

DESIGN AND EVALUATE A CELLULAR
MANUFACTURING FACILITY FOR SELECTED
COPPER PRODUCTS IN ZAMBIA

By

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requirements for the award of the Master of Engineering in
Production Engineering and Management.

The University of Zambia
School of Engineering

Lusaka

2007



DECLARATION

I make a declaration in here that the content of this dissertation are my own work and the dissertation has not been submitted anywhere before.

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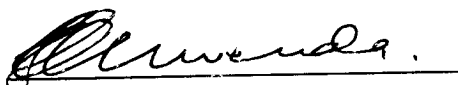
APPROVAL

This dissertation of Agripa Hamweendo is approved as fulfilling the partial requirements for the award of the degree of Master of Engineering in production Engineering and Management by the University of Zambia.

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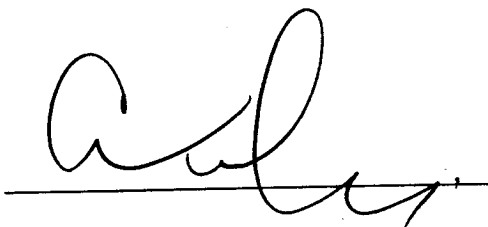
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ABSTRACT

The economic advancement of any country depends on its ability to add value (through manufacturing) to its available local raw material resources. Zambia for a long time has been exporting copper as a raw material and importing finished copper products. This economic situation deprives Zambia of more foreign exchange earning which is necessary for national development. It is therefore important that researches on viability of adding value to locally available raw material resources (such as copper) are encouraged to promote value addition before export. This research aims to address the problem of exporting copper as raw material without adding value to it. The research focuses on designing and evaluating a cellular manufacturing facility for adding value to selected copper products. Cellular manufacturing was chosen in this research because it has become a popular manufacturing system for medium demand and medium variety products. In addition, cellular manufacturing facilitates job design, job flow, capacity planning, utilization, machinery arrangement and modernization. The products selected in this research included: cable lugs, contact terminals, earth rods, neutral blocks, copper washers, copper connectors, top plugs and sockets.

A market survey was conducted to identify and select the copper products. The parts from the selected copper products were grouped into part families using poly-code classification system. Production Flow Analysis was applied to identify the process engineering and the required machinery. To design the cells (to form the Part-Machine Clusters), simultaneous part family formation and machine grouping solution strategy i.e. the Ranking Order Clustering Algorithm was used. Cellular layout and evaluation processes followed the cell design stage. Cell evaluation involved cell balancing, cost, and benefit analysis. To balance the cells, the Killbridge and Wester method was used.

Two (2) linked cells were formed and designed. The cell balance efficiencies were 94.2% and 88.3% indicating good capacity utilization. The cost benefit analysis was done to appraise the facility. The calculated amount of copper cathodes required per week was 3.9591 tonnes which cost US\$ 7,773.74. If copper was to be supplied in ready-made-form, the cost per week would be US\$ 85,083. This implies that a tonne of copper when processed to primary product would cost US\$ 21,490.09 (330% of value of copper cathode). When a tonne of copper undergoes secondary processing, the value increases to US\$ 27,390.20 (420% of the copper cathode value). The total revenue per week from the sales of the selected copper products was US\$ 113,488.37. The total cost of production was estimated at US\$98,408.17 giving a gross Profit US\$15,080.20 (13.3% profit margin).

In conclusion, this research has brought out important synoptic issues indicating the urgency of considering adding value to copper to earn more foreign exchange necessary for national development. It is therefore encouraged that investors and the government invest into research and development of primary and secondary copper processing industries. Continuing to export raw copper as cathode is not a good economic setup.

DEDICATION

I dedicate this dissertation to my wife Mutinta and my children: Claire, Carter, Caster, Castra and Clara for their patience

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I am greatly indebted to my supervisors: Dr Siaminwe L., Dr. Mwenda H.M and Dr. Phiri J. all from the School of Engineering, Department of Mechanical Engineering at the University of Zambia, for their professional guidance and support during this research. Without them this research would have been difficult.

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LIST OF SYMBOLS

e	tolerable sampling error,
x	variable,
μ	Population average,
n	sample size
p	population proportion
Z	standard normal deviate

LIST OF ABBREVIATIONS

CM	Cellular Manufacturing
C & C	Coding and Classification
DRAW	Drawing Machine
DR	Drilling machine
E _b	Line balance efficiency
GR	Grinding machine
GL	Guillotine machine
GT	Group Technology
LT	Lathe machine
Max .TT _{si}	Maximum total available service time
MC	Milling machine
PN	Punching machine
PS	Power Saw
PFA	Production Flow Analysis
RV	Riveting machine
T _{wc}	Total work content
T _s	Service time
TT _{si}	Total service time
TH	Threading machine
W _j	weighted column values
w	Manning level
RV	Riveting machine
DRAW	Drawing Machine
GR	Grinding machine
TH	Threading machine
GL	Guillotine machine
PN	Punching machine
LT	Lathe machine
PS	Power Saw
DRIL	Drilling machine
MC	Milling machine
AD	Adapter
BC	Block Connector
BS	Bonding Strip
BH	Bulb Holder
BT	Battery Terminal
CL	Cable Lug
CC	Copper Connectors
CS	Cooker Switch Units
CW	Copper Washers
ER	Earth Rods
FS	Fuse
NB	Neutral Block
TP	Top Plug
SC	Stator Contact Diesel
SC	Stator Contact Petrol

SCT
SB
ST

Socket
Starter Bush
Switch

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The economic development of a nation is accelerated by focusing on adding value to raw material resources using modern manufacturing technologies. However, in Zambia, as revealed by **Munakaampe (2000)**, by 1992 the manufacturing engineering sub sector had collapsed. Before 1992, firms were manufacturing a wide variety of products. Manufacturing a wide variety of products favored the application of process (job shop) layout. However, some companies were seen to use process flow layout. The prevalence of either job shop or process flow layout implied that Cellular Manufacturing was not common.

1.2 CELLULAR MANUFACTURING IN ZAMBIA

Munakaampe (2000) revealed that only one company (Boart Long Year in Ndola) out of the 28 companies that were studied was using Cellular Manufacturing. In this company, machines were grouped according to processing sequence in cells and a product was started and finished in one cell, except for out of cell processes like heat treatment. Cross training of the operators was implemented so that each operator could attend to more than one machine. The company was able to reduce its work force from 350 in 1997 to 96 in 1999, with production and labor cost saving going up to 17%. Teamwork, quality inspection arrangements and Just-In-Time (JIT) were easy to apply. The benefits seen at Boart long year created pressure for urgent need to 'cellularize' the manufacturing systems in Zambia. Further, **Munakaampe (2000)** recommended that firms (machine shops) should change their traditional job shop to cellular arrangements to facilitate job design, job flow, capacity planning, utilization, machinery arrangement and modernization (**Munakaampe, 2000**).

1.3 MOTIVATION IN THIS RESEARCH

The motivation in this research was derived from the fact that Cellular Manufacturing had become a popular and modern manufacturing facility. **Stanley(2005)**, reports that “many manufacturers are switching from traditional manufacturing facility to Cellular Manufacturing because they have recognized the opportunities for significant operational and quality improvements and Cellular Manufacturing is product and customer focused instead of process focused” (**Stanley,2005**). Cellular Manufacturing facilities respond very well when mechanization, robotization and automation of manufacturing systems are integrated. Flexible Manufacturing Systems and Transfer Lines are examples of automated Cellular Manufacturing facilities that have been linked and integrated. The encouragement in this research is to design and evaluate a Cellular Manufacturing facility for selected copper products in Zambia. The products include: cable lugs, contact terminals, earth rods, neutral blocks, copper washers, copper connectors, top plugs, sockets and switches.

1.4 STATEMENT OF THE PROBLEM

Industrialization of a country depends on many factors including how modern the technologies used to add value to the resources are. A problem of slow industrialization arise when little effort is made to research and develop latest technologies to add value to the raw material resource and yet the by-products from the same raw material is consumed in the country, like is the case of copper in Zambia. The bulk of the Copper from Zambia is exported to industrialized countries as cathodes without adding much value but the finished copper products that could have been made locally are imported to Zambia at higher value, depleting Zambia of much needed and scarce foreign exchange reserves. This economic setup will continue to deprive Zambia of foreign exchange earning. The retention of the market edge by industrialized countries over Zambia will continue to slow down the development of copper processing industries. This research aims to address the problem of exporting copper without adding value to it.

1.5 RESEARCH QUESTIONS AND OBJECTIVES

1.5.1 RESEARCH QUESTIONS.

This research intends to assess the viability of processing copper locally into finished products using modern technologies like Cellular Manufacturing. The questions to be answered in this research are: is adding value to copper in Zambia possible? Is it economical? Can Cellular Manufacturing be applied to add value to copper? What are the implications of this technology on the cost of copper products?

1.5.2 THE OBJECTIVES.

1.5.2.1 THE GENERAL OBJECTIVE

The general objective of this research is to design and evaluate a Cellular Manufacturing system for selected copper products in Zambia.

1.5.2.2 THE SPECIFIC OBJECTIVES OF THIS RESEARCH ARE:

- a) To identify and determine the demand levels of selected copper products in Zambia.
- b) To design a Cellular Manufacturing facility for identified discrete copper products with a view to minimize intra and inter-cellular movements.
- c) To evaluate the designed Cellular Manufacturing facility.

1.6 JUSTIFICATION OF THE RESEARCH

The current economic environment for manufacturing is more competitive than ever before because of globalization. Customers demand variety and customized better quality products that must be delivered on time and at lower prices. The pressure exerted on the manufacturers by the customers to supply goods necessitates technological changes in manufacturing systems. More benefits can be derived from globalization if the value addition process is done within the country of origin of the raw materials.

In light of this view, it is justifiable for this research to focus on designing and evaluating the Cellular Manufacturing system for processing copper into finished products in Zambia.

Further, when Cellular Manufacturing is practiced, it can lead to technological advancement due to process re-engineering, productivity improvement and research and development in manufacturing systems. The benefit of increase in productivity leads to satisfaction of local and export markets. The creation of regional markets like Common Market for Eastern and Southern Africa (COMESA) gives more opportunities to export the copper products and contribute to the economic growth through foreign exchange earnings.

1.7 METHODOLOGY OF THE RESEARCH

The methodology in this research was focused on the objective of designing and evaluating a cellular manufacturing facility for the selected copper products.

In order to achieve this objective, literature study was done to understand cell formation strategies. According to literature, cell formation for cellular manufacturing deals with identifying products and machines that can be grouped into manufacturing cells and to identify part families to be processed within each cell (**Foulds et al., 2002**).

To select the copper products, a pilot market research was conducted. The copper products were selected based on market value and demand rate. Questionnaires were used to collect the data on demand rate. The sampling method used was multistage. The parts from the selected copper products were grouped into part families using poly (chain) code classification system. Production Flow Analysis was employed to generate information about processing engineering, parts routings, machine types and the cell formation procedures. To design the cells, simultaneous part family formation and machine grouping solution strategy i.e. the ranking order clustering algorithm was used. Cell evaluation involved cell balancing and cost and benefit analysis.

To balance the cell, the Killbridge and Wester approach was adopted .The cost and benefit analysis in the form of costs and profit comparison were done.

1.8 THE SCOPE AND ORGANIZATION OF THE DESSERTATION

The scope of this dissertation was to design and evaluate a manufacturing system to transform copper into some selected finished products using Group Technology or Cellular Manufacturing approach. The selected products are: cable lugs, contact terminals, earth rods, neutral blocks, copper washers, copper connectors, top plugs, sockets and switches.

The outline of this dissertation is as follows: **Chapter 1** introduces the background information to the problem, the problem to be solved by the research, the research objectives and the summary of the methodology. **Chapter 2** provides a general overview of manufacturing systems and then focuses on the Cellular Manufacturing systems. The chapter also looks at some of the cell formation and evaluation procedures. **Chapter 3** focuses on the methodology used to select the copper product. This chapter also indicates how the part families and the parts-machine clusters or cells were formed. **Chapter 4** explains the design process for the cells using the Ranking Order Clustering Algorithm. The chapter also explains how the cellular layout was done. **Chapter 5** describes the cells evaluation procedures to ascertain the capacity of the cells and their cost implication. **Chapter 6** presents discussion of findings. **Chapter 7** highlights the conclusions and the recommendations for future work.

CHAPTER 2

CELLULAR MANUFACTURING SYSTEMS

2.1 INTRODUCTION.

This chapter discusses product focused and process focused manufacturing systems. The chapter also examines the Cellular Manufacturing System as a derivative of the Product Focused and Process Focused Manufacturing System. The theory underlying cell designing and cell evaluation procedures is also presented.

2.2 MANUFACTURING SYSTEMS.

Unlike Henry Ford, today's manufacturers cannot just make "any color as long as it's black." Fragmented markets, stiff competition and sophisticated customer demand have led to increased product variety and often with lower volume (**Strategos inc., 2005**). This situation has brought about innovations in layouts of manufacturing systems presented in sections: 2.2.1, 2.2.3 and 2.2.3.

2.2.1 PRODUCT FOCUSED LAYOUT.

This layout seeks the best utilization of personnel and machine resources that are arranged according to the processing sequence of the product as illustrated in figure 2.1. The facility is suitable for repetitive work and standardized products that are required in high volume. Examples of product focused layout are: assembly lines, fabrication shop and flow lines.

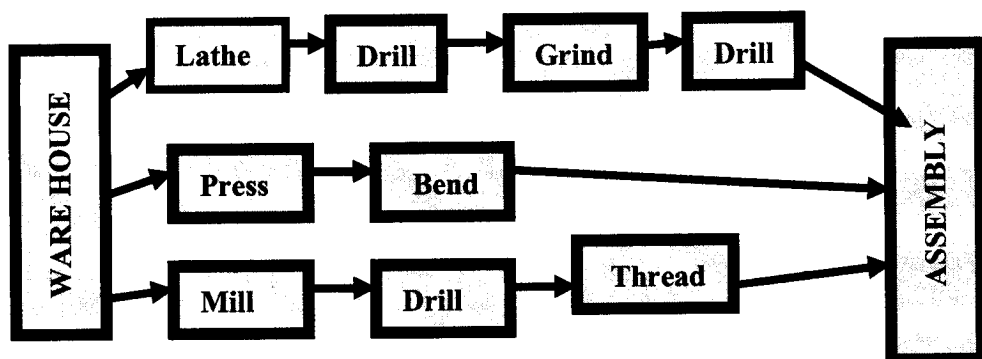


Figure 2.1: *Illustration of product focused layout.*

The advantages of product focused layout are: smooth flow of products, little work in progress inventory, less production time, less material handling, less skills required, simple production planning and lower variable costs. The disadvantages of product focused layout include: break down of one machine leads to whole line stoppage, inflexibility, production rate is determined by the slowest machine and the cost of investment for this system are large.

2.2.2 PROCESS FOCUSED LAYOUT

This is a layout whereby similar machines are located in one area of processing. A typical example is a job shop. The materials to be processed are moved to the area of processing. Figure 2. 2 illustrates the process focused layout.

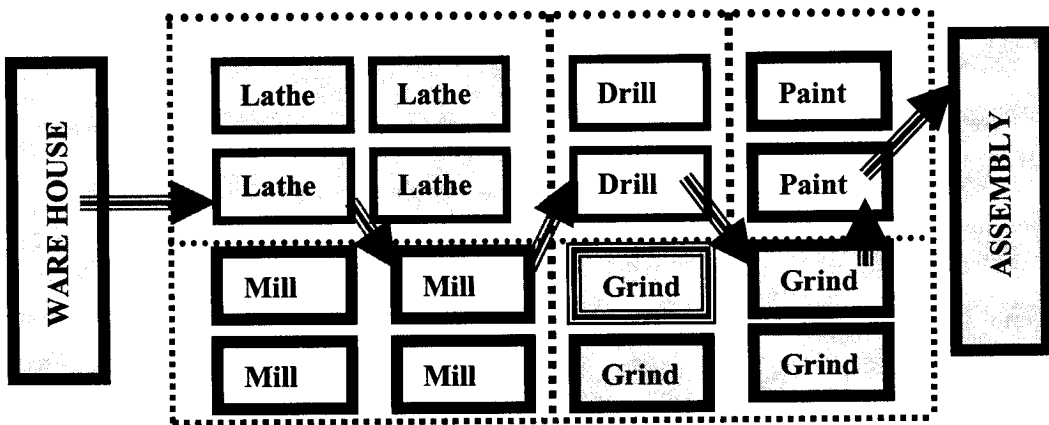


Figure 2.2: *Illustration of process focused layout.*

The advantages of this layout include: better labour and machine utilization, excellent flexibility, low investment cost and specialized supervision is possible. The disadvantages of this layout are: lots of material handling, difficult production planning and control, longer throughput times, low output, lots of work in progress inventory and high skills required.

The above highlighted disadvantages of the product or process focused layout necessitates the development of an intermediate layout that combine the advantages of each one of these layouts. One such layout is Cellular Manufacturing.

2.2.3 CELLULAR MANUFACTURING

Cellular Manufacturing combines the advantages of product and the process focused layout systems. Cellular manufacturing is an arrangement of machines in order of processing sequence as illustrated in figure 2.3. It is meant to process medium variety products. Cellular Manufacturing necessitates a variety of product parts to be grouped into families of similarities in geometry and manufacturing attributes. The products during processing move from one stage to the next without much delay.

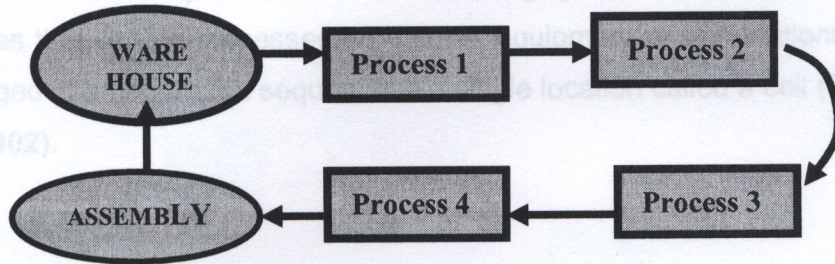


Figure 2.3: Illustration of Cellular manufacturing.

2.2.4 COMPARISON OF MANUFACTURING SYSTEMS

The process focused and the product focused layouts are not economical when manufacturing medium variety and moderate demand products meant for fragmented and competitive markets. The manufacturing system suitable in this situation is Cellular Manufacturing. Figure 2.4 illustrates the conditions suitable for each of the manufacturing systems (Norman, 1994; Forgarty, 1989; Wild, 1987).

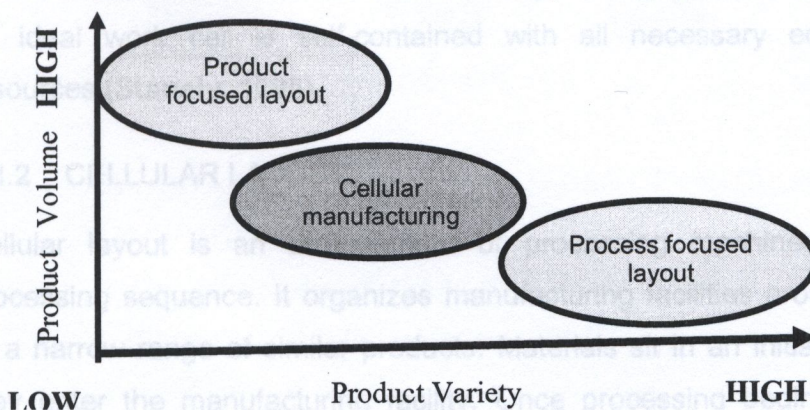


Figure 2.4: Comparison of manufacturing systems.

2.3 CELLULAR MANUFACTURING SYSTEM.

The concept of Cellular Manufacturing began with Skinner in 1974 in USA. He proposed the formation of focused factories in which small manufacturing systems operate independently within a large production system for medium variety, medium volume batch production. These focused factories can be either Flexible Manufacturing Systems or Cellular Manufacturing systems in which certain production processes are dedicated to a family of related parts in a cell. Burbidge popularized the idea in 1975, which was subsequently adopted in industry. Cellular Manufacturing groups similar products into families that can be processed on a set of equipment or workstations that are arranged in an operation sequence in a single location called a cell **(Foulds et al., 2002)**.

2.3.1 A WORK CELL

A cell is a group of workstations, machines or equipment arranged such that a product can be processed progressively from one workstation to another without having to wait for a batch to be completed and without additional handling between operations. Cells may be dedicated to a process, a sub-component, or an entire product. Cells are conducive to single-piece and one-touch-manufacturing methods and may be designed for service or manufacturing operations. A work cell is a work unit larger than an individual machine or workstation but smaller than the usual department. Typically, it has 3 to 12 people and 5 to 15 workstations in a compact arrangement. An ideal work-cell manufactures a narrow range of highly similar products. Such an ideal work cell is self-contained with all necessary equipment and resources **(Stanely, 1996)**.

