University of Southern Queensland
Faculty of Engineering and Surveying

Production Flow Analysis & Inventory Control for Orford Refrigeration

A dissertation submitted by

Yip Soon YEW

In fulfillment of the requirements of

Course ENG4111 and 4112 Research Project

Towards the degree of

Bachelor of Engineering (Mechatronics)

Submitted: October, 2004

Abstract

Group technology is an important technique in the planning of manufacture that allows the advantages of flow production organization to be obtained in what otherwise would be jobbing of batch manufacture. The approach is to arrange separate machines groups with appropriate internal group layout to suit the production of specific component families, formed in accordance with the similarity of operations that to be performed on them.

Due to the limited time available for this research project, only one of the techniques of Group Technology will be use to conduct the analysis, which is the Production Flow Analysis. The reason of choosing this technique is because it is more simple and easy to implement and also due to lots of research and background has been done on this technique.

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111 and ENG 4112 Research Project

Limitations of Use

Certification

I certainly that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledge.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

YEW YIP SOON

Student Number: W0006618

____

Signature

____

Date

Acknowledgements

I would like to take this opportunity to express my sincere appreciation towards my supervisor, Dr. Harry Ku for his valuable guidance and supervision throughout the course of my thesis. He has not only allowed me to explore my capabilities and skills, but also helped cultivate in me a keen interest in the area of manufacturing processes. It has been a truly memorable and beneficial experience to have him as my supervisor.

I would also like to show my appreciation towards Dr. Selvan Pather for his time and guidance during the course of my thesis. He has been an inspiration to me and given me many intellectual challenges to face. He also allowed me to expand my boundaries to where I would never have thought I could reach.

A very important and valued person whom without which the success of this research project would not have been possible is Mr Ian Otto, the Product Development Advisor of Orford Refrigeration. He has provided enormous amount of help, guidance and valuable information for this research project. He is a man of great patience and it has been wonderful to work with him. With all the support and valuable times he has given to me, he has indeed made this research project a great one to work on despite all odds.

I would also like to thank the following important Orford Refrigeration staffs members for their help and guidance.

Jason Peters (New Product Team Member)

Shane Geitz (Department Head – Machine Shop)

Alex Bom

Last but not least, I would like to express my appreciation to Sharene Ng who helped me throughout the writing of my thesis and to my family who has given the moral and financial support throughout my study.

Table of Contents

List of Figures

Lists of Tables

Appendices

1. Introduction

Manufacturing environments and production processes have changed substantially over the past two decades. Rather than producing as much possible with limited options, customer buying habits now require just in time delivery as well as more “made-to order” products. Customers are demanding the latest and greatest in technology before the new product is barely off the drawing board. In 1971, Opitz [1] related that at least 48% of all components designs produced each year are new. Today, that number is considered to be higher. In order to maintain profitability, companies must find ways to bring new products to market more expediently and cost effectively while engaging in continuously improving these products.

Recently, Cellular Manufacturing (CM) has emerged as a strong approach for improving operations in batch and job shop environments. In CM, Group Technology (GT) is used to form part families based on similar processing requirements. Parts and machines are then grouped together based on sequential or simultaneous techniques. This approach results in cells where machines are located in relative proximity based on processing requirements rather than similar functional aspects. Decision making and accountability are more locally focused, often resulting in quality and productivity improvements.

With the increase in global competition, many manufacturers have shifted from traditional job-shop work to utilizing GT and CM. Similar to mass production, GT harness resources for small lot production. However, unlike mass production lines used for large quantities of a single part, families of similar parts with similar processes are manufactured. Parts are grouped into families based on these similarities and produced in manufacturing cells where machines are dedicated to a particular family (shown in Figure 1.1a and 1.1b).

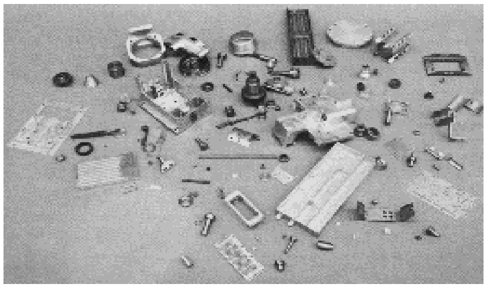

Figure 1.1: (a) Ungrouped parts

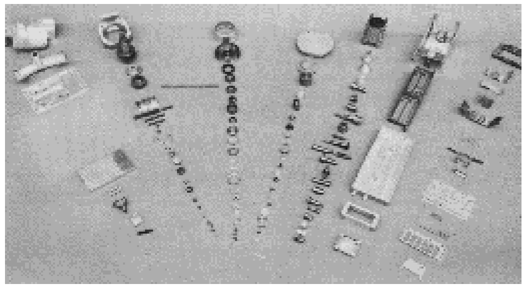

Figure 1.1: (b) Grouped parts

Inventory control is needed in every organization. A typical manufacturing company holds 20% of its production as stock, and this has annual holdings costs of around 25% of value. All organizations, not just manufacturers, hold stocks of some kind and these represent a major investment which should be managed efficiently. If stocks are not controlled properly the costs can become excessive and reduce an organization's ability to compete. Efficient inventory control then becomes a real factor in an organization's long term survival.

Generally, the aim and objective of this research project is to investigate to see if the Group Technology principles can be applied to Orford Refrigeration, as well as to improve the company current inventory system. This thesis can be divided into two main categories which are Group Technology analysis and Inventory control. For Group

Technology analysis, the first part of the analysis will be focus on the basic concept of Group technology. In this section, some of the technique such as Parts classification and Coding and also Production Flow Analysis will be discuss to show how to group parts together and to form parts families. After part families have been identified, the following section will be focus on how grouping the machines into a cells. Here, two common techniques will be illustrated which are Rank Order Clustering and Direct Clustering, and also what is the advantages and disadvantages of these techniques. In the last section of the first part of the thesis, methods like using a “From - To” chart to organize the machines into the most logical arrangement, and to maximizes the proportion of in – sequence moves will be discuss here.

Second part of the thesis is about inventory management. Two types of inventory control system will be discussed here, which are the Periodic Reorder System and Reorder point System. Also, a general description of *economic order quantity* (EOQ) will be discussed in this section to determine the optimize order size that minimize the inventory costs in Reorder Point System.

2. Literature Review

2.1 Background

Cellular manufacturing emerged as a production strategy capable of solving the problem of complexity and long manufacturing lead times in batch production systems in the beginning of the 1960s. Burbidge (1979) defined group technology (GT) as an approach to the optimization of work in which the organizational production units are relatively independent groups, each responsible for the production of a given family of products.

The fundamental problem in cellular manufacturing is the formation of product families and machine cells. The objective of this product-machine grouping problem is to form perfect (i.e. disjoint) groups in which products do not have to move from one cell to the other for processing.

2.2 Types of algorithms in GT

The most common algorithms for GT found in the literature can be classified into the following four method categories: array-based, clustering, and mathematical programming-based, and graph theoretic.

2.2.1 Array – based

Array-based clustering methods perform a series of column and row permutations to form product and machine cells simultaneously. King (1980) and later King and Nakornchai (1982) developed the earliest array-based methods. King and Nakornchai (1982), Chandrasekharan and Rajagopalan (1987), Khator and Irani (1987), and Kusiak and Chow (1987) proposed other algorithms. A comprehensive comparison of three array-based clustering techniques is given in Chu and Tsai (1990). The quality of the solution given by these methods depends on the initial configuration of the zero-one matrix.

2.2.2 Clustering

McAuley (1972) and Carrie (1973) developed the first algorithms using clustering and similarity coefficients. Since then, Mosier and Taube (1985), Seifoddini (1989), Gupta and Seifoddini (1990), Khan et al. (2000), Yamada and Yin (2001), and Dimopoulos and Mort (2001) proposed hierarchical methods. These methods have the disadvantage of not forming product and machine cells simultaneously, so additional methods must be employed to complete the design of the system.

GRAFICS, developed by Srinivasan and Narendran (1991), and ZODIAC, which is a modular version of MacQueen's clustering method, developed by Chandrasekharan and Rajagopalan (1987), are examples of non-hierarchical methods.

Miltenburg and Zhang (1991) present a comprehensive comparison of nine clustering methods where non-hierarchical methods outperform both array-based and hierarchical methods.

2.2.3 Mathematical programming

Mathematical programming methods treat the clustering problem as a mathematical programming optimization problem. Different objective models have been used. Kusiak (1987) suggested the *p*-median model for GT, where it minimizes the total sum of distances between each product/machine pair. Shtub (1989) modeled the grouping problem as a generalized assignment problem. Choobineh (1988) formulated an integer programming problem which first determines product families and then assigns product families to cells with an objective of minimizing costs. Co and Araar (1988) developed a three-stage procedure to form cells and solved an assignment problem to assign jobs to machines. Gunasingh and Lashkari (1989) formulated an integer programming problem to group machines and products for cellular manufacturing systems. Srinivasan et al. (1990) modelled the problem as an assignment problem to obtain product and machine cells. Joines et al. (1996) developed an integer program that is solved using a genetic algorithm. Cheng et al. (1998) formulate the problem as a travelling salesman problem and solve the model using a genetic algorithm. Chen and Heragu (1999) present two stepwise decomposition approaches to solve large-scale industrial problems. Won (2000) presents a two-phase methodology based on an efficient *p*-median approach. Akturk and Turkcan (2000) propose an integrated algorithm that solves the machine/product grouping problem by simultaneously considering the within-cell layout problem. Plaquin and Pierreval (2000) propose an evolutionary algorithm for cell formation taking into account specific constraints. Zhao and Wu (2000) present a genetic algorithm for cell formation with multiple routes and objectives. Caux et al. (2000) address the cell formation problem with multiple process plans and capacity constraints using a simulated annealing approach. Onwubolu and Mutingi (2001) develop a genetic algorithm approach taking into account cell-load variation. Uddin and Shanker (2002) address a generalized grouping problem, where each part has more than one process route. The problem is formulated as an integer programming problem and a procedure based on a genetic algorithm is suggested as a solution methodology.

2.2.4 Graph theoretic

Rajagopalan and Batra (1975) were the first to use graph theory to solve the grouping problem. They developed a machine graph with as many vertices as the number of machines. Two vertices were connected by an edge if there were parts requiring processing on both the machines. Cliques obtained from the graph were used to determine machine cells. The limitation of this method is that machine cells and part families are not formed simultaneously. Kumar et al. (1986) solved a graph decomposition problem to determine machine cells and part families for a fixed number of groups and with bounds on cell size. Their algorithm for grouping in flexible manufacturing systems is also applicable in the context of GT. Vannelli and Kumar (1986) developed graph theoretic models to determine machines to be duplicated so that a perfect block diagonal structure can, be obtained**.** Kumar and Vannelli (1987) developed a similar procedure for determining parts to be subcontracted in order to obtain a perfect block diagonal structure. These methods are found to depend on the initial pivot element choice.

Vohra et al. (1990) suggested a network-based approach to solve the grouping problem. They used a modified form of the Gomory-Hu algorithm to decompose the part-machine graph. Askin et al. (1991) proposed a Hamiltonian-path algorithm for the grouping problem. The algorithm heuristically solves the distance matrix for machines as a TSP and finds a Hamiltonian path that gives the rearranged rows in the block diagonal structure. The disadvantage of this approach is that actual machine groups are not evident from its solution. Lee and Garcia-Diaz (1993) transformed the cell formation problem into a network flow formulation and used a primal-dual algorithm developed by Bertsekas and Tseng (1988) to determine the machine cells. Other graph approaches include the heuristic graph partitioning approach of Askin and Chiu (1990) and the minimum spanning tree approach of Ng (1993, 1996).

