a pressing machine, a facing machine, and a lipping machine. The second cell has a grooving machine, a hole puncher, and a counter-sinking machine. The third cell has a deburring machine, a back-brush machine, a washer, and a broaching machine. Finished parts, stacked in wire baskets, are moved by light-duty carts.

There are currently three cells in operation and a fourth cell in the planning stage. It took this company three years to implement them. The motives for introducing CM systems in the medium-volume line were: (i) to increase quality and reduce material handling; (ii) to reduce manufacturing lead-time by reducing the number of set-ups; and (iii) to reduce work-in-process inventory. The medium-volume line involves a significant number of set-ups when changing from one part to another. On the other hand, the high-volume line is a continuous line that requires no changes in set-ups because it produces the same products all the time; the low-volume product demand is so low that there is no cost justification for a change in layout. About 8% of all production is currently done in cells and the eventual plan is to implement cells throughout the entire production system, provided the cost can be justified and cells are found to be appropriate.

The part-family forming approach is based on part-diameter ranges. In all, there are 69 different diameter ranges. Since all parts are semi-circular with almost the same details, they are very similar from a design standpoint. Also, there is a high routing similarity of all parts produced in the cells. In forming part-families, the design similarity was considered first by company personnel to determine the diameter ranges. The manufacturing similarity was then used to break the diameter ranges into sub-groups of similar routings.

6.2.4 *Verification of attributes and measures*

Verification of the attributes and their measures by using information from the interviews is discussed in this section. The verification of the attributes relating to the feasibility issue is discussed first.

Feasibility issue: The interviewees felt that the attribute "occurrence of part-families and machine cells" was relevant for the implementation of CM. The parts manufactured in this facility are characterized by high design and manufacturing similarity. The attribute "occurrence of indivisible processes" was also deemed relevant by the interviewees. They were of the opinion that part processing in centralized units would increase manufacturing time through increased material movement. In this facility, almost none of the parts require any visits to processing centers outside their respective cells; only one part requires a visit to a degreaser unit. The degreaser unit is centralized and is in another part of the plant. Degreasing is necessary for this part due to customer specifications.

The interviewees felt that the attributes "stability of product demand" and "stability of product mix" are important. This company operates in a stable product market. Also, there is very little fluctuation in the product-mix. This is so because of the standard product line. Variations experienced at present in the product demand or product-mix do not cause serious under or overloading of the cell capacities.

The attribute "complexity of components" was thought to be important by the interviewees because increased component complexity would result in increased material flow. In this facility, 10% of all components produced in all cells have a maximum of 9 operations; 43% of the components require 3 operations; and 47% require between 3 and 8 operations. Thus, 90% of all components produced in the cells require fewer than 9 operations. The low complexity in terms of the average number of operations required per part resulted in small cell sizes. The average machining time per component is about 5 minutes. Reduced material handling also resulted in better job tracking. Overall, complexity of components is low for this facility.

The interviewees felt that the attribute "weight of components" was important because of material handling considerations. According to them, heavy components could be handled by handling equipment or carriers like AGV's, but they also felt that lighter components would provide easier and cheaper handling possibilities. Therefore, they felt that light-weight components were better suited to CM than heavy-weight components. Individually, none of the components manufactured in this facility weigh more than a half-pound and over 95% of them weigh only a few ounces each. Wire baskets are used for transporting almost all components on hand carts.

The attribute "capacity balance" was felt by the interviewees to be important because it is necessary to know beforehand where capacity shortages exist. In their case, since the majority of the machines are specially designed and built, they have tried in the past to ensure that all machines run at approximately the same speed for functional capacity balance of each operation. There are, however, some machines where there is a slight capacity imbalance. This does not deteriorate production performance in any way. For all practical purposes, the interviewees felt that they did have a reasonable capacity balance in all their primary and secondary operation machines.

The attribute "flexibility of labor" was also noted to be important by the interviewees because of multiple machine operating requirements in a cell. In this facility, there are operators who can operate multiple machine types. The nature of the company's operations do not require tool and die makers or very skilled machinists. By labor contract, the company has operator Categories 1 and 2. Once operators reach Category 1, they can operate any piece of machinery they are able to without being restricted by the labor contract. An operator in Category 1 can set up and operate several pieces of equipment on which the operator is trained. An operator belonging to Category 2 does not set up or operate multiple machines types. Thus, the flexibility of the operator is determined by the ability to set-up and operate multiple machine types. The operators are also responsible for some material handling.

With respect to the attribute "availability of computer support" the opinion of the plant superintendent was that it was unnecessary for the creation of cells. This interviewee stressed the importance of this attribute more from the shop-floor control point of view. According to him, the requirement of computer support for shop-floor control is largely dependent upon the complexity of the components. Since the company manufactures very simple parts, sophisticated computer support was not felt necessary. In fact, he stressed that the company wanted to move away from computerized shop-floor control systems. Also, computer simulation of the work-centers had not been done in the past although it was felt desirable. His view identifies the importance of computer support with respect to the support of the CM system. However, the question of data visibility also arises from the observations made by this interviewee. If parts are simple and their design and manufacturing characteristics known, then computer support may not be necessary for cell design. Conversely, for complex routings or designs, a computer analysis may be necessary to determine cell configurations. The engineering manager, however, felt that computer support will normally be necessary in any plant to run other software for plant operations, if not for shop-floor control purposes.

There were also conflicting views among the interviewees with regard to the importance of the attribute "computer literacy of personnel." The engineering manager felt that it will become increasingly necessary in the future for managers to be computer literate. The plant superintendent, however, felt that computer literacy of middle-line managers was not important for CM purposes if the product line is simple. This second view is consistent with the view of computer support requirements expressed by them earlier. The engineering manager used computers daily in his work. He also stated that spreadsheet analysis was often used by the industrial engineers, and that most of the middle-line managers were conversant with a programming language. However, he had not attended any computer-oriented seminars.

The interviewees were of the opinion that some form of identification of parts was necessary to determine the part groups. The interview revealed that the participants were not aware of the availability of commercial classification and coding packages or formal classification principles. (The company does not have a classification and coding system in place.) Part numbers are in use, however, for the identification and tracking of parts.

The attribute "skill level of operator" was thought by the engineering manager to be important, because, for CM operation, the operators should be able to set up and operate any machine type in the cell. The company had few operators that were highly skilled; most were in a lower skill category. It was stressed by the interviewees that process technology of the company does not require highly skilled operators. The operators were only required to be able to set up and operate the machines. The company has a plan to train and cross-train all operators to be able to do their own set-ups.

With regard to the attribute "reliability of forecasting" the interviewees felt that the more accurate the product forecast, the better the plant could function, more so in a CM environment because of the limited availability of machines. Therefore, deviations of the part-demand forecast from actual should be low. They felt that the more complex the product and the higher the supplier lead time, the better the forecast should be. They said that the plant has an accurate forecast for up to two months and a fairly good forecast for periods of two to six months.

The attribute "reliability of equipment" was thought to be a very important factor, more so with CM in place because machine breakdown can stop workflow in a cell. The interviewees felt that this attribute should be higher in the attribute ranking list. Equipment reliability, in general, was thought by the interviewees to be high in the plant. The percentage uptime was quoted to be between 70%-80%. However, it is seen from this estimate that an average of 75% machine uptime translates to an average downtime of two hours out of every eight-hour working day. This is not a very encouraging machine uptime figure.

The attribute "implementation time" was also thought important by the interviewees because it was inconceivable to them that a CM system could be deployed in a month or six months. Therefore, they felt that management should be aware of the need for long-term commitment; the measure reflected by implementation history of previous projects was thought appropriate by the participants. In their case, conversion of their medium-volume line to a CM system had taken 3 years. Also, the design and building of machining work-centers -- viewed as major projects -- had taken between 12-15 months for successful completion at the company.

The attribute "reliability of suppliers" was thought important by the interviewees because stable production in a CM environment necessitates reliable supply of raw materials. The engineering manager cited examples of severe set backs to certain production plans on the medium-volume line due to suppliers not being to able to supply raw material at the right time. Therefore, he felt that the extent of on-time delivery of raw material was important. He also felt that the frequency of the supply of defect-free material needed to be high, because the increased lead-time necessary for supply of fresh material would seriously offset all production schedules; more so in a CM environment with lower inventory buffers.

The attribute "type of material control system" was thought important, because it provides an opportunity to set production schedules based on product demand with priority loading to determine workload at individual workcenters. At this facility, this method provided a significant improvement over manual loading methods practiced previously. The company is in the process now of installing an MRP II system. The purpose is to tie together all manufacturing functions with a common database.

Measures used for the attribute "workload on process planners" were thought by the engineering manager to be appropriate indicators of this attribute. He also thought that this attribute could be used as one indicator of the possibility of implementing a CM system because process planning overload via duplication of process plans can be a real possibility in a functional system. However, he thought that the possibility of process planning overtime without process planning duplication was less. The company has three full-time process planners and standard process plans are used for orders of existing parts. For new parts (parts not manufactured before) the tooling engineer develops new plans if a manual check on existing plans reveals that a standardized plan does not exist.

The engineering manager felt that the attribute "scheduling procedure" was a valid indicator for the feasbility of implementation of CM; however, he felt that the measure "centralization of scheduling" was unnecessary. Scheduling is the responsibility of production control at this firm. There are three schedulers on the shop floor and they report to a master scheduler. It is the responsibility of the master scheduler to prepare long-term schedules. The shop-floor schedulers modify the long-term schedules as and when required, depending on events such as shortage of material, equipment breakdown, etc. Thus scheduling is centralized with first-line supervisors having authority to override the schedules as and when necessary.

The interviewees felt that the attribute "managerial support" expressed by long-term planning was extremely important for effective CM operations. One of the participants noted that there has been a shift in upper management's thinking about employee involvement, quality, etc. However, he also noted that "unfortunately our strategic planners haven't gotten to the point where they are looking at manufacturing as a strategic issue." The interviewees also said that they were encouraging upper management to think at least in terms of five-year plans. The measure "the extent to which senior personnel help subordinates" was also thought significant because they thought that it was important for senior managers to help their subordinates to implement changes. In this company, management was viewed to be very supportive while encouraging active participation of all its employees. The measure "length of time taken to get capital allocation through" was not thought to be important as long as the length of time was known, so that it could be factored into the planning. It takes about two months to get capital allocation approved in this company. The measure "extent of yearly increase in manufacturing budget" was agreed to be an indicator for CM feasibility, because it indicated availability of funds. In this company, there was a 10% annual increase in the manufacturing budget and the participants thought that that was adequate for their purposes.

With respect to the attribute "resistance to change," the measure "the extent to which supervisors stick to old ways of doing things" was seen by the engineering manager as a big problem everywhere. The measure "extent of employee turnover" was also thought to be an important indicator of this attribute. Typical turnover in this company is less than 1% per year. The measure "frequency of strikes" was not thought to be important as an indicator of this attribute. The company has a union but has not had a strike in the last ten years. This was attributed by the engineering manager to everyone's working together rather than on an adversarial basis. Such a low occurrence of strikes could have led the engineering manager to believe that this measure was not important in determining resistance to change.

This completes the discussion of Company A's managers' opinions as to the validity of the attributes for the feasibility for CM implementation. All attributes, except "availability of computer support" and "computer literacy of personnel" were thought important; some measures were thought to need refinements. These measures were related to "scheduling procedures" and "workload on process planners." A summary of the results of the relevance verification is shown in Table 8.

Table 8. Attribute relevance verification for feasibility – Company A

Validity verification of attributes – feasibility issue

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
1. Occurrence of part families and machine cells		✓			CENTRAL TO THE CONCEPT OF CM
	Component design similarity	✓			
	Component manufacturing similarity	✓			
2. Occurrence of indivisible processes		✓			
	Extent of intermediate visits to centralized processes	✓			
3. Stability of product demand		✓			IMPORTANT
	Fluctuation in long term product demand	✓			
4. Stability of product mix		✓			IMPORTANT
	Fluctuation in long term product mix	✓			
5. Complexity of components		✓			
	Average # of machines needed to complete a component	✓			
	Average # of operations needed to complete a component	✓			
	Average machining time per component	✓			
6. Weight of components		✓			
	Equipment needed to transport components	✓			
7. Capacity balance		✓			
	Extent of machine utilization	✓			

Table 8 continued

Table 8 continued

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
8. Flexibility of labor		✓			
	Ability of operators to operate multiple machine types	✓			
9. Availability of computer support			✓		DEPENDS ON PART COMPLEXITY
	Availability of computer resource in terms of memory of a single computer	✓			
10. Availability of a coding and classification system				✓	DIDN'T KNOW ABOUT CLASSIFICATION AND
	Availability of/and access to a coding & classification package			✓	CODING
11. Computer literacy of personnel			✓		
	The frequency of direct use of computer at work	✓			
	The frequency of use of spreadsheet analysis on computer	✓			
	The frequency of programing using FORTRAN, GPSS or APL	✓			
	Of all the time spent in workshops and/or seminars, the percentage spent in attending workshops and/or seminars directly related to computer education	✓			
12. Skill level of operators		✓			
	In terms of tool and die makers class A and class B machinists	✓			

Table 8 continued

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
13. Forecasting reliability		✓			
	Deviation of part demand forecast from actual	✓			
14. Reliability of equipment		✓			EXTREMELY IMPORTANT
	Frequency of machine breakdown	✓			
15. Implementation time		✓			
	Planning horizon (short or long term)	✓			
	Implementation history of past large-scale projects	✓			
16. Reliability of suppliers		✓			
	Extent of on-time delivery in the supply of raw materials	✓			
	Frequency of time that material is delivered free of defect	✓			
17. Material control system		✓			
	Type of MCS currently in use	✓			
18. Work load on process planners		✓			
	Extent to which process planners work overtime	✓			
	Extent of duplication in process planning	✓			

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
19. Scheduling procedures		✓			
	Centralization of Scheduling		✓		SHOULD BE CENTRALIZED
	Authority of foremen to override schedules	✓			
20. Managerial support		✓			
	Extent of management to plan ahead	✓			
	Extent to which senior personnel help subordinates	✓			
	Length of time taken to get capital allocation approved		✓		NOT IMPORTANT AS LONG AS IT IS KNOWN BEFOREHAND
	Extent of yearly increase in manufacturing budgets	✓			
21. Resistance to change		✓			BIG PROBLEM EVERYWHERE
	Extent to which supervisors stick to old ways of doing things	✓			
	Extent of employee turnover	✓			
	frequency of strikes	✓			

Choice-of-method issue: This section discusses the results of the validity verification of the attributes of the choice-of-method issue. The importance of the attribute "component design similarity" for this firm was substantiated by the fact that the subject firm's manual grouping of parts was based on 69 different diameter ranges. This was their initial approach to part grouping. Component manufacturing similarity was then used to further determine sub-groups. These were the only two considerations in the selection of procedures for part-family grouping. Therefore, the verification of the remaining attributes and their measures is based largely on the participants' perceptions of the importance of the attributes and not on whether they were considered during the implementation process at this site.

The attribute "availability of a CAD system" was thought to be useful due to the ability to store drawing information on a database for future access. A CAD system is not in place in the company.

The interviewees did not express any knowledge about part classification systems or computerized production-oriented approaches to part-family formation. Therefore, the relationship between the attributes "monetary support," "implementation time," and the choice of method had to be explained to them. They then concluded that the attributes "monetary support" and "implementation time" were important because these attributes dictate which "avenue you choose to implement."

The importance of the attribute "availability of computer support," with regard to the approach to part-family formation, was thought by the interviewees to be dependent on the product line. According to them, the requirement of computer literacy for part-family formation would be dictated by the complexity of the parts. The interviewees noted that the components manufactured in this facility have simple process routes and, therefore, there was no need for computer-based part-family forming procedures.

The engineering manager personally felt that the attribute "computer literacy of personnel" is important because computer literacy of middle-level personnel would be an important factor to consider for the future.

With regard to the attribute "inter-departmental information requirements," the engineering manager felt that a computer database of all products would be extremely important for such requirements.

The engineering manager also thought the attribute "value analysis" to be important. Value analysis (VA) is currently being considered by them for the elimination of non-value processes in manufacturing.

The attributes "design standardization and retrieval" and "process planning standardization and retrieval" were perceived to be important by the engineering manager. Both design and manufacturing departments are engaged in the standardization of component design and manufacturing process plans. Standard component designs and routings are checked against incoming part orders to facilitate the use of existing process routings. Customers are sometimes encouraged to change their designs if possible to fit one that is existing as it is easier to manufacture.

The interviewees lacked knowledge of the attribute "usage of graphics and product standards" as used in this research. The company does not use any graphics standards or product standards of the type mentioned in the definition of this attribute. The company has its own product standard in the form of standard material specification for its products. A summary of the results of the relevance verification is shown in Table 9.

Table 9. Attribute relevance verification for choice of method – Company A

Validity verification of attributes of the choice of method issue

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
1. Component design similarity		✓			
	Grouping based on design categories	✓			
2. Component manufacturing similarity		✓			
	Grouping based on routing similarity	✓			
3. Availability of a CAD system		✓			
	Availability of/accessibility to a CAD system	✓			
4. Monetary support		✓			REQUIRED EXPLANATION ABOUT RELEVANCE
	Availability of funds for a classification and coding scheme	✓			
5. Implementation time		✓			REQUIRED EXPLANATION ABOUT RELEVANCE
	Amount of time given/to be given to the approach	✓			
6. Availability of computer support			✓		
	Same as feasibility issue	✓			
7. Computer literacy of personnel			✓		
	Same as feasibility issue	✓			

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
8. Interdepartmental information requirements		✓			
	Desire to identify similar items for bulk purchases	✓			
	Desire to estimate products cost accurately	✓			
9. Value analysis (VA)		✓			
	Desire to use VA for least cost design	✓			
10. Design standardization and retrieval		✓			
	Desire to standardize product designs and retrieve similar designs	✓			
11. Process plan standardization and retrieval		✓			
	Desire to standardize and retrieve similar process plans	✓			
12. Use of products and graphic standards				✓	UNAWARE
	Desire to use products and graphic standards			✓	

This discussion on the verification of the relevance of attributes for the choice of method issue has provided additional insights into Company A's CM system. The significance of this field work regarding the validity of the attributes, their measures, and ranks will be discussed next.