2.3.2 CELLULAR LAYOUT

Cellular layout is an arrangement of processing machines in order of processing sequence. It organizes manufacturing facilities around a product or a narrow range of similar products. Materials sit in an initial queue when they enter the manufacturing facility. Once processing begins, they move directly from process to process. The result is fast throughput. Communication is easy since operators are close to each other.

Cellular layout arrangement improves product quality and workers' coordination. Proximity of workers to each other and common mission enhance teamwork within a cell. Commonly used cellular layouts are: in-line (figure 2.5), u-shaped (figure 2.6) or rectangular (figure 2.7) (Norman, 1990; Forgarty, 1989).

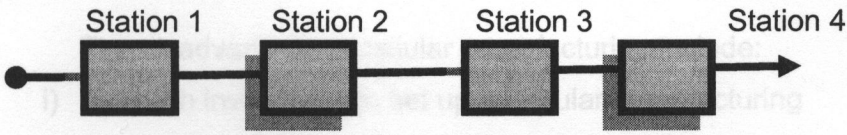


Figure 2.5 : In -line cellular layout.

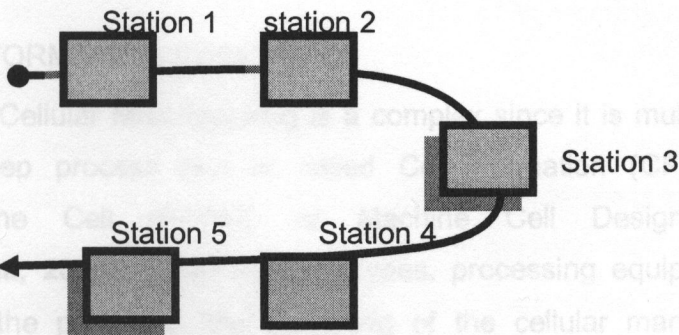


Figure 2.6 U- shapes cellular layout.

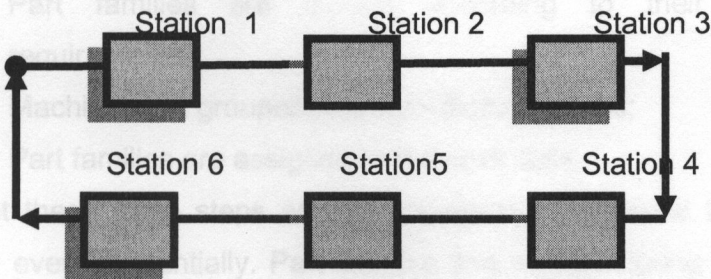


Figure 2.7 Rectangular cellular layouts.

2.3.3. ADVANTAGES AND DISADVANTAGES OF CELLULAR MANUFACTURING.

a) The advantages of cellular manufacturing include the following: (Stanley, 1996; Quarterman, 1997).

- i) Reduction in work in progress inventory
- ii) Increased space utilization
- iii) Reduction in lead-time

- iv) Productivity improvement
 - v) Quality improvement
 - vi) Teamwork, morale, ownership and communication are enhanced
 - vii) Enhanced flexibility and visibility
- b) The disadvantage of cellular manufacturing include:
- i) High investment to set up a Cellular Manufacturing facility compared to a job shop.
 - ii) Duplication of machines within the cell and in linked cells.

2.4 CELL FORMATION STRATEGIES

Designing of Cellular Manufacturing is a complex since it is multi criterion and multi step process and is called Cell Formation (CF) or Part Family/Machine Cell (PF/MC) or Machine Cell Design (MCD). **(Mungwattana, 2000)**. Given the part types, processing equipment and demand for the part type, the designing of the cellular manufacturing system consist of the following three steps:

- i) Part families are formed according to their processing requirements;
- ii) Machines are grouped into manufacturing cells;
- iii) Part families are assigned to the work cells.

Note that these three steps are not necessarily performed in the above order, or even sequentially. Part families and manufacturing cells can be formed simultaneously, along with the assignment of part families to the cells.

After the design steps have been completed, a cell(s) configuration is made. This configuration is referred to as a cellular manufacturing system. This system consists of manufacturing cells. Each cell constitutes a group of machines and is dedicated to produce a family of parts.

Ballakur and Steudel (1987) suggested three solution strategies based on the procedure used to form part families and cells. The three solution strategies are as follows:

- i) Part families are formed first. Machines are then grouped into cells according to the part families. This is called Part Family –Machine grouping solution strategy.
- ii) Manufacturing cells are created based on similarities in part routings, and then allocated to cells. This is called Machine Grouping solution strategy.
- iii) Part families and manufacturing cells are formed simultaneously. This is called Simultaneous Part- Machine Grouping Solution strategy.

In the design of cellular manufacturing systems, design objectives must be specified. The objectives may include: minimizing inter-cells movement; minimizing distances; minimizing costs; and minimizing the number of exceptional parts. Exceptional parts also called exceptional elements or bottlenecks are parts that need more than one processing cell. **Mungwattana (2000)** stated that the following are the cellular manufacturing classification methods; part coding analysis; cluster techniques; similarity co- efficiency; graph positioning; mathematical programming; heuristic search. There has also been a proliferation of algorithms to solve the work-cell formation problems (**Mungwattana, 2000**).

The general information required to form a cell include the following:
(**Foulds et al., 2002**).

- a) Type of products to be manufactured
- b) Types of machine to be used
- c) Process plans and routings required for each part
- d) Production rate or demand level.

2.5 CELL FORMATION STAGES.

The Production Flow Analysis is the modern practice in cell formation. This method involves material flow analysis, part family formation, cell design and facility layout. Proper design of work cells is an engineering problem. Like any other engineering design, it proceeds through a logical sequence of stages. These stages are: product selection, Group Technology, Process Engineering, Cell Formation, Work cell layout and Workstation Design. The processes at each of these stages are illustrated in figure 2.8. At each of these stages, the designers make compromises between conflicting requirements and technical limitations (Shahrukh, 2005; Quarterman, 1997). An experienced designer performs many of these stages informally or just mentally. The process is not as complex or lengthy as Figure 2.8 may indicate. However, failure to perform each step results in risky and accidental design.

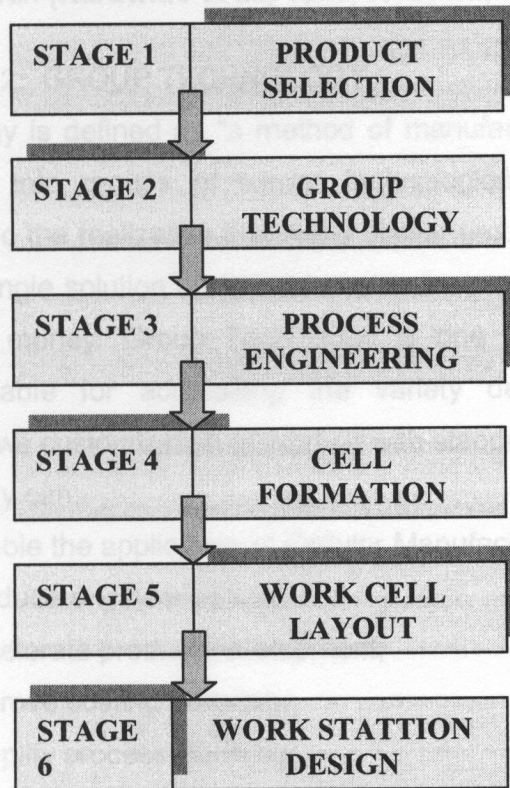


figure 2.8; Illustration of cell formation process stages (Figure: Quarterman, 1997).

2.5.1 STAGE 1: PRODUCT SELECTION

The goal of product selection is to find compatible families of products that a group of machines can process without undue changeovers. Where the products already exist at the manufacturing site, the drawings or designs of the products or the actual products are selected based on similarities in geometry or manufacturing attributes. In case the products do not exist, market survey is done (**Strategos inc., 2005**). A market survey is a *formalized means of obtaining research information for decision-making and to answer the research question. Before a market survey is conducted, a pilot survey is done to investigate the accuracy of the research tools and to detect flaws in the questioning. A pilot survey guides the decision about the main research so that a detailed research could be carried out and reliable data collected. The data collected during the pilot research may be counted as part of the main research* (**Hardwide et al., 1996; Hossein, 2002**).

2.5.2 STAGE 2: GROUP TECHNOLOGY.

Group Technology is defined as “a method of manufacturing piece parts by classifying them into groups of similar technological operations”. Group Technology is also the realization that many similar problems can be grouped together and a single solution be found to solve the problems thereby saving time, effort and money. Group Technology is one of the most effective techniques available for addressing the variety demanded by today's customers. It allows customization of product with standardization of process.

Group Technology can:

- i) Enable the application of Cellular Manufacturing;
- ii) Reduce engineering cost;
- iii) Accelerate product development;
- iv) Improve costing accuracy;
- v) Simplify process planning;
- vi) Reduce tooling cost; and
- vii) Simplify purchasing.

Group Technology is applied in electronics, paper products, foundry and many other products and services.

Group Technology encourages more savings through reduced setups and tooling cost. The reduction in setup times result in smaller lot sizes and smaller queues, which mean faster throughput, shorter lead times and decreased inventory. Combined with NC equipment, Group Technology simplifies programming, fixturing, tooling, robotization and automation. Group Technology combines tasks, equipment, gages, tooling and schedules into larger groups of similar elements for similar solutions. When a designer produces many hundreds designs of parts, without formal methods, designers have difficulties to track the drawings. The designer may duplicate many existing parts. To lessen this problem grouping and identification of items becomes necessary. The method widely used to identify and group items in Group Technology is coding and classification (**Shahrukh, 2005**).

2.5.2.1 CODING AND CLASSIFICATION (C&C)

Coding is a process of assigning numbers, letters, or a combination to an item for identification. A "Code Number" contains information about the part. This number might identify material, size, shape, function, process or other information. Classification is grouping parts with similarities. Coding and classification is part of Production Flow Analysis. Coding and classification systems are useful in manufacturing, design and purchasing. Several schemes of coding and classification have been developed. Some of the coding and classification schemes discussed here are:

1. Hierarchical structures (monocodes):
2. Chain codes (polycodes):
3. Hybrid structure

1. HIERARCHICAL STRUCTURES (MONOCODES):

In this system, the first digit represents an entire group. The next digit represents sub-groups of the feature, and so on. In this sense, the preceding digits qualify each subsequent digit i.e. each subsequent digit inherits the properties of the previous digits. Importantly, consider all parts to be classified in terms of a feature like rotational, non-rotational (prismatic) parts, with holes, without holes, etc as shown in Figure 2.9.

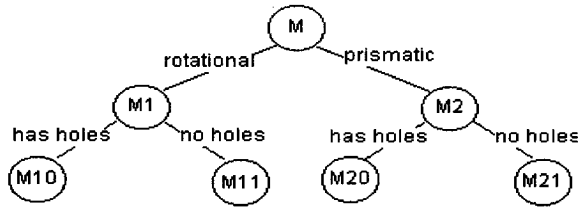


Figure 2.9. *Illustration of hierarchical structure.*

Advantages of monocodes:

- i) Very large amount of information can be stored with just a few digits.
- ii) The hierarchical structure allows parts of the code to be used for information at different levels of abstraction.

Disadvantages:

- i) Impossible to get a good hierarchical structure for most features or groups
- ii) Different sub-groups may have different levels of sub-groups, thereby leading to blank codes in some positions.

2. CHAIN CODES (POLYCODES):

In this method, the code digit represents one feature. Thus, the value of any given digit (or position) within the code is not related to the other digits. This coding system is easy to formulate. However, less information is stored per digit. Therefore, to get a meaningful comparison of, say, shape, very long codes will be required. In addition, it requires comparison of coded parts (to check for similarity), which is extra work.

3. HYBRID 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. Examples are Opitz and KK3.

a) OPITZ CODE:

The original Opitz code is a 5-digit code indicated in table 2.1.

Table 2.1: *digit classification in OPTZ code*

Digit/Position	Type	Feature/Group
1	Integer	part class (rotational/non-rotational)
2	Integer	external shape
3	Integer	internal shape
4	Integer	plane surface features and machining
5	Integer	auxiliary features (off-axis holes, gear teeth etc.)

Later, four more digits were added to the coding scheme in order to increase the manufacturing information. These last four digits are also called supplementary digits.

b) THE KK-3 CODE

The Japanese Society originally developed the KK3 coding system for promotion of Machining Industry. The domain is machining and grinding parts. The KK3 is a 21-digit coding system, each of which is an integer as illustrated in Table 2.2.

2.5.3 STAGE 3: PROCESS ENGINEERING

Process engineering identifies and describes every process event and the times required for setups, personnel activities and machine cycles. From this, we calculate the number of people required and the number of machines or workstations. Infrastructural elements that support the process but do not touch the product include: containers, scheduling, balance methods and motivation. **(Shahrukh, 2005).**

Table 2.2: *KK3 coding system.*

Digit	Items (Rotational Components)		
1	Part Name	General classification	
2		Detailed Classification	
3	Material	General classification	
4		Detailed Classification	
5	Chief Dimension	Length	
6		Diameter	
7	Primary shape and ratio of major dimensions		
8	Shape details and kinds of processes.	External	External primary shape
9			Concentric screw threaded parts
10			Functional cut -off parts
11		Surface	Extraordinary shaped parts
12			Forming
13			Cylindrical surfaces
14		Internal Surface	Internal primary shape
15			Internal curved surface
16			Internal flat/cylindrical surface
17		End surface	
18		Non -Concentric holes	Regularly located holes
19			special holes
20		Non cutting process	
21	Accuracy		

2.5.4 STAGE 4: CELL FORMATION STRATEGIES

The three cell formation strategies are as follows: (Foulds et al., 2002).

1. Simultaneous part family formation and machine grouping solution strategy.
2. Separately part family formation and machine grouping solution strategy
3. The heuristic methods.

2.5.4.1 SIMULTANEOUS PART FAMILY FORMATION AND MACHINE GROUPING.

In this method, part families are formed by grouping together parts with similarities in part coding and classification. Processing machines are identified from process engineering of parts and routings data.

This information is then used to make part- machine incidence matrices. The matrix can be used for clustering using: i) Ranking Order Cluster Algorithm or ii) Direct Clustering. If the clustered machines are not in processing sequence, then Production Flow Analysis is used to position them.

a) PART- MACHINE INCIDENCE MATRIX.

This matrix specifies which part must be processed on a specified machine.

If n = the number of types of parts (type: 1,2...n) to be processed on different machines,

m = the number of machine types, 1,2...m and

P = number of cells to be formed,

Then the matrix elements $a_{ij} = 1$ if part j is processed on machine i and
 $= 0$ if the part is not operated on a machine.

Where i = machine index ($i = 1,2...m$) and

j = part index ($j = 1, 2...n$)

So that the incidence matrix = $\left[a_{ij} \right]_{m \times n}$

The incidence matrix needs to be transformed into block diagonal matrix (Figure 2.10) where the values in the blocks are 1's and elsewhere are 0's. Each block represents the part family – machine cluster or a cell. One method of block formation is the clustering process called the Ranking order cluster technique whose algorithm is as explained next (Foulds et al., 2002; Strategos inc., 2005).

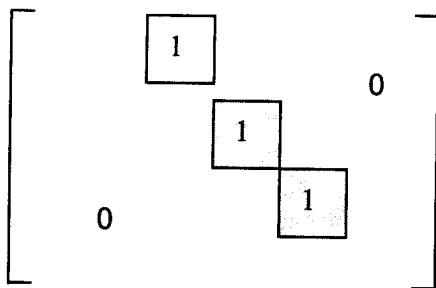


Figure. 2.10: part- machine diagonal machine matrix .

b) RANKING ORDER CLUSTER ALGORITHM

The steps in Ranking Order Cluster Algorithm are as follows:

- Step 1 Represent the processing information of each part into a matrix as indicated in Table 2.3

- Step 2 Transform processing information table into an incident matrix of binary numbers 1's (refer to Table 2.4). Interpret the 1's as indications that a part has to be processed at a respective machine in each column of the incidence matrix.

- Step 3 Calculate total weight of each column, $W_j = \sum 2^{j^*} M_{ij}$, as illustrated in Table 2.5.

- Step 4 Rank the columns in the order of ascending weight, W_j as shown in Table 2.6. In case of a tie, rank the columns in the same order as they appear in the current matrix.

- Step 5. Calculate total weight of each row, $W_j = \sum 2^{j^*} M_{ij}$, as indicated in Table 2.7 and arrange rows in ascending weight.

- Step 6 Repeat steps 3, step 4 and step 5 until there are no further change noticed on the matrix. Tables 2.8, Table 2.9 and Table 2.10 shows the result of this algorithm.

Table 2.3: *processing information for each part.*

PART	MACHINES			
	SAW01	LATHE 02	GRING 05	INSP 06
A12	SAW01	LATHE 02	GRING 05	INSP 06
A15	MILL02	DRILL 01	INSP 03	
A120	SAW01	LATHE 02	INSP 06	
A123	SAW01		INSP 06	
A131	SAW01	LATHE 02	INSP 06	
A212	MIL03	INSP 03		
A230	MIL03	INSP 03		
A432	SAW01	LATHE 02	INSP 06	
A451	SAW01	LATHE 02	INSP 06	
A510	MIL05	DRILL 01	GRING 06	INSP 06

Table 2.4: Incidence matrix.

MCs/Parts	A12	A15	A120	A123	A131	A212	A230	A432	A451	A510
SAW01	1		1	1	1			1	1	
LATHE 01				1						
LATHE 02	1		1		1			1	1	
DRILL 01		1								1
MILL02		1								
MIL05						1	1			1
GRIND 05	1									
GRIND 06	1		1							1

Table 2.5: matrix with the column weight calculated.

MCs/Parts	A12	A15	A12 0	A12 3	A13 1	A21 2	A23 0	A43 2	A45 1	A51 0	2^j
SAW01	1		1	1	1			1	1		2
LATHE 01				1							4
LATHE 02	1		1		1			1	1		8
DRILL 01		1								1	16
MILL02		1									32
MIL05						1	1			1	64
GRIND 05	1										128
GRIND 06	1		1							1	256
W_i	138	48	10	6	10	64	64	10	10	326	
Rank	9	6	2	1	3	7	8	4	5	10	

Table 2.6: Ranked column matrix.

MCs/Parts	A123	A120	A131	A432	A451	A15	A212	A230	A12	A510	2^j
SAW01	1	1	1	1	1				1		2
LATHE 01	1										4
LATHE 02		1	1	1	1				1		8
DRILL 01						1				1	16
MILL02						1					32
MIL05							1	1		1	64
GRIND5									1		128
GRIND6		1							1	1	256
W_i	6	10	10	10	10	48	64	64	138	326	
Rank	1	2	3	4	5	6	7	8	9	10	

Table 2.7: Rows weighted and ranked matrix.

MCs/Parts	A123	A120	A131	A432	A451	A15	A212	A230	A12	A510	w_j	Rank
LATHE 01	1										2	1
MILL02						1					64	2
GRIND05									1		512	3
SAW01	1	1	1	1	1				1		572	4
LATHE 02		1	1	1	1				1		602	5
GRIND 06		1								1	1024	6
DRILL 01						1				1	1088	7
MIL05							1	1		1	1408	8
2^j	2	4	8	16	32	64	128	256	512	1024		

Table 2.8: weighted column matrix.

MCs/Parts	A123	A120	A131	A432	A451	A15	A212	A230	A12	A510	2^j
LATHE 01	1										2
MILL02						1					4
GRIND 05									1		8
SAW01	1	1	1	1	1				1		16
LATHE 02		1	1	1	1				1		32
GRIND 06		1								1	64
DRILL 01						1				1	128
MIL05							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	

Table 2.9: Ranked column matrix.

MCs/Parts	A123	A120	A131	A432	A451	A12	A15	A212	A230	A510	2^j
LATHE 01	1										2
MILL02							1				4
GRIND 05						1					8
SAW01	1	1	1	1	1	1					16
LATHE 02		1	1	1	1	1					32
GRIND 06		1								1	64
DRILL 01							1			1	128
MIL05								1	1	1	256
W_j	18	48	48	48	48	56	132	256	256	448	
Rank	1	2	3	4	5	6	7	8	9	10	

Table 2.10: The desired part- machine cluster

MCs/Part	A123	A120	A131	A432	A451	A12	A15	A212	A230	A510	W_j	Rank
LATHE 01	1										2	1
GRIND 05						1					64	2
LATHE 02		1	1	1	1	1					124	3
SAW01	1	1	1	1	1	1					126	4
MILL02							1				128	5
GRIND 06										1	1024	6
DRILL 01							1			1	1152	7
MIL05								1	1	1	1792	8
2^j	2	4	8	16	32	64	128	256	512	1024		

c) THE DIRECT CLUSTERING ALGORITHM

A problem with the Rank-Order Clustering is that computation of weights can become problematic when the number of parts is large. For instance, if the data is for 200 parts, then the weight factor for the rightmost column will be 2^{200} , which is too large to compute directly. To avoid this problem, King and Nakornchai proposed the direct clustering algorithm, which is as explained below: (Strategos inc., 2005). Step 1. Calculate weight of each row,

$$W_j = \sum M_{ij}$$

Step 2. Sort rows in descending order

Step 3. Calculate weight of each column, $W_j = \sum M_{ij}$.