Selim et al. (1998) provide a comprehensive mathematical formulation of the cell formation problem and present a methodology-based classification of prior research.

2.3 Manufacturing Application

The most common applications of GT are in manufacturing. And the most common application in manufacturing involves the formation of cells of one kind or another. Not all companies rearranging machines to form cells. There are three ways in which group technologies can be applied in manufacturing:

- Informal scheduling and routing of similar parts through selected machines. This approach achieves setup advantages, but no formal part families are defined, and no physical rearrangement of equipment is undertaken.
- Virtual machine cells. This approach involves the creation of part families and dedication of equipment to the manufacture of these part families, but without the physical rearrangement of machines into formal cells. The machines in the virtual cell remain in their original locations in the factory. Use of virtual cells seems to facilitate the sharing of machines with other virtual cells producing other part families.
- Formal machine cells. This is the conventional GT approach in which a group of dissimilar machines are physically relocated into a cell that is dedicated to the production of one or a limited set of part families. (See Figure 2.1)

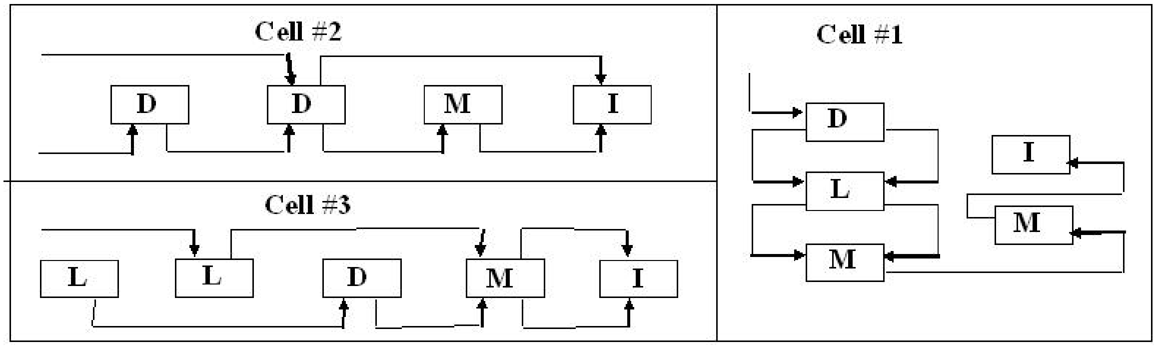

Figure 2.1 The machines in a formal machine cell are located in close proximity to minimize Part handling, throughput time, setup, and work – in progress.

2.4 Product Application

The application of group technology in product design is found principally in the use of design retrieval systems that reduce part proliferation in the firm (see Figure 2.2). It has been estimated that a company's cost to release a new part design range between $2000 and $12,000. In a survey of industry reported in, it was concluded that in about 20% of new part situations, an existing part design could be used. In about 40% of the cases, an existing part design could be used with modifications. The remaining cases required new part design. If the costs savings for a company generating 1000 new part designs per year were 75% when an existing part design could be used (assuming that there would still be some cost of time associated with the new part for engineering analysis and design retrieval) and 50% when an existing design could be modified, then the total annual savings to the company would lie between $700,000 and $4,200,000, or 35% of the company's total design expense due to part release.

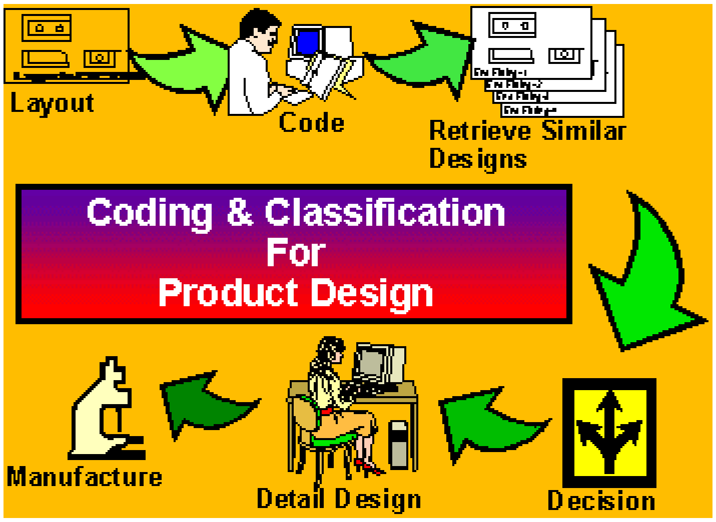

Figure 2.2 The database of existing parts is then scanned to find items with identical or similar codes.

2.5 Summary

Group technology is an important technique in the planning of the manufacture that allows the advantages of flow production organization to be obtained in what otherwise would be jobbing or batch manufacture. The approach is to arrange separate machine groups with appropriate internal group layout to suit the production of specific component families, formed in accordance with the similarity of operations that to be performed on them.

3. Basic Principle of Group Technology

3.1 Introduction

Group technology (GT) is a manufacturing philosophy that identifies and exploits the underlying sameness of parts and manufacturing processes. In batch – type manufacturing for multi – products and small – lot – sized production, conventionally each part is treated as unique from design through manufacture. However, by grouping similar parts into part families based on either their design or processes, it is possible to increase the productivity through more effective design rationalization and data retrieval, manufacturing standardization and rationalization.

3.2 Part families

The biggest single obstacle in changing over to group technology from a conventional production shop is the problem of grouping the parts into families. A part family is a group of parts that have some specific sameness and similarities in design features or production processes. Example of two basic types of part families are shown in Figure 3.1 and 3.2 below. A part family may be grouped with the parts having similar design features such as geometric shape, size, materials and etc, while a part family may be grouped with respect to production operations, that is, machine, processes, operations, tooling and etc. There are three general methods for solving this problem. All three are time consuming and involved the analysis of much data by proper trained personnel. The three methods are: (1) visual inspection, (2) parts classification and coding, and (3) production flow analysis.

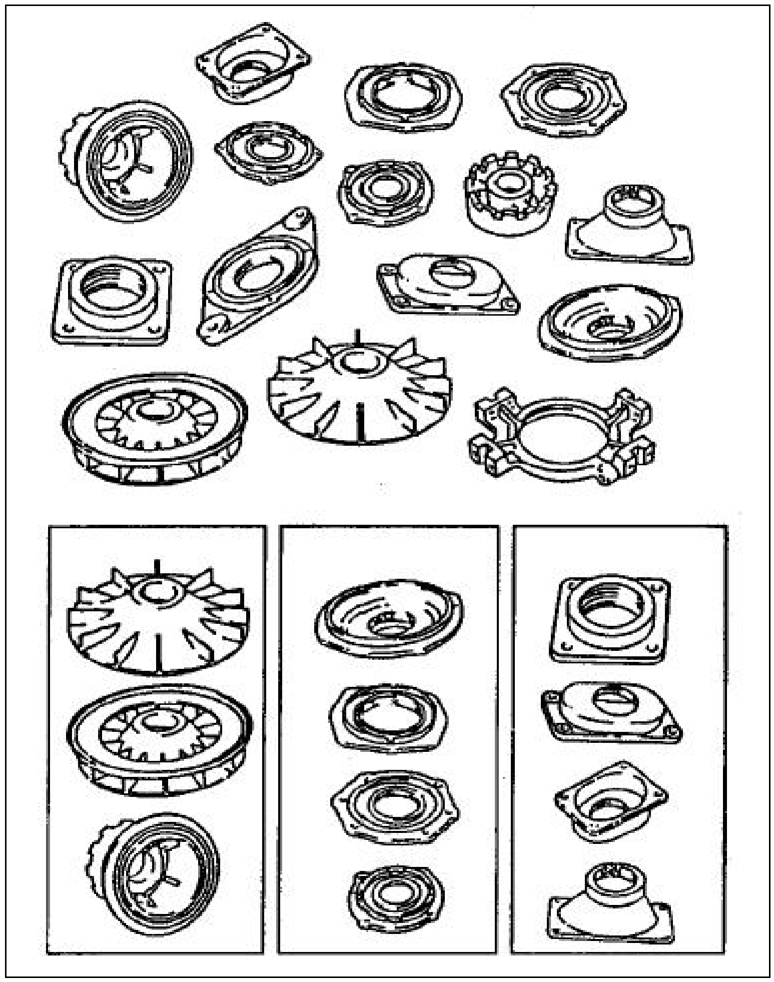

Figure 3.1 part family may be grouped with respect to production operations, that is, machine, processes, operations, tooling and etc.

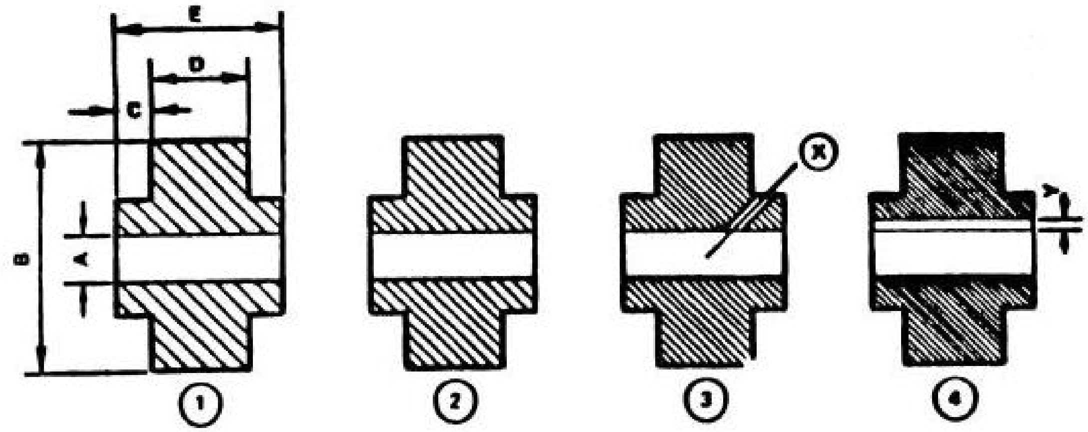

Figure 3.2 Parts having similar design features such as geometric shape, size, materials and etc.

3.3 Visual inspection (Intuitive grouping)

This method is the least sophisticated and least expensive method. It involves the classification of parts into families at either the physical parts or their photographs and arranging them into groups having similar features. Experienced engineer and shop people examine the product mix and separate products and parts into processing families. These part families become the basis for workcell, as shown in Figure 3.3. This method is fast and simple. However, when parts and processes are of complex mixes, the method does not give good results.