Significance of the verification: The verification procedure of the attributes indicated that computer support and computer literacy of middle-line personnel were not perceived to be of importance in the cell-design process. This finding is in conflict with reports of researchers in CM (Wemmerlov and Hyer 1986) where the view is that computer support for cell design and implementation is mandatory. However, it must be remembered that this is a small sample. One interpretation of this finding is that component complexity may be directly related to the requirement of computer support and literacy. Thus, it would be desirable in the future to study companies with similar product lines to develop a relationship between computer support in the cell-design process and the type of products made. Another salient point is the interviewees' lack of knowledge of some of the attributes of the choice-of-method issue. This could be due to the lack of GT education in this firm. The participants' responses to some of these attributes were based on their perceptions of the importance of the attributes after the relevance of the attributes in relation to the choice of method was explained to them.

6.2.5 Verification of attribute weight categories

The participants were in agreement with most of the established rankings of the attributes for feasibility by categories. However, they were of the opinion that the attribute "reliability of equipment" should be in Category II instead of Category III because they thought it to be important for the operation of the flow-line. With regard to the ranking of attributes for the choice-of-method issue, the attribute rankings were thought acceptable. The participants also agreed with the suggested score ranges of the categories. They felt that establishment of the score ranges or the assignment of scores to each category could be easily done by the researcher once the attribute rankings are verified. Tables 10 and 11 present the results of this verification process for firm A.

Table 10. Feasibility weight verification – Company A

Weighted attribute categories of the feasibility issue

Category	Attribute	Suggested Score range	Validity of Category	Rank	Don't know	Comments
I	1. Occurrence of part families and machine cells	90-100	✓	✓		
II	2. Stability of product demand	75-89	✓	✓		
	3. Stability of product-mix			✓		
	4. Complexity of components			✓		
	5. Occurrence of indivisible processes			✓		
	6. Weight of components			✓		
	7. Managerial support			✓		
	8. Resistance to change			✓		
	9. Implementation time			✓		
III	10. Availability of computer support	60-74	✓	X		
	11. Computer literacy of personnel			X		
	12. Material control system			✓		
	13. Capacity balance			✓		
	14. Reliability of equipment			X		GOES IN II
	15. Flexibility of labor			✓		
	16. Skill level of operators			✓		
	17. Reliability of suppliers			✓		
	18. Forecasting reliability			✓		
	19. Scheduling procedures			✓		
IV	20. Workload on process planners	45-59	✓	✓		
	21. Availability of a classification and coding system				✓	

Category	Attribute	Suggested Score range	Validity of Category	Rank	Don't know	Comments
others						NONE OFFERED IN THIS CATEGORY

6.2.6 *The score*

The score for the feasibility issue will be discussed next. For each attribute, the average value of its measures were computed. Scores were determined by using the scoring procedure described in Chapter V. To determine the level of each attribute, the specification scale was used first to determine attribute measures. For example, the level of the attribute "occurrence of indivisible processes" was measured on a 1 to 5 scale by using its operational measure "extent of intermediate visits to centralized processes." Interviewee responses to each operational measure for every attribute were recorded. Average values of these measures were then computed. The relationship between attribute levels and feasibility (developed by using the propositions and presented in Chapter V) was used for each attribute to compute feasibility measures. For example, if the measure of the attribute "occurrence of indivisible processes" was 4, then according to its specification, the attribute level is high. From the attribute level and feasibility relationships, the weight of this attribute is allocated to the feasibility column. Similarly, by measuring the levels of all other attributes, the attribute weights were allocated to either the feasibility column or the infeasibility column. Thus at the end of this procedure, a feasibility measure results. Table 12 below lists the measured values for each attribute and their corresponding weights.

Table 11. Choice of method ranking verification – Company A

Weighted attribute categories of the choice of method issue

Category	Attribute	Suggested Score range	Validity of Category	Validity of Rank	Validity of Don't know	Comments
I	1. Component design similarity	90-100	✓	✓		
	2. Component manufacturing similarity			✓		
II	3. Monetary support	75-89	✓	✓		
	4. Implementation time			✓		
	5. Availability of computer support			×		
	6. Computer literacy of personnel			×		
	7. Inter-departmental information requirements			✓		
	8. Value analysis			✓		
	9. Design standardization and retrieval			✓		
	10. Process plan standardization and retrieval			✓		
III	11. Availability of a CAD system	60-74	✓	✓		
	12. Usage of standards				✓	
Others						NONE OFFERED

Table 12. Feasibility score for Company A

Attribute	Scale value	Weight Feasibility	Weight Infeasibility
1. Occurrence of part-families/machine cells	5	0.0620	
2. Occurrence of indivisible processes	5	0.0552	
3. Stability of product demand	5	0.0552	
4. Stability of product-mix	5	0.0552	
5. Complexity of components	4.67	0.0552	
6. Weight of components	5	0.0552	
7. Capacity balance	4	0.0456	
8. Flexibility of labor	4	0.0456	
9. Availability of computer support	5	0.0456	
10. Availability of a classification system	1	NA	
11. Computer literacy of personnel	3.25		0.0456
12. Skill level of operators	5	0.0456	
13. Forecasting reliability	4	0.0456	
14. Reliability of equipment	4	0.0456	
15. Implementation time	4.5	0.0552	
16. Reliability of suppliers	4	0.0456	
17. Material control system	5	0.0456	
18. Workload on process planners	2		0.0365
19. Scheduling procedures	3.5		0.0456
20. Managerial support	4.25	0.0552	
21. Resistance to change	3.67		0.0552
Feasibility score		0.8132	

The score given by this scoring procedure (simple addition of weights of the attributes contributing to feasibility as determined by the rules) = 0.8132. The weights were derived by using the mean score of the suggested score range for each weight category.

The score reflects a high potential for CM -- the manufacturing system in this case is actually a CM system. A few points merit consideration. The attribute "computer literacy of personnel" has an average value of 3.25. This is due to the low value of its last measure (% of time spent in computer education). Thus, one implication is that computer literacy may not be overly important for CM implementation purposes, at least not for Company A. It is also possible that the measure is not an accurate reflection of computer literacy in the manufacturing environment. The attribute "availability of a classification and coding system" did not enter the scoring procedure (the facility does not possess this resource) as the unavailability of this resource does not automatically imply CM infeasibility. This required re-normalizing the weights to derive the weights without this attribute. The attribute "workload on process planners" received a score of 2. This is expected because, typically, in a CM environment there will be less duplication of process plans and process planning overtime. The attribute "scheduling procedures" received an average score of 3.5. This is due to a low score on the first measure (centralization of scheduling). This suggests revision of the measure(s) of this attribute. Finally, the attribute "resistance to change" received an average score of 3.67. This is due to a low score on the first measure (propensity to stick to old ways). This suggests that "resistance to change" is not an insurmountable problem and even in a CM system, there is a tendency to revert to old ways. The matrix of CM feasibility is also given in Figure 10. The matrix shows that CM is deemed infeasible for the firm due to the critical attribute "resistance to change" being at an unfavorable level. Thus, a contradiction is noted here. On the one hand, the feasibility score is high while, on the other hand, the feasibility matrix deems CM to be infeasible. It is, therefore, possible the attribute "resistance to change" may not be critical. Thus, it may be necessary to reexamine and modify the feasibility matrix in the future by conducting more field studies.

The cell-type matrix for this company is shown in Figure 11. A family of products (bearings) are processed in the cells in this facility and the material flow is straight. Therefore, the company is placed in Block 7 of this matrix. In reality, there is no backflow of material in the cells in this facility.

6.2.7 The choice of method

The choice of method could not be executed here because the interviewees were unaware of the relationship between the attributes, "monetary support" and "implementation time," and the choice of method. Thus, the levels of these attribute could not be gathered. However, the choice of method may be tested with the values of attributes that were available and by assuming values of attributes that were not available.

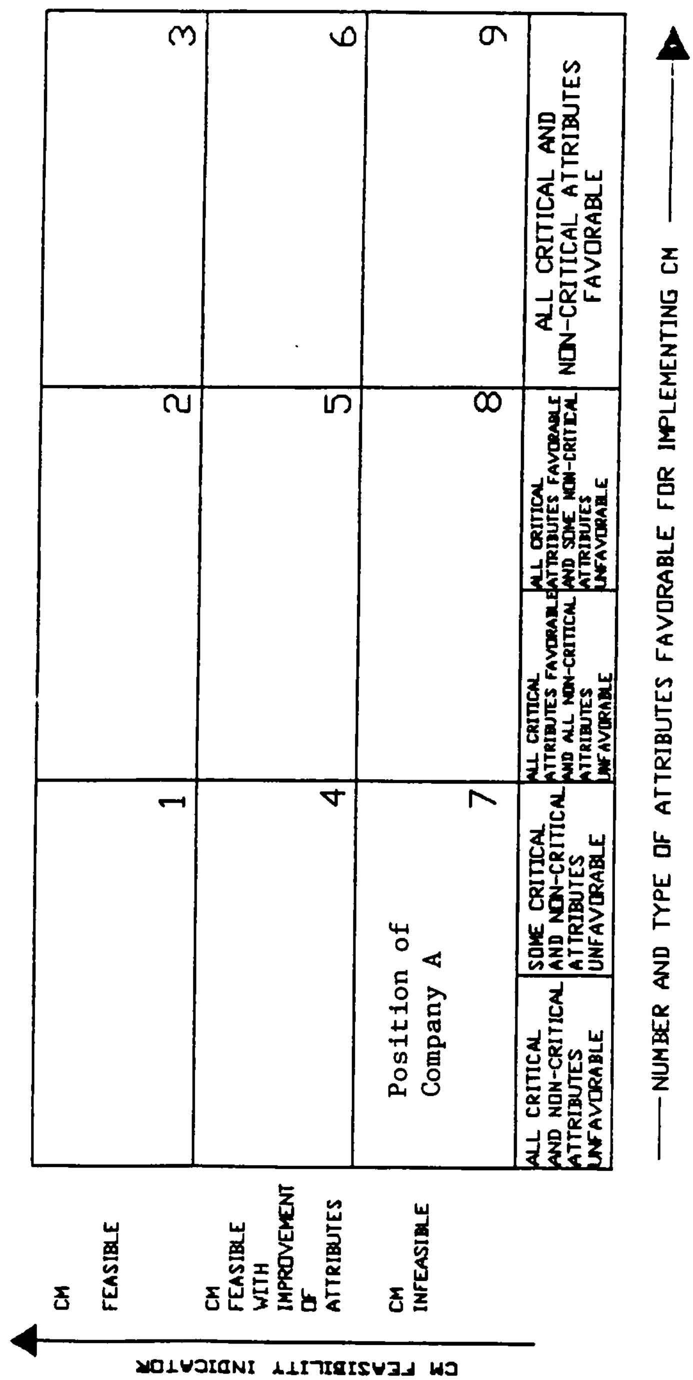

Figure 10. Feasibility matrix for Company A

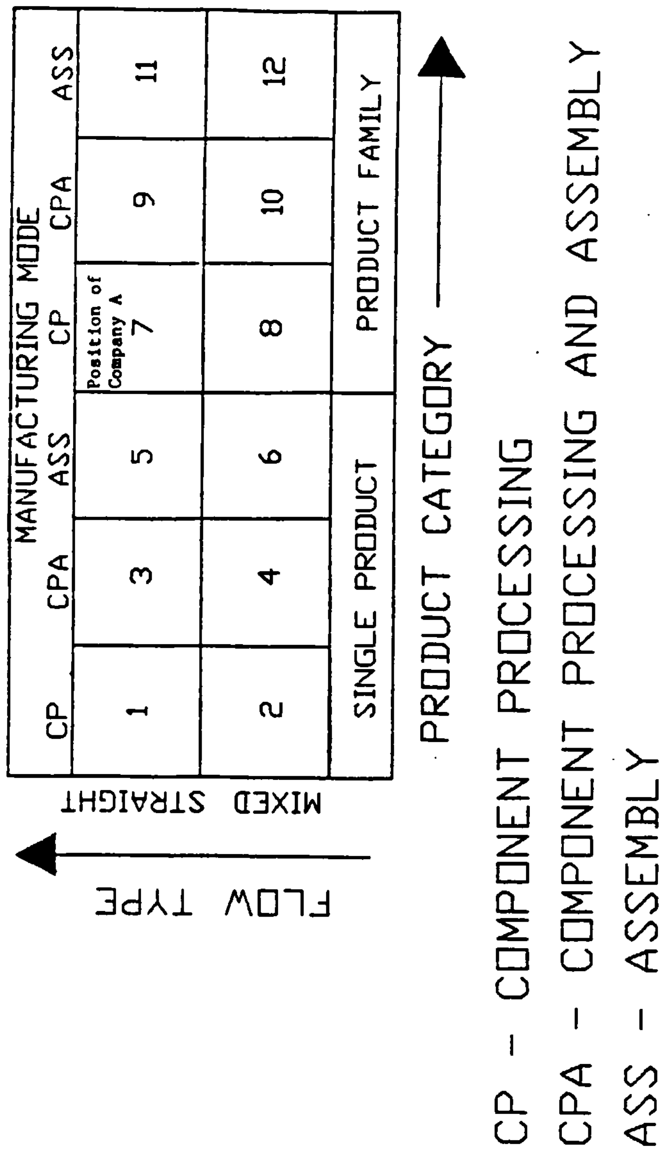

Figure 11. Cell-type matrix for Company A

The "component design similarity" and "component manufacturing similarity" were both at high levels. The attribute "availability of computer support" was at a high level. However, the attribute "computer literacy of personnel" was at a low level. The attributes "interdepartmental information requirement," "value analysis," "design standardization and retrieval," and "process planning standardization and retrieval" were all at high levels. Suppose the levels of the attributes "implementation time" and "monetary support" are both high. Then by Rule 9 the choice is a manual hybrid classification system. Also, if the levels of the attributes are both low or one of them is low (or high), then Rules 4 and 12 again point to a manual hybrid approach.

6.3 Case 2 - Company B

6.3.1 The plant and the product line

The second company visited as a part of the field work employs 614 people, and is located in the Southeastern United States. The visit was conducted in November, 1988. The interview was approximately one hour and forty-five minutes. The Director of Manufacturing was the chief contact. The other participant was the plant manager of one of the company's divisions.

The company manufactures drilling equipment at this location. The product line includes tall drills, down-hole drills and hammers, hoists and winches, hand-held tools, drills, air-starter motors, down-hole drill bits, and threaded accessories.

6.3.2 Production description

The plant is basically a job shop with order quantities ranging from one or two to 1,000 pieces. Parts range in size from a few ounces to some in excess of three to four hundred pounds. Materials used are basically alloy steels, some grey iron, some malleable iron, some brass and bronze, and aluminum. Operations vary from part to part but parts and operations are all limited to individual cells.

6.3.3 Cell characteristics

Cellular manufacturing was defined by the plant manager as "a group of machine tools (or processes) which perform sequential operations on a family of parts in the same geographic location."

The cells in this company are configured as independent units and have a mixed flow of parts. That is, there is backtracking of parts within a cell. Raw material flows in at one end and, after processing, exits the cell as a completed unit. Sufficient space is provided within the cell for in-process inventory. Part movement within the cell is done manually or with the use of hoists. Currently there are 11 cells in operation. The time taken to implement individual cells ranged from less than a year to more than two years. The number of machines per cell varies from two to nine and, on the average, there are two machines per operator.

The first cell has 2 NC lathes, an NC hob, a gun drill, and 2 NC machining centers for a total of 6 machines. Six machines also constitute the second cell. There are 2 manual lathes, 2 NC lathes, and 2 gundrills in this cell. The third cell comprises 2 NC machining centers, 2 multiple screw machines, and 2 NC lathes for a total of 6 machines. There are 7 NC machining turret drills in the fourth cell. The fifth cell consists of a robot, 2 NC lathes, 1 automatic turret lathe, and 1 thread whirler for a total of 4 machines. A radial drill press, a hydraulic press, and packaging equipment make up the sixth cell. The seventh cell consists of 1 thread roller and 1 lathe for a total of two machines. The eighth cell has three machines, of which two are NC lathes; the other is a spline mill. There are two machining centers and 1 NC lathe, for a total of three machines, in the ninth cell. The tenth cell consists of 2 NC lathes, 1 engine lathe, and 1 horizontal automatic hone for a total of three machines. This cell also includes a wash-station. Finally, the last cell, cell eleven, has a total of 5 machines, of which 2 are NC lathes, 2 are horizontal borers, with the remaining machine a hone. From the description of the machines, it is evident that the majority of the parts produced in the cell are rotational.

The motives for introducing cells at this firm were better machine utilization via multiple machine operation per operator; reduced work-in-process inventory; improved quality control; improved operator involvement; better scheduling visibility; improved production control; reduced set-up of parts; standardization of product design; improved tooling; and better material utilization.

Currently, 15% of all production is done in cells. Eventually the interviewees expect 50% of all production to be done in cells. There are no plans for adding new cells; however, expansion of the existing cells is planned to add more operations. A robot-controlled cell has been in the planning stage for the past 12 months. Its implementation was estimated by the interviewees to require another 12 months.

The part-family formation procedure was to group geometrically similar parts requiring similar set-ups and machine tools and processes and weighing roughly the same. Thus, the part-family approach considered geometric similarities first for identification of common parts and then further subdivided these common parts according to their routing commonalities.

6.3.4 Verification of attributes and measures

This section discusses the verification of the attributes and their measures by using information from the interview. The verification of the attributes of the feasibility issue is discussed first.

Feasibility issue: The interviewees felt that the attribute "occurrence of part-families and machine cells" measured by component design and manufacturing similarities was valid. The parts manufactured in the cells here are characterized by high design and manufacturing similarities. These parts are mostly rotational and are grouped by design and manufacturing similarities.: The attribute "occurrence of indivisible processes" was also thought important by the interviewees. The plant manager stressed that visits to centralized processes should be totally avoided. In this facility, he said, it was ensured that parts undergo sequential machining operations without breaks. If the disruption of the machining sequence is absolutely necessary, then separate cells are designed for the processing of parts prior to and after the visits to the centralized process. This finding is significant from the view point of cell design, because it provides one solution for situations characterized by intermediate centralized processing requirements.

With respect to the attribute "stability of product demand," the respondents were of the opinion that it was important for the functioning of the cell, but it does not control the creation of the cell. They also thought product demand stability to be important because the cost of creating a cell can only be recouped by steady production resulting from a stable demand. They thought this attribute is related to cell performance; high product instability results in deteriorating cell performance and is, therefore, undesirable. This facility uses labor flexibility to overcome short-term product demand instability; usually this instability is low.

The attribute "stability of product-mix" was thought important from the point of view of "not having to reprocess or retool every five minutes because the product-mix changes." In this facility, cells are designed with a view to future product development and evolution. The changes in the product plans for the future are considered seriously in the designs of cells. The participants felt that a loss of one particular product type would have to be offset by a volume increase of another for the CM system to be successful. Their facility was characterized by a relatively stable product-mix with some phasing in and out of products over a long time period.