Step 4. Sort columns in ascending order

Step 5. For $i = 1$ to n , move all columns j where $M_{ij} = 1$, to the right while maintaining the order of the previous rows.

Step 6. For $j = m$ to 1, move all rows i , where $M_{ij} = 1$, to the top, maintaining the order of the previous columns.

Step 7. If current matrix is equal to the previous matrix, then stop or else go to step 5.

The results of the above steps are shown in Table 2.11 up to Table 2.16.

Table 2.11: column and row totals for sort 1

MCs/Part	A112	A115	A120	A123	A131	A212	A230	A432	A451	A510	□r
Saw01	1		1	1	1			1	1		6
Lathe01				1							1
Lathe02	1		1		1			1	1		5
Drill01		1								1	2
Mill02		1									1
Mill05						1	1			1	3
Grind05	1										1
Grind06										1	1
□c	3	2	2	2	2	1	1	2	2	3	

Table 2.12: column and row totals for sort 1.

MCs/Part	A212	A230	A115	A120	A123	A131	A432	A451	A112	A510	□r
Saw01				1	1	1	1	1	1		6
Lathe02				1		1	1	1	1		5
Mill05	1	1								1	3
Drill01			1							1	2
Lathe01					1						1
Mill02			1								1
Grind05									1		1
Grind06										1	1
□c	1	1	2	2	2	2	2	2	3	3	

Table 2.13: column and row totals for sort 2.

MCs/Part	A212	A230	A115	A510	A120	A123	A131	A432	A451	A112	
Saw01					1	1	1	1	1	1	6
Lathe02					1		1	1	1	1	5
Mill05	1	1		1							3
Drill01			1	1							2
Lathe01						1					1
Mill02			1								1
Grind05										1	1
Grind06				1							1
	1	1	2	3	2	2	2	2	2	3	

Table 14: column and row totals for sort 3.

MCs/Part	A115	A212	A230	A510	A123	A120	A131	A432	A451	A112
Saw01					1	1	1	1	1	1
Lathe02						1	1	1	1	1
Mill05		1	1	1						
Drill01	1			1						
Lathe01					1					
Mill02	1									
Grind05										
Grind06				1						1

Table 2.15: column and row totals for sort 4.

MCs/Part	A115	A212	A230	A510	A123	A120	A131	A432	A451	A112
Saw01					1	1	1	1	1	1
Lathe02						1	1	1	1	1
Grind05										1
Mill05		1	1	1						
Drill01	1			1						
Lathe01					1					
Mill02	1									
Grind06				1						

Table 2.16: part machine clusters.

MCs/Part	A115	A212	A230	A510	A123	A120	A131	A432	A451	A112
Saw01					1	1	1	1	1	1
Lathe02						1	1	1	1	1
Grind05										1
Lathe01					1					
Mill05		1	1	1						
Drill01	1			1						
Grind06				1						
Mill02	1									

2.5.4.2 SEPARATELY PART FAMILY FORMATION AND MACHINE GROUPING SOLUTION STRATEGY.

In this strategy, part families are formed first and then machines are grouped into cells according to the part families. This is called part family formation and machine grouping solution strategy. Examples are Graph partitioning, heuristic and similarity coefficient method.

a) GRAPH PARTITIONING METHOD

In this method, the machine -part assignment problems are solved with an objective of minimizing the material flow and material handling costs between cells. The assignment problem can be modeled as a graph partition, where the nodes on the graph correspond to the parts being processed on given machines with a view to determine a minimum-cost. The advantage of this method is that cell formation process incorporates cost minimization in parts movement. A draw back to this method is that it requires preliminary knowledge of the solution to the machine-grouping problem and costs. To reduce the computational efforts in solving the graph-partitioning problem, it is recommended to use a heuristic method first to assign parts to machines as long as the machine capacities are not exceeded.

b) HEURISTIC METHOD

In this method, part families are formed after examining the similarities on part geometries, shape and routings. The processing sequence is used to identify the type and number of machines. After forming families and machine groups, the parts are assigned to the machines. Assignment continues until maximum capacity of the machine is reached, then the next machine is loaded or another similar machine is brought in. The method is therefore sub optimal, as it tends to concentrate on part assigning and ignores costs of movements. The advantage of this method is that it is relatively easy to apply. However it has a draw back of not being able to minimize distances parts have to move in between machines and cells. This is up to the designer of the cell. . (Foulds, et., al, 2002; Gupta, 1998).

c) *SIMILARITY COEFFICIENTS.*

Similarity Coefficients method is required mainly because it shows quantitative measure of how 'similar' two parts are, allowing the use of the algorithms to process information about them. The similarity here refers to quantitative measures of how similar two parts are in shape, size and other properties such as hardness, surface finish, color etc.

i) **ASSIGNING A NUMBER TO SIMILARITY**

Consider parts P2 , P3, and P5 assigned to be processed on machines A and B as shown in Table 2.17 and parts P1 and P4 are un assigned.

Table 2.17: *Parts and machine assignment.*

Parts	P1	P2	P3	P4	P5
m/c A			1		1
m/c B		1	1		

To define similarity of Machines A and B, it would be necessary to look at how many parts visit both the machines in relation to the total number of parts that go to either machine. In this case, here is one part, P3, which visits both machines. Therefore the measure will give a similarity = $1/3$, or 0.333. Other examples are: Similarity (A, B) = (number of parts visiting A and B)/ (number of parts visiting A) = $1/2 = 0.5$. Similarity(B, A) = (number of parts visiting B and A)/(number of parts visiting B) = $1/2 = 0.5$,and then define common-similarity(A,B) = $\max(\text{Similarity(A,B), Similarity(B,A)})$ or, if we are conservative, common-similarity(A,B) = $\min(\text{Similarity(A,B), Similarity(B,A)})$.

ii) **APPLYING SIMILARITY COEFFICIENT TO GROUP TECHNOLOGY**

One way to use similarity in forming groups is by making a dondegram table shown in Table 2.18. We can calculate the similarity matrix shown in Table 2.19.

Table 2.18: *dendogram table*.

Part / Machine	P1	P2	P3	P4	P5	P6
Machine A			1		1	
Machine B		1	1			
Machine C	1			1		
Machine D		1	1		1	

Table 2.19 similarity matrix

	Machine A	Machine B	Machine C	Machine D	Machine E
Machine A	1	0.33	0	0.67	0
Machine B	0.33	1	0	0.67	0
Machine C	0	0	1	0	0.67
Machine D	0.67	0.67	0	1	0.67
Machine E	0	0	0.67	0.67	1

iii) INTERPRETATION

Thus, since A or D are in the same 0.67-group, and B is in the same group as D, then all A, B, and D belong to the same group. However, this is arguable depending on the designer. For example, if it is felt that Machine D is an expensive machine, but is used only for small periods by the parts that need it, it may be decided to share this machine between groups. In this case, the similarity of machine B with Group (A, D) can be defined as the maximum of the similarity of B with A or D: $\text{Similarity}(B, (A, D)) = \max(\text{Similarity}(B, A), \text{Similarity}(B, D)) = \max(1/3, 2/3) = 2/3$. Under this assumption, it can be said that the 0.67-group contains machines A, B, D. (of course, C and E form another 0.67-group). Merging the machines into groups, yields the dendogram shown in Figure 2.11

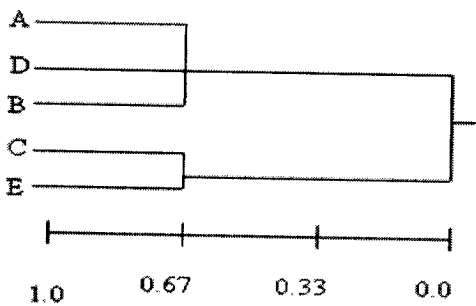


Figure 2.11: *dendogram*

Alternatively, similarity level of 0.33, all of A, B and D results in a new dendrogram as in Figure 2.12:

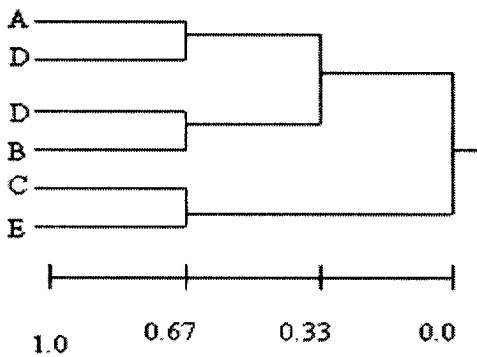


Figure 2.12: *new dendrogram*

In general, all measures of similarity are mappings from a complex, multi-dimensional domain (e.g. design description) to real numbers. Once the machine families have been identified, we can isolate them to form cells within the manufacturing system. The advantages of reduced material handling through cells are easy to visualize in this system.

2.5.5 STAGE 5: CELL FORMATION AND INFRASTRUCTURE DESIGN

The fourth task in work cell design is positioning tangible and the intangible infrastructure and their interlink. The tangible infrastructure refers to items that directly touch the parts to be processed. The intangible infrastructure concerns items that alter the surrounding and the working environment. Infrastructure design is often straightforward if the previous stages have been done thoughtfully (**Strategos inc., 2005**).

2.5.6 STAGE 6: WORK CELL LAYOUTS AND WORKSTATION DESIGN.

2.5.6.1 WORK CELL LAYOUT

This is the stage where the shape of the cell is determined. The shape can be in-line, u-shaped, loop or rectangular. The factors to consider when deciding on the shape of the cells are: container, floor area available, distances parts are to travel, cell manning levels, number of machines per station, number of work station, parts transfer mechanism, mechanization and automation issues, cell link and parts flow rates.

The shape of the cell should be that which minimize the overall cost caused by these factors (**Shahrukh, 2005; Phillip, 1997**).

2.5.6.2 WORKSTATION DESIGN

At the level of workstation design, Ergonomics and Motion Economy dominate the design. Motion Economy maximizes individual productivity by making tasks faster and easier. Ergonomics optimizes the integration of people with equipment. It also ensures that workers can perform the task with minimal risk of injury and fatigue. Initially, the designer needs information on products, processes, equipment, tools and components. The next task defines the process and allocates functions to machines or people. This is where automation and mechanization decisions are made. The final task places elements into a spatial arrangement. It parallels tasks at other levels of plant layout. (**Strategos inc., 2005; Quarter man, 1997**).

A satisfactory workstation facilitates tasks, provides privacy, and recognizes employees' individualities. Open-plan office design should help reduce the distractions of the open area and facilitate the occupants' tasks. A good workstation environment is created through the interaction of many elements and design strategies that include:

- i) Marking boundaries between public and private space;
- ii) Allowing personalization;
- iii) Providing work surfaces, furniture, and equipment appropriate to the occupant and his or her tasks.

When creating cell cubicles in workstation design, designers can use the following to modify the environment.

- a) Partitions (partial-height screens)
- b) Furnishings: chairs, desks, tables, storage units and work surfaces
- c) Windows
- d) Control systems
- e) Workstation size

- f) Location relative to important personnel and equipment
- g) Policies, status and recognition

a) **PARTITIONS**

Partitions are used in open-plan offices to create acoustic and visual privacy. They can provide a feeling of enclosure and mark the boundaries of an occupant's office space. Partitions are an excellent way to differentiate between public and private areas and should be used to block occupants off from the distracting interaction that occur in public spaces, such as corridors, meeting rooms, kitchens, break rooms, and space for communal equipment like a photocopiers and printers

b) **FURNISHINGS**

Office furnishing respond to employee's physical, task needs and recognition needs. A combination of two horizontal work surfaces, some storage space such as shelves or filing cabinets and a good chair tends to be satisfactory to most occupants. However, furnishing requirements will depend greatly on employees' tasks.

c) **WINDOW**

Most occupants prefer to have some access to a window to provide for access to:

- i) Daylight and ventilation.
- ii) View because it offers connection with the outside world and relaxing image.

d) **LAYOUT**

Layout refers to the organization and arrangement of workstations and equipment in an open-plan office. By creating a good arrangement, designers can improve the functionality and the environment of an open-plan office.

e) **ADJUSTABILITY AND CONTROL SYSTEMS**

All needs of the occupants in a cell depend on the individuals, the time of day, the activity and other factors that an office designer cannot control.

When providing the occupant with the adjustable furnishings and control systems consider the individual factors in order to increase occupant satisfaction. Designers can give control to the occupant by implementing personal lighting and ventilation controls, window blinds or shades, adjustable chairs, desks and shelves and moveable storage units. Both policies and actual control systems have to allow for adjustability. Most occupants are much more satisfied with some control over their personal environment, even when they can not change the base environment.

f) WORKSTATION SIZE AND BOUNDARIES

The most common complaints about open-plan offices relate to the size and boundaries of workstations. These may reflect conflicts between individual needs and management theories. For example, the desire to improve communication leads some organizations to have low panels or none at all. However, whether this design strategy promotes relevant communication or simply increases unwanted noise and distractions is questionable. More than half of professionals' time is spent at the computer and in quiet work requiring concentration which requires that they should not be distracted by extraneous conversations. Larger workstations with more floor area assure more privacy and greater environmental satisfaction. However, very large areas which the occupants consider unsatisfactory result in longer travel distances to shared resources and might contribute to feelings of social isolation.

g) POLICIES, STATUS AND RECOGNITION

Organizational policies contribute to employee recognition while creating a good social and working environment in open-plan offices. These policies can be as simple as allowing employees to display personal items in their cubicles, encouraging quiet office etiquette to keep noise levels down, and distributing desirable workstation features fairly. Office etiquette can be an important factor in reducing acoustic distractions. Organizations can also allow employees to contribute to office design and furniture selection both during the design process and afterwards. Good communication between employees and facility managers gives employees the opportunity to voice their needs.

Satisfaction is greater when designs match employees' expectations for their positions. Furthermore, environmental satisfaction, job satisfaction and well-being are greater when employees are permitted to personalize their workstations. Regardless of status issues, an investment in well-built, attractive furniture will pay off in increased comfort and satisfaction. Regular maintenance and cleaning are also important contributors to a good office environment because they influence aesthetic impressions of the space and show regard for employee well-being. **(Phillips, 1997; Quarterman, 1997; Skinner et al., 1974).**

2.6 CELL EVALUATION

Cell evaluation, cell balancing and cell costing are done in order to establish the capacity of the cell in relation to the demand. Costing will be done to determine the worth of the value added to the raw material for products costing.

2.6.1 CELL BALANCING

Cell balancing follows cell formation and involves allocating equitably the amounts of tasks to various stations or machines in a work cell. Cell balancing answer such questions as: how much output do we need? How much capacity does each station have? What is the total capacity of the cell?

Two types of balancing exist:

2.6.1.1 Static

2.6.1.2 Dynamic.

2.6.1.1 STATIC BALANCE

Static balance refers to long -term differences in the capacity of the cell covering several hours. Static imbalance results in under utilization of certain workstations, machines or people.

2.6.1.2 DYNAMIC BALANCE.

This is short-term variation in capacity that occurs over a period of few minutes, hours or days. Dynamic imbalance arises from product mix or variation in work time unrelated to product mix.

2.6.2 BALANCING PEOPLE AND EQUIPMENT

In balancing a work cell, it is necessary to balance people and machines separately because of the costs effects and the impact of each resource on the cell efficiency. Internal balancing refers to balancing resources within the cell. External balancing refers to balancing the cell with respect to external demand and supply.

2.6.2.1 BALANCING EQUIPMENT

In this balancing, each machine must have the same amount of work and maximum machine utilization. Maximizing machine utilization may lead to high work in progress inventory and poor delivery performance. Some of the equipment balancing methods include:

1. Inherent equipment balance;
2. Queuing for equipment;
3. Surplus machine capacity.

1. INHERENT EQUIPMENT BALANCE

This method aims at providing each workstation with the same amount of work. In high volume mechanized and automated assembly lines, it is difficult to achieve good balance because it is rare to find equipment with identical cycle times. In manual assemblies, it is possible because people are flexible.

Inherent equipment balanced line has a problem of inflexibility when new products are launched. The line requires be reconfiguring and rebalancing especially when multiple products run on the line and have different cycle times at some operations. The line needs to be stopped and re-balanced at each changeover. When the cycle time on a station is longer than average, it slows down the entire line .If the cycle time is less that average, it cannot speed up the process. This result in real performance being less than the average cycle time indicates. The more the number of stations, the more the variations in cycle times, and the more the performances will be affected.

2. QUEUING FOR EQUIPMENT

This is an approach where mean queues of work are allowed between the workstations as buffers for cycle-to-cycle variations to lessen the problems of inherent balancing system (Figure 2.13). Queuing increases the level of work in progress inventory especially with the increase in the workstation utilization rate and vice versa. With excessive variations in work times, the system chokes itself when work stations are underutilized.

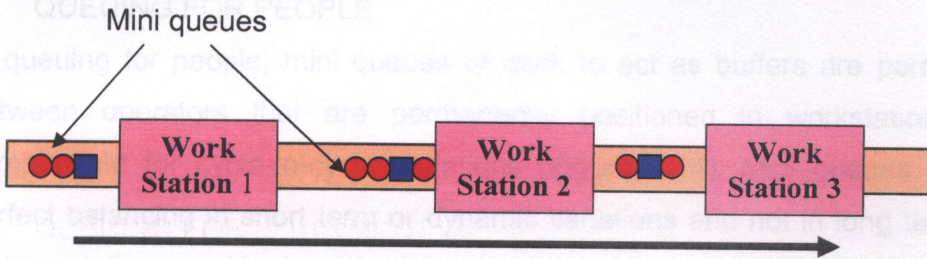


Figure 2.13: *mini queues*.

3. SURPLUS MACHINE CAPACITY

This means supplying an additional machine resource to a station in excess of the required capacity. A cell with surplus machine capacity may operate with far less internal work in progress inventory than a cell with balanced work times. In effect, the surplus capacity is a trade off for reduced work in progress inventory and fast throughput. This system is only constrained by the slowest operation, the bottleneck.

2.6.2.2 BALANCING PEOPLE METHOD

Balancing people in a cell is more important than balancing equipment because the hourly cost of a person is far greater than that of a machine or work station. Moreover, when there is variation in the workloads among people in a cell, people desert away from their teams. Balancing people in a cell differs from balancing equipment because people are flexible, mobile, can perform more than one task and can communicate. Some methods to balance people are:

1. Surplus people capacity;
2. Queuing for people;
3. Floating;
4. Circulation.

1. SURPLUS PEOPLE CAPACITY

Just like in balancing machines, surplus people capacity implies positioning extra person(s) where there is extra load due to variation in customer densities or demand rate. Surplus people capacity can also mean having one person with more workload than others can. This over loaded person becomes a bottleneck.

2. QUEUING FOR PEOPLE

In queuing for people, mini queues of work to act as buffers are permitted between operators that are permanently positioned in workstations to compensate for cycle-to-cycle variations (Figure 2.14). Mini queues make perfect balancing in short term or dynamic variations and not in long term or static variations.

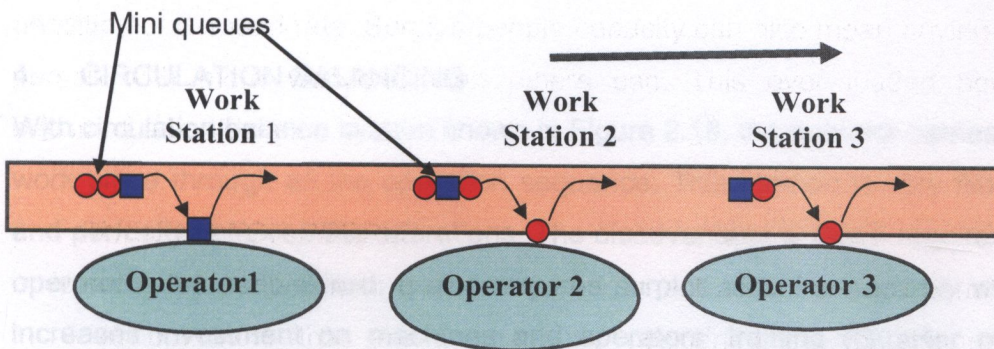


Figure 2.14: *queuing for people balance.*

3. FLOATING BALANCING

This is a balancing method combined with queuing. The operators monitor the queues of work at each workstation to determine which workstation is working ahead and fast reducing the queues and that workstation falling behind. The operator moves to a station that is falling behind to assist until that work station catches up. This requires that each work station allow multiple operators. Figure 2.15 shows how the operators shift position in floating balancing to assist falling stations.