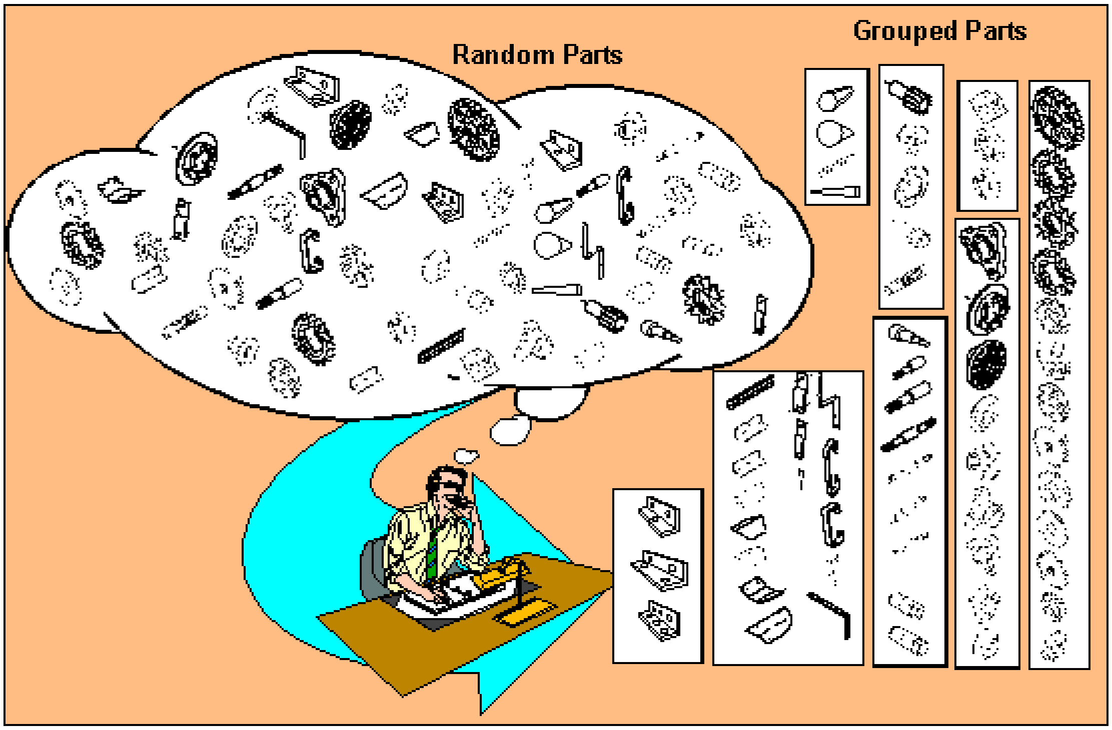

Figure 3.3 Intuitive grouping or visual inspection for simple part/process mixes.

3.4 Parts classification and coding

Group technology may be practiced without a classification and coding system. Yet it is an essential and effective tool for successful implementation of group technology concept, in particular for implementation of computer – integrated – manufacturing (CIM). This is the most time consuming of the three methods. In parts classification and coding, similarities among parts are identified, and these similarities are related in a coding system. Two categories of parts similarities can be distinguished: (1) design attributes, which are concerned with part characteristics such as geometry size, and material; and (2) manufacturing attributes, which consider the sequence of processing steps required to make a part. While the design and manufacturing attributes of a part usually correlated, the correlation is less than perfect. Accordingly, classification and coding systems are devised to include both a part’s design attributes and its manufacturing attributes. Reasons for using a coding scheme include:

- Design retrieval. A designer faced with the task of developing a new part can use a design retrieval system to determine if a similar part already exists. A simple change in an existing part would take much less time designing a whole new part from scratch.
- Automated process planning. The part code for a new part can be used to search for process plans for existing parts with identical or similar codes.
- Machine cell design. The part codes can used to design machine cells capable of producing all members of a particular part family, using the composite part concept.

To accomplish parts classification and coding requires examination and analysis of the design and/or manufacturing attributes of each part. The examination is sometimes done by looking in tables to match the subject part against the features described and diagrammed in the tables. An alternatives and more – productive approach involves interaction with a computerized classification and coding system, in which the user responds to questions asked by the computer. On the basis of the responses, the computer assigns the code number to the part. Whichever method is used, the classification results in a code number that uniquely identifies the part’s attributes. Coding and classification present some major challenges that are not usually evident to an inexperienced practitioner. This is especially true of large database. But then, large project have correspondingly large return. A successful project requires experience and judgment in coding system design, initial coding and family development. It is not a task for the novice.

The classification and coding procedure may be carried out on the entire list of active parts produced by the firm, or some sort of sampling procedure may be used to establish part families. For examples, parts produced in the shop during a certain time period could be examined to identify part family categories. The trouble with any sampling procedure is the risk that the sample may be unrepresentative of the population.

3.4.1 Features of parts classification and coding systems

The principal functional areas that utilize a parts classification and coding system are design and manufacturing. Accordingly, parts classification systems fall into one of the three categories:

1. systems based on part design attributes
2. systems based on part manufacturing attributes
3. systems based on both design and manufacturing attributes

Table 3.1 presents a list of common design and manufacturing attributes typically included in classification schemes. A certain amount of overlap exists between design and manufacturing attributes, since a part’s geometry is largely determined by the sequence of manufacturing processes performed on it.

Part Design Attributes	Part Manufacturing Attributes
Basic external shape	Major processes
Basic internal shape	Minor operations
Rotational or rectangular shape	Operation sequence
Length – to diameter ratio (rotational part)	Major dimension
Aspect ration (rectangular part)	Surface finish
Material type	Machine tool
Part function	Production cycle time
Major dimensions	Batch size
Minor dimensions	Annual production
Tolerances	Fixture required
Surfaces finish	Cutting tools

Table 3.1 Design and Manufacturing Attributes typically included in a Group Technology classification and coding system.

In terms of the meaning of the symbols in the code, there are three structures used in classification and coding systems:

1. *Hierarchical structure*, also known as a monocode, in which the interpretation of each successive symbol depends on the value of the preceding symbol.

Example:

Consider all parts to be classified in terms of a feature: rotational symmetry.

1 == Non-rotational (prismatic) parts

2 == Rotational parts.

Within these groups, we can further classify by feature: presence of hole(s).

0 == No holes

1 == Has holes

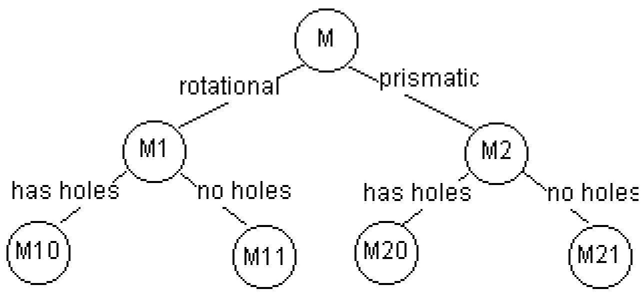

Figure 3.4 Hierarchical structure.

Advantages of monocodes:

1. With just a few digits, a very large amount of information can be stored

2. The hierarchical structure allows parts of the code to be used for information at different levels of abstraction.

Disadvantages:

1. Impossible to get a good hierarchical structure for most features/groups

2. Different sub-groups may have different levels of sub-sub-groups, thereby leading to blank codes in some positions.

2. *Chain – type structure***,** also know as a polycode, in which the interpretation of each symbol in the sequence is always the same; it does not depends on the value of preceding symbol.

Advantages:

1. Easy to formulate

Disadvantages:

1. Less information is stored per digit; therefore to get a meaningful comparison of, say, shape, very long codes will be required.

2. Comparison of coded parts (to check for similarity) requires more work.

3. *mixed – mode structure*, In this case, the code for a part is a mixture of polycodes and monocodes. Such coding methods use monocodes where they can, and use polycodes for the other digits -- in such a way as to obtain a code structure that captures the essential information about a part shape. This is the most commonly used method of coding and classification.

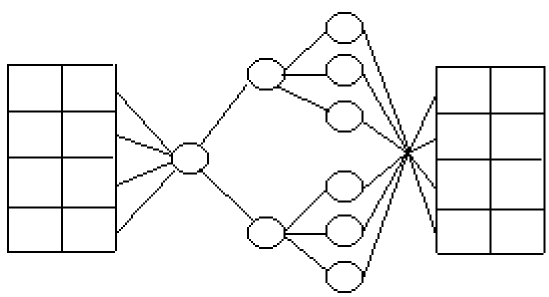

Figure 3.5 Mixed – mode structure.

Many different types of classification and coding systems have been developed and used around the world. Selected examples of worldwide classification and coding systems are shown in Table 3.2. Adaptation and implementation of a classification and coding systems for group technology applications is an important and complex task. Although many systems are available, each company

SYSTEM	*ORGANIZATION & COUNTRY*
OPITZ	Aachen Tech. Univ. (Germany)
OPITZ's SHEET METAL	Aachen Tech. Univ. (Germany)
STUTTGART	Univ. of Stuttgart (Germany)
PITTLER	Pittler Mach. Tool Co. (Germany)
GILDEMEISTER	Gildemiser Co. (Germany)
ZAFO	(Germany)
SPIES	(Germany)
PUSCHMAN	(Germany)
DDR	DDR Standard (Germany)
WALTER	(Germany)
AUSERSWALD	(Germany)
PERA	Prod. Engr. Res. Assn. (U.K)
SALFORD	(U.K)
KK – 1	(Japan)
KK – 2	(Japan)
KK – 3	(Japan)
TOSHIBA	Toshiba Machine Co., Ltd (Japan)
BUCCS	Boeing Co., (U.S.A)
ASSEMBLY PART CODE	Univ. of Massachusetts
HOLE CODE	Purdue Univ. (U.S.A)
MICLASS	TNO (Holland & U.S.A)

Table 3.2 Selected examples of worldwide classification and coding systems.

should search for or develop a system suited to its needs and requirements. One of the essential requirements of a well – designed classification and coding system for group technology applications is to group part families as needed, based on specified parameters and should be capable of effective data retrieval for various functions as required.

Other types of classification and coding systems for general purposes have been developed and are used as libraries, museums, office supplies, commodities, insurance, credit cards and etc. One of the important factors in selecting a classification and coding system is to maintain a balance between the amount of information needed and the number of digit columns required to provide this information.

Even though it is well recognized that a classification and coding system is a key element for full exploitation of the group technology benefits, in fact a classification and coding system as a tool and suitable system is just a prerequisite first step for group technology applications. After installing a suitable system, further efforts should be made to rationalize design works, standardize process plans, optimize production scheduling, group tooling set – up, improve inventory and purchasing requirements and etc, through maximum utilization of a classification and coding system for effective data retrieval.

3.4.2 Opitz Classification System

This system was developed by H.Opitz of the University of Aachen in Germany. It represents one of the pioneering efforts in group technology and is probably the best known, if not the most frequently used, of the parts classification and coding systems. It is intended for mechanical parts. The Opitz coding sheme uses the following digit sequence:

12345 6789 ABCD

The basic code consists of nine digits, which can be extended by adding four more digits. The first nine digits are intended to convey both design and manufacturing data. The interpretation of the first digits is defined in Figure 3.5. The first five digits, 12345, are called the form code. It describes the primary design attributes of the part, such as external shape (e.g. rotational vs. rectangular) and machined features (e.g. holes, threads). The next four digits, 6789, constitute the supplementary code, which indicates some of the attributes that would be use in manufacturing (e.g. dimension, work material). The extra four digits, ABCD, are referred to as the secondary ode and are intended to identify the production operation type and sequence. The secondary code can be designed by the user to serve its own particular needs.