With respect to the attribute "complexity of components" the respondents felt that forming cells depends on the component complexity. They also felt that it is much easier to form cells with less complex components because a lower number of machines is involved. They were also of the opinion that it is better (from a material handling point of view) if the number of machines required for individual component processing is ten or less. However, they also thought that, if the operations were sequential and that if the volume justified a CM approach, then there should be no reason why the number of machines required to complete a component should be a factor in the decision-making process. According to them, one way to handle increased machine requirements is to fragment the larger cells into smaller cells and feed the components successively through the cells in stages, if the machining sequence permits. This finding suggests a solution to cell forming procedures in situations where parts require a large number of machines for processing.

The average number of machines per cell in this company is about six. The average number of operations needed to complete a component in a cell is about 20. The average total machining time per component was estimated to be between 10 and 20 minutes. However, it must be noted here that most of the cells make extensive use of machining centers and NC machines. Therefore, it is possible that quite a few operations are done in one set-up. This suggests the possibility of refining the measure "average number of operations needed to complete a component." One possibility is the average number of operations per machine.

The attribute "weight of components" was considered by the interviewees to be a significant factor in the operation of a CM system. It was considered to be a factor from the material handling point of view. The respondents felt that if components are heavy, such that they cannot be easily handled manually or by lightweight mechanical means (jib cranes or hoists), then the complexity of the cell is increased because of increased material handling. As a result, they felt that the cell operators also have to devote more time to material handling than in the case of light-weight components. Most of the components produced at Company B are relatively light. They can be handled manually or by the use of light handling machines.

The attribute "capacity balance" was thought to be an important factor in determining the feasibility for the implementation of CM. The respondents thought that one of the major drawbacks of a cell was the loss of machine capacity on account of imbalances in operations. Approximately 30% more capacity was estimated to be necessary when cells are implemented. Therefore, existing functional capacity balance should be checked in order to determine additional capacity requirements in a cellular layout. The cells in this facility have a high degree of machine utilization of the primary machines and a reasonable utilization of the secondary machines, according to the interviewees.

The attribute "flexibility of labor" was deemed critical by the participants. According to them, flexibility of labor not only implies the ability to operate multiple machine types, but also the ability to set-up the machines as well. Furthermore, they thought, for operators to be flexible, they must be capable of minor maintenance work, quality checks, and secondary operations such as greasing, deburring, washing, and material handling. This indicates the necessity of refining the definition of this attribute and its measure by including additional operation or maintenance work specifications in the measure.

The interviewees were also of the opinion that the flexibility of labor could be used to smooth out short-term demand fluctuations by transferring operators among cells. On an average, two machines are operated by each operator in the cells. The operators are also capable of setting up any machine within the cell, and they routinely perform secondary operations and cross-train each other.

The attribute "availability of computer support" was not thought to be a critical factor for the creation of a cell but was thought to be a factor for future enhancements. The respondents also thought that the requirement for computer support for family formation was minimized for them by good data visibility of part shapes or their routings. According to them, CM minimizes the need for computer support which they felt was greater in a functional layout because of increased control problems. At the cell level they felt computer support was unnecessary because parts enter the cells as distinct entities and are easily tracked and controlled. At the factory level, the need for computer support was thought to be dependent on part inter-relationships in final assemblies and overall business operations. The company has an operational mainframe computer system and personal computers. This finding suggests a closer examination of the relationship between data visibility and computer support requirements that could be a researchable issue.

The attribute "availability of a classification and coding scheme" was thought unnecessary for the CM feasibility analysis; especially if it is known what the high-volume common parts are. The participants observed that, in their plant, manufacturing personnel were all aware of the common, high-volume parts. Therefore, they felt that a company-wide parts classification system was unnecessary for their operations at this time. However, they do have a coding system for tooling and a coding system for the articles of stores (for hardware items). A corporate-wide DCLASS system is available, but the respondents felt it unnecessary for their operations due to high part visibility, and also because of the substantial front-end user logic-input requirements of this system. The participants also discussed plans of implementing a classification system in conjunction with a CAD/CAM system in the near future. This was also necessary, they explained, because of expansion of the cellular system and increased data requirements.

With regard to the attribute "computer literacy of personnel" the respondents felt that it was not a significant factor in CM implementation. A certain degree of computer literacy was preferable, they said, but probably unnecessary for cell operation because of easier control of cells. However, they thought it to be important for overall business operations. Computers (usually PC's) and computer-generated reports are used daily by the interviewees in their work. They also noted their familiarity with programming languages and stated that they had attended computer-oriented seminars in the past but do not now as "most of us are fairly literate." The company implemented a PC programming training course (for BASIC, dBASE, LOTUS, and other packages) for its employees two years ago. Currently, a course is being offered to teach employees a new software package developed in FORTRAN.

The attribute "skill level of operators" was thought to be a significant factor in the cell design procedure. The respondents were of the opinion that all the machine operators in all cells in their facility are of the class category A (as defined in this research). The operators are considered skillful because they can set-up and operate any machine in the cell and can perform whatever operations are necessary to complete a part. They are flexible because they are prepared to set-up and operate any machine. It was also stated by the interviewees that the cell operators did not experience deskilling effects if job requirements required them to perform operations below their skill levels. This finding is in conflict with Leonard and Rathmill's (1977a, 1977b) studies where the authors stated that CM is suited for conditions requiring low operators skills and concluded that deskilling effects of skilled workers is a major factor in the cellularization process. Another implication is that a possible review of this attribute, its measures, and the proposition relating this attribute and the feasibility issue should be undertaken in future research.

The attribute "forecasting reliability" was thought to be important because an accurate forecast is necessary to set-up the cell in the first place. Also, inaccurate product forecasts can completely disrupt CM operations. According to the interviewees, this facility has a 90% accuracy of its product forecast.

The attribute "reliability of equipment" was important to the participants because, if one machine malfunctions, then production within the cell stops. Also, there is not enough in-process inventory to carry over while the cell is down. Machine reliability was stated by the interviewees to be good at their company with infrequent breakdown of machines. A skilled maintenance workforce is also available.

The attribute "implementation time" was seen as fairly important because implementing CM involves a very significant capital commitment and, therefore, long-term planning is absolutely necessary. Also, the respondents thought that implementation history of past large-scale projects should provide a reasonable indication of managerial commitment. The company releases a firm plan for the following year at the beginning of the current year. It also releases a two-year plan subject to changes at the same time. The overall planning horizon is for 5 years. The success in the implementation of past large-scale projects is evident from the successful cellular lines.

The attribute "reliability of suppliers" was deemed critical with respect to effective CM operation. The reason stated was the necessity to minimize raw material inventory while maintaining continuity of supply. Therefore, the interviewees felt it necessary to have a reliable supplier who will provide quality material on-time. It is also necessary, noted the participants, to develop a long-term relationship with the suppliers. The supply reliability was rated "good to excellent" in the supply of bars and tubings, and "good" in the supply of castings. Most supplies of bars and tubings conform to standards and, therefore, are usually defect-free. The quality of the castings supplied is sometimes a problem.

The respondents were of the opinion that an assembly-driven MRP or MRP II system is necessary for the effective operation of a CM system. Currently, an MRP system is in use in this facility.

The attribute "workload on process planners" and its measures were seen by the participants as a fair indicator of the feasibility for the implementation of CM. In their experience, routing duplication and anomalies in the past were often detected when standard costs of similar parts were found to be significantly different because of differences in the routings. They perceived a high possibility of routing duplication in a functional layout. In their facility, there is some process-planning overtime but it is mostly on an as-needed basis and is not a regular occurrence. Standardized process plans are always used (with or without modification) to develop process plans for new parts. Thus, duplication of process planning is almost non-existent.

With respect to the attribute "scheduling procedures" the interviewees felt that overall scheduling has to be centralized and scheduling within the cell has to be the responsibility of the cell supervisor. There is no shop-floor production planning or individual machine production planning in this factory. A master schedule is generated on a monthly basis in the production control department. The supervisor of a cell is given the monthly schedule for the cell and it is the responsibility of the supervisor to complete the product by the due date on the master schedule. He/she does not have the authority to change the due date of the master schedule but has complete authority on job planning within the cell. With centralization of scheduling seen as important, it is necessary to review and adjust, if necessary, the first measure of this attribute.

The attribute "managerial support" was viewed as critical by the participants. According to them, it is the responsibility of management to determine the direction of manufacturing. In this company, manufacturing is treated as a strategic issue and strategic planning is for a period of three years.

The respondents also thought that senior personnel "have to be available to do what is necessary to assure that the business plan is met." To do so, the interviewees said, they should be capable of supporting junior personnel as and when necessary and they also should take charge if situations require it. It was the opinion of the respondents that short capital approval time lengths are critical for effective planning. The maximum time required for capital approval in this plant was estimated to be about 3 months with the minimum being 2 weeks. The last measure of this attribute "extent of yearly increase in manufacturing budgets," was felt to be an important indicator because it reflects the availability monetary resources. The company's manufacturing budget has actually decreased by 2% yearly for the last 5 years. This was attributed to better management, lower production costs through increased manufacturing efficiency and better quality, and extensive employee involvement regarding costs of doing business. Thus, the company required less capital than before and, thus, experienced a decrease in the budget. The participants were satisfied with such a decrease because they thought that it indicated more efficiency and effectiveness in their operations.

The last attribute "resistance to change" was viewed as critical, although not insurmountable. The respondents believe that if management is willing to change (and practices what it preaches), then subordinates will change. In this plant, management and supervisors are not resistant to changes and see themselves as leaders of their subordinates. Employee turnover is almost negligible; the only turnover results from retirement. The plant is not unionized and there have been no major labor troubles in the last few years.

This completes the discussion of the validity of the attributes and their measures for the feasibility issue. The interviewees expressed some disagreement with the relevance of the following attributes: "availability of computer support," "availability of a classification and coding system," and "computer literacy of personnel." They were also of the opinion that master scheduling should be centralized. Furthermore, they suggested the incorporation of tangible factors, such as manufacturing lead time, inventory levels, and the number of overdue orders in the attribute list. Table 13 summarizes the results of the relevance verification of the attributes. The discussion of the relevance of the attributes of the choice-of-method issue follows.

Table 13. Attribute relevance verification for feasibility – Company B

Validity verification of attributes -- feasibility issue

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
1. Occurrence of part families and machine cells		✓			
	Component design similarity	✓			
	Component manufacturing similarity	✓			
2. Occurrence of indivisible processes		✓			IMPORTANT
	Extent of intermediate visits to centralized processes	✓			
3. Stability of product demand		✓			IMPORTANT FOR THE FUNCTIONING OF THE CELL; NOT FOR ITS CREATION
	Fluctuation in long term product demand	✓			
4. Stability of product mix		✓			
	Fluctuation in long term product mix	✓			
5. Complexity of components		✓			
	Average # of machines needed to complete a component	✓			THE FEWER THE BETTER
	Average # of operations needed to complete a component	✓			
	Average machining time per component	✓			
6. Weight of components		✓			
	Equipment needed to transport components	✓			
7. Capacity balance		✓			
	Extent of machine utilization	✓			

Table 13 continued

Table 13 continued

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
8. Flexibility of labor		✓			CRITICAL
	Ability of operators to operate multiple machine types		✓		INCLUDE ABILITY TO SET-UP, MAINTENANCE AND MATERIAL HANDLING
9. Availability of computer support			✓		COMPUTER REQUIREMENT NOT MANDATORY
	Availability of computer resource in terms of memory of a single computer	✓			
10. Availability of a coding and classification system			✓		NOT A PRE-REQUISITE
	Availability of/and access to a coding & classification package	✓			
11. Computer literacy of personnel			✓		NOT FOR CELL DESIGN BUT FOR OPERATION
	The frequency of direct use of computer at work	✓			
	The frequency of use of spreadsheet analysis on computer	✓			
	The frequency of programing using FORTRAN, GPSS or APL	✓			
	Of all the time spent in workshops and/or seminars, the percentage spent in attending workshops and/or seminars directly related to computer education	✓			
12. Skill level of operators		✓			SIGNIFICANT
	In terms of tool and die makers class A and class B machinists	✓			

Table 13 continued

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
13. Forecasting reliability		✓			
	Deviation of part demand forecast from actual	✓			
14. Reliability of equipment		✓			CRITICAL
	Frequency of machine breakdown	✓			
15. Implementation time		✓			
	Planning horizon (short or long term)	✓			
	Implementation history of past large-scale projects	✓			
16. Reliability of suppliers		✓			
	Extent of on-time delivery in the supply of raw materials	✓			
	Frequency of time that material is delivered free of defect	✓			
17. Material control system		✓			
	Type of MCS currently in use	✓			
18. Work load on process planners		✓			
	Extent to which process planners work overtime	✓			
	Extent of duplication in process planning	✓			

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
19. Scheduling procedures		✓			
	Centralization of Scheduling		✓		SCHEDULING SHOULD BE CENTRALIZED
	Authority of foremen to override schedules	✓			
20. Managerial support		✓			CRITICAL
	Extent of management to plan ahead	✓			
	Extent to which senior personnel help subordinates	✓			
	Length of time taken to get capital allocation approved	✓			
	Extent of yearly increase in manufacturing budgets	✓			
21. Resistance to change		✓			IMPORTANT BUT NOT INSURMOUNTABLE
	Extent to which supervisors stick to old ways of doing things	✓			
	Extent of employee turnover	✓			
	frequency of strikes	✓			

Choice-of-method issue: The attributes "component design similarity" and "components manufacturing similarity" were thought to be inseparable. The respondents were of the opinion that both attributes are equally important because usually the parts that are high in design similarity also have a high manufacturing similarity. While this was certainly the case in their plant, it may not always be so. A set of geometrically similar parts are grouped together here because of similar manufacturing requirements. No computer support was used in the determination of the part groups because of high part visibility. That is, there is a good understanding of part commonality. The attribute "availability of a CAD system" was not thought to be a determinant of the approach but only an enhancement to a CM system. The plant is currently in the process of implementing a McDonnel-Douglas CAD/CAM system.

With regard to the attribute "monetary support," the respondents felt that the expenses involved with a classification and coding system are unnecessary if there is a clear idea of what parts are produced. They claim it to be true in their case that they have a clear idea of what they produce; therefore, a classification system is redundant at the present time. However, they implied the possibility of acquiring such a system in the future because increased CM operation will require a part database. It is seen that the question of "data visibility" emerges as a significant issue in the determination of the approach.

With respect to the attribute "implementation time," the interviewees were of the opinion that the time to implement cells could be slowed down by at least one year or more if a formal classification were to be installed. Thus, they felt that, if a company were willing to spend that amount of time and cost prior to forming cells, then it would be better served with a classification system. On the other hand, CM implementation could be speeded up, they felt, with informal (manual) grouping approaches.

The attribute "availability of computer support" was not thought to be critical in the part-family formation approach. The respondents stated that part groupings in their plant are easily done from a knowledge of part shapes and routings. However, they also noted that computer support will be necessary if a classification system or a CAD system is in use or is desired.

The attribute "computer literacy of personnel" was also viewed as uncritical for purposes of part-family formation. The interviewees perceived this attribute to be directly related to the requirements of the firm and the availability of computer resources.

The attribute "inter-departmental information requirements" was thought important because such requirements dictate the development or the acquisition of classification systems. The company has a system that enables the identification of existing parts for use in a product. However, there is no classification system for parts. There is a desire to use a classification system in the future but the expense of creating such a system is not justified at present.

The attribute "value analysis" was perceived to be important by the participants. They felt that a value analysis procedure in the design stage could result in significant cost savings in manufacturing. Value analysis is informally done in the plant; there is no formal VA program. Design and manufacturing cooperate closely in the VA program. There is a desire to implement a formal VA program in the near future.

The attributes "design standardization and retrieval" and "process planning standardization and retrieval" were perceived to be important from the standpoint of CM and the choice of method. The company has standardized design procedures and a manual design-retrieval system. Presently, the firm is in the process of installing a CAD/CAM system and has plans for installing a classification system in the near future. The participants felt strongly that such a combination would significantly improve their design and process planning procedures and enhance the design and process planning standardization procedures. An informal process planning standardization and retrieval procedure in use now is followed at all times.

The last attribute "use of products and graphics standards" was thought to be an enhancement rather than a decision criterion for the cell-forming approach. The company does not use any of these approaches.

In summary, the participants expressed some disagreements with the relevance of the following attributes: "availability of computer support," "computer literacy of personnel," "availability of a CAD system," and "use of products and graphics standards." Table 14 presents the summary of the relevance verification procedure.

Table 14. Attribute relevance verification for choice of method – Company B

Validity verification of attributes of the choice of method issue

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
1. Component design similarity		✓			
	Grouping based on design categories	✓			
2. Component manufacturing similarity		✓			
	Grouping based on routing similarity	✓			
3. Availability of a CAD system			✓		ENHANCEMENT AND NOT A NECESSITY
	Availability of/accessibility to a CAD system	✓			
4. Monetary support		✓			
	Availability of funds for a classification and coding scheme	✓			
5. Implementation time		✓			
	Amount of time given/to be given to the approach	✓			
6. Availability of computer support			✓		UNNECESSARY
	Same as feasibility issue	✓			
7. Computer literacy of personnel			✓		UNNECESSARY
	Same as feasibility issue	✓			

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
8. Interdepartmental information requirements		✓			IMPORTANT
	Desire to identify similar items for bulk purchases	✓			
	Desire to estimate products cost accurately	✓			
9. Value analysis (VA)		✓			IMPORTANT
	Desire to use VA for least cost design	✓			
10. Design standardization and retrieval		✓			IMPORTANT
	Desire to standardize product designs and retrieve similar designs	✓			
11. Process plan standardization and retrieval		✓			IMPORTANT
	Desire to standardize and retrieve similar process plans	✓			
12. Use of products and graphic standards			✓		ENHANCEMENT
	Desire to use products and graphic standards	✓			

Significance of the verification: The verification procedure of the attributes for the choice-of-method issue indicated that computer support and computer literacy of middle-level personnel was not perceived to be important. This is in conflict with observations of GT researchers (Wemmerlov and Hyer 1986) that computer support is mandatory in the cell design process. The question of data visibility of parts with respect to the choice of grouping approach was also raised from the verification procedure. It would be desirable to study the relationship between part-data visibility and the use of computer support in the part-grouping approach in different companies.

This completes the discussion of the verification of the attributes for the choice of method issue. The discussion of the verification of the weighted attribute categories is done now.