Figure 2.15: *circulation balance*

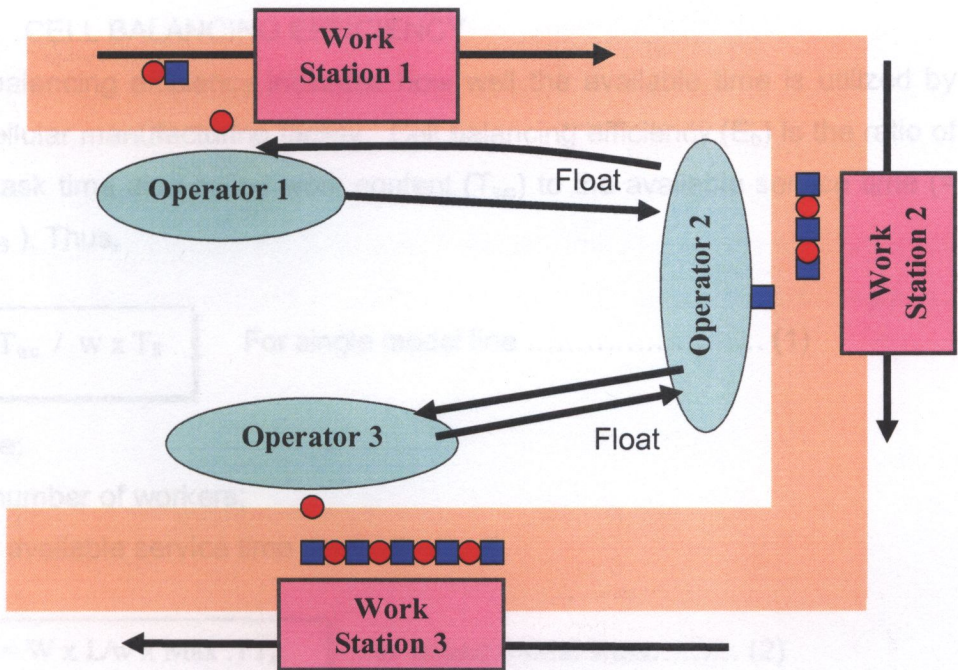


Figure 2.15: *floating and circulation balance.*

4. CIRCULATION BALANCING

With circulation balance system shown in Figure 2.16, the operator carries the work piece through all the operation sequence. This method is very flexible and perfectly balances the operations. The disadvantage is that it requires an operator to be multi-skilled. It also requires surplus machine capacity which increases investment on machines and operators' training (Quarter man, 2000)..

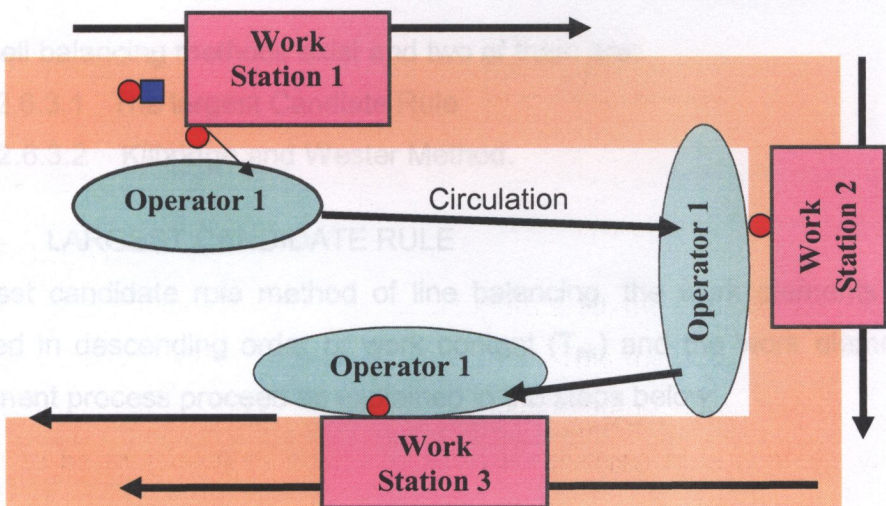


Figure 2.16: *circulation balance.*

2.6.3 CELL BALANCING EFFICIENCY

Cell balancing efficiency indicates how well the available time is utilized by the cellular manufacturing facility. Cell balancing efficiency (E_b) is the ratio of total task time also called work content (T_{wc}) to the available service time ($= w \times T_s$). Thus,

$$E_b = T_{wc} / W \times T_s \quad \text{For single model line (1)}$$

Where:

W = number of workers;

T_s = available service time per worker and,

$$E_b = W \times L / w \times \text{Max} .TT_{si} \quad \text{For mixed model lines..... (2)}$$

Where: E_b = balance efficiency for mixed model line

WL = work load = Σ production rate of each model *work content for the model.

W = number of workers = number of stations
(when manning level = 1)

$\text{Max} .TT_{si}$ = maximum value of the total service time among all stations.

Many cell balancing methods exist and two of them are:

2.6.3.1 The largest Candidate Rule

2.6.3.2 Kilbridge and Wester Method.

2.6.3.1 LARGEST CANDIDATE RULE

In largest candidate rule method of line balancing, the work elements are arranged in descending order of work content (T_{ek}) and the work elements assignment process proceed as explained in the steps below:

STEP 1:

Assign the work elements to the worker at the first workstation beginning at the top of the list, selecting the first elements that satisfies the precedence requirements and does not cause the total sum of Work Content (T_{ek}) values at the station to exceed the allowable Service Time (T_s). When an element is selected for assignment to the station, start back at the top of the subsequent assignment.

STEP 2:

When no more elements can be assigned without exceeding T_s , then proceed to the next station.

STEP 3:

Repeat steps 1 and 2 for other stations until all elements have been assigned.

2.6.3.2 KILBRIDGE AND WESTER METHOD.

This method has become a popular heuristic line balancing system that selects work elements for assigning to work stations following their position in the precedent diagram. The elements continue to be assigned to the station until full capacity is reached and if more work elements are still to be assigned, they go to the next station. It is similar to the largest candidate rule in work element assignment procedure. In this method assignment of work element is irrespective of their order of size (**Wild, 1987**).

2.6.4 DATA FOR CELL BALANCING

The data required for cell balancing is: cycle time, annual demand, work content, machine capacities and manning levels. To obtain this information market survey, work measurement and machine performance have to be determined. Cycle Time is the total elapsed time to move a work piece from the beginning to the end of a physical process as agreed or determined by the customer. Cycle time includes process time and delay time. Cycle time can also be fixed by the demand rate of the products. To determine the cycle time, the total work content (time) for the item need to be measured.

The appropriate method used to determine the work content time is work measurement or time study. The cell balancing information can be used to determine the number of machines required and manning levels iteratively until level capacity utilization is reached (Bently, 2006).

2.6.5 COST EVALUATION

The objective of cost evaluation is to determine the worth of the designed facility in terms of the cost of the value it adds to the raw materials and the viability of investing in the facility.

When assessing how much value the facility imparts to the raw materials, the cost of the capital (fixed cost); the variable cost (materials, energy, labor) and the associated overhead costs must be included. The knowledge of these costs is required to appraise the facility; to determine its break even point and the pay back period.

Some of the appraisal methods that are commonly used include:

2.6.5.1 Net Present Value

2.6.5.1 Payback Period

2.6.5.1 NET PRESENT VALUE (NPV)

This is the investment appraisal method where all the projected cash in flows and out flows are discounted to the present value at an appropriate discount rate usually the borrowing rate. The present values of the cash flows are summed up to get the Net Present Value (NPV). If the NPV is equal to zero, the facility breaks even. If the NPV is more than zero, then the facility is profitable. If the NPV is less than zero, then the facility is loss making. The NPV formula is:

$$\boxed{NPV = A \cdot (1 + r)^{-n}} \dots\dots\dots(1)$$

Where: A = Cash in/out flow
r = discount rate
n = number of discount period

2.6.5.2 PAYBACK

This is an investment appraisal method where the period it takes to recover the capital of the investment by the stream of cash receipts flowing from the investment is calculated. The period it takes to recover the capital is called the pay back period. The length of the pay back period determines the acceptability of the investment. The decision to be made on the viability of the investment depends on the permissible time to tie up the capital in the project. Payback period is calculated using the formula:

Pay back period = cost of the investment / projected annual net cash in flow

The choice of the appraisal method depends on the type of information required to make decision. If the emphasis is monetary, then the NPV method is appropriate. If it is on how long it takes to recoup the investment, then the payback method is better. One or both investment appraisal methods can be used. **(Millichamp, 1997; Francis, 1988).**

CHAPTER 3

MARKET SURVEY AND PART FAMILY FORMATION

3.1 INTRODUCTION

This chapter discusses the methodology used to identify, select and collect data on the types of copper products and their demand rates per week. The chapter describes how the part families for the copper parts were formed. The method used to form cells is also presented. The chapter gives the preliminary activities done before the cell design process, whose details are presented in chapter 4.

3.2 COPPER PRODUCT IDENTIFICATION.

In order to identify the copper products to be used in this research, a pilot market research was conducted. To ensure normality in the distribution of the pilot collected data, more than 30 questionnaires (Appendix A) were used. However, these questionnaires gave respondents problems to complete due to the long structured questions and essay type of answering. In the revised version of the questionnaire (Appendix B), the questions were made short and answering was made easy by simply ticking the appropriate answer. The selection of the copper products was as described in section 3.3.

3.3 COPPER PRODUCTS SELECTION

The selection criteria for the copper products were the market value and the demand rate per week. The products with higher market value were selected. The selected products are shown in table 3.1.

3.4 THE APPROACH TO THE RESEARCH

The initial approach to the research was to proceed as follows: questionnaire design. Data collection; data summarization and analysis; cellular facility design and cellular facility evaluation. After realizing that it was necessary to collect as much data as possible in one survey, then the research approach was changed to: begin with a pilot market survey and design a pilot cellular facility research model. This pilot market survey was also meant to provide input data for the design of the pilot cellular facility research model.

The design of the pilot cellular facility research model at this stage was meant to sharpen the focus of data collection methodology and broaden the scope of data to be collected in the field to lessen the number of data collection journeys.

Table 3.1: *selected copper products. (Note: as at May 2006)*

No.	Copper products selected	Weekly Demand	Price (as at May 2006)	Value K' 000
1	Cooker Switch units	1538	45000	69,210
2	Adapters	2636	25000	65,900
3	Bonding strips	805	65000	52,325
4	Fuses 50A ,100A	3889	10000	38,890
5	Copper connector	2489	15000	37,335
6	Bulb holders	6955	5000	34,775
7	Sockets	3361	10000	33,610
8	Switches	2929	10000	29,290
9	Stator contacts	1417	20000	28,340
10	Earth rods	1245	15000	18,675
11	Battery cables	439	38500	16,902
12	Top plugs	2929	5000	14,645
13	Cable lugs	1025	12500	12,813
14	Block Connectors	1245	8500	10,583
15	Battery terminals	828	12500	10,350
16	Copper washers	694	3000	2,082
17	Neutral bars	1245	1500	1,868
18	Stator bushes	467	3500	1,635
19	Cable lugs	389	3500	1,362
Total value per week				K 488,000

The outcome of the pilot research encouraged changing the course of the main research that was then divided into three stages as illustrated in Figure3.1.

- Stage 1: Designing of a pilot cellular facility design: This was a research model for the main research.
- Stage 2: secondary or main researches – country wide sampling
- Stage 3: Final cellular facility design. These involved cells re-design, data collection for cell balancing evaluation, cost, and benefits analysis.

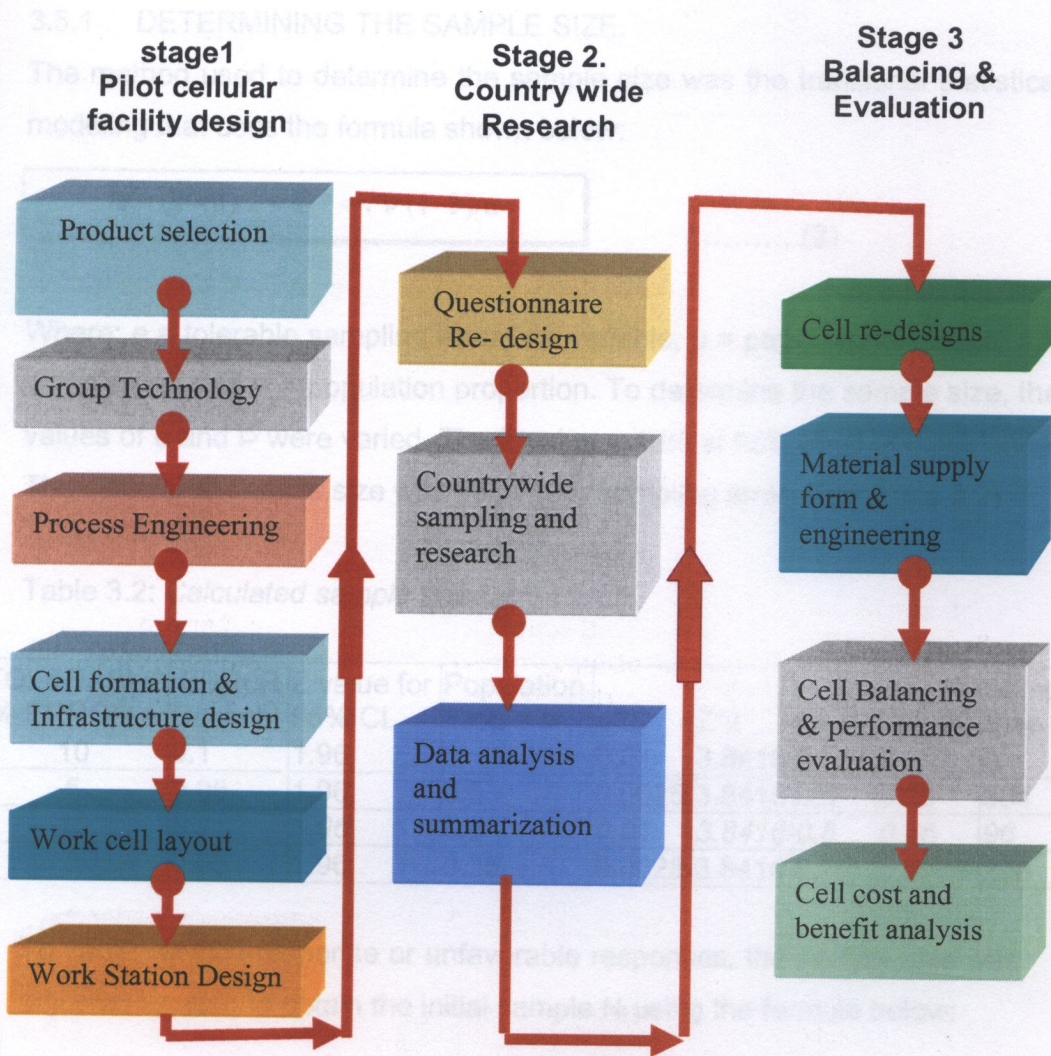


Figure 3.1: Approach to the research.

3.5 DATA COLLECTION AND SAMPLING METHODS.

The sampling frame was within the Zambian boundaries. The sampled subjects were scattered all over the country. The appropriate sampling method was multistage sampling. This method involved dividing the country into local authority areas (provinces and districts) and select sample subjects from the selected areas. This sampling strategy has the advantage of being representative enough and requiring small samples, thus economizing on sampling costs. From within the chosen district, a required number of distribution centers like shops were chosen. The Provinces sampled were: Lusaka, Copperbelt, Western, Central and Southern and the selected districts were: Lusaka, Kitwe, Ndola, Mongu, Livingstone and Mazabuka.

3.5.1 DETERMINING THE SAMPLE SIZE.

The method used to determine the sample size was the traditional statistical modeling that uses the formula shown below:

$$e = (x - \mu)/2 = Z * \sqrt{P(1-P)/n} \dots\dots\dots(2)$$

Where: e = tolerable sampling error, x = variable, μ = population average, n = sample size and P = population proportion. To determine the sample size, the values of e and P were varied. The Z value = 1.96 at 95% level of confidence. The calculated sample size was 96 at 10% sampling error. (See table 3.2)

Table 3.2: Calculated sample sizes.

TOLERABLE % ERROR e	ERROR Decimal	Z value for 95% CL	Population Prop = P	e*2	Z*2	(1- P)	P(1- P)	Sample Size = n
10	0.1	1.96	1	0.01	3.8416	0	0	0
5	0.05	1.96	0.5	0.0025	3.8416	0.5	0.25	384
10	0.1	1.96	0.5	0.01	3.8416	0.5	0.25	96
5	0.05	1.96	0.25	0.0025	3.8416	0.75	0.1875	288

To cater for non-response or unfavorable responses, the sample size was adjusted upward to obtain the initial sample Ni using the formula below:

$$N_i = \frac{2X + Z(ZQ + \sqrt{\{(ZQ)^2 + 4Q\}}}{2P} \dots\dots\dots(3)$$

Where:
 Ni = initial sample,
 X = required sample size = 96.
 P = (The incidence proportion for the characteristics) x (the response rate).
 The incidence proportion for characteristic defines the probability that a sampled place will have a characteristic being looked for i.e. in this study the presence of discrete copper product = 0.5 (50%). The estimated response rate was 100% since the questionnaires were physically delivered.

$P = 0.5 * 100\% = 0.5$, $Q = 1 - P = 0.5$ and $Z = 1.96$ for a 95% confidence level. Replacing these values in formula (5) and simplify gave the initial sample, $N_i = 196$.

The required number of sample size per selected district were calculated out of the total of 196 proportionate with the people's population density in the district and the results are as shown in table 3.3. However, when the actual sampling was done the actual samples sizes and the targeted sample sizes varied.

Table 3.3: Targeted sample sizes in each town.

TOWN	People population as @2000 census	Targeted Sample Size
Mazabuka	240116	17
Mongu	166609	12
Kafue	162262	11
Kabwe	178341	13
L/Stone	158149	11
Lusaka	1103413	77
Ndola	393793	28
Kitwe	388646	27
TOTAL	2791329	196

3.5.2 SAMPLE VARIANCES

The actual sample sizes from each town showed variances with the targeted sample sizes as indicated in the table 24. The variances in the samples were due to the skewness in the distribution of copper products demand rates where some areas with more people buy less copper products. The survey revealed that more copper products buying business in the country is done in Lusaka than in the combined sampled towns. At the same time, it was difficult to get more respondents in Lusaka to compensate the shortfall from other towns because of low responses.

Table 3.4. *Variances in the sample sizes.*

TOWN	Targeted Sample Size	Sample Size taken	% Sample Size actual	Variances	% Variances
Mazabuka	17	7	4	-10	5
Mongu	12	12	6	0	0
Kafue	11	3	2	-8	4
Kabwe	13	10	5	-3	1
L/Stone	11	16	8	5	2
Lusaka	77	64	33	-13	7
Ndola	28	16	8	-12	6
Kitwe	27	23	12	-4	2
Total	196	151	77	-45	23

The data for the copper products demand rates was collected (see table 3.5) using the questionnaires shown in Appendix II.

3.6 MARKET SURVEY FINDINGS

- a) The sample size coverage in the data collection was 157 (77%).
- b) When collecting the data, the opinions of people on the following questions were collected:

Question 1: What do you think Zambia should do with its copper produced locally: continue exporting or process copper into final products locally?

Question 2: Are you willing to buy or use locally produced copper final products?

The objectives of collecting people's opinions were to establish acceptability of the locally produced products and people' opinions on exporting raw copper without adding value. It was observed that 94.04% (142 out of 151) of dealers in copper products were willing to buy and sale locally manufactured copper products as long as the quality was assured. The majority of the respondents (93.9% or 138 out of 147) were not in favor of Zambia continuing to export copper as raw material.

Table 3.5: Copper products demand rates.