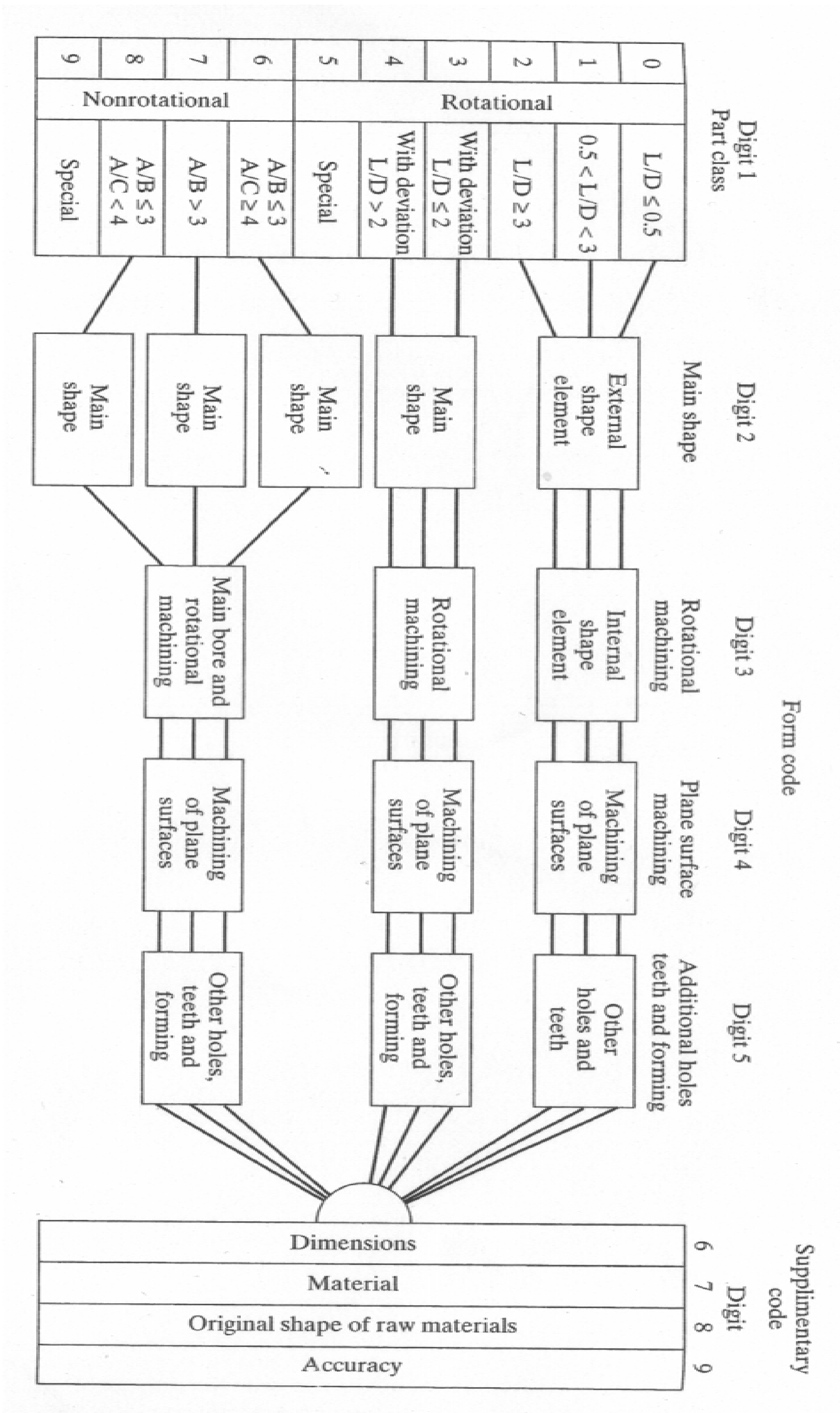

Figure 3.6 Basic structure of the Opitz system of parts classification and coding.

3.3 Production Flow Analysis

This is an approach to part family identification and machine cell formation that was pioneered by J. Burbidge. Production Flow Analysis (PFA) is a method for identifying part families and associated machine groupings that uses the information contained on production route sheets rather than on part drawings. Workparts with identical or similar routings are classified into part families. These families can then be used to form logical machine cells in a group technology layout. Since PFA uses manufacturing data rather design data to identify part families, it can overcome two possible anomalies that ocuur in parts classification and coding. First, parts whose basic geometries are quite different may nevertheless require similar or even identical process routings. Second, parts whose geometries are quite similar may nevertheless require process routings that are quite different.

The procedure in production flow analysis must begin by defining the scope of the study, which means deciding on the population of parts to be analyzed. Should all of the parts in the shop should be included in the study, or should a representative sample be selected for analysis? Once this decision is made, then the procedure in PFA consists of the following steps:

1. Data collection

The minimum data needed in the analysis are part number and operation sequence, which is contained in shop documents called route sheets or operation sheets or some similar name. Each operation is usually associated with a particular machine, so determining the operation sequence also determines the machine sequence. Additional data, such as lot size, time standards, annual demand might be useful for designing machine cells of the required capacity.

2. Sortation of routing processes

In this step, the parts are arranged into groups according to the similarity of their process routings. To facilitate this step, all operations or machines included in the shop are reduced to code numbers, such as those shown in Table 3.3 below. For each part, the operation codes are listed in the order in which they are performed. A sorting procedure is then used to arrange parts into packs which are groups of parts with identical routings. Some packs may contain only one part number, indicating the uniqueness of the processing of that part. Other packs will contain many parts, and these will constitute a part family.

Operation or Machine	Code
Cut off	01
Lathe	02
Turret lathe	03
Mill	04
Drill: manual	05
NC drill	06
Grind	07

Table 3.3 Possible code numbers indicating operation and/or machines for sortation in PFA.

3. PFA chart

The processes used for each packs are then displayed in a PFA chart, a simplified example of which is illustrated in Table 3.4. The chart is a tabulation of the process or machine code numbers for all of the packs. This chart can also be referred to as *part-machine incidence matrix*. In this matrix, the entries have a value of 1 or 0. 1 indicates that corresponding part requires processing on the particular machine, and 0 indicates that no processing of component is accomplished on that particular machine. For clarity of presenting the matrix, 0's are often indicated as blank (empty) entries, as in the Table 2.

Machines	Parts: A	B	C	D	E	F	G	H	I
1	1			1				1	
2					1				1
3			1		1				1
4		1				1			
5	1							1	
6				1					1
7		1				1	1		

Table 3.4 PFA chart, also know as Part – Machine Incidence Matrix.

4. Cluster analysis

From the pattern of data in the PFA chart, related groupings are identified and rearranged into new pattern that brings together packs with similar machine sequences. One possible rearrangement of the original PFA chart is shown in Table, where different machine groupings are indicated within blocks. The blocks might be considered as possible machine cells. It is often the case that some packs do not fit into logical groupings. These parts might be analyzed to see if a revised process sequence can be developed that fits into one of the groups. If not, these parts must continue to be fabricated through a conventional process layout. A systematic technique called *Direct Clustering Technique* that can be used to perform the cluster analysis.

4. Clustering technique & arranging machines in GT cells

4.1 Introduction

In general, GT layout planning includes three kinds of problem to be solved, (1) machine group (GT cell) formation; (2) the layout problem of machine groups determined; and (3) the layout problem of individual machines for each machine group. A mathematical layout model that covers all three layout problems for group technology has not yet been developed. Among the three problems of GT layout planning, the problem of formation machine groups is considered most important by many researchers. For this thesis, only two problems area will be considered, which is (1) grouping parts and machines into families, and (2) arranging machines in a GT cell.

Basically, the problem of machine grouping is defined as follows: Given the machine – part matrix showing which machines are required to produce each part, find groups of machines and families of parts in such a way that each part in a family can be fully processed in a group of machines (that is, a GT cell). A most primitive method to solve this problem is to rearrange rows and column of the matrix on trial and error until a good solution is obtained.

4.2 Grouping Parts and Machines by Rank Order Clustering

Rank order clustering technique, first proposed by King, is specifically applicable in production flow analysis. It is an efficient and easy – to – use algorithm for grouping machines into cells. In a starting part – machine incidence matrix that might be compiled to document the part routings in a machine shop, the occupied locations in the matrix are organized in a seemingly random fashion. Rank order clustering works by reducing the part – machine incidence matrix to a set of diagonalized blocks that represent part families and associated machine groups. Starting with the initial part – machine incidence matrix, the algorithm consists of the following steps:

1. In each row of the matrix, read the series of 1's and 0's (blank entries = 0's) from left to right as a binary number. Rank the rows in order of decreasing value. In case of a tie, rank the rows in the same order as they appear in the current matrix.

2. Numbering from top to bottom, is the current order of rows the same as the rank order determined in the previous step? If yes, go to step 7. If no, go to the following step.

3. Reorder the rows in the part – machine incidence matrix by listing them in decreasing rank order, starting from the top.

4. In each column of the matrix, read the series of 1's and 0's (blank entries = 0's) from top to bottom as a binary number. Rank the columns in order of decreasing value. In case of a tie, rank the columns in the same order as they appear in the current matrix.

5. Numbering from left to right, is the current order of columns the same as the rank order determined in the previous step? If yes, go to step 7. If no, go to following step.

6. Reorder the columns in the part – machine incidence matrix by listing them in decreasing rank order, starting with the left column. Go to step 1.

7. Stop.

Figures 4.1 to Figure 4.5 show how this algorithm works,

	A-112	A-115	A-120	A-123	A-131	A-212	A-230	A-432	A-451	A-510	2^i
SAW01	1		1	1	1			1	1		2
LATHE01				1							4
LATHE02	1		1		1			1	1		8
DRL01		1								1	16
MILL02		1									32
MILL05						1	1			1	64
GRIND05	1										128
GRIND06										1	256
w_j	138	48	10	6	10	64	64	10	10	326	
Rank	9	6	2	1	3	7	8	4	5	10	

Figure 4.1 First iteration in the Rank Order Clustering.

	A-123	A-120	A-131	A-432	A-451	A-115	A-212	A-230	A-112	A-510	w_i	Rank
SAW01	1	1	1	1	1				1		574	4
LATHE01	1										2	1
LATHE02		1	1	1	1				1		602	5
DRL01						1				1	1088	7
MILL02						1					64	2
MILL05							1	1		1	1408	8
GRIND05									1		512	3
GRIND06										1	1024	6
2^j	2	4	8	16	32	64	128	256	512	1024		

Figure 4.2 Second iteration in the Rank Order Clustering.

	A-123	A-120	A-131	A-432	A-451	A-115	A-212	A-230	A-112	A-510	2^i
LATHE01	1										2
MILL02						1					4
GRIND05									1		8
SAW01	1	1	1	1	1				1		16
LATHE02		1	1	1	1				1		32
GRIND06										1	64
DRL01						1				1	128
MILL05							1	1		1	256
w_j	18	48	48	48	48	132	256	256	56	448	
Rank	1	2	3	4	5	7	8	9	6	10	

Figure 4.3 Third iteration in the Rank Order Clustering.

	A-123	A-120	A-131	A-432	A-451	A-112	A-115	A-212	A-230	A-510	w_i	Rank
LATHE01	1										2	1
MILL02							1				128	5
GRIND05						1					64	2
SAW01	1	1	1	1	1	1					126	4
LATHE02		1	1	1	1	1					124	3
GRIND06										1	1024	6
DRL01							1			1	1152	7
MILL05								1	1	1	1792	8
2^j	2	4	8	16	32	64	128	256	512	1024		

Figure 4.4 Fourth iteration in the Rank Order Clustering.