6.3.5 Verification of attribute weight categories

The respondents suggested a few changes in the rankings of the attributes. With regard to the feasibility issue, they were of the opinion that the attributes "flexibility of labor," "skill level of operators," and "managerial support" should be in Category I. Some of the attributes in Category III were perceived as belonging to Category II. These attributes are "reliability of suppliers," "reliability of equipment," and "material control system." The attribute "implementation time" was thought to belong to Category III instead of Category II. Finally, "availability of computer support" and "computer literacy of personnel" were delegated to Category IV from Category III. The last ranking contradicts opinions of GT/CM researchers who claim that computer support in the cell-design procedure is absolutely necessary. Table 15 shows the results of the verification of the attributes' weights.

Table 15. Attribute weight verification – Company B

Weighted attribute categories of the feasibility issue

Category	Attribute	Suggested Score range	Validity of Category	Validity of Rank	Don't know	Comments
I	1. Occurrence of part families and machine cells	90-100	✓	✓		
II	2. Stability of product demand	75-89	✓	✓		
	3. Stability of product-mix			✓		
	4. Complexity of components			✓		
	5. Occurrence of indivisible processes			✓		
	6. Weight of components			✗		GOES IN III
	7. Managerial support			✗		GOES IN I
	8. Resistance to change			✓		
	9. Implementation time			✗		GOES IN III
III	10. Availability of computer support	60-74	✓	✗		GOES IN IV
	11. Computer literacy of personnel			✗		GOES IN IV
	12. Material control system			✗		GOES IN II
	13. Capacity balance			✓		
	14. Reliability of equipment			✗		GOES IN II
	15. Flexibility of labor			✗		GOES IN I
	16. Skill level of operators			✗		GOES IN I
	17. Reliability of suppliers			✗		GOES IN I
	18. Forecasting reliability			✓		
	19. Scheduling procedures			✓		
IV	20. Workload on process planners	45-59	✓	✓		
	21. Availability of a classification and coding system			✓		

Category	Attribute	Suggested Score range	Validity of Category	Validity of Rank	Don't know	Comments
others	LEAD TIME INVENTORY LEVEL ORDERS OVERDUE					

With respect to the choice-of-method issue, the participants felt that the choice depended on the requirements and availability of resources. Therefore, they verified indirectly the validity of the rule-based procedure for determining part-families. They noted that, if implementation of a classification system was decided upon and a CAD system was available, then computer support and computer literacy were imperative. Although manual classification systems are available, the respondents' points are well taken. It was suggested by the participants to move the attribute "interdepartmental information requirements" to Category I because open lines of communication are tremendously important for the functioning of a CM system. The other rankings were acceptable. With regard to the suggested score ranges they were in agreement. Table 16 shows the results of the verification of the attribute rankings for the choice-of-method issue.

Table 16. Attribute ranking verification – Company B

Weighted attribute categories of the choice of method issue

Category	Attribute	Suggested Score range	Validity of Category	Validity of Rank	Validity of Don't know	Comments
I	1. Component design similarity	90-100	✓	✓		
	2. Component manufacturing similarity			✓		
II	3. Monetary support	75-89		✓		
	4. Implementation time			✓		
	5. Availability of computer support			×		
	6. Computer literacy of personnel			×		
	7. Inter-departmental information requirements			✓		GOES IN I
	8. Value analysis			✓		
	9. Design standardization and retrieval			✓		
	10. Process plan standardization and retrieval			✓		
III	11. Availability of a CAD system	60-74		×		ENHANCEMENT, SHOULD NOT BE A DETERMINANT
	12. Usage of standards			×		
Others						NONE OFFERED IN THIS CATEGORY

The interviewees felt this study to be very comprehensive in its scope. They also requested a copy of the back-up document, as they thought its contents would be particularly useful for future discussions within the company.

6.3.6 The score

The score for the feasibility issue will be presented and discussed now. For each attribute, the value for the average of the attribute measures is given. The score determined by using the approach (discussed in the previous chapter) is given and the implications discussed.

Interviewee response to each operational measure of an attribute was recorded. The specifications were then used to determine the level of an attribute. Once the levels of attributes were determined, the relationship (developed in Chapter V) between attribute level and feasibility was used to allocate the attribute weight to the feasibility or infeasibility column. This procedure was repeated for every attribute and a total sum of feasibility weights computed. Table 17 shows the score for Company B.

Table 17. Feasibility score for Company B

Attribute	Scale value	Weight Feasibility	Weight Infeasibility
1. Occurrence of part-families/machine cells	5	0.0621	
2. Ocurrence of indivisible processes	5	0.0552	
3. Stability of product demand	4	0.0552	
4. Stability of product-mix	4	0.0552	
5. Complexity of components	3.75		0.0552
6. Weight of components	4	0.0552	
7. Capacity balance	4	0.0456	
8. Flexibility of labor	5	0.0456	
9. Availability of computer support	5	0.0456	
10. Availability of a classification and coding scheme	3	NA	
11. Computer literacy of personnel	4.25	0.0456	
12. Skill level of operators	2		0.0456
13. Forecasting reliability	4	0.0456	
14. Reliability of equipment	4	0.0456	
15. Implementation time	5	0.0456	
16. Reliability of suppliers	5	0.0456	
17. Material control system	5	0.0456	
18. Workload on process planners	2		0.0366
19. Scheduling procedures	3		0.0456
20. Managerial support	4.5	0.0552	
21. Resistance to change	4.67	0.0552	
Feasibility weight		0.8137	

The score computed by the scoring procedure (simple addition of weights for feasibility as determined by the rules) = 0.8137. The score is a reflection of the high potential for CM. It is pertinent to point out here that this derived score is for a company with an operational CM facility. Certain observations are to be noted. The score for the attribute "complexity of components" is 3.75. From the specification of this attribute, this complexity is unsuitable for CM purposes. This suggests a re-examination of one measure of this attribute. The relatively low importance of the attribute "availability of a classification and coding scheme" is reflected by its measured value. The attribute "skill level of operators" also has a low value. This is contrary to reports in literature that CM is suited for jobs requiring medium or low skills. Process planning overload and duplication is low at this facility. Such a situation is expected because one of the benefits of CM is the reduction in process planning redundancy. The attribute "scheduling procedures" also received a low score. This is due to the low score received by its first measure (centralization of scheduling). There is a possibility that this measure should be excluded. Further research should be done on this.

The position of the company on the feasibility matrix is shown in Figure 12. The conclusion from this figure is that CM is infeasible for this company due to the unfavorable level of the attribute "complexity of components." This is in contrast to the feasibility score. Thus a contradiction is observed here. The feasibility score indicates high potential for CM whereas the feasibility matrix determines CM to be infeasible because of the low level of the attribute "complexity of components." Thus it may be necessary to reexamine the criticality of this attribute. It may also be necessary to reexamine and perhaps modify the feasibility matrix through additional field studies.

The cell-type matrix is shown in Figure 13. The products manufactured in the cells belong to two categories -- single component processing and component processing for product families. Assembly of these components into final products is done elsewhere within this facility. As material flow is mixed, the cell-types are indicated by Blocks 2 and 8.

6.3.7 The choice of method

The components manufactured in this facility are characterized by high design and manufacturing similarity. As noted before, a CAD system is not available presently. The respondents also felt that a classification system was unnecessary at this time, as it would slow down the implementation process by at least one year; so they did not want to invest in it. High part visibility is also a reason for not acquiring a classification system. Currently, company-wide data interchange facilities are very limited, although the interviewees expressed a desire for such facilities. To alleviate this problem, the company plans to install a classification system eventually. In conjunction with a CAD/CAM system, management expects significant enhancements in the design and process planning procedures. There is also a desire for a formal VA program in the future. Computer support and literacy of middle level personnel are both sufficient. Based on the preceding discussion, the attribute levels are the following: component design similarity -- high; component manufacturing similarity -- high; computer literacy of personnel -- high; computer support -- high; implementation time -- low; monetary support -- low; desire for design standardization and retrieval -- high;

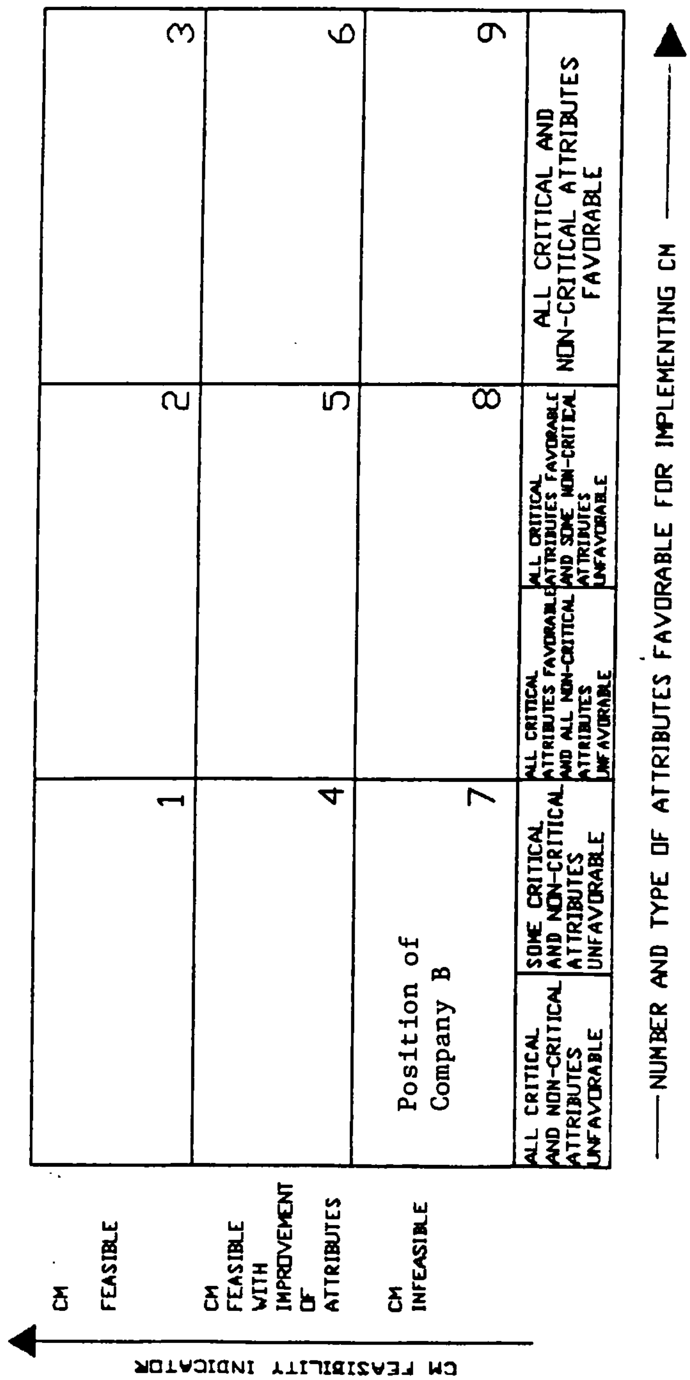

Figure 12. Feasibility matrix for Company B

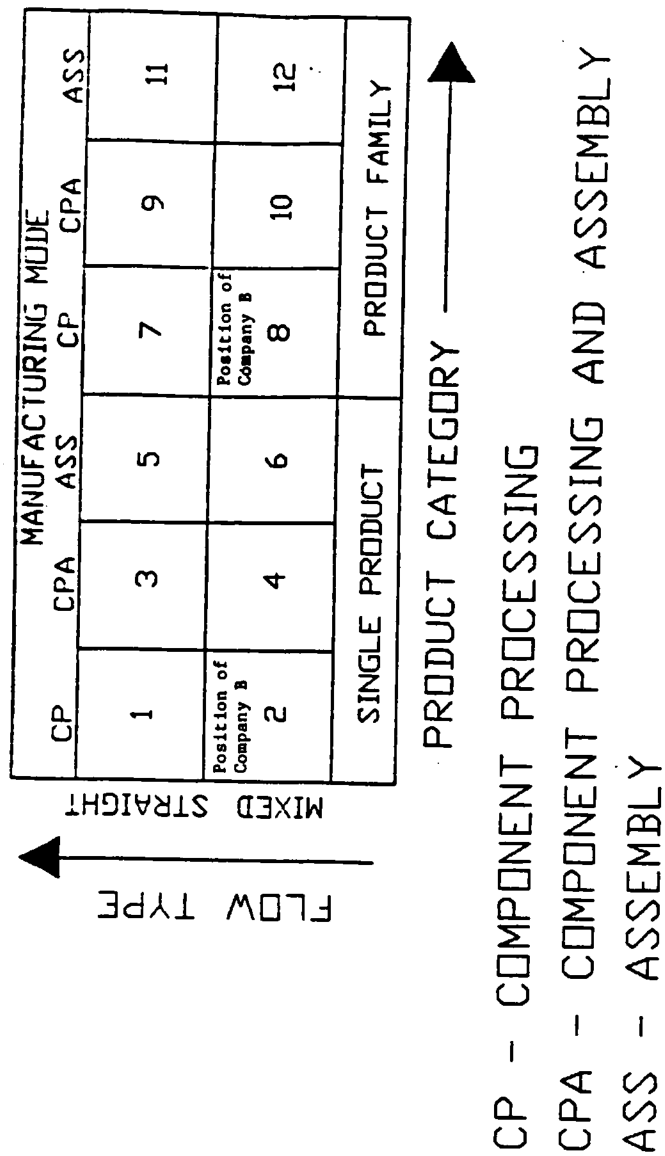

Figure 13. Cell-type matrix for Company B

value analysis -- high; desire for process planning standardization and retrieval -- high; interdepartmental information requirements -- high. Considering the levels of these attributes Rule 7 indicates the choice of method to be a hybrid approach.

This completes the detailed study of this facility. The overall feasibility measure reflects suitability to CM, and is, therefore, a direct verification of the attributes and the propositions. Certain attributes and measures need closer re-examination and may need to be modified. Changes to the weighted attribute categories were also suggested by the respondents. Overall, the study of this facility was interesting and useful and served the purposes of this research.

6.4 Case 3 - Company C

6.4.1 The plant and the product line

The third company included in the field work, Company C, employs 1200 people and is located in the Southeastern United States. The date of the company visit was December 8, 1988. The approximate interview length was about two hours.

The engineering manager was the chief contact. The company assembles components, such as transformers and inductors. This is an assembly facility; machining is not done here. Although the focus of this research was on metal machining, it was felt that valuable information about CM implementation could be gained through field work in this facility because of its operational CM system.

6.4.2 Production description

In this facility, the individual components required for the assembly of transformers and inductors, are acquired from external sources. The assembly operations include winding operations, soldering operations, core insertion, varnishing of assemblies, and testing. Assembly operations are performed sequentially. Components of assemblies are very light in weight and are metallic. The number of units assembled range from single pieces to hundreds of thousands of pieces per order.

6.4.3 Cell characteristics

The cells in this assembly facility are configured as independent units. There is no backtracking of parts. Most of the individual machines are light in weight and are bench-top units. There are a few winding machines that are heavy. The material handling is done manually in the cells. Currently there are ten cells in operation. The information on the number and type of machines in each cell could not be gathered because the engineering manager did not recall such information. Oftentimes, one machine within a cell is the responsibility of one operator. However, cross-training enables operators in this facility to operate multiple machines. Also, operators are transferred from machine to machine when demand variations occur.

The motives for introducing the CM system was to improve quality, improve service and delivery performance to customers, and effect cost reduction of the products. Currently, 40% of all assembly is done in cells. It has taken approximately two months (starting from planning) to implement each of the cells. Physical relocation of the machines requires very little time (about two weeks) because of the easy maneuverability of the machines due to their light weight. Currently, plans are being developed to install a cell consisting of robots, AGV's, and assembly equipment. It was estimated by the engineering manager that approximately two-and-a-half years will be required to install this cell. It is planned to form cells throughout the entire facility by the end of 1989.

The part-family approach to forming cells at this company is by determining similarly shaped parts of a relatively high-volume product family. Once the similar parts are identified, the cells are designed around their assembly requirements.

6.4.4 *Verification of attributes and measures*

This section discusses the verification of the attributes and their measures by using information from the interview. The discussion of the results of the verification of the attributes of the feasibility issue is done first.

Feasibility issue: The interviewee felt that the attribute "occurrence of part-families and machine cells" was important because, for cellular manufacturing to be feasible, parts should fall into naturally occurring families, such that they can be produced by using similar equipment. This facility, however, is slightly different because components are assembled, not processed. However, a parallel exists here because parts that belong to the product family are assembled using similar machines. The individual components are both of the rotational and non-rotational type and are specific to company designs.

The participant agreed with the relevance of the attribute "occurrence of indivisible processes" and its measure. The varnishing operations required for a certain percentage of parts is centralized in nature because of safety and environmental stipulations. The participant noted that such centralization of the process caused some hindrances in the assembly of the products. He, however, did not state that any remedial measures were taken for overcoming this problem.

With respect to the attribute "stability of product demand" the interviewee felt that it was not relevant to their operations because once it is decided to implement cells, fluctuation of product demand is accommodated by feeding additional components from the low-volume line to the cell or by the transfer of labor in and out of the cell. This facility has a substantial variation of product demand.

The attribute "stability of product-mix" was thought to be important by the interviewees. They stressed the need for the stability of product-mix because cells were designed for a certain range of components and a large fluctuation in the product mix can result in starving or overloading of cells. This facility has a substantial fluctuation in the product-mix and this is handled by transfer of labor.

The attribute "complexity of components" was thought important because with fewer complex components, fewer machines are involved. However, the participant noted that in their case the measure "average machining time per component" was actually the "average assembly time per component." In this facility, the average number of machines required to complete a component is between 5 and 9. The average number of operations is between 10 and 19, and the average assembly time per component is less than one-half hour.

The attribute "weight of components" was thought to be a significant factor because of increased material handling requirements within a cell with heavy components as compared to light weight components. Components assembled in this facility are very light in weight and all components can be handled manually.

The interviewee felt that the attribute "capacity balance" was important because it was necessary to know additional machine capacity requirements, if any, when a CM system is implemented. In this facility, there is a high to medium utilization of primary machines and low to medium utilization of secondary machines.

The attribute "flexibility of labor" was thought to be extremely important by the participant. The operators in the cellular lines in this facility are able to operate multiple machines. However, the participant noted that transferring operators to different cells due to changes in product demand or mix is a problem at present due to unionized labor. Management is trying to rectify this problem by holding talks with the union.

The attribute "availability of computer support" was thought by the interviewee to be irrelevant for the implementation of CM. According to him, computer support was unnecessary for installing cells, but he felt it could be required for its support. The parts in this facility are simple enough not to warrant any computer analysis to determine their similarity. A mainframe computer is in place here.