Products	Towns	Mazabuka	Mongu	Kafue	Kabwe	L/Stone	Lusaka	Ndola	Kitwe	Total	Corrected Totals = Total/77%
Adapters		10	50	30	65	75	915	190	145	1480	1922
Block Connector		40	45	10	25	75	990	80	100	1365	1773
Bonding Strip		50	20	10	65	105	500	90	140	980	1273
Bulb Holder		50	110	105	130	185	1200	240	320	2340	3039
Battery Terminal		10	5	0	115	115	380	95	100	820	1065
Cable Lug		30	30	30	25	140	1200	170	350	1975	2565
Cooker Switch Units		20	40	35	55	50	595	190	175	1160	1506
Copper Connectors		20	45	10	125	95	840	185	275	1595	2071
Copper Washers		10	5	0	15	45	360	60	75	570	740
Earth Rods		20	35	15	65	65	815	95	135	1245	1617
Fuses		10	5	0	105	155	500	20	14	809	1051
Neutral Blocks		40	55	15	20	40	965	75	95	1305	1695
Starter Bushes		10	5	0	45	115	355	40	50	620	805
Stator Contacts		20	10	0	15	115	385	80	95	720	935
Sockets		50	90	65	145	185	1225	240	235	2235	2903
Switches		50	70	65	145	185	1195	265	275	2250	2922
Top Plugs		50	60	105	145	185	1250	335	240	2370	3078
Sample size (n)		7	12	3	10	16	64	16	23	151	

3.7 PART FAMILY FORMATION

The selected copper products were dismantled and the component parts (Appendix G) were grouped according to similarities in geometry and manufacturing attributes. Poly or chain code classification system was used. The major benefit of this coding and classification system is that the copper-parts were easily identified with their respective products. The product initials were used, e.g. Cooker Switch Unit was abbreviated as CS as part of the code (Table 3.6). Each copper part was identified with the serial number (01 to 67) and part families (F1 to F10) as illustrated in Table 3.7. The formation of part-families reduced the part groups to 10 making it possible to apply the part family- machine grouping algorithm.

Table 3.6: Copper Product Abbreviation.

PRODUCT	ABBREVIATION	PRODUCT	ABBREVIATION
Adapter	AD	Earth Rods	ER
Block Connector	BC	Fuse	FS
Bonding Strip	BS	Neutral Block	NB
Bulb Holder	BH	Starter Bush	SB
Battery Terminal	BT	Socket	SCT
Cable Lug	CL	Switch	ST
Copper Connectors	CC	Top Plug	TP
Cooker Switch Units	CS	Stator Contact Diesel	SC
Copper Washers	CW	Stator Contact Petrol	SC

Table 3.7: Copper Product Part Families and their codes.

FAMILY	CODE	FAMILY	CODE	FAMILY	CODE	FAMILY	CODE
F1	AD 1	F1	ST 18	F2	CS 35	F4	BC 52
F1	AD 2	F1	SC 19	F2	CS 36	F4	ER 53
F1	AD 3	F1	SC 20	F3	SC 37	F4	BT 54
F1	AD 4	F1	SC 21	F3	ER 38	F4	BT 55
F1	AD 5	F1	ST 22	F3	BT 39	F4	BT 56
F1	AD 6	F2	CS 23	F3	BT 40	F5	ER 57
F1	AD 7	F2	ST 24	F3	TP 41	F6	BT 58
F1	CL 8	F2	CS 25	F3	NB 42	F6	CC 59
F1	CS 9	F2	SCT 26	F3	SCT 43	F6	SC 60
F1	CS 10	F2	SCT 27	F3	TP 44	F7	CS 61
F1	CS 11	F2	TP 28	F4	BH 45	F7	ST 62
F1	CS 12	F2	TP29	F4	NB 46	F8	BH 63
F1	CS 13	F2	CS30	F4	SCT 47	F9	BS 64
F1	CS 14	F2	SCT31	F4	TP 48	F9	CW 65
F1	FS 15	F2	SCT 32	F4	TP 49	F10	CC 66
F1	SCT 16	F2	SCT 33	F4	TP 50	F10	SB 67
F1	SCT 17	F2	CS 34	F4	TP 51		

3.8 PROCESS ENGINEERING

The approach used to establish the process engineering was the Production Flow Analysis. Production Flow Analysis (PFA) is a comprehensive method applied in cellular manufacturing to:

- 1 Analyze the material flow;
- 2 Form part families;
- 3 Design manufacturing cells and
- 4 Layout the cellular facility

In this research, Production Flow Analysis made it possible to identify the following: technological process; machines required to process the copper parts; and copper part – families. The identification process involve following up the sequence of the technological process for each copper part.

The copper parts with similar technological process and passing through similar sets of machines were group as parts that belong to one family. This process led to formation of 10 processing machines and the 67 copper parts presented in this research were grouped into 10 part-families. This data was summarized into a 10 X 10 Part-Machine Incidence Matrix shown in Table 3.8. *The tasks that follow this process are: assign part – families to machines and grouping machines performing related functions to form part-machine clusters or cells.*

Table 3.8: part- machine incidence matrix.

Part Families	Machines									
	DRAW	PS	LT	DR	TH	RV	PN	GL	MC	GR
F1	1						1			
F2	1					1	1			
F3					1		1	1		
F4		1			1				1	1
F5		1	1		1					
F6		1		1	1		1			
F7		1	1	1	1					
F8				1	1		1	1		
F9							1			
F10		1	1	1						

Where:

- | | |
|-------------------------|-----------------------|
| RV = Riveting machine | PN = Punching machine |
| DRAW = Drawing Machine | LT = Lathe machine |
| GR = Grinding machine | PS = Power Saw |
| TH = Threading machine | DR = Drilling machine |
| GL = Guillotine machine | MC = Milling machine |

3.9 CELL FORMATION METHOD.

The method chosen to form the part-machine cluster was the Ranking Order-Clustering Algorithm. This algorithm has the advantage of being able to assign parts to processing machines at the same time it is grouping the machines into cells. In this research 10 part- families were assigned to respective 10 processing machines to form the part – machine cluster. After part family-machine clusters were formed, the machines were placed in the processing sequence. The activity following machine sequencing is cellular

layout. Cellular layout describes the shape taken by the sequenced machines. Chapter 4 explains how the cells were formed.

Table 4.1 *part-machine incidence matrix.*

Part Family Parks	Machines										2^j
	DRAW	PS	LT	DR	TH	RV	PN	GL	MC	GR	
	2^1	2^2	2^3	2^4	2^5	2^6	2^7	2^8	2^9	2^{10}	
F1	1						1				2^1
F2	1					1	1				2^2
F3					1		1	1			2^3
F4		1			1				1	1	2^4
F5		1	1		1						2^5
F6		1		1	1		1				2^6
F7		1	1	1	1						2^7
F8				1	1		1	1			2^8
F9							1				2^9
F10		1	1	1							2^{10}

Table 4.2: ranked *matrix after first stage of ranking the incidence matrix.*

Part Family Parks	Machines									Ranked W_i	
	RV	DRAW	MC	GR	GL	PN	TH	LT	PS		
F9						1					128
F1		1				1					132
F2	1	1				1					134
F3					1	1	1				224
F4			1	1			1			1	344
F6						1	1			1	448
F5							1	1	1		832
F7							1	1	1		832
F8					1	1	1				1248
F10								1	1		1792
W_i	4	6	16	16	264	504	846	1184	1264		

Table 4.3: Ranked matrix after second and third stage of ranking.

Part Family Parks	Machines										Ranked W_j
	RV	DRAW	MC	GR	GL	PN	TH	LT	PS	DR	
F9						1					64
F1		1				1					68
F2	1	1				1					70
F3					1	1	1				224
F4			1	1			1		1		664
F5							1	1	1		896
F8					1	1	1			1	1248
F6						1	1		1	1	1728
F10								1	1	1	1792
F7							1	1	1	1	1920
Ranked W_j	8	12	32	32	528	606	1008	1408	1504	1856	

Table 4.4: partitioned cells.

part Family Parks	Machines									
	RV	DRAW	MIL	GR	GL	PN	TH	LT	PS	DR
F9						1				
F1		1	CELL 1			1				Common zone
F2	1	1				1				
F3					1	1	1			
F4			1	1			1		1	
F5							1	1	1	CELL 2
F8					1	1	1			1
F6						1	1		1	1
F10								1	1	1
F7							1	1	1	1

4.3 ADJUSTMENTS TO THE PART-MACHINE CLUSTERS

At the final stage of ranking (Table 4.3 and Table 4.4), a common zone was created. This zone suggested that:

- i) Either part families F3 and F4 were to be processed in cell 1 and cell 2 permitting intercellular movements

- ii) Guillotine and Punching machines need to be duplicated in cell 1 and cell 2.

The choice between permitting intercellular movements and duplicating machines in the cells depend on available initial capital and the cost of material handling during parts transportation. It was opted in this design to permit intercellular travel between cell 1 to cell 2. However to minimize on the intercellular travels and to minimize on the number of machines, the primary cutting of part family F8 was assigned to the power saw instead of the Guillotine. The assignment of part family F8 eliminated the need of duplicating the Guillotine machine in cell 2.

Further, part family F3 that were assigned to be punched in cell 1 was assigned to be punched in cell 2 in order to reduce overloading punching machine in cell 1. Also, in order to lessen intercellular travel for part family F4, the milling machine and the grinding machine were re allocated to cell 2 from cell 1. These adjustments improved the part – machine clusters by reducing intercellular movements and the number of machines. The improved part-family clusters are shown in Table 4.5 and Table 4.6.

Table 4.5: *Cell 1 cluster.*

M/Cs	GL	PN1	RV	DRAW
F1	1	1		1
F2	1	1	1	1
F3	1			
F4				
F9	1	1		

Table 4.6: Cell 2 cluster.

M/Cs	PS	PN 2	Mil	LT	DR	TH	GR
F3						1	
F4	1		1	1		1	1
F5	1	1		1		1	
F6	1	1			1	1	
F7	1			1	1	1	
F8	1	1			1		
F10	1			1	1		

The machines in Table 4.5 and Table 4.6 needed to be laid out in the order of parts processing sequence. This is the cellular layout activity illustrated below.

4.4 CELLULAR LAYOUT

The considerations made when deciding on the layout of the cell included: number of workstations, proximity of workers, distances parts must flow and where the parts from the cell must go. In this research, the U-shaped cell arrangement was chosen because it encourages proximity of workers thereby promoting teamwork and parts flow distances are short. Figures 4.1 and 4.2 illustrate the cellular layout for cell 1 and cell 2, respectively. Production Flow Analysis was used to sequence the machines.

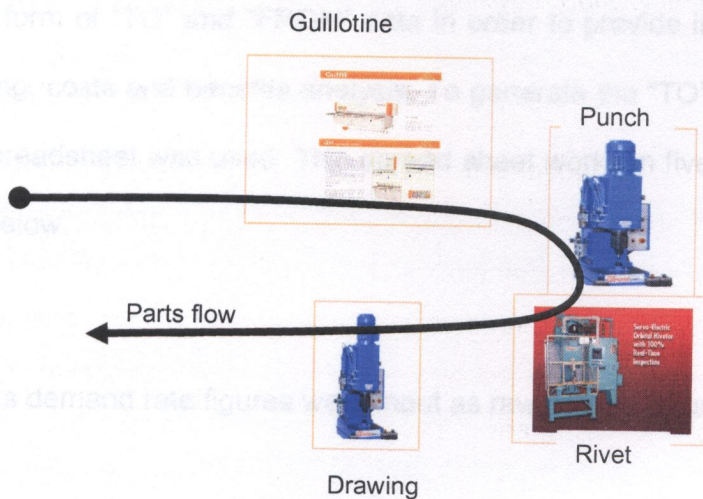


Figure 4.1: Cellular layout for cell 1.

Table 4.7. Data in our study

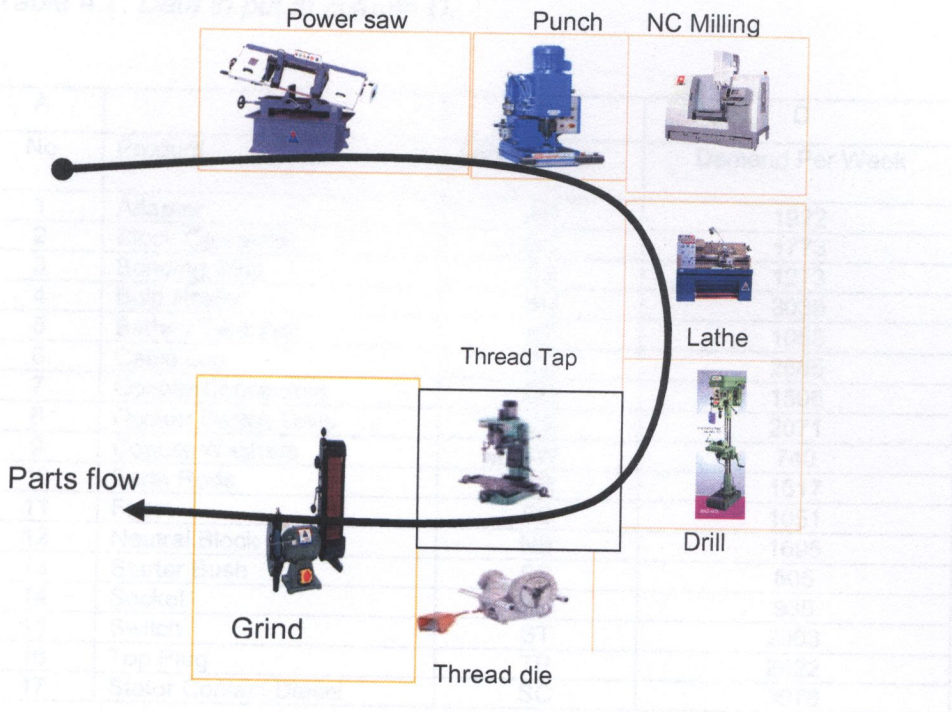


Figure 4.2: Cellular layout for cell 2.

Column D figures of Table 4.7 were posted to column G (Table 4.8 and Table

4.5 COPPER PARTS FLOW RATES

The data on parts flow rates was used to describe the total numbers of copper piece-parts in each product that pass through a workstation or machine per hour in the form of "TO" and "FROM" data in order to provide information for cell balancing, costs and benefits analysis. To generate the "TO" and "FROM" data, the spreadsheet was used. This spread sheet works in five (5) levels as described below.

Level 1:

The products demand rate figures were input as raw data in column D of Table 4.7.

Table 4.7: Data in put in column D.

A	B	C	D
No	Product	Abbreviation	Demand Per Week
1	Adapter	AD	1922
2	Block Connector	BC	1773
3	Bonding Strip	BS	1273
4	Bulb Holder	BH	3039
5	Battery Terminal	BT	1065
6	Cable Lug	CL	2565
7	Copper Connectors	CC	1506
8	Cooker Switch Units	CS	2071
9	Copper Washers	CW	740
10	Earth Rods	ER	1617
11	Fuse	FS	1051
12	Neutral Block	NB	1695
13	Starter Bush	SB	805
14	Socket	SCT	935
15	Switch	ST	2903
16	Top Plug	TP	2922
17	Stator Contact Diesel	SC	3078

Level 2:

Column D figures of Table 4.7 were posted to column G (Table 4.8 and Table 4.10) and later assigned to respective product components. The number of copper parts (column I) were calculated by multiplying column G by the number of parts per product indicated in column H. To obtain the number of parts per hour in column J, column I was divided by number of working hours per week = 35 (equal to 5 working days per week x 7 hours per day permitting 1 hour for workers and machines to rest per 8 hours shift in a day).

Level 3:

This level assigned the copper components to respective machines as indicated in columns K, L, M and N in Table 4.8 and Table 4.10.

Level 4:

This level summed up the total number of components assigned to each machine to give the "TO" and "FROM" data shown in table 4.9 and table 4.11.

Table 4.8: Parts flow rate data for cell 1.

E Part Family	F Part Code	G Product Qty	H Quantity Per Product	I Per Week	J Per Hour	Machines			
						K GL	L PN	M RV	N DRAW
F1	AD1	1922	1	1922	55	55	55		55
F1	AD2	1922	4	7688	220	220	220		220
F1	AD3	1922	1	1922	55	55	55		55
F1	AD4	1922	8	15377	439	439	439		439
F1	AD5	1922	1	1922	55	55	55		55
F1	AD6	1922	2	3844	110	110	110		110
F1	AD7	1922	1	1922	55	55	55		55
F1	CL8	2565	1	2565	73	73	73		73
F1	CS9	2071	2	4143	118	118	118		118
F1	CS10	2071	1	2071	59	59	59		59
F1	CS11	2071	1	2071	59	59	59		59
F1	CS12	2071	1	2071	59	59	59		59
F1	CS13	2071	1	2071	59	59	59		59
F1	CS14	2071	1	2071	59	59	59		59
F1	FS15	1051	1	1051	30	30	30		30
F1	SCT16	935	1	935	27	27	27		27
F1	SCT17	935	1	935	27	27	27		27
F1	ST18	2922	2	5844	167	167	167		167
F1	SC19	935	2	1870	53	53	53		53
F1	SC20	935	1	935	27	27	27		27
F1	SC21	935	1	935	27	27	27		27
F1	ST22	2922	2	5844	167	167	167		167
F2	CS23	2071	2,2	5753	164	164	164	164	164
F2	ST24	2922	2	5844	167	167	167	167	167
F2	CS25	2071	1	2071	59	59	59	59	59
F2	SCT26	935	1	935	27	27	27	27	27
F2	SCT27	935	1,1	8513	243	243	243	243	243
F2	TP28	3078	1	3078	88	88	88	88	88
F2	TP29	3078	1	3078	88	88	88	88	88
F2	CS30	2071	2	4143	118	118	118	118	118
F2	SCT31	935	2	1870	53	53	53	53	53
F2	SCT 32	935	1	935	27	27	27	27	27
F2	SCT 33	935	1	935	27	27	27	27	27
F2	CS34	2071	2	4143	118	118	118	118	118
F2	CS35	2071	1	2071	59	59	59	59	59
F2	CS36	2071	1	2071	59	59	59	59	59
F3	SC37	935	2	1870	53	53			
F3	ER38	1617	1	1617	46	46			
F3	BT39	1065	1	1065	30	30			
F3	BT40	1065	2	2130	61	61			
F3	TP41	3078	24,2,4,2,2	62052	1773	1773			
F3	NB42	1695	5,10,3	23279	665	665			
F3	SCT43	935	5,5,4,2,6	34695	991	991			
F3	TP44	3078	1	3078	88	88			
F9	BS64	1273	1	1273	36	36	36		
F9	CW65	740	1	740	21	21	21		

Table 4.9: TO” and “FROM” data for cell 1.

		TO					
FROM	Machines	GL	PN	RV	DRAW	CELL 2	Total
	GL	58	58			3708	3823
	PN		58	1298	2000		3356
	RVT			1298	1298		2597
	DRAW				0		0
	Total	58	9068	2272	2886	3708	9776

Table 4.10: Parts flow rate data for cell 2.

E	F	G	H	I	J	K	L	M	N	O	P	
Part Family	Part Code	Product Quantity	parts per Product	Parts/wk	Parts/hr	Machines						
						PS	PN	MIL	LT	DRIL L	THT	GR
F3	SC37	935	2	1870	53		53				53	
F3	ER38	1617	1	1617	46		46				46	
F3	BT39	1065	1	1065	30		30				30	
F3	BT40	1065	2	2130	61		61				61	
F3	TP41	3078	(34)	62052	1773		1773				1773	
F3	NB42	1695	(18)	23279	665		665				665	
F3	SCT43	935	(22)	34695	991		991				991	
F3	TP44	3078	1	3078	88		88				88	
F4	BH45	3039	2	6078	174	174		174			174	174
F4	NB46	1695	1	1695	48	48		48			48	48
F4	SCT47	935	3	2805	80	80		80			80	80
F4	TP48	3078	1	3078	88	88		88			88	88
F4	TP49	3078	1	3078	88	88		88			88	88
F4	TP50	3078	1	3078	88	88		88			88	88
F4	TP51	3078	1	3078	88	88		88			88	88
F4	BC52	1773	12	21273	608	608		608			608	608
F4	ER53	1617	1	1617	46	46		46			46	46
F4	BT054	1065	1	1065	30	30		30			30	30
F4	BT55	1065	1	1065	30	30		30			30	30
F4	BT56	1065	1	1065	30	30		30			30	30
F5	ER057	1617	1	1617	46	46			46		46	
F6	BT58	1065	2	2130	61	61	61			61	61	
F6	CC59	1506	2	3013	86	86	86			86	86	
F6	SC60	935	2	1870	53	53	53			53	53	
F7	CS61	2071	4	8286	237	237			237	237	237	
F7	ST62	935	3&4	4545	130	130			130	130	130	
F8	BH63	3039	2	6078	174	174	174			174		
F9	BS64	1273	1	1273	36							
F9	CW65	740	1	740	21							
F10	CC66	1506	1	1506	43	43			43	43		
F10	SB67	805	1	805	23	23			23	23		

Table 4.11: "TO" and "FROM" DATA FOR CELL 2.

		TO								
		Machines	PS	PN	MIL	LT	DRILL	THR	GR	Total
FROM	CELL 1			3708						3708
	PS		2252	374	1399	479				4504
	PN					479	374	3708		4561
	MIL							1399		1399
	LT						433	46		479
	DRILL							567		567
	THR								1399	1399
	GR									0
	Total		2252	4082	1399	958	807	5721	1399	16618

Level 5.