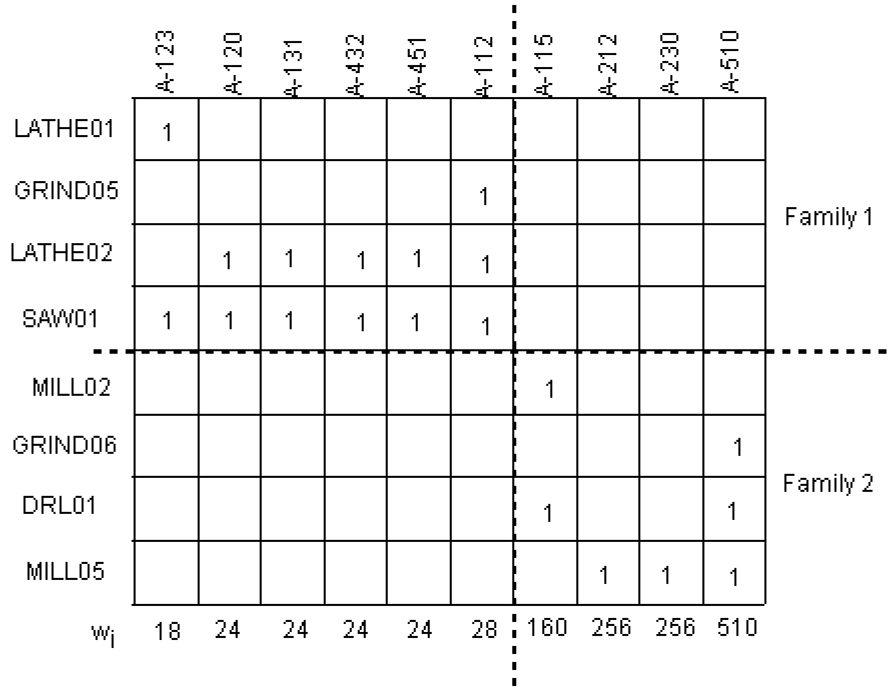

Figure 4.5 A part – machine groupings in the Rank Order Clustering.

4.3 Direct Clustering Algorithm

A problem with the Rank order clustering algorithm is that computation of weights can become problematic when the number of parts is large. For instance, if a shop has data for 2000 parts, then the weigh factor for the right most columns will be 2**2000, which is too large to compute directly. To avoid this problem, King and Nakornchai proposed the direct clustering algorithm, which is given as:

Step1. Calculate the weight of each row.

Step2. Sort rows in descending order.

Step3. Calculate the weight of each column.

Step4. Sort columns in ascending order.

Step5. Move all columns to the right while maintaining the order of the previous rows.

Step6. Move all rows to the top, maintaining the order of the previous columns.

Step7. If current matrix same as previous matrix, stop; else go to step 5.

Figure 4.6 to Figure 4.11show how this algorithm works.

		A-112 1	A-115 2	A-120 3	A-123 4	A-131 5	A-212 6	A-230 7	A-432 8	A-451 9	A-510 10	Σ r
A	SAW01	/		/	/	/			/	/		6
B	LATHE01				/							1
C	LATHE02	/		/		/			/	/		5
D	DRL01		/								/	2
E	MILL02		/									1
F	MILL05						/	/			/	3
G	GRIND05	/										1
H	GRIND06										/	1
	Σ c	3	2	2	2	2	1	1	2	2	3	

Figure 4.6 First iteration in Direct Order Clustering.

	6	7	2	3	4	5	8	9	1	10	Σ r
A				/	/	/	/	/	/		6
C				/		/	/	/	/		5
F	/	/								/	3
D			/							/	2
B					/						1
E			/								1
G									/		1
H										/	1
Σ c	1	1	2	2	2	2	2	2	3	3	

Figure 4.7 (above) & Figure 4.8 (below) 2nd & 3rd iteration.

	6	7	2	10	3	4	5	8	9	1	Σ r
A					/	/	/	/	/	/	6
C					/		/	/	/	/	5
F	/	/		/							3
D			/	/							2
B						/					1
E			/								1
G										/	1
H				/							1
Σ c	1	1	2	2	2	2	2	2	3	3	

	2	6	7	10	4	3	5	8	9	1	Σ r
A					/	/	/	/	/	/	6
C						/	/	/	/	/	5
F		/	/	/							3
D	/			/							2
B					/						1
E	/										1
G										/	1
H				/							1
Σ c	1	1	2	2	2	2	2	2	3	3	

Figure 4.9 (above) & Figure 4.10 (below) 3rd &4th iteration.

	2	6	7	10	4	3	5	8	9	1	Σ r
A					/	/	/	/	/	/	6
C						/	/	/	/	/	5
G										/	3
F		/	/	/							2
D	/			/							1
B					/						1
E	/										1
H				/							1
Σ c	1	1	2	2	2	2	2	2	3	3	

	2	6	7	10	4	3	5	8	9	1	Σ r
A					/	/	/	/	/	/	6
C						/	/	/	/	/	5
G										/	3
B					/						2
F		/	/	/							1
D	/			/							1
H				/							1
E	/										1
Σ c	1	1	2	2	2	2	2	2	3	3	

Figure 4.11 Two groups of families have been formed.

4.4 Arranging Machines in a GT Cell

After part-machine groupings have been identified by direct clustering technique, the next problem is to organize the machines into the most logical arrangement. A simple yet effective method suggested by Hollier, use data contained in From – To charts to arrange the machines in an order that maximizes the proportion of in-sequence moves within the cell. The method can be outlined as follows:

1. *Develop the From - To chart from the routing data.* The data contained in the chart indicates numbers of part moves between the machines in the cell.
2. *Determine the "From" and "To" sums for each machine.* This is accomplished by summing all of the "From" trips and "To" trips for each machine. The "From" sum for a machine is determined by adding the entries in the corresponding row, and the "To" sum is found by adding the entries in the corresponding column.
3. *Assign machines to the cell based on minimum "From" or "To" sums.* The machine having the smallest sum is selected. If the minimum values is a "To" sum, then the machine is placed at the beginning of the sequence. If the minimum value is a "From" sum, then the machine is placed at the end of the sequence.
4. *Reformat the From – To chart*. After each machine has been selected, restructure the From – To chart by eliminating the row and column corresponding to the selected machine and recalculated the "From" and "To" sums. Repeat steps 3 and 4 until all machines have been assigned. An example shown below:

From / To	1	2	3	4
1	0	5	0	25
2	30	0	0	15
3	10	40	0	0
4	10	0	0	0

Table 4.1 From – To chart. (example)

From / To	1	2	3	4	**"From sums"**
1	0	5	0	25	30
2	30	0	0	15	45
3	10	40	0	0	50
4	10	0	0	0	10
"To" sums	50	45	0	40	135

Table 4.1a From and To sums: First Iteration.

From / To	1	2	4	**"From sums"**
1	0	5	25	30
2	30	0	15	45
4	10	0	0	10
"To" sums	40	5	40	135

Table 4.1b From and To sums: Second Iteration with Machine 3 removed.

From / To	1	4	**"From sums"**
1	0	25	25
4	10	0	10
"To" sums	10	25	

Table 4.1c From and To sums: Third Iteration with Machine 2 removed.

5. Plant Layout

Generally, layouts can be classed into three major categories, process layout, product layout and fixed position, although several offshoots are possible.

5.1 The Job Shop (or Process) Layout

The process type layout groups (as shown in Figure 5.1) similar machines together. Such a layout makes sense if jobs are routed all over the place, there is no clear dominant flow to the process, and tooling and fixturing need to share. For example, if the process sheets calls next for grinding, in process type layout, it is clear where the job is to be routed. The job can then enter the queue of work for the next available grinder in the group. If, on the other hand, grinding machines were scattered throughout the factory, there would be chaos. The job of production control and materials handling would be difficult; priorities and machine availabilities would be very tough to track and to execute well.

There are some other benefits to grouping like machines together, as well. For example, maintenance and setup equipment can be stored nearby. And, operators, without through cross – training, can run two or more pieces of equipment to enjoy the productivity gains inherent in such a scheme.

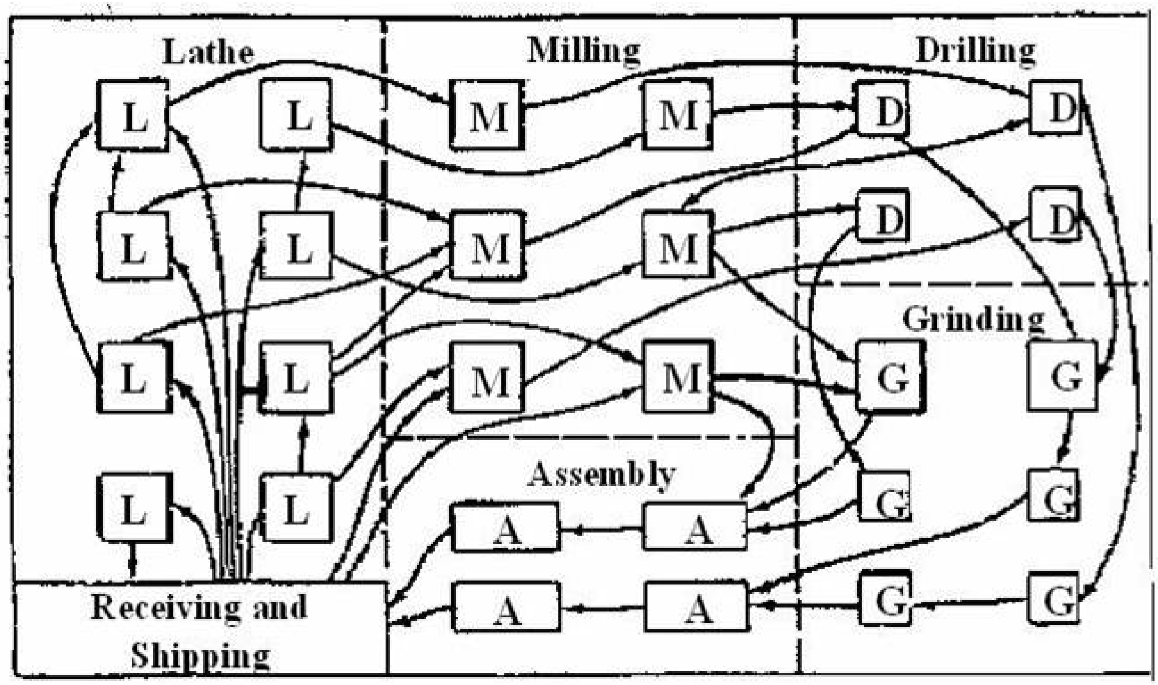

Figure 5.1 Process type layout.

5.2 The Line Flow (Product – Specific) Layout

If there is a discernible, dominant flow to the process, then a line flow layout (see Figure 5.2) has tremendous advantages over a job shop layout. Materials handling can be greatly simplified and the space necessary for production can be reduced. Production control is easier; the paperwork trail to each job in the job shop can be largely abandoned. In effect, the layout itself acts to control priorities. Work – in process inventories can be shrunk to a fraction of what they would be in a job shop layout. Production cycle times can be similarly reduced, making the feedback of quality information that much quicker and more effective, as well.

There are a variety of line flow or product specific layouts. At one extreme are the continuous flow process layouts, with their very high capital intensity. For these processes, it is very true that the process is the layout and the layout is the process. Changing one mean changing the other and any changes involve tremendous expense, and, for that reason, are accomplished only occasionally.