A classification and coding package is not in use at Company C. The participant was not aware of commercial classification and coding systems or their capabilities. A product numbering system is used in conjunction with an MRP-driven package to manage materials and production. Parts are associated with the product family number to which they belong.

The participant felt that the attribute "computer literacy of personnel" was irrelevant for CM implementation purposes because usually, in Company C's case, part and process visibility was good enough to enable identification of families. Any computerized analysis of parts or process features is, therefore, unnecessary. The respondent noted the frequent use of computers for spreadsheet analysis in his work. However, he seldom engaged in computer programming and was not in the practice of attending computer-related seminars. He thought the first two measures of this attribute to be relevant and disagreed with the other two.

The attribute "skill level of operators" was thought to be relevant when considering feasibility for CM implementation. According to the interviewee, it was necessary for operators to have skills necessary to set-up and operate their own machines. The process technology of this firm does not require high operator skills. Currently, the majority of the operators can only operate certain machine types. A program for training operators to set-up all machines is currently being developed.

The attribute "forecasting reliability" was thought to be very important for CM implementation purposes. According to the participant, knowledge about the expected product demand and mix through accurate product forecast can help tremendously in smoothing cell performance by enabling a levelled loading of cells. The product forecasts in this facility are "generally inaccurate" and often affect cell loading.

The participant felt that the attribute "reliability of equipment" was very important for CM implementation purposes, because machine breakdown results in a complete halt in cell production as other machines are generally not available. A preventive maintenance program is in operation in this plant. There are occasional breakdowns of all machines.

The attribute "implementation time" and its measures were perceived to be relevant because the participant felt that CM involves long-term planning; previous successes in implementing large-scale projects would seem to indicate management commitment to them. The long-term planning horizon in this plant is five years. Some of the previous large-scale projects were only partially successful because of misplanning.

The attribute "reliability of suppliers," in terms of on-time delivery of defect-free raw material, was deemed critical because additional lead times are incurred when defective materials are delivered and because lateness in production occurs due to late raw materials deliveries. The frequency of on-time delivery of raw material is high as is the frequency of time that material is delivered free of defect.

The participant perceived an MRP-type system to be helpful in the functioning of cells because of its ability to determine schedules based on end-product requirements. An MRP-driven control system is in use in this facility.

The participant was unable to relate the attribute "workload on process planners" as an indicator for the feasibility of implementing CM. With respect to the attribute "scheduling procedures" the interviewee felt that scheduling should be centralized with shop-floor personnel having the authority to adjust the scheduling depending on machine, material, and labor availability. The respondent also noted that, though scheduling was a centralized function in this facility, there are plans for scheduling at the shop-floor level where a team consisting of a material planner, a scheduler, and an operations supervisor can devise their schedules based on current material and resource availability.

The attribute "managerial support" was also deemed important. The interviewee felt that the undertaking of any major project would require support from the top. The measures "extent of management to plan ahead," "extent to which senior personnel help subordinates," and "leadership capabilities," were thought relevant. The other two measures ("length of time taken to get capital allocation requests approved" and "extent of yearly increase in manufacturing budgets") were not thought relevant.

Finally, the attribute "resistance to change" was also perceived to be important. In this facility, there are layoffs (not turnover) and unionized strikes. The respondent felt that strikes are an inhibiting factor in the functioning of their plant.

This completes the discussion of the validity verification of the attributes for the feasibility issue. The participant expressed disagreement with the relevance of the attributes "stability of product demand," "availability of computer support," and "computer literacy of personnel." He was also unaware of the attributes "availability of a classification and coding scheme," and "workload on process planners." Finally, two measures for the attribute "computer literacy of personnel," one measure for the attribute "scheduling procedures," and two measures for the attribute "managerial support," were disagreed with. It was found that the centralized part-processing requirement was a problem as were the fluctuation in product-mix, unionized strikes, and lack of product forecasting reliability. This finding is important for this study because it shows that CM operation is possible even with the problems noted above. Thus there is a possibility that none of these attributes may be critical. Table 18 summarizes the results of the relevance verification of the attributes.

Table 18. Attribute relevance verification for feasibility – Company C

Validity verification of attributes -- feasibility issue

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
1. Occurrence of part families and machine cells		✓			
	Component design similarity	✓			
	Component manufacturing similarity	✓			
2. Occurrence of indivisible processes		✓			
	Extent of intermediate visits to centralized processes	✓			
3. Stability of product demand			✓		NOT AS IMPORTANT AS IT CAN BE ACCOMMODATED
	Fluctuation in long term product demand	✓			
4. Stability of product mix		✓			CELL STARVES IF PRODUCT-MIX CHANGES FREQUENTLY
	Fluctuation in long term product mix	✓			
5. Complexity of components		✓			LESS COMPLEXITY IMPLIES FEWER MACHINES
	Average # of machines needed to complete a component	✓			
	Average # of operations needed to complete a component	✓			
	Average machining time per component	✓			
6. Weight of components		✓			
	Equipment needed to transport components	✓			
7. Capacity balance		✓			
	Extent of machine utilization	✓			

Table 18 continued

Table 18 continued

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
8. Flexibility of labor		✓			EXTREMELY IMPORTANT
	Ability of operators to operate multiple machine types	✓			
9. Availability of computer support			✓		NOT RELEVANT
	Availability of computer resource in terms of memory of a single computer	✓			
10. Availability of a coding and classification system				✓	DID NOT KNOW ABOUT CLASSIFICATION AND CODING
	Availability of/and access to a coding & classification package			✓	
11. Computer literacy of personnel			✓		NOT NECESSARY
	The frequency of direct use of computer at work	✓			
	The frequency of use of spreadsheet analysis on computer	✓			
	The frequency of programing using FORTRAN, GPSS or APL		✓		
	Of all the time spent in workshops and/or seminars, the percentage spent in attending workshops and/or seminars directly related to computer education		✓		
12. Skill level of operators		✓			
	In terms of tool and die makers class A and class B machinists	✓			

Table 18 continued

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
13. Forecasting reliability		✓			
	Deviation of part demand forecast from actual	✓			
14. Reliability of equipment		✓			
	Frequency of machine breakdown	✓			
15. Implementation time		✓			
	Planning horizon (short or long term)	✓			
	Implementation history of past large-scale projects	✓			
16. Reliability of suppliers		✓			CRITICAL
	Extent of on-time delivery in the supply of raw materials	✓			
	Frequency of time that material is delivered free of defect	✓			
17. Material control system		✓			
	Type of MCS currently in use	✓			
18. Work load on process planners				✓	
	Extent to which process planners work overtime			✓	
	Extent of duplication in process planning			✓	

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
19. Scheduling procedures		✓			
	Centralization of Scheduling		✓		
	Authority of foremen to override schedules	✓			
20. Managerial support		✓			IMPORTANT
	Extent of management to plan ahead	✓			
	Extent to which senior personnel help subordinates	✓			
	Length of time taken to get capital allocation approved		✓		
	Extent of yearly increase in manufacturing budgets		✓		
21. Resistance to change		✓			IMPORTANT
	Extent to which supervisors stick to old ways of doing things	✓			
	Extent of employee turnover	✓			
	frequency of strikes	✓			

Choice-of-method issue: This section discusses the verification of the relevance of the attributes of the choice-of-method issue. The respondent perceived the attributes "component design similarity" and "component manufacturing similarity" to be equally important. In this firm, components are grouped based on their shape and affiliation to the same product line and on their requiring similar assembly procedures. The attribute "availability of a CAD system" was thought to be a valid attribute insofar as a design tool for design purposes and not as a driving force behind the choice of method. With respect to the attributes "monetary support" and "implementation time" the respondent expressed unawareness about their validity because of his unfamiliarity with classification and coding principles, and the cost and time involved with its implementation. The attributes "availability of computer support" and "computer literacy of personnel" were not thought to be relevant to the choice-of-method issue. The interviewee could not relate the attribute "interdepartmental information requirements" with the choice-of-method issue. However, he noted that cost estimation is done actively for all products. Also, common material identification and purchase was observed by the interviewee to be frequent. Value analysis is done mainly by the design group located at a different geographic location. No design is done in this facility. Design standardization is done at a design facility located elsewhere. Process planning standardization is done here, however, and assists in the process planning of new parts. The participant expressed unawareness of the attribute "usage of standards."

It was observed by the interviewee that the decision to implement cellular manufacturing was made up-front for the assembly of new parts and component grouping was primarily based on shape and product affiliations. The attributes of the Objectives or Resources category have not been considered in the past in relation to the choice of method for part grouping. Therefore, the relevance of these attributes could not be explicitly addressed; respondent perception of the relevance of the attributes was the only way of determining it.

This completes the discussion of the verification of the relevance of the attributes for the choice-of-method issue. The attributes "component design similarity" and "component manufacturing similarity" were perceived to be valid by the interviewee. He expressed absence of knowledge about the relevance of the attributes "monetary support," "implementation time," and "usage of standards," and perceived the attributes "availability of computer support" and "computer literacy of personnel" to be irrelevant. Finally, he stated that none of the attributes of the Objectives category were considered in the determination of the choice of method. Table 19 shows the results of the verification of relevance of attributes of the choice-of-method issue.

Table 19. Attribute relevance verification for choice of method – Company C

Validity verification of attributes of the choice of method issue

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
1. Component design similarity		✓			
	Grouping based on design categories	✓			
2. Component manufacturing similarity		✓			
	Grouping based on routing similarity	✓			
3. Availability of a CAD system		✓			
	Availability of/accessibility to a CAD system	✓			
4. Monetary support				✓	DID NOT KNOW ABOUT CLASSIFICATION AND CODING
	Availability of funds for a classification and coding scheme			✓	
5. Implementation time				✓	
	Amount of time given/to be given to the approach			✓	
6. Availability of computer support			✓		
	Same as feasibility issue	✓			
7. Computer literacy of personnel			✓		
	Same as feasibility issue	✓			

Attribute	Measure	Validity of attributes and measure: Yes	No	Don't know	Comments
8. Interdepartmental information requirements				✓	
	Desire to identify similar items for bulk purchases			✓	
	Desire to estimate products cost accurately			✓	
9. Value analysis (VA)				✓	
	Desire to use VA for least cost design			✓	
10. Design standardization and retrieval				✓	
	Desire to standardize product designs and retrieve similar designs			✓	
11. Process plan standardization and retrieval		✓			
	Desire to standardize and retrieve similar process plans	✓			
12. Use of products and graphic standards				✓	UNAWARE ABOUT THIS ATTRIBUTE
	Desire to use products and graphic standards			✓	

6.4.5 Verification of the attribute weight categories.

The participant agreed to the ranking established by this researcher for both the feasibility and the choice-of-method issues. The participant did not comment on the suggested score ranges. Tables 20 and 21 show the results of the attribute weight and ranking verifications.

Table 20. Attribute weight verification – Company C

Weighted attribute categories of the feasibility issue

Category	Attribute	Suggested Score range	Validity of Category	Validity of Rank	Validity of Don't know	Comments
I	1. Occurrence of part families and machine cells	90-100	✓	✓		
II	2. Stability of product demand	75-89	✓	✓		
	3. Stability of product-mix			✓		
	4. Complexity of components			✓		
	5. Occurrence of indivisible processes			✓		
	6. Weight of components			✓		
	7. Managerial support			✓		
	8. Resistance to change			✓		
	9. Implementation time			✓		
III	10. Availability of computer support	60-74	✓	×		
	11. Computer literacy of personnel			×		
	12. Material control system			✓		
	13. Capacity balance			✓		
	14. Reliability of equipment			✓		
	15. Flexibility of labor			✓		
	16. Skill level of operators			✓		
	17. Reliability of suppliers			✓		
	18. Forecasting reliability			✓		
	19. Scheduling procedures			✓		
IV	20. Workload on process planners	45-59	✓		×	
	21. Availability of a classification and coding system				×	

Category	Attribute	Suggested Score range	Validity of Category	Validity of Rank	Validity of Don't know	Comments
others						NONE OFFERED IN THIS CATEGORY

Table 21. Attribute ranking verification – Company C

Weighted attribute categories of the choice of method issue

Category	Attribute	Suggested Score range	Validity of Category	Validity of Rank	Don't know	Comments
I	1. Component design similarity	90-100	✓	✓		
	2. Component manufacturing similarity			✓		
II	3. Monetary support	75-89			✓	
	4. Implementation time				✓	
	5. Availability of computer support			✗		
	6. Computer literacy of personnel			✗		
	7. Inter-departmental information requirements				✓	
	8. Value analysis				✓	
	9. Design standardization and retrieval				✓	
	10. Process plan standardization and retrieval			✓		
III	11. Availability of a CAD system	60-74		✓		
	12. Usage of standards				✓	
Others						

6.4.6 The score

The score for the feasibility issue will be presented and discussed now. For each attribute, the value for the average of the attribute measures is given. The score determined by using the scoring procedure is also presented in Table 22, and its implications are discussed. Interviewee response to each operational measure of an attribute was recorded. The specifications were then used to determine attribute levels. Once the attribute levels were determined, attribute weights were allocated to the feasibility column based on the relationship between attribute level and feasibility (see Chapter V). The weights in the feasibility column were added to yield a final feasibility score.

From the average scale values it is seen that the attributes "occurrence of indivisible processes," "stability of product demand," "stability of product-mix," "resistance to change," "computer literacy of personnel," "forecasting reliability," "reliability of equipment," and "scheduling procedures," are at low levels. The requirement of varnishing (a centralized process) was stated by the interviewee to be a problem. The instability of product demand and mix are tackled by transferring labor. The participant also noted the problem caused by unionized strikes. Low forecasting reliability and equipment reliability were also noted as problem areas. The above low levels also point to the fact that the implementation of CM is possible even with low levels of certain attributes (although it is not known how well the CM system in this company performs with the low level of these attributes -- in contradiction to the rationale of this research. Thus, the score can be used effectively to point to the deficiencies associated with the attributes. Remedial measures can, therefore, be taken once these deficiencies are known. This is believed to be a contribution of the scoring procedure. The ability to detect deficiencies of the attributes with respect to the implementation of CM is as important as presenting the feasibility score. The feasibility matrix of the company is given in Figure 14 and places the company in the infeasible range because the critical attributes "stability of product demand," "stability of product-mix," and "resistance to change" are at low levels.

Table 22. Feasibility score for Company C

Attribute	Scale value	Weight Feasibility	Weight Infeasibility
Occurrence of part-families/machine cells	5	0.0655	
Occurrence of indivisible processes	2		0.0577
Stability of product demand	2		0.0577
Stability of product-mix	2		0.0577
Complexity of components	4	0.0577	
Flexibility of labor	5	0.0577	
Managerial support	4	0.0577	
Resistance to change	2.67		0.0577
Implementation time	4	0.0577	
Computer literacy of personnel	3.75		0.0471
Skill level of operators	4	0.0471	
Forecasting reliability	2	0.0471	
Reliability of equipment	3		0.0471
Availability of computer support	5	0.0471	
Reliability of suppliers	4	0.0471	
Material control system	5	0.0471	
Scheduling procedures	3.5		0.0471
Capacity balance	4	0.0471	
Workload on process planners	NA		
Availability of classification and coding system	NA		
Feasibility score		0.5789	

The cell-type matrix for the company is shown in Figure 15. Since the material flow is straight in this facility and a family of different product types are assembled, the company is located in Block 11 of the cell-type matrix.

6.4.7 The choice of method

The choice-of-method issue cannot be resolved conclusively here because the level of the attributes "implementation time" and "monetary support" could not be determined due to the participant's unawareness of the relevance of this attribute. However, the level of the other attributes were determined from participant responses. It is pertinent to mention here that the attribute "component manufacturing similarity" does not apply here because this is an assembly facility. However, a parallel may be drawn between assembly and machining because there is a high likelihood that com-