The "TO" and "FROM" data for each cell were posted to the respective cellular layout to show the parts flow rate per machine per hour as indicated in figure 4.3 and figure 4.4

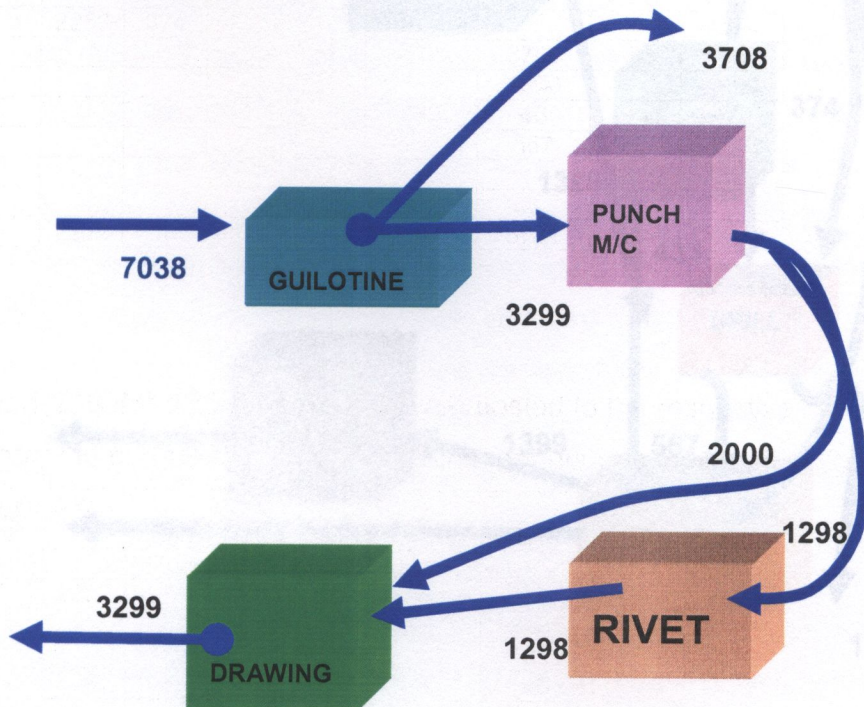


Figure 4.4: Parts flow rates per hour for cell 1

Figure 4.3: Cellular layout and parts flow rate per hour for cell 1

The designed cellular facilities do not consider the number of working machines per station. The facilities only indicate the number of parts passing a given workstation per hour. The process of determining the number of machines required per station is presented in chapter 5 that discusses the process of evaluating the manufacturing cell.

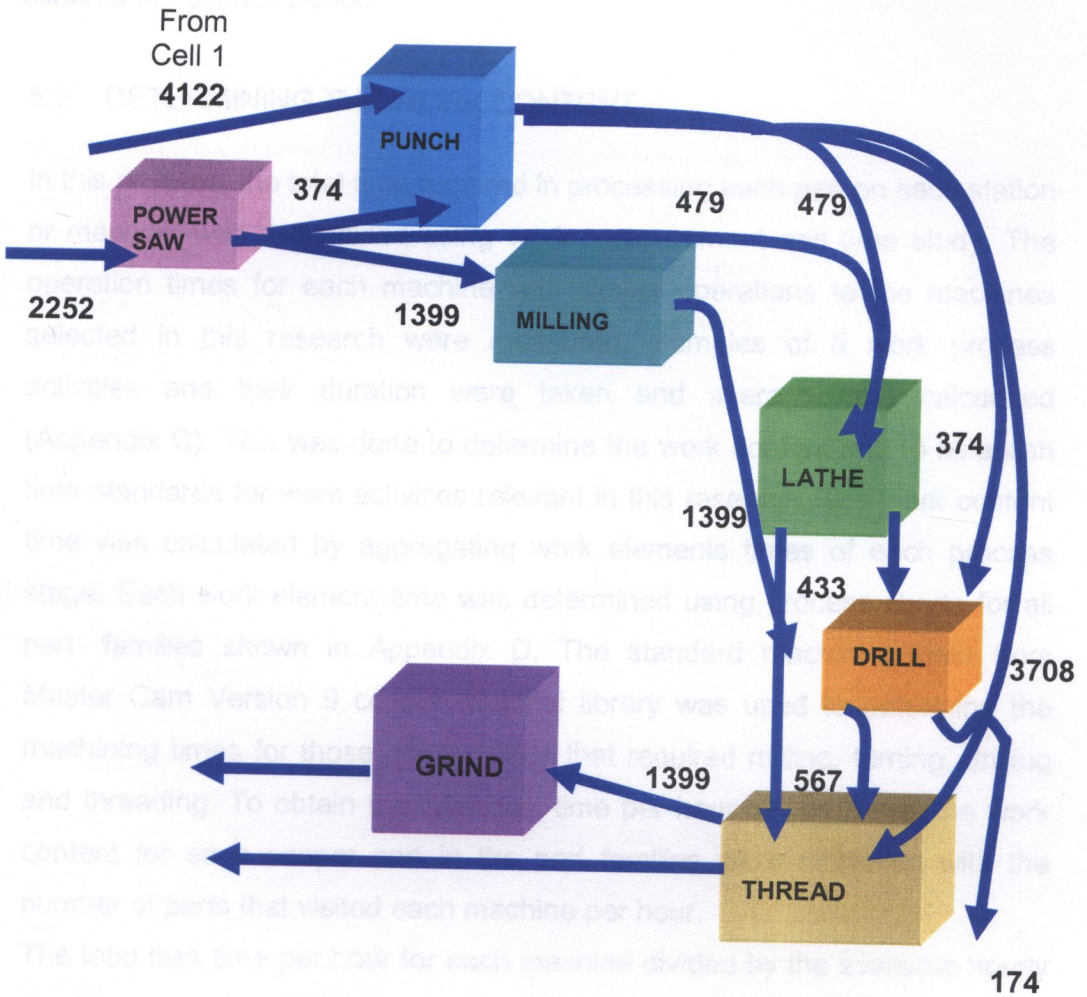


Figure 4.4: Parts flow rates per hour for cell 2.

CHAPTER 5

EVALUATING THE DESIGNED CELLULAR FACILITY

5.1 INTRODUCTION

This chapter discusses the cellular facility evaluation procedures. The chapter focuses on cell balancing, cost and benefits analysis. The method used to generate the preliminary data for costing and cell balancing is presented. The focus of costing is to appraise the cells. The method used in the appraisal scheme is Payback period.

5.2 DETERMINING THE WORK CONTENT.

In this process, the total time required in processing each part on each station or machine was determined using work measurement and time study. The operation times for each machine with similar operations to the machines selected in this research were measured. Samples of 5 work process activities and their duration were taken and average time calculated (Appendix C). This was done to determine the work content and to establish time standards for work activities relevant in this research. The work content time was calculated by aggregating work elements times of each process stage. Each work element time was determined using process charts for all part- families shown in Appendix D. The standard machining data from Master Cam Version 9 copper material library was used to determine the machining times for those copper parts that required milling, turning, drilling and threading. To obtain the total task time per hour per machine, the work content for each copper part in the part families were multiplied with the number of parts that visited each machine per hour.

The total task time per hour for each machine divided by the available hourly machine capacity of 3600 seconds gave the number of machines required per hour for the cells (Table 5.1 and Table 5.2).

Table 5.1: Work content summary for cell1.

Part Families	Machines				Total
	GL	PN	RV	DRAW	
F1 Process time	992	2412		1337	4741
F2 Process time	635	1809	25196	1003	28643
F9 Process time	6095	14807			20902
Total process time(Work content)	7722	19028	25196	2340	54286
Calculated no. of machines	2.1	5.3	7.0	0.7	15.1
Required no. of machines	2	6	7	1	16
No. of operators per machine = 1	2	6	7	1	16
Available service time	7200	21600	25200	3600	57600

Table 5.2: Work content summary for cell 2.

Part-Families	Machines								Total
	PS	PN	MILL	LT	DR	TH-D	TH-T	GR	
F3 Process time						3424			3424
F4 Process time	698		7208		8980		3076	3600	23562
F5 Process time	1070			4397		1594			7061
F6 Process time	7069	1652			616	2100			11437
F7 Process time	4524			3584	5371		2202		15681
F8 Process time	3828	1437			1044				6309
F10 Process time	1141			1318					2459
Work Contents	18330	3089	7208	9299	16011	7118	5278	3600	69933
Calculated no. of machines	5.1	0.9	2.0	2.6	4.4	2.0	1.5	1.0	19.5
Required no. of machines	5	1	2	3	5	2	2	2	22
No. of m/c operators =1	5	1	2	3	5	2	2	2	22
Available service time	18000	3600	7200	10800	18000	7200	7200	7200	79200

5.3 CELL BALANCING

Cell balancing involves allocating equitably the amounts of tasks to various stations or machines in a work cell. Cell balancing helps in determining the amount of resources (labour, machines and energy) required in the manufacturing cells. The preliminary data required for cell balancing is work content. Cell balancing can be expressed by line balancing efficiency.

5.4 LINE BALANCE EFFICIENCY CALCULATION.

(Data refer to Table 5.1 and Table 5.2)

Line balance Efficiency for **cell 1**:

$$\begin{aligned} E_{b1} &= (\text{Total work content / Total service time}) \times 100\% \\ &= (54286/57600) \times 100\% = \underline{\underline{94.2\%}} \end{aligned}$$

Line balance Efficiency for **cell 2**:

$$\begin{aligned} E_{b2} &= (\text{Total work content / Total service time}) \times 100\% \\ &= (69933/79200) \times 100\% = \underline{\underline{88.3\%}} \end{aligned}$$

The obtained line balance efficiency figures indicate good time resource allocation and utilization

5.5 COSTING

5.5.1 COSTING THE CELLULAR FACILITY.

The designed cells in this research were linked. Therefore, they were costed together. The cost inputs used were machines, labour, raw material and energy. *(The exchange rate for US\$ 1.00 = ZMK 4300 as at March 2007).*

1 COSTING THE MACHINES.

The cost of machines was based on the purchase price, depreciation and maintenance cost. The prices of the machines were based on the market price as obtained on web sites (Table 5.3). The machines were depreciated using straight line at 10% per annum for 5 years. The maintenance cost was also budgeted at 10% per annum for 10 years. The period of 10 years was the budgeted period after which the machines would have to be scrapped or replaced. The machine cost contribution per week was calculated (assuming 1 year = 50 working weeks). The weekly cost of machines was **US\$ 5,047.81** (Appendix F).

2 COSTING LABOUR

The labour charge was fixed at ZMK2.25 million per month per operator and ZMK3.0 million per supervisor. For 22 operators, labour cost = ZMK 2.25 million x 22 = ZMK 49.5million and per supervisors, labour cost = ZMK 2.7million. For 2 supervisors = ZMK 5.4milliom. The total labour cost = ZMK54.9 million per month = **US\$ 3,197.67** per week.

3 RAW MATERIALS COSTING

The raw materials identified in this research are i) copper and ii) plastic components that make up the assemblies of the selected copper products.

i) Costing copper

To determine the amount of copper to be used per week, the volume of the stock piece for each of the 67 selected copper parts was measured. The standard raw material supply forms of (Appendix E) were used as sources of raw materials. To facilitate identification, the copper raw materials were coded as CUM 1 up to CUM 29. Multiplying the volume of each stock piece with density of copper (8900 kg/m^3) gave the mass of each stock piece. The total mass of copper necessary to be supplied to the cells per week was obtained by multiplying the demand rate per week of the copper pieces and the respective mass each copper piece. The estimated quantity of copper material required per week was **3.9591** ton per week (Appendix H), which cost **US\$ 27,773.74** as cathodes at US \$ 6510 / ton (see pricing at London Metals Exchange in Appendix I). When sourced in already made supply form (Appendix E) the total cost of copper per week was **US\$ 85,083**.

ii) Costing plastics

In order to cost the plastic insulators for the selected copper products, standard costing was implemented. The cost of processing 1kg of plastic pellets was estimated to be US\$ 3.57/kg. The total mass of plastics requires per week was calculated by weighing each plastic insulator and multiply with the weekly demand. The total mass was 1412kg (Table 5.4). Total cost of plastic processing was $1412 \times 3.57 = \text{US\$ } 5047.81$

Table 5.3: Costing of machines and energy.

No	Machine	No. of machines	Price in US \$	Suppliers	Input power (Kw)	Total input power (kW)	Total machine cost in US \$
1	Drilling	5	395	IM	0.4	2	1,975
2	Grinding	2	809	TPH	0.4	0.8	1,618
3	Power saw	5	3,076	IM	1.9	9.5	15,380
4	Lathe	3	4,836	TPH	3.7	11.1	14,508
5	Guillotine	2	9,950	IM	3.7	7.4	19,900
6	Milling -NC	2	18,950	IM	3.7	7.4	37,900
7	Punching	7	4,500	CDG	5.6	39.2	31,500
8	Thread -Tap	2	3,968	TPH	0.4	0.8	7,936
9	Thread- Die	2	3,110	TPH	0.4	0.8	6,220
10	Reverting	7	10,285	GR	2.2	15.4	71,995
11	Draw	1	4,500	CDG	5.6	5.6	4,500
TOTALS						100kW	\$ 213,432

IM = industrial machines suppliers; Columbus, Ohio; site: www.industrialmachines.com

TPH= TPH Machine tools. Site: www.tphmachinetools.co.uk

CDG= SDUGARD, Sussex, England. Site: www.cdugard.com

GR = Grand Riveters. Site: www.grandriveters.com

Table 5.4: Costing of Plastic insulators.

No.	Product	Mass of plastics (g)	Demand/ week (kg)	Mass of plastic/week (Kg)
1	SCT	130	2903	377
2	CS	165	1506	248
3	BC	10	1773	18
4	NB	12	1695	20
5	ST	65	2922	190
6	BH	30	3039	91
7	TP	30	3078	92
9	AD	195	1922	375
Total				1412 kg

4 COSTING ENERGY

The cost of energy was determined by identifying the input power to each machine frame and multiplied the total with the local tariff structure of K164/kWh. The total power aggregate was 100kW. Assuming 7 working hours per shift and 5days per week the total kWh was $100 \times 7 \times 5 = 3,500 \text{ kWh}$. The cost of this energy was $3,500 \text{ kWh} \times \text{ZMK}164/\text{kWh} = \text{ZMK } 574,000 = \text{US\$ } 133.49$. Table 5.5 shows the summary of the above calculated costs.

Table 5.5: *summary of the costs per week* (See sample calculations in APPENDIX F)

No.	Description	Cost when copper is sourced as cathodes.	Cost when copper is sourced as primary product
1	Cost Of Copper	27,773.74	85,083.00
2	Plastics	5,047.81	5,047.81
3	Labor	3,197.67	3,197.67
4	Machine Cost	5047.81	5047.81
5	Energy	133.49	31.88
Total		US\$ 41,200.52	US\$ 98,408.17

5.5.2 COST AND PROFIT EVALUATION.

Revenue / week = ZMK488 000 000 = **US\$ 113,488.37**

Total cost = US\$ 98,408.17

Gross Profit per week = US\$ (113,488.37-98,408.17) = **US\$ 15,080.20**

Payback period = $113,488.37 / 15,080.20 = 7.5 \text{ weeks} = \mathbf{8 \text{ weeks}}$

Note: *That the total cost calculated in this analysis ignored setup costs and other fixed costs such as rentals, cost of buildings and premiums as these costs will still be incurred whether one was using cellular manufacturing or conventional methods. An inclusion of these costs slightly lowers the gross profits and increase the payback period.*

CHAPTER 6

DISCUSSION OF FINDINGS

6.1 INTRODUCTION

This chapter discusses the findings of the research in as far as the design and evaluation of the Cellular Manufacturing facility is concerned. The chapter presents some difficulties encountered in the research and the ultimate adjustments made to make it possible to proceed,

6.2. THEORY AND THE RESEARCH

The theories presented in chapter 2 provided the fundamental framework for which the research progressed. However their ultimate application required selection of assumptions and adjustments for smooth progression. The examples given in 6.2.1, 6.2.2 and 6.2.3 confirm this phenomenon.

6.2.1 SAMPLING AND DATA COLLECTION

The designed sampling frame was country wide and the initial sample size was 196. It proved difficult to sample fairly because of the fact that the subjects to be sampled were found mostly in towns leaving peri-urban and rural areas unrepresented. Therefore sampling bias was unavoidable. The effect of sample bias was ignored because the data required for the number of copper products consumed per week was aggregate and not the statistic mean. Hence, as much data as possible was needed. The number of sample subjects limited at 157 (77% of the target of 196). The survey aimed at 50% representation. This resulted into the sampling error increasing from planned 5% to 6.125%, which is still acceptable because it is below 10% limit.

6.2.2 PART -FAMILY FORMATION

The theoretical framework requires that part families – machine cluster are formed simultaneously using the Ranking Order Clustering Algorithm. This proved difficult because of large number of parts (67) which were to be grouped with 10 machines. The solution to this problem was to pre-group the copper parts into 10 families of similarities in manufacturing processes.

These families were coded; F1 to F10 using PFA (note that 10 part families were obtained independent of the number of machines). It was these pre-groups that were clustered into part families – machine clusters using Ranking Order Clustering Algorithm. In this research part families imply groups of parts clustered with machines.

6.2.3 ADJUSTMENTS TO CELLS.

Adjustment to the designed cellular facility was inevitable. The objective of this adjustment was to make the cells cost effective through minimization of intercellular travels, minimization of within cell distances work pieces had to travel and minimization of the number of machines to be allocated to stations. .

6.2.4 COST ANALYSIS.

The calculated amount of copper material required per week was 3.9591 tonne which cost US\$ 27,773.74 as cathodes of copper (at US\$ 6510 / ton). When supplied in ready-made-form (Appendix E) the total cost of copper per week was US\$ 85,083. This implies that a tonne of copper when processed to primary product would cost US \$ 21,490.09 (330% of the copper cathode value). When a tonne of copper undergo secondary processing, the value addition is increased to US\$ $(113,488.37 - 5,047.81)/3.9591 =$ US\$ 27,390.20(420% of the copper cathode value). This analysis is based on low to medium value items selected in the research. For high value copper products high percentages of value addition are expected.

CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION.

The main purpose of the research was to design and evaluate the cellular manufacturing facility for selected copper products. Therefore the following conclusions can be made about this research.

1. The cellular manufacturing facility has been designed using Group Technology and Production Flow Analysis. The evaluation has brought up some important economic issues that require serious attention of considering adding value if Zambia is to forge forward economically with its abundantly available natural resources such as copper
2. The demand rate for copper products in Zambia was determined. However this demand rate was representing 50% of the total demand rate.
3. The designed cellular facility has reasonably high rate of capacity utilization as indicated by high values of line balancing efficiencies of 94.2% for cell 1 and 84.3% for cell 2.
4. About 94% of consumers are willing to purchase locally manufactured copper products –indication availability of market.
5. Exporting copper cathodes and importing finished or a semi-finished copper product is not a good economic strategy as highlighted by section 6.2.4. Loss of earnings from value added copper translates into reduced foreign exchange earnings that could have been channels to urgent national development programmes and construction of more industries. The continued export of copper cathodes retards technological progression in copper processing industries.
6. Local market for local products is assured as long as quality is guaranteed.

7.2 RECOMENDTATIONS

The following recommendations are therefore made:

1. The application of Group Technology and Production Flow Analysis in process design must be encouraged .They greatly assisted in this research to design a manufacturing facility for a large number of copper parts. Group Technology can as well be use in areas of research and management where many tasks or problems can exist and if similar problems or tasks are grouped together, one or just a few solutions can be applied to solve them, thereby saving time.
2. The research was done within Zambia only .The sub region (COMESA) is a potential market for the Zambian copper products. A research on the viability of this regional market is encouraged.
3. A further research on the cost of technology to transform copper cathode into cellular facility input raw materials of Appendix E need to be done. The worth of such technology was not evaluated in this research because of capacity and scope.
4. Copper mining firms and other investors must be encouraged to add value to copper cathode before export as it can be seen form the research that there is great potential in it and can encourage the development of secondary copper processing industries.

REFERENCES:

Bentley T.J. and Whitmore D.A., 2004,"the management services handbook and work measurement", Institute of Management Services, USA.

Foulds L.R. and Wilson J.M., 2002,"Approaches to general cell formation". Research Paper presented at Loughborough University Institute.

Francis A., 1988, "Business mathematics and statistics" 2nd Edition, DP Publications. UK.

Gupta R.S. and Anital K, 1998, "Design and Manufacturing systems", Santya Prakashash,Tech, India Publication.

Hardwide, Khan and Langmead 1996," Introduction to Economics", pp446-450).

Hussein Arsham, 2002 ," Questionnaire Design and survey sampling".
Lecture materials on USA site Website: [http://home .lialt.edu/ntsbash/stat-data](http://home.lialt.edu/ntsbash/stat-data) (April 2006).