At the other extreme are worker – paced line flow processes that do not involve much plant and equipment. Rather, they are more labor and materials intensive. These processes are very flexible; they can be rebalanced, turned, lengthened, chopped up, and so on with comparative ease. Lying in between the extremes are machine – paced lines that are more flexible than the continuous flow process but not as flexible as worker – paced lines.

The worker – paced lines can typically produce a number of different product at the same time. This is often also true of some machine – paced lines. These mixed – model lines are equipped and their workers trained to do quick setup where needed, and to choose the proper materials to the model indicated. In these mixed- model lines, similar models are typically interspersed among the other models assembled. Often, this helps balance the line by not tossing a succession of overcycle tasks at key workers. Here overcycle tasks means those that take a worker longer than the others on the assembly line; thus more than one worker must be assigned to such tasks if the assembly line is to produce at the planned rate. An example of product – specific layout is shown in Figure5.2

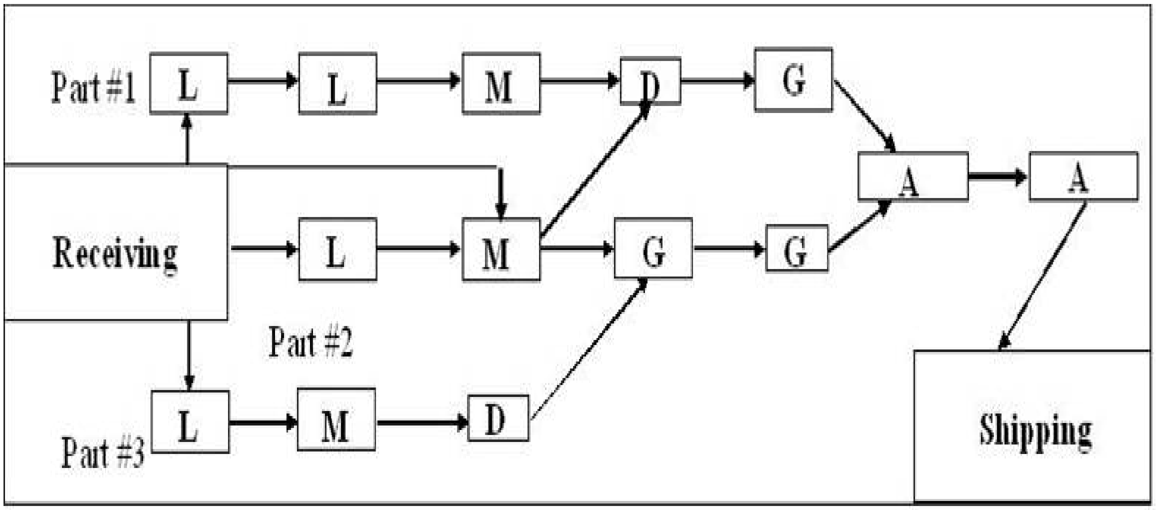

Figure 5.2 Product – specific layout.

5.3 Fixed position layout

A layout in which materials are brought to a stationary product is termed a fixed position layout. It is common when the product itself is so massive and awkward that transporting it through the process is unreasonable. Construction and shipbuilding are readily recognizable examples of fixed position layouts. Fixed position layouts are typically chosen by defaults. There are several crippling aspects of fixed position layouts that do not recommend them for a wide variety of products. First, they make materials handling more difficult because the similar parts has to be broken up and distributed at the proper time to a variety of products – in – process rather than delivered to a single point along the line. Second, workers of different type and skills have to move from product to product, or else a single set of workers has to remain with the entire job. In the former case, scheduling worker movements a chore, while in the latter case training workers to do the entire job takes time and resources. Third, quality control becomes more problematic in fixed position layouts. Inspectors often have to roam, and that may waste operators' time as they wait on inspection. Moreover, one does not have the luxury of evaluating the process capabilities of just one machine or one station along the line; there many stations to evaluate, as many stations as there are stalls filled with worker – in process.

5.4 Group Technology Layout

In essence, group technology (or Cell manufacturing), as shown in Figure 5.3, is the conversion of a job shop layout into a line flow layout. Instead of grouping similar machines together, group technology may call for grouping dissimilar machines together into a line flow process all its own. In the new arrangement, a part can travel from one machine to another without waiting between operations, as would be customary in the job shop. Work – in – process queues of material are thus reduced; individual parts move more quickly through the process.

Group technology takes a hard look at the products or parts manufactured in a job shop layout and identify those that are similar enough to share the same dominant flow. These products/parts are then grouped together and routed through series machines that are placed in close proximity to one another. These machines cells, typically U – shaped, may be manned by one or by several individuals. (See Figure 5.4). In its most common application, the U – line is a spur off of a main assembly line that feeds the main assembly line with precisely the parts required to synchronize with the main assembly line's schedule of production. With a U – line, parts fabrication that traditionally was accomplished elsewhere in the factory and in big batches is done

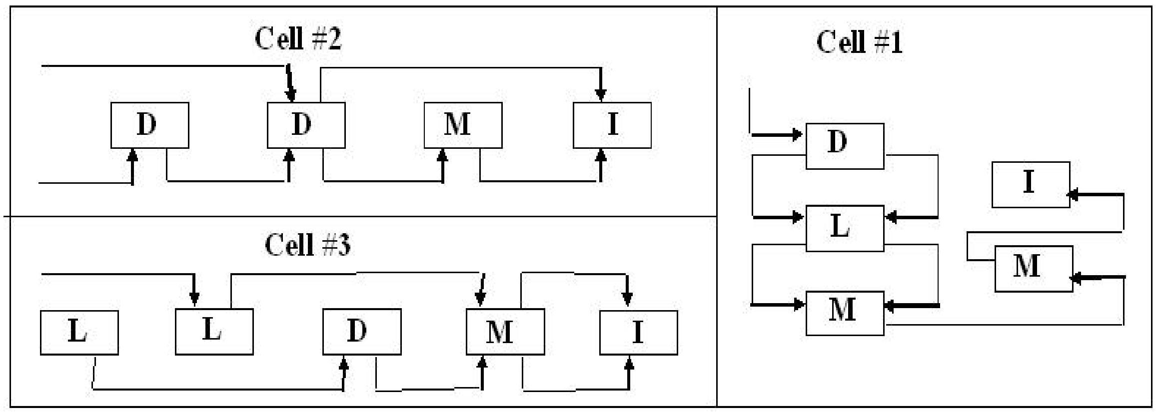

Figure 5.3 A group technology layout.

adjacent to the main assembly line and in just the quantities needed by that time. The U – line is generally responsible for several different models or options of parts, so it must maintain considerable flexibility with the ability to make quick setup of the machines along its line. One of the advantages of the U – shape is that one, or just a few workers can handle the line without having to make too many steps and can even help one another out merely by turning around. There are also some materials handling advantages to the U – line layout, as well as quick feedback about quality issue. However, the most persuasive argument for U – line layout is their ability to feed the main line precisely, without the buildup of any inventory and without interrupting the smooth flow of the process.

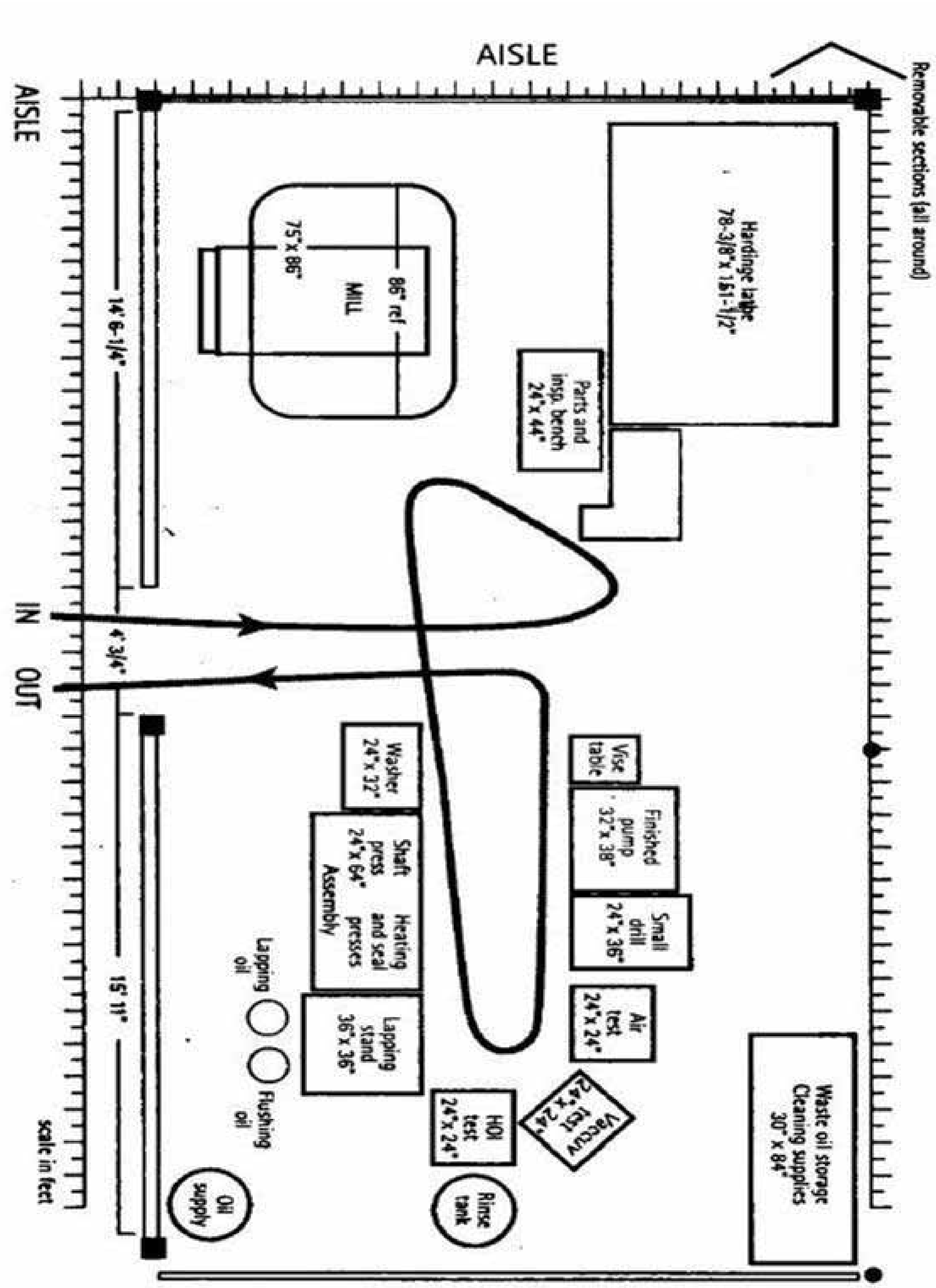

Figure 5.4 U – shape machine layout.

5.5 Orford Refrigeration Machine Shop Layouts.

Current machine shop layout of this company is more on functional layout where it consists of two main sections. The two sections are folding and cutting/punching (see Appendix B). The reason that the machine shop is choose to study are due to the following: 1) Most of the sample parts selected to study are going through this department. 2) Technique used to conduct the analysis (Production Flow Analysis) required to form a parts – machines matrices, and for other section of the factory, not much machines involved in the processes.