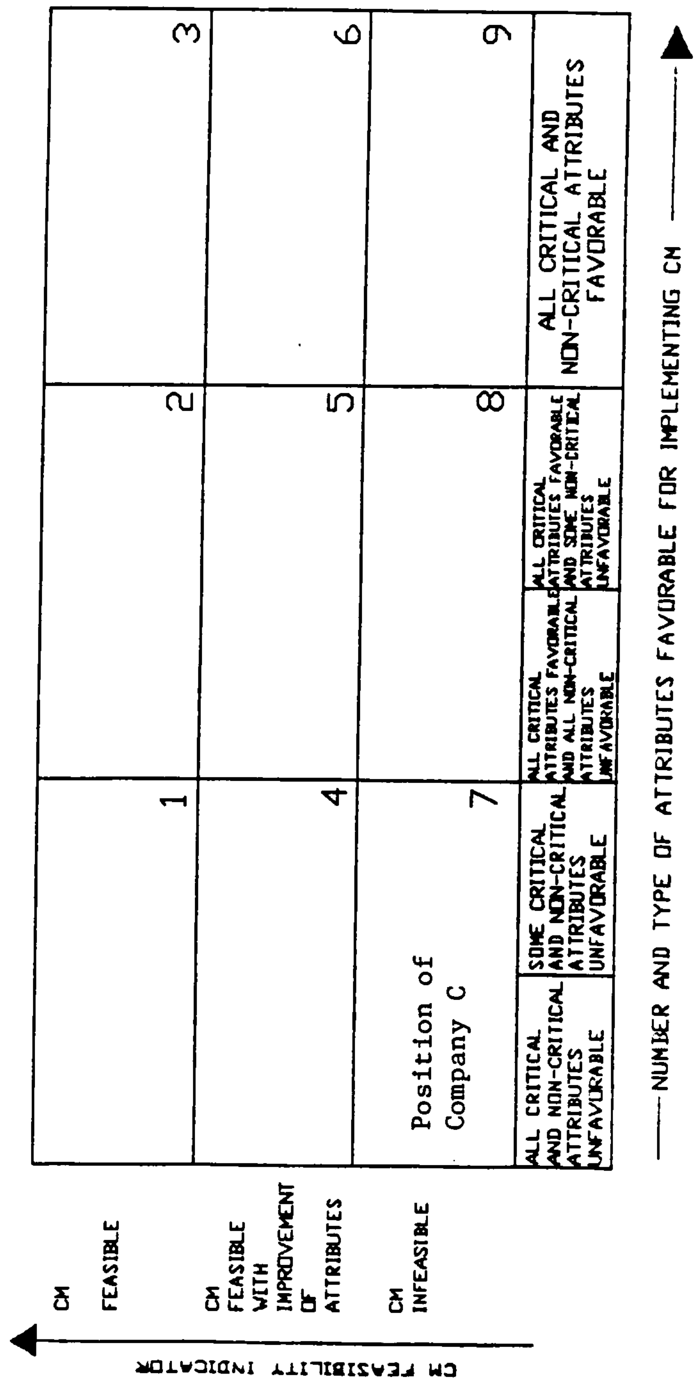

Figure 14. Feasibility matrix for Company C

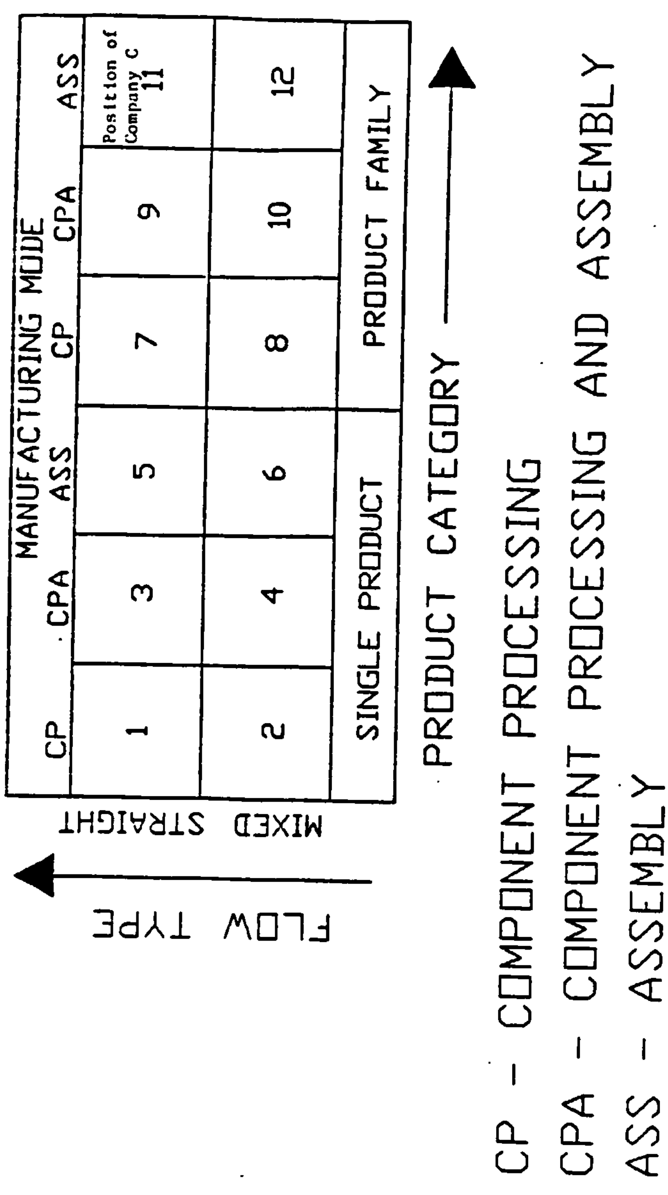

Figure 15. Cell-type matrix for Company C

ponents requiring the same assembly operations can be grouped together. Therefore, for illustrating the rule-based procedure the level of the attribute "component manufacturing similarity" will be used. A similar logic is used for the attribute "process planning standardization and retrieval." In this case, the attribute is viewed from process planning with respect to assembly rather than with respect to machining.

The following are the levels of the attributes: component design similarity -- high; component manufacturing similarity -- high; availability of computer support -- high; computer literacy of personnel -- high; interdepartmental information requirement -- high; desire for value analysis -- low; desire for design standardization and retrieval -- low; desire for process planning standardization and retrieval -- high. Suppose "monetary support" and "implementation time" are both at high levels. The choice of method by Rule 2 is an interactive production-oriented classification system. If "monetary support" and "implementation time" are both at low levels, or if one of them is at a low level, then the choice, given by Rules 8 or 16, is also a computerized production-oriented approach.

6.5 Case 4 - Company D

6.5.1 The plant and the product line

The fourth company included in the field work, Company D, employs 800 people and is located in the Southeastern United States. The visit was conducted in December, 1988. The interview time was approximately 45 minutes.

The production control manager was the chief contact. The company manufactures electro-mechanical devices for a variety of uses. Some clients are in the areas of aerospace and defense.

6.5.2 Production description

The machining shop in this production facility is arranged in a functional layout. There is a turning center, a milling center, and a CNC milling center. Machining, soldering, plating, and assembly are the operations performed to complete a part. All parts do not necessarily require all of the above operations. Manufacturing lead time varies from 18 weeks to a year, and a lot of set-ups are involved in part processing. The largest share of the inventory is in work-in-process. There is an expediter for each department.

6.5.3 Attribute level determination

The respondent felt that the majority of their components can be distinctly grouped into separate families because of common machining requirements. There is, however, a variation in size of the machined parts. None of the components require intermediate visits to any centralized process. Components, however, require chemical processing after machining operations are completed.

The respondent stated that there is little fluctuation in the long-term product demand. Thus, it can be inferred that the product demand is relatively stable. However, there is an extreme fluctuation in the product-mix. This is because all products are made to order and none is made for stock.

The average number of machines required to complete a component was stated by the interviewee to be between 5 and 9. The average number of operations required to complete a component is between 10 and 19. The average machining time per component was estimated to range between 8 minutes and 150 hours with a mean of approximately 8 hours. Almost all components can be handled manually.

The key CNC machines are 100% utilized, while the lathes are about 60% utilized. On the whole, the interviewee felt that there was high to medium utilization of all primary machines and low to moderate utilization of secondary machines.

In this facility, all machine operators can operate multiple machines. The respondent noted that this was necessary because of the complexity of the parts. An apprenticeship program trains all apprentices to a minimum Class B (defined earlier) level.

Mainframe and PC computing facilities are available and routinely used. There is frequent use of computers and spreadsheets by middle managers in their line of work. Commercial software usage (as-is or through modification) by mainframe programmers is common in this facility. Very little time is spent, however, by middle line managers in attending computer workshops for educational purposes. The interviewee stated that a commercial classification and coding package is not used in this facility.

Most of the machine operators are of the Class A or Class B (as specified in this research) category with a few tool and die makers. Thus, the skill level of operators is high.

The respondent observed that machine breakdowns are an infrequent occurrence. Back-up machines of each type are available. No product forecasting is done here as all products are custom made and not for stock.

The planning horizon is usually for a period of two years, with longer-range planning of five years. This planning is with respect to future markets and product development for new markets. The implementation of past large-scale projects, such as expansion of the existing facilities, has been largely successful.

Supplier reliability (with respect to the on-time delivery of defect-free material) is high. Material purchasing (or ordering) is based on the explosion of the product structure and is partially manual. It is intended to computerize this procedure completely.

There is some process planning overtime. Process planning is done separately for each part. The interviewee, however, said that he did not perceive the possibility of any duplication of process plans, even though process planning is done separately for each part.

Work scheduling is accomplished by production control and is a centralized function. The first-line supervisors have to meet the due dates set by production control. In case of machine breakdowns the supervisor has to report to production control for the issuance of a new plan. However, the interviewee stated that the first-line supervisors of the various departments have complete authority to set their own schedules, as long as they meet the due dates set by production control.

Management planning has a long-term emphasis (two years or five years). Managers are also supportive and helpful to subordinates. Capital allocation approval time is extremely short, and there is an adequate increase in yearly manufacturing budget. The interviewee also noted that management was dynamic, and the extent of employee turnover and strikes was very low.

6.5.4 The score

Based on the information above, Table 23 presents the levels of the attributes and their associated weights.

Three attributes did not enter the weight computation procedure. The attribute "forecasting reliability" is irrelevent because the firm does not have any product forecasting policy as all its products are made to order and not for stock. The attributes "workload on process planners" and "availability of a classification and coding scheme" were not considered in the weighting procedure because by theory (propositions -- Chapter IV), while a high level of these attributes indicate potential for CM implementation, their low levels do not imply infeasibility for implementing CM. In this case, both attributes are at low levels.

Table 23. Feasibility score for Company D

Attributes	Scale value	Weight Feasibility	Weight Infeasibility
Occurrence of part-families/machine cells	4	0.070	
Stability of product demand	4	0.0656	
Stability of product-mix	1		0.0656
Complexity of components	2.67		0.0656
Occurrence of indivisible processes	5	0.0656	
Weight of components	5	0.0656	
Managerial support	4.4	0.0656	
Resistance to change	4.3	0.0656	
Implementation time	4.5	0.0656	
Availability of computer support	5	0.0494	
Computer literacy of personnel	3		0.0494
Material control system	4	0.0494	
Capacity balance	4	0.0494	
Reliability of equipment	5	0.0494	
Flexibility of labor	4	0.0494	
Skill level of operators	2		0.0494
Reliability of suppliers	4.5	0.0494	
Forecasting reliability	NA		
Scheduling procedures	3		0.0494
Workload on process planners	2	NA	
Availability of a classification and coding system	1	NA	
Feasibility score		0.7600	

From the weights and the score, it is seen that critical attributes "stability of product-mix" and "complexity of components" are at levels unfavorable for the implementation of CM. The other attributes that are at low levels are "computer literacy of personnel," "skill level of operators," and "scheduling procedures." The score points to the fact that cells could be possible. Since the average machining time per component is high, there might be queueing problems in a cellular environment. Figure 16 shows the position of the company in the feasibility matrix. From the figure, it is clear that CM implementation is infeasible because of product-mix instability and component complexity -- both critical attributes.

Since the feasibility score indicated a moderate possibility of the implementation of CM, the cell-type matrix is also shown for this company. Figure 17 shows the cell-type matrix.

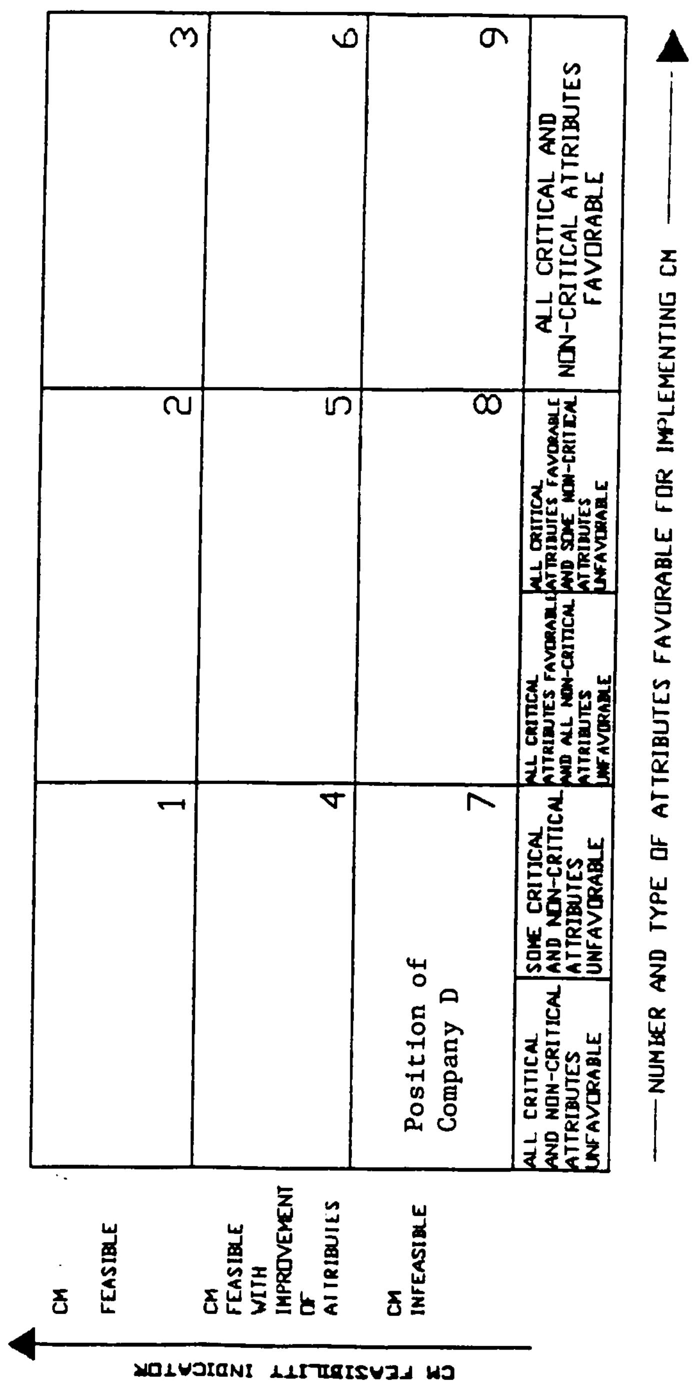

Figure 16. Feasibility matrix for Company D

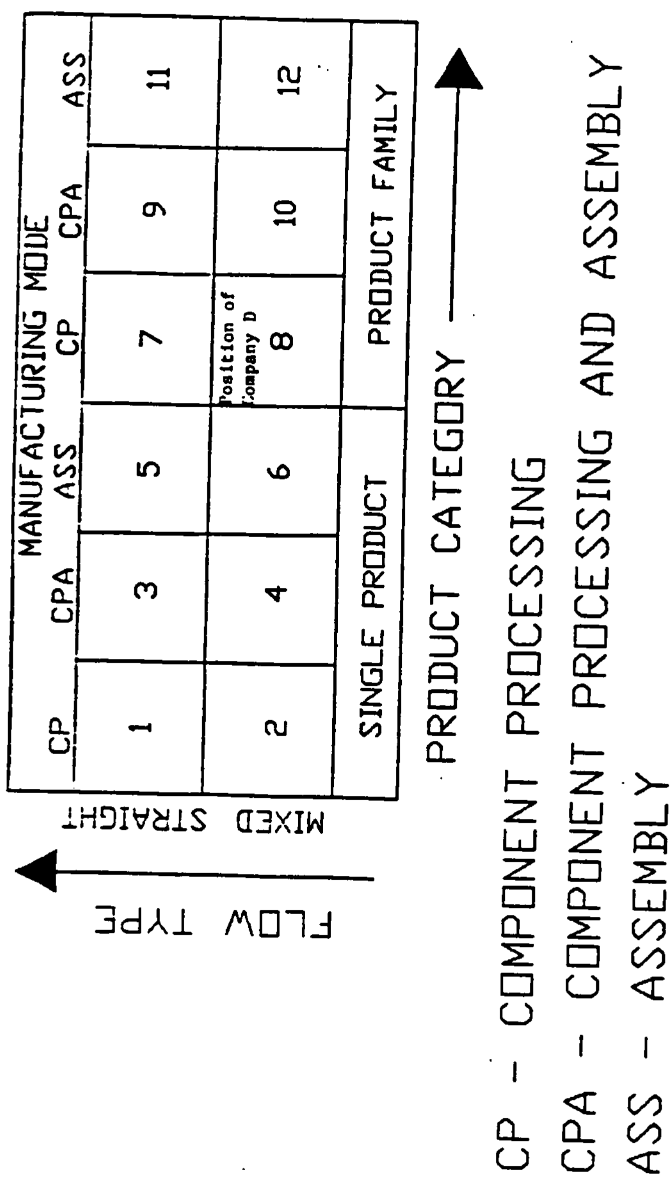

Figure 17. Cell-type matrix for Company D

6.5.5 The choice of method

With respect to the attributes of the choice of method, the interviewee felt that many components produced in the facility could be distinctly grouped into one or more categories according to their design or manufacturing similarity. With regard to the objectives, the respondent stated cost estimation to be an important objective. An informal value analysis program is in place for determining manufacturing methods at lower costs and value analysis was stated by the interviewee to be a desired function. The participant stated that there was little desire or necessity to standardize component designs, although there was considerable desire to standardize process plans. The participant expressed unawareness about the attributes "monetary support," "implementation time," and "usage of standards." Therefore, the levels of these attributes could not be determined. The facility does have sufficient availability of a CAD system.

Since the levels of some attributes could not be determined, the rule-based procedure as it stands now cannot be used to determine the appropriate choice of method. This was found to be a shortcoming of the choice-of-method procedure, and its implication is discussed in detail in the following section. However, by assuming the values of the unknown attribute levels the rule-based procedure may be exercised.

The attribute levels determined for this facility are given now: component design similarity -- high; component manufacturing similarity -- high; computer support -- high; computer literacy -- high; desire for value analysis -- high; desire for design standardization and retrieval -- low; desire for process planning standardization and retrieval -- high. The levels of the attributes "indepartmental information requirements," "monetary support," and "implementation time" could not be determined. Suppose the levels of all unknown attributes are high. The choice, then, given by Rule 1 is an interactive hybrid classification system. It either of the attributes "implementation time" and "monetary support" are at low levels or both of them are at low levels, then the choice given by Rules 7 and 15 also calls for hybrid approaches.

This completes the detailed discussion of the field work at the subject firms. The significance of this field work is discussed now.

6.6 Analysis of results

The analysis of the results from the field work indicates that there are certain conflicts between the results given by the feasibility analysis procedure, the feasibility matrix (as designed), and reality. The feasibility matrix indicated infeasibility for CM implementation for all the companies actually engaged in CM. On the other hand, the scores computed by the feasibility analysis procedure for the three companies indicated an overall suitability for CM implementation. For Company A, the feasibility score was 0.8132. This indicates overall suitability for the implementation of CM. However, the feasibility matrix indicates infeasibility for the implementation of CM. This is because the critical attribute "resistance to change" was at a low level. This result may be interpreted to mean that "resistance to change" is not insurmountable and, therefore, may not be a critical attribute. Another implication may be that "resistance to change" may still be a problem even after the implementation of CM in the subject firm. Yet another implication may be the incorrectness of the attribute or its measure.

For Company B, the feasibility score was 0.8137. This indicates an overall suitability for the implementation of CM. However, the feasibility matrix indicates infeasibility for the implementation of CM. In particular, the low level of the attribute "complexity of components" was instrumental in determining infeasibility for the implementation of CM. The measure "average number of operations per part" contributed to the low level of this attribute. Therefore, it is possible that this measure needs refinement. If this attribute had been at a favorable level, then feasibility for CM implementation would be indicated in the feasibility matrix.

For Company C, the feasibility score was 0.5789. This indicates that the overall suitability is mediocre. In particular, the attributes "occurrence of indivisible processes," "stability of product demand," "stability of product-mix," and "resistance to change," are the critical attributes that are at unfavorable levels. The levels of these attributes were also instrumental in indicating infeasibility in the feasibility matrix. The interviewee at this facility indicated that the occurrence of indivisible processes was indeed a problem. He also stated that instabilities in product demand and mix were tackled by labor transfers.