Millichamp A.H, 1997," Finance for non –financial managers", Third Edition, continuum.ISBN. London. New York.

Munakaampe G.M., 2000." Analysis of Performance of Manufacturing Industry in Zambia, the Engineering Manufacture Sub sector", M.eng dissertation University of Zambia.

Mungwattana A, 2000,"Design of Cellular manufacturing system for dynamic and uncertain production requirements. Thesis (PhD) presented at Virginia State University and Poly Technique Institute, USA. *Web site* <http://scholars.google.com/scholars> (April 2006)

Norman Geither, 1990, "Production and Operations Management", 7th Edition, Duxbury Press, AIWPC, ITP London, NY, Bonn, Boston.

Forgarty W.D, 1989," Production and Operations Management" APICS, Cincinnati,USA.

Phillips, Edward J, 1997, "Manufacturing Plant Layout: Fundamentals and Fine Points Optimum Facility Design", Society of Manufacturing Engineers, Dearborn, Michigan, USA.

Quarter man Lee, 1997 "Facilities & Workplace Design", Engineering & Management Press, Norcross, Georgia.

Quarter man LEE, 2000,"How to balance a manufacturing work cell" paper presented at Industrial Engineers IE Solutions Conference, Cleveland, Ohio, May 21-23.

Shahrukh, A. Iran, 2005, "Production Flow Analysis and Simplification Tool Kit ", Home Research and Development, Success stories, Ohio State University.

Skinner, Wick ham, 1974, "The Focused Factory", Harvard Business Review, USA, May- June ".

Stanley D Stone, 1996, "Cellular Manufacturing. Taking a practical approach'. The performance advantage, case study Publication number 5 APISC,ISSN, NY ,pp34-38.

Strategos inc. international, 2005, Consulting Engineers," Group Technology and Cellular Manufacturing ".*Website:<http://www.strategosinc.com/cm/htm> May, June 2006).*

Wild R, 1987, "Production and operations management", fourth Edition, Henley, The management College and Brunel University,UK.

APPENDIX A

QUESTIONNAIRE -TYPE I



The University of Zambia, School of Engineering, Department of Mechanical Engineering.

RESEARCH QUESTIONNAIRE

PURPOSE: To provide information for designing a focused factory to process copper into final products in Zambia using Cellular Technology.

Dear respondent,

You have been randomly selected. The answers you will provide in this questionnaire will be used for academic exercise only. Your assistance is VERY IMPORTANT and looked forward to.

PART I

Q1 What is your main business?.....

Tick one choice from each of the questions below.

Q2 Do you deal in some copper parts or some copper finished products?

Yes

No

If Yes go to Q3 , If No go to Q4.

Q3 What do you generally need the copper finished products for?

APPENDIX A: *Cont'd.*

Q4 What do you think Zambia should do with its copper produced locally?

Zambia should continue exporting copper as raw material:

Zambia to process copper into final products for local and international market:

Q5. Are you willing to buy or use locally produced copper final products?

Yes

No

Q6 What products would you suggest to be made from locally produced copper?

_____	_____
_____	_____
_____	_____
_____	_____

END OF PART I

APPENDIX A: *Cont'd.*

PART II

Tick or state to indicate the cost, source and the quantity of copper products you daily monthly or quarterly use, order or sale

NO	Copper product or parts Name	Source : local or imported	Order price & Quantity	Monthly quantity				Monthly quantity			
				Used <input type="checkbox"/>	Sold <input type="checkbox"/>	ordered <input type="checkbox"/>	Others-specify	Used <input type="checkbox"/>	Sold <input type="checkbox"/>	ordered <input type="checkbox"/>	Others-specify
				0 To 10	10 to 50	50 to 100		0 to 100	100 to 500	500 to 1000	1000 to 5000
1											
2											
3											
4											
5											
6											
7											
8											

End of questionnaire.

Thank you very much for your cooperation

APPENDIX B

QUESTIONNAIRES - TYPE II



The University of Zambia, School of Engineering, Department of Mechanical Engineering.

RESEARCH QUESTIONNAIRE FOR HARDWARE

PURPOSE: To provide information for designing a focused factory to process copper into final products in Zambia using Cellular Technology.

IMPORTANT: You have been randomly selected. The answers you will provide in this questionnaire will be used for academic exercise only. Your assistance is VERY IMPORTANT and looked forward to.

A] Tick one choice from each of the questions below.

Q1 What do you think Zambia should do with its copper produced locally?

Zambia should continue exporting copper as raw material:

Zambia to process copper into final products for local and international market:

Q2. Are you willing to buy or use locally produced copper final products?

Yes

No

B] TICK to indicate how many of each of the following copper Products you sale per week.

APPENDIX B: *Cont'd.*

1 Adapters

0 to 10	10 to 20	20 to 50	Others.....
---------	----------	----------	-------------

2	Bonding strips	0 to 10	10 to 20	20 to 50	Others.....
3	Bulb holders	0 to 10	10 to 20	20 to 50	Others.....
4	Cable lugs	0 to 10	10 to 20	20 to 50	Others.....
5	Cooker units	0 to 10	10 to 20	20 to 50	Others.....
6	Copper connector	0 to 10	10 to 20	20 to 50	Others.....
7	Earth rods	0 to 10	10 to 20	20 to 50	Others.....
8	Neutral bars	0 to 10	10 to 20	20 to 50	Others.....
9	Sockets	0 to 10	10 to 20	20 to 50	Others.....
10	Switches	0 to 10	10 to 20	20 to 50	Others.....
11	Top plugs	0 to 10	10 to 20	20 to 50	Others.....

END.

THANK YOU VERY MUCH FOR YOUR SUPPORT.

APPENDIX B: *Cont'd.*



The University of Zambia, School of Engineering, Department of Mechanical Engineering.

RESEARCH QUESTIONNAIRE FOR AUTO SHOPS

PURPOSE: To provide information for designing a focused factory to process copper into final products in Zambia using Cellular Technology.

IMPORTANT: You have been randomly selected. The answers you will provide in this questionnaire are for academic exercise only. Your assistance is VERY IMPORTANT and looked forward to.

A] Tick **one choice from each of the questions below.**

Q1 What do you think Zambia should do with its copper produced locally?

Zambia should continue exporting copper as raw material:

Zambia to process copper into final products for local and international market:

Q2. Are you willing to buy or use locally produced copper final products?

Yes

No

B] TICK **to indicate how many of each of the following copper products you sale per week.**

- 1 Battery terminals 0 to 10 10 to 20 20 to 50 Others.....
- 2 Copper washers 0 to 10 10 to 20 20 to 50 Others.....
- 3 Cable lugs 0 to 10 10 to 20 20 to 50 Others.....
- 4 Fuses 50A, 100A 0 to 10 10 to 20 20 to 50 Others.....
- 5 Stator bushes 0 to 10 10 to 20 20 to 50 Others.....
- 6 Stator contacts 0 to 10 10 to 20 20 to 50 Others.....

END.

THANK YOU VERY MUCH FOR YOUR SUPPORT.

APPENDIX C

TIME STUDY

Table 1: Time study data for selected machines.

NO.	MACHINE FRAMES	OPERATIONS	TIME (seconds)	TIME per FEATURE
1	Hole punching	Punching 5 holes	47.54	1 hole = 9.51
		Tool grinding (once per week)	10	
2	Trimming	Trimming x 5	167.29	1 trimming = 33.56
3	Power saw	Cutting 85mmØ = 5675.23mm ² (½ blade life)	752.79	1mm ² = 0.13s
4	drill	Setting	60	1mm thick = 2.12 1mm thick = 1.82
		Drill 20mm thick	42.33	
		Drill 20mm thick	36.33	
5	1	Work piece setting	30	1 face run = 32.25
		Facing 3 runs	96.75	
		Tool changing	30	
		Work piece removal	30	
6	Guillotine	Setting	40.68	Cut 1 line = 1.78
		Cutting 7 lines	12.41	
7	Deep drawing	Oiling x 5	29.43	Oiling x 1 wp = 5.89 1 d- drawing = 10.67
		Deep drawing x 5	53.34	
8	Rivet	riveting	23.24, 20.56, 23.19, 19.16, 28.18, 22.80, 19.59,	1 riveting = 22.16

Table I Cont'd.

			20.53	
9	Punching	Punching 3lines in 1 stroke	9.10, 7.04, 7.55, 6.45. 7.63, 7.15, 7.55, 6.82, 6.84	Punch 1 stroke = 8.26s
		Tool changing time	150	150
10	Light forming (Drawing)	Shape forming	4.54, 4.58 4.39, 4.57 5.47, 4.28 4.21, 4.59	1shape forming = 4.58

APPENDIX D

PROCESS SHEETS FOR PART FAMILIES.

Table 2: Process sheet for part family F1.

A	B	C	D	E	F	G	H	I	J	K	
Family	Parts Code	No. of parts per hour	No of cut lines per hr	Time for the part on the:						Total Time per group of Copper Parts	Work content per piece
				Guillotine Time = (40.68 +1.78x D)	Punching			Drawing Duration (seconds)			
					Parts per punch/ draw	No. of Punch strokes/ hour	Punch time per hour for each part family				
F1	AD1	48	1	42.42	4	12	99.12	54.96	196.50	49.13	
F1	AD2	192	4	48.46	10	20	165.20	91.60	305.26	30.53	
F1	AD3	48	1	42.07	4	12	99.12	54.96	196.15	49.04	
F1	AD4	384	9	56.80	10	39	322.14	178.62	557.56	55.76	
F1	AD5	48	1	42.21	4	12	99.12	54.96	196.29	49.07	
F1	AD6	96	2	44.01	20	5	41.30	22.90	108.21	5.41	
F1	AD7	48	1	41.72	20	3	24.78	13.74	80.24	4.01	
F1	CL8	64	2	44.20	4	16	132.16	73.28	249.64	62.41	
F1	CS9	104	4	47.00	4	26	214.76	119.08	380.84	95.21	
F1	CS10	52	1	42.56	10	6	49.56	27.48	119.60	11.96	
F1	CS11	52	1	42.71	10	6	49.56	27.48	119.75	11.98	
F1	CS12	52	1	43.01	10	6	49.56	27.48	120.05	12.01	
F1	CS13	52	1	42.56	10	6	49.56	27.48	119.60	11.96	
F1	CS14	52	1	42.56	10	6	49.56	27.48	119.60	11.96	
F1	FS15	26	2	43.88	10	3	24.78	13.74	82.40	8.24	
F1	SCT16	23	1	42.08	4	6	49.56	27.48	119.12	29.78	
F1	SCT17	23	11	59.78	4	36	297.36	164.88	522.02	130.51	
F1	ST18	146	2	44.46	20	8	66.08	36.64	147.18	7.36	
F1	SC19	47	4	47.59	5	11	90.86	50.38	188.83	37.77	
F1	SC20	23	2	44.36	4	19	156.94	87.02	288.32	72.08	
F1	SC21	23	2	44.02	4	19	156.94	87.02	287.98	72.00	
F1	ST22	146	2	43.62	10	15	123.90	68.70	236.22	23.62	
TOTAL TIME				992.08			2411.92	1337.36			

APPENDIX D *cont'd.*

Column C = Column J table A

Column D = Column J table A

Column E (guillotine time) = Job setting time (40.68) + 1.78s per cut line x Column D.

Column F = Approximated number or copper piece parts to be punched per stroke

Column H = Column G x Time per punch (8.26s)

Column I = Column G x Time per Draw (=4.58s)

Column J = Column E + Column H + Column I

Column K = Column J / Column C

APPENDIX D cont'd

Table 3: Process sheet for part family F2.

A	B	C	D	E	F	G	H	I	J	K	
Family	P/Code	No. of parts per hour	No of cut lines per hr	Time for the part on the:						Total Time per group of Copper Parts	Work content per piece
				Guillo tine	Punching			Riveting			
				Time = (40.68 +1.78x C)	Parts per punch/ draw	No. of Punch/hr	punch time /part family	Total riveting time (s)	Duration (s) (seconds)		
F2	CS23	144	4	48.18	10	15	123.90	3191.04	68.70	3431.82	23.83
F2	ST24	146	2	44.04	20	8	66.08	3235.36	36.64	3382.12	23.17
F2	CS25	52	6	50.61	1	52	429.52	1152.32	238.16	1870.61	35.97
F2	SCT26	23	3	45.57	2	12	99.12	509.68	54.96	709.33	30.84
F2	SCT27	213	8	55.48	6	36	297.36	4720.08	164.88	5237.8	24.59
F2	TP28	77	1	43.00	6	12	99.12	1706.32	54.96	1903.4	24.72
F2	TP29	77	1	43.22	10	8	66.08	1706.32	36.64	1852.26	24.06
F2	CS30	104	3	45.20	10	11	90.86	2304.64	50.38	2491.08	23.95
F2	SCT31	47	1	41.90	10	5	41.30	1041.52	22.90	1147.62	24.42
F2	SCT 32	23	1	42.01	6	4	33.04	509.68	18.32	603.05	26.22
F2	SCT 33	23	1	42.04	4	6	49.56	509.68	27.48	628.76	27.34
F2	CS34	104	2	43.39	10	11	90.86	2304.64	50.38	2489.27	23.94
F2	CS35	52	4	47.15	2	26	214.76	1152.32	119.08	1533.31	29.49
F2	CS36	52	2	43.39	4	13	107.38	1152.32	59.54	1362.63	26.20
TOTAL				635.1			1808.9	25195.9	1003.0		

APPENDIX D cont'd

Table 4: Process sheet for part family F3.

A	B	C	D	E	F	H	I	J	J	K	
Family	P/Code	No. of parts per hour	Time for the part on the:							Total Time per group of Copper Parts	Work content per piece
			Guillotine	Punching			Threading				
			Time = $(40.68 + 1.78x C)$	Parts per punch/thread	No. of Punch/hr	punch time /part family	Threading time (s)/Part	Total Threading time			
F3	SC37	154	274	1	154	1272	5	770	2316	15	
F3	ER38	40	71	1	40	330	5	200	601	15	
F3	BT39	27	48	1	27	223	5	135	406	15	
F3	BT40	53	94	1	53	438	5	265	797	15	
F3	TP41	1550	2759	5	311	2569	5	311	5639	4	
F3	NB42	582	1036	5	117	966	5	117	2119	4	
F3	SCT43	866	1541	5	866	7153	5	866	9560	11	
F3	TP44	152	271	1	152	1256	5	760	2287	15	
TOTAL			6095			14207 + 600 (TCC) = 14807		3424			

APPENDIX D cont'd

Table 5: Process data sheet for part family F4.

Family	code	Part/hr	X-Area (mm ²)	Cutting time
F4	BH45	174	30	4
F4	NB46	48	693	90
F4	SCT47	80	88	11
F4	TP48	88	248	32
F4	TP49	88	189	25
F4	TP50	88	132	17
F4	TP51	88	91	12
F4	BC52	608	210	27
F4	ER53	46	360	47
F4	BT54	30	1665	216
F4	BT55	30	1665	216
F4	BT56	30	0	0
Σ				698 s

Total power saw operation time = 698s + 11 parts x 15s changing time per part = 863s

Base feed rate/tooth/rev = 0.102mm

Number of teeth per tool = 2

Spindle speed = 900rev/min = 15 rev/s

Feed rate = 15rev/s x 2 teeth x 0.102mm/tooth/rev = 3.06mm/s

Maximum cutting depth = 0.7 x tool diameter

Percentage feed = 100% of the feed rate

APPENDIX D cont'd

Table 6: Processing sheet for Part Family F4 on milling machine

Family	code	Part/hr	Process number	Process Description	Tool	Tool Ø	Maximum Cutting depth	Number of passes	Cutting length	Time for cutting	Total time
F4	BH45	174	1	Sizing	Face	20	14	1	5.2	1.7	296
F4	NB46	48	1	Sizing	Face	20	14	1	154	50	2400
F4	SCT47	80	1	sizing	face	10	7	2	12	6	480
F4	TP48	88	1	sizing	face	10	7	2	30	20	2464
			2	sizing	face	10	7	1	24	8	
F4	TP49	88	1	sizing	face	10	7	2	30	20	2464
			2	sizing	face	10	7	1	24	8	
F4	TP50	88	1	sizing	face	10	7	2	30	20	2464
			2	sizing	face	10	7	1	24	8	
F4	TP51	88	1	sizing	face	10	7	2	12	6	704
			2	sizing	face	10	7	1	7	2	
F4	BC52	608	1	sizing	face	10	7	2	12	6	3648
F4	ER53	46	1	sizing	face	10	7	2	15	10	1840
			2	sizing	face	10	7	2	18	12	
			3	sizing	face	10	7	2	9	6	
			4	sizing	face	10	7	1	12	4	
			5	Slot milling	slot	10	7	1	12	4	
			6	Slot milling	slot	10	7	1	12	4	
F4	BT54	30	1	Profile	mill	10	7	1	150	50	3420
			2	Profile	mill	5	3.5	1	150	50	
			8	Split	End mill	8		1	12	4	
			9	Split	End mill	3		1	30	10	
F4	BT55	30	1	Profile	mill	10	7	1	150	50	3420
			2	Profile	mill	5	3.5	1	150	50	
			8	Split	End mill	8		1	12	4	
			9	Split	End mill	3		1	30	10	
Total											23600 s
Total for Face milling (avoidable by supplying correct size raw materials –no resizing machining)											16392 s
Total for Profile milling											7208 s

APPENDIX D cont'd

Table 7: Processing sheet for Part Family F4 on the drilling machine.

Family	code	Part/hr	Process number	Process Description	Tool	Tool Ø	Maximum Cutting depth	Number of passes	Cutting length	Time for cutting	Total time
F4	BH45	174	1	Drill hole	drill	3	2	1	5	1.7	348
				Drill hole	drill	2	1.4	1	1	0.3	
F4	NB46	48	1	Drill holes	drill	5	3.5	8	6	16	1440
			2	Drill holes	drill	4	2.8	8	3	8	
				Drill holes	drill	3	2.1	2	9	6	
F4	SCT47	80	1								400
			2	Drill hole	drill	5	3.5	1	9	3	
			3	Drill hole	drill	5	3.5	1	6	2	
F4	TP48	88	1	Drill hole	drill	5	3.5	1	6	2	352
				Drill hole	drill	5	3.5	1	6	2	
F4	TP49	88	1	Drill hole	drill	5	3.5	1	6	2	352
				Drill hole	drill	5	3.5	1	6	2	
			2								
F4	TP50	88	1	Drill hole	drill	3	3.5	1	6	2	176
F4	TP51	88	1	Drill hole	drill	4	2.8	1	6	2	440
			2	Drill hole	drill	3	2.1	1	6	2	
			3	Drill hole	drill	3	2.1	1	2	1	
F4	BC52	608	1	Drill hole	drill	3	2.1	2	3	2	4256
				Drill hole	drill	5	3.5	1	15	5	
F4	ER53	46	1	Drill hole	drill	5	3.5	1	3	1	46
F4	BT54	30	1	Dill	drill	10	7	1	9	3	630
			2	Dill	drill	15	10.5	1	9	3	
			3	Taper Drilling	drill	15	10.5	1	9	3	
			4	Dill	drill	10	7	2	9	6	
			5	Dill	drill	10	7	1	18	6	
F4	BT55	30		Dill	drill	10	7	1	9	3	540
				Dill	drill	15	10.5	1	9	3	
				Dill	drill	10	7	2	9	6	
				Dill	drill	10	7	1	18	6	
Total											8980

APPENDIX D *cont'd*

Table 8: *Processing sheet for Part Family F4 on the threading machine.*

Family	code	Part/hr	Process number	Process Description	Tool	Tool Ø	Maximum Cutting depth	Number of passes	Cutting length	Time for cutting	Total time
F4	BH45	174		Tap thread	tap	2	-	1	1	1	174
F4	NB46	48		Tap thread	tap	3	-	2	9	6	288
				Tap thread	tap	4	-	8	3	8	
F4	SCT47	80		Tap thread	tap	5	-	1	3	2	640
F4	TP48	88		Tap thread	tap	4	-	1	3	1	88
F4	TP49	88		Tap thread	tap	4	-	1	3	1	88
F4	TP50	88									88
F4	TP51	88		Tap thread	tap	3	-	1	3	1	88
F4	BC52	608		Tap thread	tap	3	-	2	3	2	1216
F4	ER53	46		Tap thread	tap	5	-	1	3	1	46
F4	BT54	30		Tap thread	tap	5	-	2	9	6	180
F4	BT55	30		Tap thread	tap	5	-	2	9	6	180
Total											3076

APPENDIX D *cont'd*

Table 9: *Processing sheet for Part Family F5.*

Family	CODE	Qty/hr	Machines time on					
			Power saw		Lathe		Thread die-head	
			Activity	Time	Activity	Time	Activity	Time
F5	ER57	46	Ø = 9mm 1.Cutting 63.63mm ² Setting work piece	63.63 x 0.13s/mm ² = 8.27s 15	W/p set x2 Chamfer x 2	30s 65.5s	w/p settingx2 threading @ 10rev/s x 20 thread pitches x2	30 4
Total for 1 w/p				23.27	Total	95.5	Total	34
Total for 46 w/p				1070	Total for 46 w/p	4397	Total for 46 w/p	1594

Table 10: *Processing sheet for Part Family F6.*

Family	CODE	Qty/hr	Machines time on				
			Power saw		punch	Drill	Thread die-head
			Cutting mm ²	Time = cutting + setting (5s)	Shape punch @8.26 s/punc h	900 rpm x 0.102mm/rev/ tooth x 2 teeth = 3.06s	w/p setting = 5s threading @ 5rev/s x 5 thread pitches =10s
F6	BT58 CC59 SC60	61 86 53	71.2 506.8 198.1	14.3x61=870 70.9x86=432 4 30.9x53=187 6	503.9 710.4 437.8	2x61 = 122 2x86 = 176 6x53 = 318	10x61 = 610 10x86 = 860 10x53 = 530
Total				7069	1652	616	2100

APPENDIX D cont'd

Table 11: Processing sheet for Part Family F7.