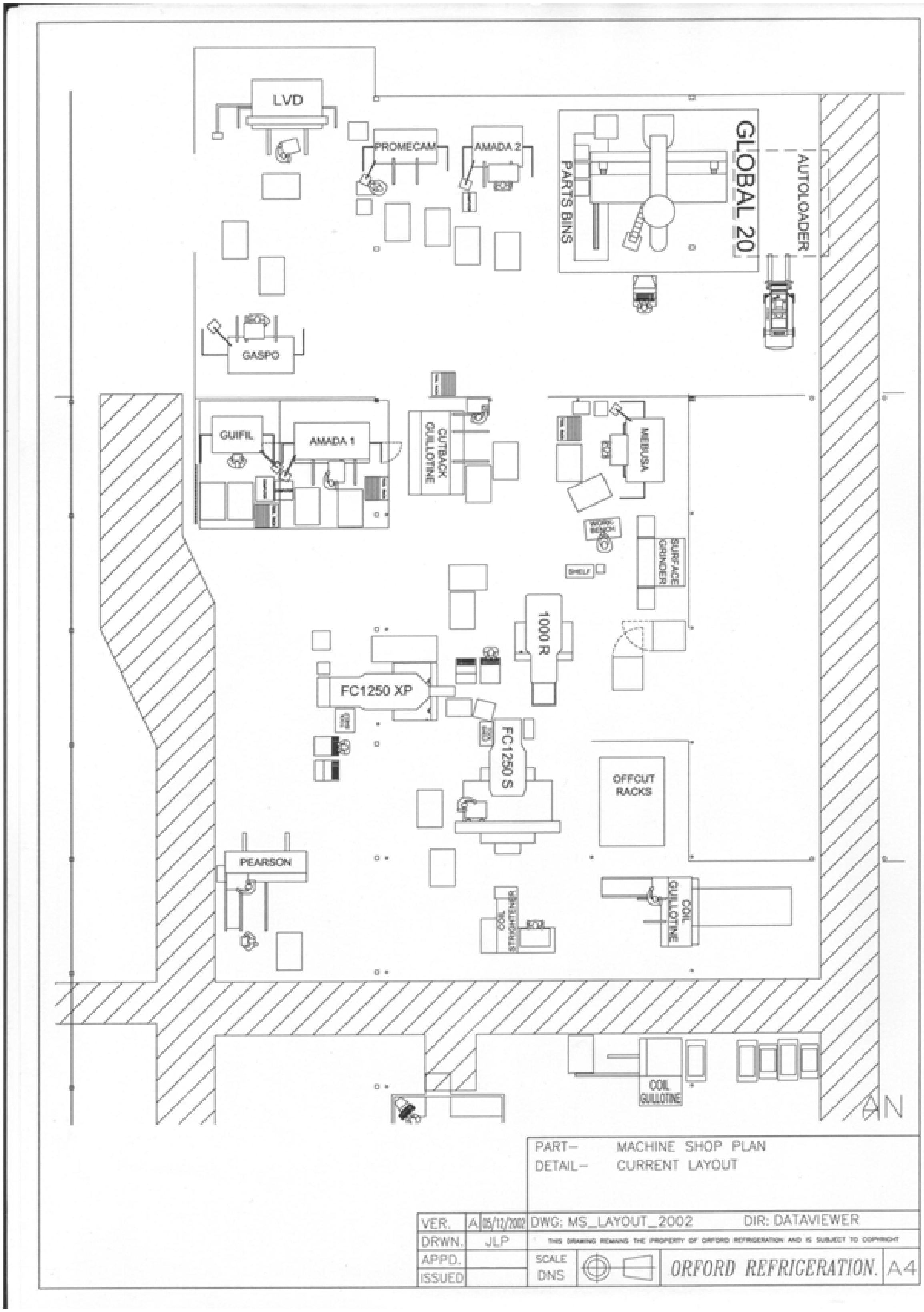

Figure 5.5 Machine shop layout.

6. Inventory Control

6.1 Introduction

It is not too far off the mark to visualize the problem of managing either raw materials inventory or finished goods inventory as one of managing piles of “stuffs” that process itself or consumes in the marketplace draw down. The objective of good inventory (see Figure 6.1) management is to offer good service to either the process or the market at reasonably low cost. This objective, in turn, means deciding how many items should be in each pile, when orders to replenish the piles ought to be placed, and how much each of those orders should contain. Managing such inventory stocks essentially means deciding the pile size, order time and order size.

6.2 The Periodic Reorder System

The periodic reorder system is governed by the simple decision rule of “order enough each period (day, week, month) to bring the pile of items inventoried back up to its desired size.” This is similar to filling the car’s gasoline tank every Friday. The working of the system can be clarified by reference to Figure 6.2 below. The solid line traces the actual level of inventory held. The replenishments arrived at equally spaced times (1, 2,3,4), but their amounts differed each times. The replenishments were also ordered at equally spaced intervals (A, B, C, D), separately from the arrival times by a consistent delivery lead time. The amount ordered each time was the difference between the desired level and the actual amount on – hand at the time the order was placed. Thus, it equals the actual demand during the previous period. Note that during the time period 2, the actual inventory dipped into the safety stock because of unforeseen demand.

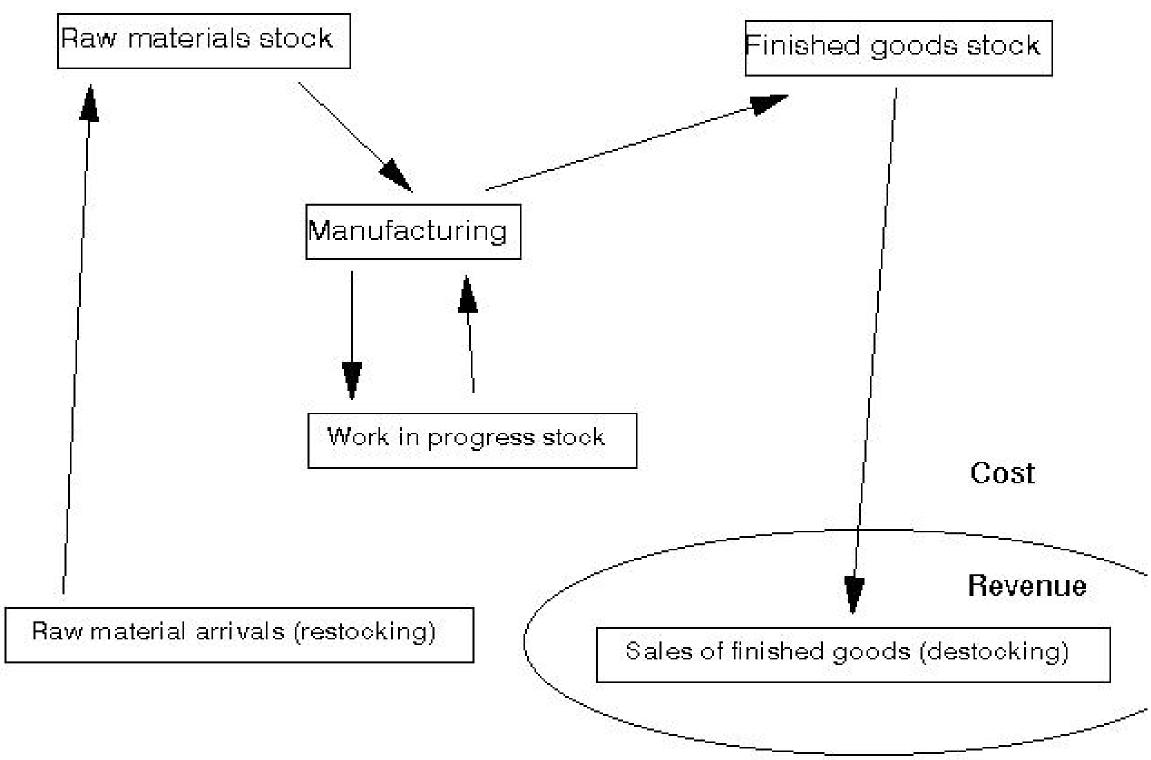

Figure 6.1. The basic function of stock (inventory) is to insulate the production process from changes in the environment.

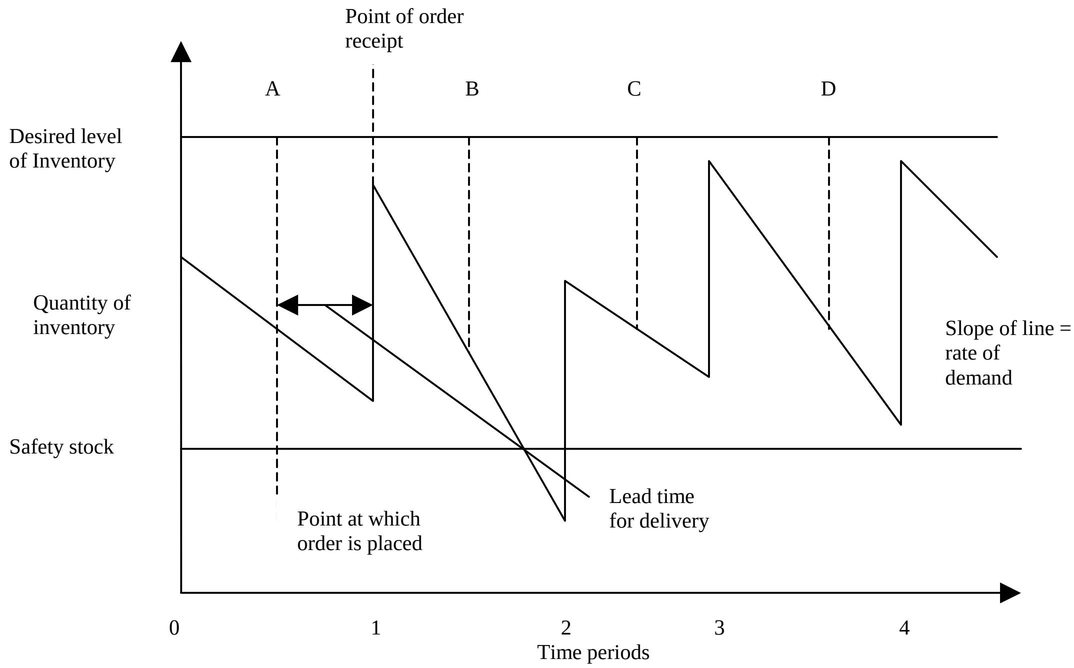

Figure 6.2. The periodic reorder system.

6.3 The Reorder Point System

The reorder point inventory system follows the decision rule of "watch withdrawals from the pile of inventory until the designed reorder point is struck and then order the fixed amount needed to build the pile back up to its desired size." This is similar to filling the gasoline tank whenever the gauges read ¼ full (refer Figure 6.3). The desired size is not determined, as in the periodic reorder system, by the expected usage over the period, since there is no regular period following which inventory needed are checked. The pile is monitored continually, not every so often. Instead, the size of the pile depends fundamentally on a quantity called the economic order quantity (EOQ).