The Conceptual Flow Model, the feasibility analysis procedure, and the choice-of-method procedure used in the modeling of this research problem is deemed logical. The results of the field work support this statement. The field work in companies actually engaged in CM indicated a valid scoring procedure. A negative evidence to the feasibility analysis procedure was provided by the feasibility matrix. The consequence of this negative evidence is discussed below.

From the case studies it was observed that the feasibility matrix consistently indicated that CM was infeasible for companies actually engaged in CM. Thus it is possible that the rationale behind the feasibility matrix needs to reexamined and the feasibility matrix restructured. The hypothesized criticality of some of the attributes may be in question here. In other words, are the attributes termed critical in this research actually critical for the implementation of CM ? Future research can be helpful in addressing this dilemma. If it can be determined conclusively that none of the attributes are critical for the implementation of CM (in contrast to opinions of researchers in GT/CM), then the scoring procedure alone can be used to identify the attributes that are at low levels and to determine the feasibility score, and the feasibility matrix may be discarded. On the other hand, if it is indeed determined that certain attributes are critical, then the feasibility matrix could be used in conjunction with the scoring procedure as proposed in this research.

It should also be noted here that, if future research indicates certain attributes are critical for the implementation, then the feasibility score computation (as proposed by this research) may be unnecessary. In such a case, the feasibility matrix can be used directly (once the attribute levels are determined) to determine the feasibility of CM in an organization.

The contribution of the feasibility analysis procedure using the feasibility matrix and the feasibility score is in the identification of the attributes that are at levels unfavorable for CM purposes for which remedial measures can be applied. The ability to detect deficiencies of the attributes with respect to the implementation of CM is as important as presenting the feasibility score. The suggestion of particular remedial measures for any company was not attempted in this research.

There are other attributes that deserve mention. The attribute "availability of computer support" and "computer literacy of personnel" were consistently preceived to be irrelevant in the cell design process by all interviewees. All participants felt that a good knowledge of part and process characteristics made computer procedures unnecessary; therefore, detailed analysis of parts or their processes were not felt necessary for determining part-families. This view is in conflict with that of researchers in CM, who feel that computer support is mandatory in the cell design process. Thus, guidelines relating part complexity and computer support necessary for cell design may be developed in future. Only a detailed statistical analysis can help resolve this issue.

All interviewees thought that scheduling should be a centralized function. This perception refutes Burbidge's (1979) assertion that scheduling should be decentralized with the introduction of CM. However, the sample size is too small to make any definitive statements.

With regard to the choice-of-method issue, it was observed that most subjects were not aware that attributes other than "component design similarity" and " component manufacturing similarity" can play a role in determining the most appropriate method for part-machine grouping. For example, participants at Company A and Company C did not consider attributes such as "value analysis" and "design standardization and retrieval" in determining the choice of method. This could be due to a lack of detailed knowledge in the area of CM. The interviewees at Company B, however, were knowledgeable about the relationship between these attributes and the choice of method. This could be due to the respondents' prior experiences in CM installation. Thus, the low level of knowledge about CM among the participants in two of the three companies actually engaged in CM, indicates that the results of extensive academic research in CM are not much used by or available to industrial practitioners. This lack of knowledge could be due to lack of employee education and training in CM (even after implementing a CM system). Thus, an implication of this finding is that cases of CM implementation in industry should be studied and reported, in detail, more frequently. This will enable potential CM implementors to be cognizant of the variables and problems involved in CM implementation. A better planning for CM implementation and a smoother execution of the plans can then be possible.

The attributes "monetary support" and "implementation time" require special attention. All interviewees, except those at Company B, were unable to provide answers as required by the proposed methodology. This is because there was a lack of knowledge about classification and coding or production flow analysis. The data for these attributes require knowledge on the part of the respondents about these two procedures. It seems highly probable that most managers of process-oriented manufacturing systems will not have sufficient knowledge about either the design-oriented approach or the production-oriented approach, unless they have implemented GT before or have been exposed to the GT/CM philosophy. The above attributes were collected from a literature review of actual GT implementations. In most of the cases, the implementers were aware of GT/CM. This may not always be the case. Therefore, it is believed that these attributes should be specified in such a manner that participant knowledge about the design- or production-oriented procedure is not required. It is believed that such a specification requires a deeper investigation about the information available in the firm and the accuracy of the available information. Also, the information required for each approach needs to be investigated at a more microscopic level. The issues of part visibility, data accuracy, and availability have been raised as important by this research for both the feasibility and choice-of-method issues.

Field work in Company D indicated a possibility of implementing CM. The feasibility matrix, however, indicated that the implementation of CM was infeasible because of the low levels of key attributes "stability of product-mix," and "complexity of components." The result indicated by the feasibility matrix for Company D is consistent with the results indicated by the feasibility matrix for other companies. The implication of the inconsistency between the results of the scoring model and the matrix has been discussed before and will not be repeated.

Finally, the relevance of all attributes and measures can only be established through complete statistical tests and is left for future research. This will help to validate and consolidate the entire decision-making framework.

Chapter VII

Conclusions and Recommendations

This chapter furnishes a summary of this research, discusses the conclusions drawn from it, and presents recommendations for future research.

7.1 Summary of Research

This research addressed two very fundamental unaddressed issues in cellular manufacturing. These two issues were organizational feasibility for the implementation of CM and the choice-of-method approach for part-family/machine grouping, if feasibility was adjudged, given organizational and manufacturing characteristics. The approach to part-machine grouping may follow one of the following options -- a design-oriented approach, a production-oriented approach, or a combination of both. An examination of published literature (in English) in cellular manufacturing indicated the need for this research. A framework was developed to address the above issues.

A conceptual flow model (CFM) was first developed to structure and rationalize the above research problem. The concept of the CFM originated from the basic input-output production model in literature. This model helped the formulation of the research problem by rationalizing that a new manufacturing approach (CM) was feasible for an organization if certain performance measures were weak and if certain criteria regarding the products, available resources, procedures used, and organizational characteristics were met. On the other hand, the model proposed that an organization could remain functionally arranged and improve its existing procedure for better performance, if these criteria were not met. This research, however, did not include this latter part of the model as a research issue.

Once feasibility for the implementation of CM was adjudged, the model hypothesized that a part-family/machine grouping approach was necessary for the initial design of the cells. This approach was to be selected from the design-oriented approach, the production-oriented approach, or a combination of both.

This model formulation enabled the identification of important attributes pertinent to the research problem. The attributes were identified through a comprehensive review of the GT/CM literature (in English). The attributes for the feasibility issue were clustered into four categories. These were the products and processes category, the resources category, the procedures category, and the organizational characteristics category. The attributes pertinent to the choice-of-method issue were clustered into the product category, the resources category, and the objectives category. The identification of the attributes was followed by an explanation of their relevance.

A set of propositions was developed to relate the level of an attribute to the feasibility for the implementation of CM and the choice of method issues. The propositions further strengthened the theoretical background of this research through the use of past research and enabled the construction of the rules necessary for the execution of the decision-making procedure. A complete set of definitions and specifications were next developed for each of the attributes for both issues. The purpose of the specifications was to enable the measurement of the attribute levels through developed measures of each attribute. All the attributes were weighted according to their perceived importance.

A scoring model was developed to determine a score for feasibility for the implementation of CM. This score represented a calculated measure of an organization's feasibility for the implementation of CM. A rule-based procedure was developed to determine the choice of method for part-machine grouping.

In order to verify the relevance of the attributes, their measures and weights, and (indirectly) the propositions, companies engaged in CM were visited and data pertinent to the feasibility analysis and choice-of-method procedures were collected. Valuable information was gained from these visits and it was found that some attribute measures will require possible refinement in future research. Scores for CM feasibility were determined for each use of the scoring model. A choice of method for part-machine grouping was also determined by using the rule-based procedure. For comparison purposes, data were collected from a company with a functional layout and used with the scoring model. The rule-based procedure could not be used for some companies because of insufficient data.

The objectives of this research were met. Formalized procedures for the feasibility analysis procedure for the implementation of CM and the choice of method for part-family/machine grouping were developed and applied in several field sites.

7.2 Conclusions

The primary conclusion drawn from this research was a general support for most of the attributes and measures. It is believed that certain attributes may need to be refined if assembly cells are considered.

The field work provided a general validity of the ranking concept of the attributes while indicating certain variations in the ranking of the attributes. While this will not affect the scoring procedure, it will affect the computed weights. It is felt that the variability of the ranks should be examined in greater detail, because this may lead to either a standardized ranking of attributes (in case of low variability) or user-supplied ranking (in case of high variability of ranks).

A general support was indicated for the scoring procedure. However, contradictory results were derived by the scoring procedure and the feasibility matrix. While the scoring procedure indicated CM feasibility for the field sites at varying levels, the feasibility matrix indicated CM infeasibility. This contradiction should be examined in future research.

The literature review indicated the attributes relevant for the implementation of CM systems. While most of the attributes were viewed by the field work participants to be relevant, some attributes (stated earlier) were not. Thus, there is some inconsistency between academic literature and participant perceptions with respect to the relevance of some attributes. However, the perceived irrelevance of these attributes may be due to the specific products manufactured and part visibility.

The feasibility score output by the scoring model is based on attribute levels. This score does not take into account the costs involved in implementing the CM system. Thus, although feasibility for the implementation of CM is addressed by the scoring procedure, it does not consider the economic implications of such a feasibility.

The deficiency of the rule-based procedure for the choice of method due to participant unawareness about some attributes was noticed. One way of redressing this deficiency presently is to use assumed values for the attributes whose values are unknown. It was also noted that the attributes "component design similarity" and "component manufacturing similarity" were almost always the only ones used to determine part-family grouping. The construction of the rules could become tedious if more attributes and more levels are involved.

This research also revealed a low level of GT/CM knowledge or awareness among participants. It is hoped that this will improve with more applications and practical research.

Results are generalizable within the scope of the field work. However, it must be stressed that no statistical validations are claimed. General support was shown for the approach as indicated by the responses of interviewees within the scope of the field work. This research has provided a framework for determining CM feasibility and the choice of method for part-machine grouping if feasibility is adjudged, given organizational characteristics. Even though modifications of the attributes, measures, and ranks can be made, the general approach developed in this research is valuable in its present state. Additional areas for future research have also been identified. They are discussed next.

7.3 Recommendations for future research

The verification of the developed framework for the analysis of feasibility for the implementation of CM and the choice of method to the approach for part-machine grouping involved field work in companies with CM systems. An expansion of this research could include more companies for identifying more attributes and verifying them. Statistical inferences about the validity of the attributes could be drawn by developing a survey instrument if a sufficient cooperative sample could be obtained. Also, the knowledge gained by doing so would be invaluable to companies willing to consider CM as a viable alternative.

It is believed that a minute examination of the information requirements of each method is required in order to resolve the inconsistencies in the choice-of-method issue. Also, all attributes should be specified in such a way that respondents can provide data without requiring any prior knowledge about the attributes or their specification in relation to the choice of method. As the rule-based procedure could become extremely tedious with an increase in attribute levels, it is perceived that other procedures should be investigated.

This research has revealed that there is very little information about the cost of implementing a design- or a production-oriented approach. This is especially important for companies considering CM as a viable production alternative. A knowledge of the implementation cost of either approach would be very helpful in the planning stage. Therefore, it is necessary to study implementation costs and/or devise methodologies for cost comparisons between the approaches.

The relationship between computer support, part data visibility and part complexity needs to be thoroughly investigated. This may provide guidelines for investigating the part-family forming approach.

To further improve the feasibility analysis procedure, certain simulation routines could be developed. These include detailed analysis procedures for determining part-families and machine cells; stability of cells with respect to changes in product demand and/or mix; and cell performance with machine breakdown, labor flexibility, and absenteeism.

Another desirable extension to this research could be the development of a taxonomy of cells and product types through surveys and/or plant visits.

Finally, one logical extension to this research could be to develop simulation methodologies to compare functional and cellular layout performances under identical conditions. Certain parameters that are thought to be important include individual part weights, the number of operations per part and their operation times, equipment breakdown, and the availability of an MRP system.

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Appendices

Appendix 1

Company Information Sheet

Company name :

Interviewee :

Location :

Rank :

Date :

Number of employees :

Product line :

Production description :

Number of cells in operation :

Number and types of machines in each cells :

Number of operators in each cell :

Number of cells planned :

Time required to implement :

Motives for introducing CM :

Part-family approach for forming cells :

Fraction of all production done in cells :

Fraction eventually planned :

Appendix 2

Fieldwork specification sheet

Feasibility issue

1. Occurrence of part families/machine groups: This attribute is defined as the existence of parts that can be grouped together because of similar processing requirements. This attribute, specified in terms of the component manufacturing similarity, is shown below.

   • Component manufacturing similarity:

   1 - Of all the components made, very few can be distinctly grouped into separate groups because of common machining requirements.

   2 - Of all the components made, few can be distinctly grouped into separate groups because of common machining requirements.

   3 - Of all the components made, some can be distinctly grouped into separate groups because of common machining requirements.

   4 - Of all the components made, many can be distinctly grouped into separate groups because of common machining requirements.

   5 - Of all the components made, almost all can be distinctly grouped into separate groups because of common machining requirements.

2. Occurrence of indivisible processes: The occurrence of indivisible processes is defined as the presence of centralized processes in the component routings. Examples of centralized processes are painting, shot blasting, heat treatment, and sub-contracted work. The specification of this attribute is done in terms of intermediate visits by parts to centralized processes.

   • Extent of intermediate visits to centralized processes:

   1 - Almost all components require intermediate visits to centralized processes.

2 - Many components require intermediate visits to centralized processes.

3 - Some components require intermediate visits to centralized processes.

4 - Few components require intermediate visits to centralized processes.

5 - Very few components require intermediate visits to centralized processes.

3. Stability of product demand: This attribute is defined as the lack of fluctuation of the long-term product demand imposed on production for all the products manufactured. The specification is shown below.

• Fluctuation in long-term product demand:

1 - Extreme fluctuation in long-term product demand for all products.

2 - Large fluctuation in long-term product demand for all products.

3 - Some fluctuation in long-term product demand for all products.

4 - Little fluctuation in long-term product demand for all products.

5 - Very little fluctuation in long-term product demand for all products.

4. Stability of product-mix: This attribute is defined as the lack of fluctuation of the long-term product-mix.

• Fluctuation in long-term product-mix:

1 - Extreme fluctuation in long-term product-mix.

2 - Large fluctuation in long-term product-mix.

3 - Some fluctuation in long-term product-mix.

4 - Little fluctuation in long-term product-mix.

5 - Very little fluctuation in long-term product-mix.

5. Complexity of components: Complexity of a component is defined in terms of these three sub-factors: total number of machines required for the manufacture of a component, the total number of operations per component and the total machining time per component. The range of permissible values for each of the three categories is shown below.

• Average number of machines needed to complete a component:

1 - more than 40.

2 - between 20 and 39.

3 - between 10 and 19.

4 - between 5 and 9.

5 - fewer than 5.

- Average number of operations required to complete a component:

1 - more than 40.

2 - between 20 and 39.

3 - between 10 and 19.

4 - between 5 and 9.

5 - fewer than 5.

- Average machining time per component:

1 - more than 10 hours.

2 - between 5 and 10 hours.

3 - between 2 and 5 hours.

4 - between 1/2 and 2 hours.

5 - less than 1/2 hour.

6. Weight of components: This attribute is defined as the heaviness of the individual components. It is also defined in terms of material handling equipment necessary for the transportation of the components.

- Equipment needed to transport components:

1 - Almost all components need heavy moving equipment (overhead cranes).

2 - Most components need moderate moving equipment (tow trucks), the rest need heavy equipment.

3 - Some components need moderate moving equipment, the rest need light mechanized equipment (tow carts, light conveyors).

4 - Some components need light mechanized equipment, the rest are handled manually.

5 - Almost all components can be moved manually.

7. Capacity balance:

Capacity balance is defined as the extent of machine utilization of all machines -- primary or secondary -- due to parts processed on them. Primary machine types are one-of-a-kind machines and are available in limited quantities. If there is more than one machine of a certain primary machine type available then it is considered to be a primary machine type with duplication. For secondary machine types, several machines of each type exist. This concept is used in specifying this attribute.

- Extent of machine utilization:

  1 - Extremely high utilization of unduplicated primary machines; extremely low utilization of secondary machines.

  2 - Extremely high utilization of unduplicated primary machines; low utilization of secondary machines.

  3 - Low to moderate utilization of unduplicated primary machines; low to moderate utilization of secondary machines.

  4 - High to medium utilization of duplicated primary machines; low to moderate utilization of secondary machines.

  5 - High to medium utilization of duplicated primary machines; high to moderate utilization of secondary machines.

8. Flexibility of labor: This attribute is defined as the ability of labor to operate multiple machine types. The specification of this attribute is shown below.

- Ability of operators to operate multiple machine type:

  1 - None - one operator can operate only one machine type.

  2 - Few - very few operators can operate multiple machine types.

  3 - Some - some operators can operate multiple machine types.

  4 - Most - most operators can operate multiple machine types.

  5 - All - all operators can operate multiple machine types.

9. Availability of computer support: The availability and access to computer support defines this attribute. The availability of this resource will be indicated in terms of computer memory available.

   • Available computer resource in terms of memory of a single computer:

   1 - Greater than 0Kb and less than or equal to 256Kb.

   2 - Greater than 256Kb and less than 640Kb.

   3 - Greater than 640Kb and less than 2000Kb.

   4 - Greater than 2000Kb and less than 10000Kb.

   5 - Over 10000Kb.

10. Availability of a classification and a coding scheme: This is defined as access to or the availability of a classification and coding package. The specification of this attribute is given below.

   • Availability of and access to a classification and coding package:

   1 - No access to a classification and coding system.

   2 - Limited access to a classification and coding system.

   3 - Some access to a classification and coding package.

   4 - Adequate access to a classification and coding package.

   5 - Sufficient access to a classification and coding package.

11. Computer literacy of personnel: This attribute is defined as the extent of computer orientation of middle management defines this attribute. The measures of computer literacy of personnel will consider the ability of the middle level management (since they are the ones who will actually implement CM) in terms of their familiarity with computers, their ability to use commercial spreadsheet packages (since middle level managers are often required to use them), and their familiarity with programming languages.