Family	CODE	Qty/hr	Machines time on						
			Power saw			Lathe		Drill	Thread tap
			Cut No. Per hr	Set wp	Cut Time	Parting @ 15rev/s x 0.102mm/rev = 1.5mm/s	Chamfer	Centre + side drilling @ 1.5mm/s	@ 5res/s x 6 threads = 6s
F7	CS61 ST62	23 7 13 0	6 1	90 + 15 = 10 5	[17x23 7]+ [3x130] = 4419	[12.7mmØ/1. 5 x237]+ [4.8 mmØ/1.5 x130]= 2549	[2x3mm m/1.5x23 7] + [(1x1mm/ 1.5)x130] =1035	[237x (20/1.5) + [130x7/1.5] + 237x3/1.5 s + 1.5/1.5x130] = 5371	6x237 + 6x130
Total			4524			3584		5371	2202

Table 12: process sheet for part family F8.

Family	CODE	Qty/hr	Machines time on		
			Power saw	Drill	Punch
			Time = cutting + setting (5s) =17s + 5s =22s	@ 1.5mm/s = 9mm/1.5 =6s	@ 8.26s per stroke
F8	Bh63	17 4	22x174	174x6	174x 8.26
Total			3828	1044	1437

APPENDIX D cont'd

Table 13: process sheet for part family F9.

Family	Part code	Qty Per hr	Machine time on:	
			Guillotine	Punch
F9	BS 64	36	36mx1 stroke/mx1.78s/stroke +40.7s for setting = 105 s	10holes/stroke @10mm space=10strokes/m x 8.26s/stroke = 82.6s
	CW 65	21	21x28mm/(1000mm/m) x (40.7+1.78) = 25s	21 strokes x8.26s/stroke = 174s
Total time			130s	257s

Table .14: process sheet for part family F10.

Family	CODE	Qty/hr	Machines time on						
			Power saw			Lathe			
			Cut No. Per hr	Set Wp @ 15s	Cut Time	Parting @ 15rev/s x 0.102mm/r ev = 1.5mm/s	Centre drilling 12mm @1.5mm/ = 8s	Finishing turning & Chamfer	Forming copper connector @ 5s x2 ends
F10	CC6 6 SB67	43 23	14 0.3	21 0 + 4.5	[43x19 0.13x1xn]+ [23x15.8 8 ² x0.13/4]= 926	23x15.88m /1.5mm/s = 244	23x8 = 184s	23[(2x12/1.5) + 6/1.5] = 460	10 x 43 = 430
Total					1141		1318		

APPENDIX E

COPPER RAW MATERIAL SUPPLY FORM DATA
 Source: e-mail: sales@onlinemetal.com.

Table 15: copper sheets

MAT CODE	Thickness (mm)	Area (mmxmm)	\$	kg/m	volume in mm ³	\$/mm ³
CUM1	0.550	304.8 X304.8	12.69	1.492	51088	0.000248393
CUM2	0.800	304.8 X304.8	22.81	2.211	74332	0.000306868
CUM3	1.016	304.8 X304.8	34.69	2.971	94389	0.00036752
CUM4	1.499	304.8 X304.8	39.06	4.470	139224	0.000280554
CUM5	2.057	304.8 X304.8	47.57	5.960	191139	0.000248877
CUM6	2.461	304.8 X304.8	78.26	6.702	228659	0.000342257
CUM7	3.112	304.8 X304.8	142.02	8.636	289068	0.000491303
CUM8	6.350	304.8 X304.8	208.76	17.272	589934	0.00035387
CUM9	9.520	9.52 X304.8	7.70	34.544	884437	8.70611E-06
CUM10	25.400	304.8 X304.8	571.49	69.088	2359737	0.000242184

Table16: Copper round bars

MAT CODE	DIAM	L	\$	kg/m	volume in mm ³	\$/mm ³
CUM11	3.175	304.8	0.99	0.07062 6	2414	0.00041019 1
CUM12	4.76	304.8	1.8	0.15883 4	5425	0.00033181 6
CUM13	9.52	304.8	2.37	0.63548 5	21699	0.00010922 3
CUM14	7.94	304.8	3.71	0.44178 5	15094	0.00024579 4
CUM15	9.52	304.8	5.64	0.63548 5	21699	0.00025992 3
CUM16	12.7	304.8	9.48	1.13016 5	38616	0.00024549 3
CUM17	15.88	304.8	14.82	1.76550 1	60376	0.00024546 3
CUM18	25.4	304.8	37.92	4.51946 8	154464	0.00024549 3
CUM19	31.75	304.8	74.05	7.06170 6	241351	0.00030681 5

APPENDIX E *Cont'd*

Table 17: *Rectangular Copper Bars.*

MAT CODE	Thickness mm	Width mm	L mm	\$	kg/m	VOLUME
CUM20	6.35	9.525	304.8	3.85	0.540	18435
CUM21	4.7498	12.7	304.8	6.94	0.720	18386
CUM21	6.35	101.6	304.8	61.63	5.754	196645

Table 18: *Copper Squares.*

MAT CODE	Thickness mm	Width mm	L mm	\$	kg/m	VOLUME
CUM22	6.350	6.350	304.8	4.52	0.360	12290
CUM23	9.525	9.525	304.8	5.78	0.810	27653
CUM24	12.700	12.700	304.8	17.00	1.439	49161
CUM25	19.050	19.050	304.8	23.10	3.239	110613
CUM26	25.400	25.400	304.8	41.06	5.757	196645
CUM27	31.750	31.750	304.8	64.15	8.996	307257
CUM23	50.800	50.800	304.8	164.22	23.043	786579

Table 19: *Copper tubes*

MAT CODE	OD mm	ID mm	thickness mm	L mm	\$	kg/m
CUM24	6.350	5.080	0.635	304.8	3.83	0.10
CUM25	6.350	4.724	0.8128	304.8	5.21	0.13
CUM26	6.350	3.048	0.8128	304.8	13.33	0.22
CUM27	12.700	11.074	0.8128	304.8	6.43	0.27
CUM28	19.050	15.748	0.8128	304.8	10.64	0.81
CUM29	19.050	17.526	0.8128	304.8	18.48	1.10

APPENDIX F

SAMPLE CALCULATIONS

1 MACHINE COST / WEEK .

Assume machines to last for 10 years and 1year = 50 weeks (for 10 years)

Machine cost /week = {US\$213,432/ (10 x 50)} + {(10% maintenance + 10% depreciation)} = US\$ 213,432/(500)x (1.2) = **\$ 512.24** per week.

2 STANDARD COSTING OF PLASTICS (source; PPZ- ZAMBIA)

This company process 60kg of plastic pellets per hour =60 x 7hrs per day x 5 days per week = 2100kg/week.

i) PLASTICS PELLETS MATERIAL COST:

60kg/hr x\$3/kg x7hr/day x 5 days/week = \$6300/week

ii) ENERGY USED ON PLASTICS FORMATION:

= 14 motors x 20Hp/motor x 0.75kW/Hp x7hr/day x K163/KWh x
5 days/week = ZMK 1,191,660/4300 = US\$ 277.13/ week

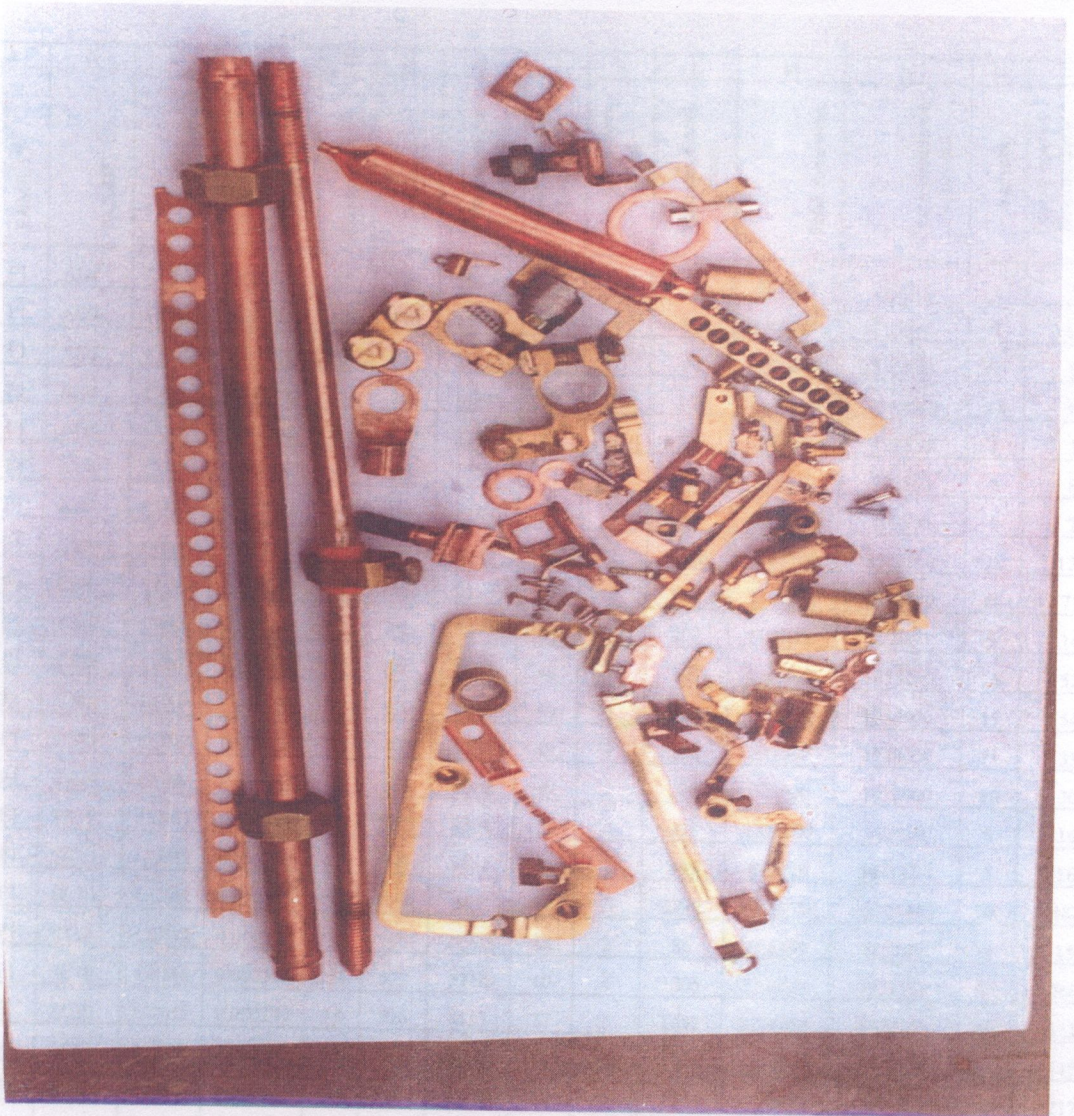
iii) STANDARD COST TO PROCESS 1 Kg OF PLASTIC

= 6300 + 277.13 + 930.23 = US\$ 7,507.36

= US\$ 7,507.36/2100kg = US\$ **3.57/kg**

APPENDIX G

SAMPLES OF SELECTED COPPER PARTS



73	CS2	CLM	0.00216	144	342	1800	14	4	72	100000	41500	4	112
74	ST24	CLM	0.00297	144	134	2000	17	6	54	100000	120000	11	194
75	CM4	CLM	0.00246	32	1100	174	9	16	102	100000	10000	2	81
76	ACT24	CLM	0.00246	24	875	101	7	10	70	100000	100000	10	100
77	ST27	CLM	0.00214	213	291	700	16	1	100	100000	100000	10	100
78	ST24	CLM	0.00216	75	304	1111	18	1	100	100000	100000	10	100
79	ST24	CLM	0.00216	75	304	1111	18	1	100	100000	100000	10	100
80	ST24	CLM	0.00216	100	200	1000	10	1	100	100000	100000	10	100

APPENDIX H

Table 20: copper material utilization analysis.

A	B	C	D	E	H	I	J	K	L	M	N	N	O
FAMILY	P/CODE	Mat code	\$/mm3	Parts/hour	Area	No. pieces per sheet	No of pieces per line width	No of cut lines per hr	Volume of stock piece	Total Area/week	Total Volume of w-pcs /wk	kg/week	Copper cost/wk (imported raw material)
F1	AD1	CUM1	0.000248	48	150	20090	49	1	75	288000	144000	1	36
F1	AD2	CUM1	0.000248	192	196	15375	44	4	98	1505280	752640	7	187
F1	AD3	CUM1	0.000248	48	120	25113	62	1	60	230400	115200	1	29
F1	AD4	CUM1	0.000248	384	203	14845	42	9	102	3118080	1559040	14	387
F1	AD5	CUM1	0.000248	48	132	22830	56	1	66	253440	126720	1	31
F1	AD6	CUM1	0.000248	96	168	17938	51	2	84	645120	322560	3	80
F1	AD7	CUM1	0.000248	48	105	28700	82	1	53	201600	100800	1	25
F1	CL8	CUM3	0.000368	64	1406	2143	32	2	1406	3599360	3599360	32	1323
F1	CS9	CUM1	0.000248	104	1386	2174	29	4	693	5765760	2882880	26	716
F1	CS10	CUM1	0.000248	52	550	5479	49	1	275	1144000	572000	5	142
F1	CS11	CUM4	0.000281	52	594	5073	46	1	891	1235520	1853280	16	520
F1	CS12	CUM4	0.000281	52	620	4860	40	1	930	1289600	1934400	17	543
F1	CS13	CUM4	0.000281	52	400	7534	49	1	600	832000	1248000	11	350
F1	CS14	CUM4	0.000281	52	350	8610	49	1	525	728000	1092000	10	306
F1	FS15	CUM1	0.000248	26	1275	2364	14	2	638	1326000	663000	6	165
F1	SCT16	CUM2	0.000307	23	743	4054	29	1	595	683928	547142.4	5	168
F1	SCT17	CUM2	0.000307	145	3390	889	14	11	2712	19660550	15728440	140	4827
F1	ST18	CUM2	0.000307	145	108	27903	68	2	86	626400	501120	4	154
F1	SC19	CUM6	0.000342	154	527	5718	40	4	1265	3246320	7791168	69	2667
F1	SC20	CUM5	0.000249	77	726	4151	37	2	1452	2236080	4472160	40	1113
F1	SC21	CUM6	0.000307	77	510	5909	41	2	1224	1570800	3769920	34	1158
F1	ST22	CUM2	0.000307	145	98	30750	88	2	1224	568400	7099200	63	2179
F2	CS23	CUM1	0.000248	144	432	6976	34	4	78	2488320	451584	4	112
F2	ST24	CUM2	0.000307	145	128	23543	77	2	216	742400	1252800	11	384
F2	CS25	CUM1	0.000248	52	8052	374	9	6	102	16748160	212992	2	53
F2	SCT26	CUM2	0.000307	23	3675	820	8	3	4026	3381000	3703920	33	1137
F2	SCT27	CUM1	0.000248	213	384	7848	26	8	2940	3271680	25048800	223	6222
F2	TP28	CUM1	0.000248	73	264	11415	56	1	192	770880	560640	5	139
F2	TP29	CUM1	0.000248	73	168	17938	51	1	132	490560	385440	3	96
F2	CS30	CUM4	0.000281	104	240	12556	41	3	84	998400	349440	3	98

APPENDIX H *Cont'd.*

F2	SCT31	CUM2	0.000307	47	144	20927	68	1	360	270720	676800	6	208
F2	SCT 32	CUM1	0.000248	23	640	4709	31	1	115	588800	105984	1	26
F2	SCT 33	CUM3	0.000368	23	574	5250	30	1	320	528080	294400	3	108
F2	CS34	CUM3	0.000368	104	198	15220	68	2	574	823680	2387840	21	878
F2	CS35	CUM2	0.000307	52	2838	1062	14	4	198	5903040	411840	4	126
F2	CS36	CUM1	0.000248	52	900	3348	34	2	2270	1872000	4722432	42	1173
F3	SC37	CUM16	0.000245	154					113	0	696769.9	6	171
F3	ER38	CUM14	0.000246	40					28	0	45244.8	0	11
F3	BT39	CUM14	0.000246	27					28	0	30540.24	0	8
F3	BT40	CUM16	0.000245	53					113	0	239797.4	2	59
F3	TP41	CUM11	0.00041	1550					7	0	438309	4	180
F3	NB42	CUM12	0.000332	582					20	0	457161	4	152
F3	SCT43	CUM11	0.00041	866					7	0	244887.5	2	100
F3	TP44	CUM12	0.000332	152					13	0	76413.44	1	25
F4	BH45	CUM8	0.000354	152	30				150	182400	912000	8	323
F4	NB46	CUM8	0.000354	42	693				4158	1164240	6985440	62	2472
F4	SCT47	CUM9	0.00021	70	88				616	246400	1724800	15	363
F4	TP48	CUM8	0.000354	73	248				1488	724160	4344960	39	1538
F4	TP49	CUM8	0.000354	73	189				945	551880	2759400	25	976
F4	TP50	CUM8	0.000354	73	132				792	385440	2312640	21	818
F4	TP51	CUM8	0.000354	73	91				455	265720	1328600	12	470
F4	BC52	CUM3	0.000368	532	210				210	4468800	4468800	40	1642
F4	ER53	CUM7	0.000491	40	360				1080	576000	1728000	15	849
F4	BT054	CUM9	8.71E-06	27	1665				14985	1798200	16183800	144	141
F4	BT55	CUM9	8.71E-06	27	1665				14985	1798200	16183800	144	141
F4	BT56	CUM9		27	0				0	0	0	0	0
F5	ER057	CUM13	0.000109	40					94200	0	1.51E+08	1341	16462
F6	BT58	CUM13	0.000109	53					64	0	134886.1	1	15
F6	CC59	CUM18	0.000245	75	1231				4927	3692640	14779968	132	3628
F6	SC60	CUM17	0.000245	154	264				792	1624762	4877389	43	1197
F7	CS61	CUM16	0.000245	207					2434	0	20149705	179	4947
F7	ST62	CUM12	0.000332	114					269	0	1227803	11	407
F8	BH63	CUM1	0.000248	152					50	0	305653.8	3	76
F9	BS64	CUM1	0.000248	32					6000	0	7680000	68	1908
F9	CW65	CUM5	0.000249	19	616				1232	468032	936064.6	8	233
F10	CC66	CUM27	0.000209	38					55425	0	83497222	743	17433
F10	SB67	CUM17	0.000245	20					2413	0	1930445	17	474
TOTAL												3959kg	\$85083

**APPENDIX I
COPPER PRICE AT LME (as at march
2007)**

LONDON METAL EXCHANGE

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ADVERTS

Daily stocks and prices: Metals

LME Official prices, US\$/tonne for 16 Mar 2007 (Data >1 day old)

	ALUMINIUM ALLOY	ALUMINIUM	COPPER	LEAD	NICKEL	TIN	ZINC	NASAAC
Cash buyer	2,191.00	2,784.50	6,510.00	1,911.00	49,495.00	14,000.00	3,224.00	2,160.00
Cash seller & settlement	2,192.00	2,785.00	6,520.00	1,912.00	49,500.00	14,025.00	3,226.00	2,170.00
3-months buyer	2,220.00	2,774.00	6,489.00	1,880.00	46,700.00	13,875.00	3,215.00	2,170.00
3-months seller	2,230.00	2,775.00	6,490.00	1,885.00	46,800.00	13,900.00	3,220.00	2,180.00
15-months seller	2,320.00	2,618.00	6,035.00	1,563.00	38,025.00	12,600.00	2,988.00	2,260.00