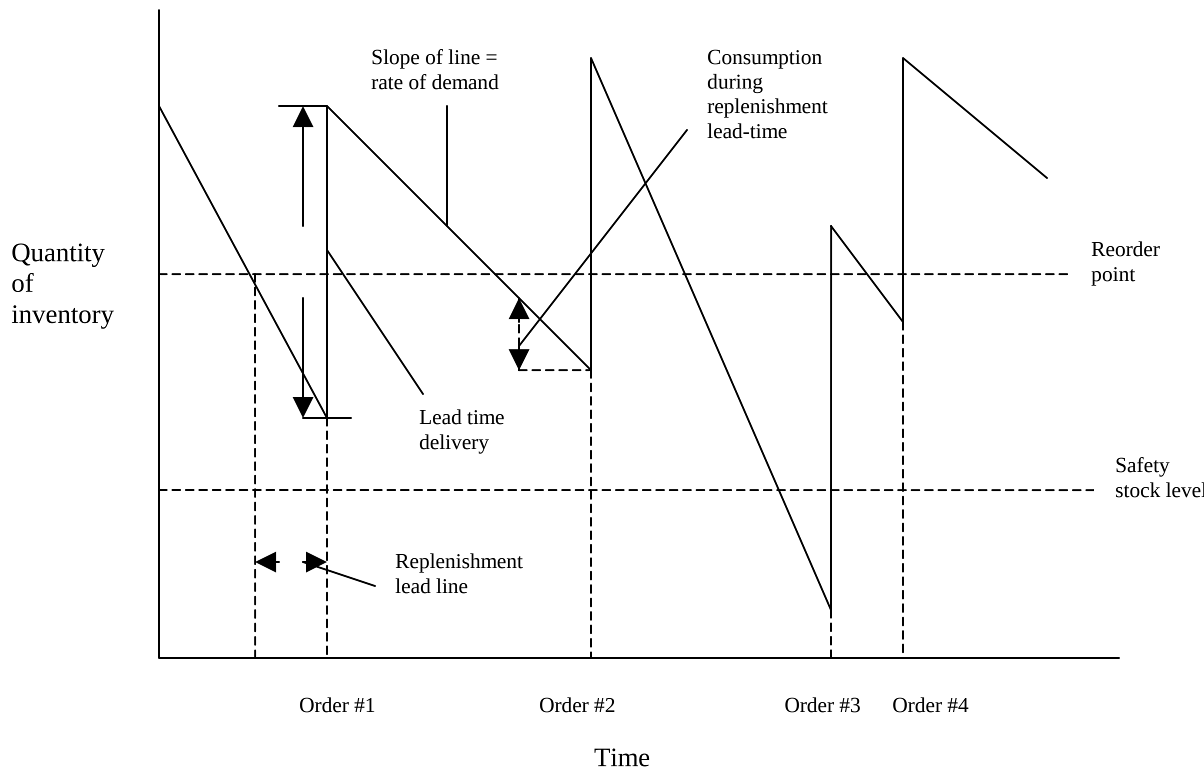

Figure 6.3. The reorder point system.

6.4 Economic Order Quantity

The basic EOQ model is a formula for determining the optimal order size that minimizes the sum of *carrying costs* and *ordering costs*. *Carrying costs* are the costs of holding items in inventory. These costs vary with the level of inventory and occasionally with the length of time an item is held; that is, the greater level of inventory over a period of time, the higher the carrying costs. *Ordering costs* are the costs associated with replenishing the stock of inventory being held. These are normally expressed as a dollar amount per order and are independent of the order size. *Ordering costs* very with the number of order made – as the number of order increases, the ordering costs increases. Figure 6.3 describe the Reorder Point inventory system inherent in the EOQ model. An order quantity, Q is received and is used up over time at a constant rate. When the inventory level decreases to the reorder point, a new order is placed; a period of time, referred to as *lead time*, is required for delivery. The order is received all at once just at the moment when demand depletes the entire stock of inventory – the inventory level reaches 0 – so there will be no shortages. This cycle is repeated continuously for the same order quantity, reorder point, and lead time.

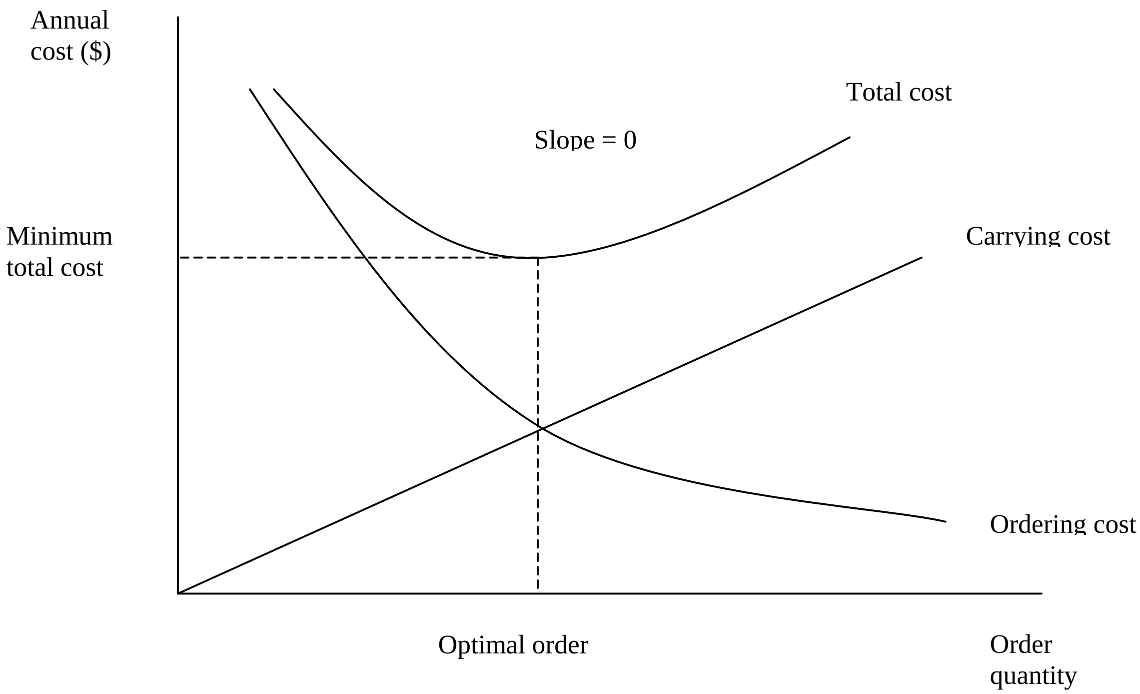

Figure 6.4 The EOQ cost model.

The graph in Figure 6.4 shows the inverse relationship between ordering cost and carrying cost, resulting in a convex total cost curve. The optimal order quantity occurs at the point in Figure 6.4 where the total costs cost curve is at minimum, which coincides exactly with the point with where the carrying cost curve intersects the ordering cost curve. This can be express by the following equation:

$$Q_{opt} = \sqrt{\frac{2C_oQ}{C_c}}$$

The total minimum cost is determined by substituting the value for the optimal order size, Q_{opt} , into the equation:

$$TC_{\min} = \frac{C_oD}{Q_{opt}} + \frac{C_cQ_{opt}}{2}$$

6.5 Orford Refrigeration Inventory Systems

The current inventory system for the machine shop does not base on the two systems mention previously. Their inventory system is basically more rely on the production schedule that plan on one week ahead (see Appendix C). The relevant staff will manually check the inventory every times before he/she placing the orders for that particular week. Normally it took 3 working days for the order to be sent to the company. This method not only ineffective, but also facing the risks of inventory shortages if something happen and causing a delay on the delivery in time.

7. Results and discussion

A few problems have been encounter when conducting Production Flow Analysis for Orford Refrigeration. And these problems have directly affected not only the aims and objectives of this project, but also the ongoing progress of the research. The problems mentions are as follows:

1. Incomplete data needed for analysis.

As mention in Chapter 3 before, the minimum data required in the analysis are the part number and operation sequence, which is contained in shop documents called route sheets or some similar name. But the route sheets that were found in Orford Refrigeration (refer to Appendix C) were not a complete route sheets. The reason is some of the machines, such as the 'Folder' (refer Figure 7.1 & 7.2), which are used to fold the parts into desired shape, is not included in the route sheets. It basically depends on which folder machine is available to perform the particular operation and generally each individual 'Folder' can do all kinds of folding operation. As a result, the PFA chart (see Appendix D), which is the third step in Production Flow Analysis, was unable to form. Even if the folding machines are randomly assigned to perform the operation, the PFA chart will not be accurately produced.

2. Parts produced are considered too simple.

Most of the parts manufactured by Orford Refrigeration are relatively simple in design and manufacturing processes. Although many types of parts have been study in order to form a part families, but it was unable to determine the parts

Figure 7.1 Folding machine.

that are more complex in manufacturing processes. The most complicated parts that can be found are those produced from sheet metal such as the refrigerator outer case, shelf support channel, housing for evaporation box unit and etc. Figure 7.3 to 7.8 illustrate how simple the parts produced by Orford Refrigeration.

Figure 7.2 Another type of machine used for folding process.

Figure 7.3 Some example of the parts produced from sheet metal.

Basically, the overall process to manufacture parts from sheet metal is either through the punching process and folding process or even sometime certain parts only went through one of the process only. Some of the machines (shown in Figure 8.0) can even perform all the complicated punching operation alone which further simplified the processes.

Figure 7.4 Outer back – upper.

Figure 7.5 Shelf support channel.

Figure 7.6 Castor plate – front.

Figure 7.7 TOM – type A.

Figure 7.8 Unit runner.

Figure 7.9 Global 2.0, a very high capacity punching machine.

Although the results achieve is not ideal, but some conclusion can be made from this research project. Generally Group technology technique is useful to improve the overall manufacturing processes of a company. A number of surveys have been conducted to learn the companies in the survey to report the benefits they enjoyed from implementing cellular manufacturing in the operations. In reality, it doesn't guarantee it will bring any benefits to all the companies who applied it in the operation. A few companies reported some costs associated with implementing cellular manufacturing such as new equipment and duplicating of equipment and higher operator wages.

References

Alan Muhlemann, John Oakland and Keith Lockyer, 1992, *Production and Operation Management*, Sixth Edition, Pitman Publishing.

Burbidge, J L, 1977, *A manual method of production flow analysis*, The Production Engineer, volume 56, 1977, p.34 – 38.

Burbidge, J L, 1977, *Production flow analysis*, The Production Engineer, volume 41, 1977, p.742 – 752.

C.D.J. Waters, 1992, *Inventory Control and Management*, John Wiley and Sons Inc, Canada, p.48 - 71

Inyong Ham, Katsundo Hitomi and Teruhiko Yoshida, 1985, *Group Technology – Applacations to Production Management*, Klumar Nijhoff Publishing.

John W. Toomey, 2000, *Inventory Management – Principles , Concepts and Techniques*, Klumer Academic Publisher, p.77 – 86.

King, J. R., 1980, *Machine – component grouping in production flow analysis: an approach using a rank order clustering algorithm,* International journal of production research, volume 18, Number 2, 1980, p.213 – 232.

Mikell P. Groover, 2001, *Automation, Production Systems, and Computed – Integrated Manufacturing,* Second Edition, Prentice Hall Inc, New Jersey, United States of America.

Richard J. Tersine, 1994, *Principle of Inventory and Materials Management,* 4th Edition, Prentice Hall, p.180 – 193.

Robert S. Russell, Bernard W. Taylor III, 2000, *Operations Management,* 2nd Edition, Prentice Hall, Inc., United States of America

Scott M. Shafer and Jack R. Meredith, 1990, *A comparison of selected manufacturing cell formation techniques,* International journal of production research, volume 28, Number 4, 1990, p.661 – 673.

William T. Akright and Dennis E. Kroll, 1998, *Computer Industrial Engineering,* Elsevier Science Ltd., volume 34, Number 1, 1998, p.159 – 171.