   • The frequency of direct use of computers at work:

   1 - Never

   2 - Seldom

   3 - Some

   4 - Quite frequent

5 - Very frequent

- The frequency of use of spreadsheet analysis on computer:

  1 - Never

  2 - Seldom

  3 - Some

  4 - Quite frequent

  5 - Very frequent

- The frequency of programming, using procedural (e.g. FORTRAN), simulation (e.g. GPSS) and/or symbolic languages (e.g. APL):

  1 - Never

  2 - Seldom

  3 - Some

  4 - Quite frequent

  5 - Very frequent

- Of all the time spent in attending workshops and/or seminars, the percentage spent in attending workshops and/or seminars directly related to computer education:

  1 - Between 0% and 20%

  2 - Between 20% and 40%

  3 - Between 40% and 60%

  4 - Between 60 % and 80%

  5 - Between 80% and 100%

12. Skill level of operators: This attribute is defined as the labor skills available according to the following categories: (i) Tool and die maker (ii) class A machinist (iii) class B machinist. A tool and die maker can operate all machining equipment and can make a part from a sketch; can set the required speeds, feeds and depth of cuts for any machining operation; can also develop tools and jigs and fixtures. The class A machinist requires a blue print to make a part and can operate the basic machines; can set the feeds, speeds and depths of cut for these machines and is less experienced than a tool and die maker. The class B machinist is an operator for a specific

machine or more than one machine; requires a blue print and a detailed process plan for manufacturing a part; and has very little knowledge about feeds, speeds and depths of cut and cannot set-up a machine.

- Skill level of operators:

  1 - Almost all machinists are tool and die makers; very few are class A.

  2 - Some machinists are tool and die makers; majority class A, rest B.

  3 - Some tool and die makers, some class A, some class B.

  4 - Majority class B, some class A, very few tool and die makers.

  5 - Almost all class B, very few class A or tool and die makers.

13. Forecasting reliability: This attribute refers to the reliability of forecast of product-demand and is defined as the lack of deviation of the product demand forecast from the actual demand. The specification of this attribute is shown below.

- Deviation of product demand forecast from the actual:

  1 - Very large deviations; extremely inaccurate forecasts.

  2 - Large deviations; quite inaccurate forecasts.

  3 - No large deviations; some accuracy in forecasting.

  4- Small deviations; fairly accurate forecasts.

  5 - Very small deviations; extremely accurate forecasts.

14. Reliability of equipment: This attribute is defined as the lack of machine breakdowns in producing the components. The specification of this attribute is with respect to the frequency of the machine breakdowns and is shown below.

- Frequency of machine breakdowns:

  1 - Frequent breakdown of all equipment.

  2 - Frequent breakdown of key machines with occasional breakdown of secondary operation machines.

  3 - Occasional breakdown of some key and secondary operation machines.

  4 - Infrequent breakdown of key machines and occasional breakdown of secondary operation machines.

5 - Infrequent breakdown of key and secondary operation machines.

15. Implementation time: This attribute is defined as the time required to implement a CM system from conception to implementation either partially or wholly. Since it is not possible to predict the exact time that will be required to implement the CM system, past project implementation history will be used as an indicator to determine the level of this attribute. The indicator of the time required to implement CM will be expressed in terms of long term planning and the success in implementing large-scale previous projects. The specifications are shown below.

   - Planning is on:

     1 - An extremely short-term view.

     2 - Short-term view.

     3 - Neither short-term nor long-term view.

     4 - Long-term view.

     5 - Extremely long-term view.

   - Implementation history of past large-scale projects:

     1 - Totally unsuccessful.

     2 - Mostly unsuccessful.

     3 - Partially successful.

     4 - Successful with minor set-backs.

     5 - Completely successful.

16. Reliability of suppliers: This attribute is defined as the timely supply of defect-free materials necessary for production. The reliability of suppliers will be measured in terms of the extent of on-time delivery and the frequency of the time that material is delivered free of defects. These measures are shown below.

   - The extent of on-time delivery in the supply of all raw material:

     1 - None.

     2 - Little.

     3 - Some.

     4 - Quite a lot.

5 - A great extent.

- The frequency of the time that material is delivered free of defect:

1 - Never.

2 - Seldom.

3 - Some of the time.

4 - Frequently.

5 - Very frequently.

17. Material control system: This attribute is defined as the type of material control system (MCS) currently in use. The specification of this attribute is shown below.

- Type of material control system currently in use:

1 - No MCS in use.

2 - A multi-cycle reorder point MCS for individual components in use.

3 - A single cycle reorder point MCS for individual components in use.

4 - A single cycle MCS based on end product demand; developed in-house.

5 - A commercial MRP or MRP II or similar type of MCS.

18. Workload on process planners: This attribute is defined as the degree to which process planners are occupied daily in the development of process plans. The workload on process planners will be measured with respect to two factors : degree of overtime worked, and on the extent of duplication in process planning.

- The extent to which process planners work overtime:

1 - None.

2 - Little.

3 - Some.

4 - Quite a lot.

5 - A great extent.

- The extent of duplication in process planning:

1 - None.

2 - Little.

3 - Some.

4 - Quite a lot.

5 - A great extent.

19. Scheduling procedures: This attribute is defined as the extent of centralization or decentralization of control for scheduling in the manufacturing facility. In particular, the aspects of interest here are: (i) centralization of scheduling and (ii) the authority of first-line supervisors to override schedules as and when necessary. Thus, this attribute focuses not on the scheduling procedures, per se, but the current organization of production scheduling. Indicators for the two aspects will be used to measure the level of this attribute.

• Centralization of scheduling:

1 - All shop-floor scheduling done in a central office.

2 - Most shop-floor scheduling done in a central office.

3 - Some shop-floor scheduling done in a central office; rest done by first-line supervisors.

4 - Most shop-floor scheduling done by first-line supervisors.

5 - Almost all shop-floor scheduling by first-line supervisors.

• Authority of first-line supervisors to override schedules:

1 - No authority of first-line supervisors to override shop-floor schedules.

2 - First-line supervisors are seldom allowed to override shop-floor schedules; management permission is necessary.

3 - First-line supervisors are allowed to override shop-floor schedules with management permission.

4 - First-line supervisors have limited authority to override shop-floor schedules without management permission.

5 - First-line supervisors have complete authority to override schedules as and when necessary.

20. Managerial Support: In the context of this research, managerial support will be defined as an intangible management attribute manifested through actions that promote organizational welfare and that contribute to its objectives.

Four dimensions of this attribute wiil be used. These are: (i) future orientation as opposed to short-term thinking; (ii) attitude toward subordinates; (iii) allocation of resources to projects; and (iv) leadership capabilities.

- Long-term thinking

  The extent of management to plan ahead:

  1 - None.
  2 - Little.
  3 - Some.
  4 - Quite a lot.
  5 - Great extent.

- Attitude toward subordinates

  The extent to which senior personnel will go out of their way to help subordinates:

  1 - None.
  2 - Little.
  3 - Some.
  4 - Quite a lot.
  5 - Great extent.

- Allocation of resources

  The length of time taken to get capital allocation requests through the approval process:

  1 - Greater than or equal to 6 months.
  2 - Greater than or equal to 4 months and less than 6 months.
  3 - Greater than or equal to 2 months and less than 4 months.
  3 - Greater than or equal to 1 months and less than 2 months.

5 - Less than 1 month.

The extent of yearly increase in total company budget for manufacturing:

1 - None.

2 - Little.

3 - Some.

3 - Quite a lot.

5 - Great Extent.

- Leadership capabilities

There is at least one individual in the management level who can take charge and get things done:

1 - Strongly disagree.

2 - Disagree.

3 - Neutral.

4 - Agree.

5 - Strongly agree.

21. Resistance to change: This attribute is defined as the propensity by personnel in the manufacturing organization to oppose changes brought about in the manufacturing environment. The propensity of doing things the "old way", employee turnover, and the frequency of strikes will be used to measure this attribute.

- The extent to which supervisors stick to old ways of doing things:

1 - Great extent.

2 - Quite a bit.

3 - Some.

4 - Little.

5 - None.

- The extent of employee turnover in manufacturing:

1 - Great extent.

2 - Quite a bit.

3 - Some.

4 - Little.

5 - None.

- The frequency of strikes:

1 - Very high.

2 - High.

3 - Occasional.

4 - Low.

5 - Very low.

Definition and specification of the twenty-one attributes pertinent to the feasibility issue have been completed. Now, definition and attributes relating to the choice of method issue will be described.

Choice-of-method issue

1. Component design similarity: This attribute is defined as the extent to which are similar with respect to their shape and size. The specification of this attribute is based on the table shown below.

Rotational Components	1. No bore 2. Blind hole 3. Through hole 4. Geared with no bore or blind hole 5. Gear with through hole 6. Company specific
Non-rotational Components	1. Flat and irregular 2. Box-like 3. Company specific

Initially, each component is classified into a rotational or non-rotational category. Components within the rotational category are further divided into those that do not have any central bores, those having blind holes, those having through holes, and those that are geared. The non-rotational components are divided into those that are flat and irregular in shape and those that are box-like. Each of these categories are exclusive.

- Component design similarity measure:

  1 - Very few components can be grouped into any one or more of the above categories.

  2 - Few components can be grouped into any one or more of the above categories.

  3 - Some components can be grouped into any one or more of the above categories.

  4 - Many components can be grouped into any one or more of the above categories.

  5 - Almost all components can be grouped into any one or more of the above categories.

2. Component manufacturing similarity: The specification of this attribute has been discussed in the feasibility section and will not be repeated here.

3. Availability of a CAD system: Availability of a computer-aided-system is defined as the extent to which a CAD system is easily accessed (not necessarily owned, if accessible). The specification of this attribute is given below.

- Availability/accessibility of a CAD system:

  1 - No availability or access to a CAD system.

  2 - Limited availability or access to a CAD system.

  3 - Some availability or access to a CAD system.

  4 - Adequate availability or access to a CAD system.

  5 - Sufficient availability or access to a CAD system.

4. Monetary support: This attribute is defined as the availability of financial resources for implementing either approach. The cost of classification and coding packages will be used as a ceiling for the specification of this attribute because employing a classification-based approach incurs the most expenditure. The specification of this attribute is stated below.

   • Availability of funds:

     1 - Less than or equal to $5,000.

     2 - Greater than $5,000 and less than or equal to $20,000.

     3 - Greater than $20,000 and less than or equal to $40,000.

     4 - Greater than $40,000 and less than or equal to $60,000.

     5 - Greater than $60,000.

5. Implementation time: This attribute is defined as the time allocated for the implementation of a design- or production-oriented approach. Since it is not possible to predict the exact time that will be required to implement the system, the estimate of time required to adopt a classification package will be used as a ceiling. The specification is given below.

   • Amount of time:

     1 - Less than 6 months.

     2 - Greater than 6 months but less than or equal to 9 months.

     3 - Greater than 9 months but less than or equal to 12 months.

     4 - Greater than 12 months but less than or equal to 18 months.

     5 - Greater than 18 months.

6. Availability of computer support: This specification of this attribute has been discussed in the feasibility section and will not be repeated here.

7. Computer literacy of personnel: The specification of this attribute has been discussed in the feasibility section and will not be discussed again.

8. Inter-departmental information requirements: Inter-departmental information requirement is defined in terms of these two subfactors: the objective of the sales department to access standard product cost data for estimating product costs accurately; and the objective of the

purchasing department to access product data for purchasing similar items for bulk purchases. The specification of this attribute is given in terms of

- The importance of the objective of accurate product costing for the firm:

    1 - Product costing is not one of our important objectives.

    2 - Product costing is one of our slightly important objectives.

    3 - Product costing is one of our somewhat important objective.

    4 - Product costing is one of our important objectives.

    5 - Product costing is one of our most important objective.

- The importance of the objective of identifying similar parts or materials for bulk purchases:

    1 - The identification of similar materials for bulk purchases is not one of our important objectives.

    2 - The identification of similar materials for bulk purchases is one of our slightly important objectives.

    3 - The identification of similar materials for bulk purchases is one of our somewhat important objectives.

    4 - The identification of similar materials for bulk purchases is one of our important objectives.

    5 - The identification of similar materials for bulk purchases is one of our most important objective.

9. Value analysis : This attribute is defined as the objective of the use of value analysis techniques for product design in the organization. The specification is as follows.

- The importance of the use of VA techniques as an objective:

    1 - The use of VA techniques is not one of our important objectives.

    2 - The use of VA techniques is one of our slightly important objectives.

    3 - The use of VA techniques is one of our somewhat important objectives.

    4 - The use of VA techniques is one of our important objectives.

    5 - The use of VA techniques is one of our most important objective.

10. Design standardization and retrieval (DSR): This attribute is defined as the process of standardizing and retrieving similar component designs. The specification of this attribute is given below.

   - The importance of DSR as an objective:

     1 - DSR is not one of our important objectives.

     2 - DSR is one of our slightly important objectives.

     3 - DSR is one of our somewhat important objectives.

     4 - DSR is one of our important objectives.

     5 - DSR is one of our most important objective.

11. Process plan standardization and retrieval (PPSR): This attribute is defined as the objective of reducing process plan redundancy. The specification of this attribute follows.

   - The importance of PPSR as an objective:

     1 - PPSR is not one of our important objectives.

     2 - PPSR is one of our slightly important objectives.

     3 - PPSR is one of our somewhat important objectives.

     4 - PPSR is one of our important objectives.

     5 - PPSR is one of our most important objective.

12. Usage of standards: This attribute is defined as the objective of the use graphics or product standards like (IGES) Initial Graphics Exchange Specification or PDDS (Product Design and Development Standards).

   - The importance of the use of standards as an objective:

     1 - The use of standards is not one of our important objectives.

     2 - The use of standards is one of our slightly important objectives.

     3 - The use of standards is one of our somewhat important objectives.

     4 - The use of standards is one of most important objectives.

     5 - The use of standards is one of our most important objective.

Appendix 3

Validity verification sheet -- feasibility issue

Validity verification of attributes -- feasibility issue

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
1. Occurrence of part families and machine cells					
	Component design similarity				
	Component manufacturing similarity				
2. Occurrence of indivisible processes					
	Extent of intermediate visits to centralized processes				
3. Stability of product demand					
	Fluctuation in long term product demand				
4. Stability of product mix					
	Fluctuation in long term product mix				
5. Complexity of components					
	Average # of machines needed to complete a component				
	Average # of operations needed to complete a component				
	Average machining time per component				
6. Weight of components					
	Equipment needed to transport components				
7. Capacity balance					
	Extent of machine utilization				

Appendix 3 continued

Appendix 3 continued

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
8. Flexibility of labor					
	Ability of operators to operate multiple machine types				
9. Availability of computer support					
	Availability of computer resource in terms of memory of a single computer				
10. Availability of a coding and classification system					
	Availability of/and access to a coding & classification package				
11. Computer literacy of personnel					
	The frequency of direct use of computer at work				
	The frequency of use of spreadsheet analysis on computer				
	The frequency of programing using FORTRAN, GPSS or APL				
	Of all the time spent in workshops and/or seminars, the percentage spent in attending workshops and/or seminars directly related to computer education				
12. Skill level of operators					
	In terms of tool and die makers class A and class B machinists				

Appendix 3 continued

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
13. Forecasting reliability					
	Deviation of part demand forecast from actual				
14. Reliability of equipment					
	Frequency of machine breakdown				
15. Implementation time					
	Planning horizon (short or long term)				
	Implementation history of past large-scale projects				
16. Reliability of suppliers					
	Extent of on-time delivery in the supply of raw materials				
	Frequency of time that material is delivered free of defect				
17. Material control system					
	Type of MCS currently in use				
18. Work load on process planners					
	Extent to which process planners work overtime				
	Extent of duplication in process planning				

Appendix 3 continued

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
19. Scheduling procedures					
	Centralization of Scheduling				
	Authority of foremen to override schedules				
20. Managerial support					
	Extent of management to plan ahead				
	Extent to which senior personnel help subordinates				
	Length of time taken to get capital allocation approved				
	Extent of yearly increase in manufacturing budgets				
21. Resistance to change					
	Extent to which supervisors stick to old ways of doing things				
	Extent of employee turnover				
	frequency of strikes				

Appendix 4

Validity verification sheet -- choice of method issue

Validity verification of attributes of the choice of method issue

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
1. Component design similarity					
	Grouping based on design categories				
2. Component manufacturing similarity					
	Grouping based on routing similarity				
3. Availability of a CAD system					
	Availability of/accessibility to a CAD system				
4. Monetary support					
	Availability of funds for a classification and coding scheme				
5. Implementation time					
	Amount of time given/to be given to the approach				
6. Availability of computer support					
	Same as feasibility issue				
7. Computer literacy of personnel					
	Same as feasibility issue				

Appendix 4 continued

Appendix 4 continued

Attribute	Measure	Validity of attributes and measure Yes	No	Don't know	Comments
8. Interdepartmental information requirements					
	Desire to identify similar items for bulk purchases				
	Desire to estimate products cost accurately				
9. Value analysis (VA)					
	Desire to use VA for least cost design				
10. Design standardization and retrieval					
	Desire to standardize product designs and retrieve similar designs				
11. Process plan standardization and retrieval					
	Desire to standardize and retrieve similar process plans				
12. Use of products and graphic standards					
	Desire to use products and graphic standards				

Appendix 5

Attribute weight verification -- feasibility

Weighted attribute categories of the feasibility issue

Category	Attribute	Suggested Score range	Validity of Category	Validity of Rank	Don't know	Comments
I	1. Occurrence of part families and machine cells	90-100				
II	2. Stability of product demand	75-89				
	3. Stability of product-mix					
	4. Complexity of components					
	5. Occurrence of indivisible processes					
	6. Weight of components					
	7. Managerial support					
	8. Resistance to change					
	9. Implementation time					
III	10. Availability of computer support	60-74				
	11. Computer literacy of personnel					
	12. Material control system					
	13. Capacity balance					
	14. Reliability of equipment					
	15. Flexibility of labor					
	16. Skill level of operators					
	17. Reliability of suppliers					
	18. Forecasting reliability					
	19. Scheduling procedures					
IV	20. Workload on process planners	45-59				
	21. Availability of a classification and coding system					

Appendix 5 continued

Weighted attribute categories of the choice of method issue

Category	Attribute	Suggested Score range	Validity of Category	Validity of Rank	Validity of Don't know	Comments
I	1. Component design similarity	90-100				
	2. Component manufacturing similarity					
II	3. Monetary support	75-89				
	4. Implementation time					
	5. Availability of computer support					
	6. Computer literacy of personnel					
	7. Inter-departmental information requirements					
	8. Value analysis					
	9. Design standardization and retrieval					
	10. Process plan standardization and retrieval					
III	11. Availability of a CAD system	60-74				
	12. Usage of standards					
Others						

Catergory	Attribute	Suggested Score range	Validity of Category	Validity of Rank	Validity of Don't know	Comments
others						

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