A NEW CELL FORMATION METHOD CONSIDERING OPERATION SEQUENCES AND PRODUCTION VOLUMES

By

PANTEHA ABEDINI

Thesis submitted in fulfillment of the requirements

for the degree of

Master of Science

February 2013

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my supervisor Assoc. Prof .Dr. Shahrul Kamaruddin for his great commitment in guiding, facilitating, motivate and support during my hard moment in completing this research work. To me personally, Dr. Shahrul is not only a mentor but also a friend. He taught me how think critically when faced with a research problem and had confidence in me when I doubted myself. Besides that, he was always there to meet and shared his own ideas to improve this research. Without his encouragement and constant guidance, I could not have finished this dissertation. A high appreciation also addressed to School of Mechanical Engineering, Universiti Sains Malaysia for all the support in completing this research work.

I would like to thanks to all my friends especially, Saber, Shye Nee, Hasnida and Ding for their kindness and support during my study. Thanks for the friendship and memory.

I would also like to extend my heartfelt gratitude to my beloved parents, Mr. Farhad and Mrs.Zari, my brother Ramin and my sister Arezoo for their endless love and support. This dissertation dedicated to my parents who supported me each step of the way and my little sister, Tina, who passed away when I was writing this thesis. She was smartest, sweetest and the most loving person I have ever known. You remain in my heart.

TABLE OF CONTENTS

CHAPTER 2 - LITERATURE REVIEW

CHAPTER 3 - DEVELOPMENT OF AN ALGORITHM FOR CELL FORMATION

CHAPTER 4 - VERIFICATION AND VALIDATION OF THE DEVELOPED ALGORITHM

APPENDIXES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BEA	Bond Energy Algorithm
CFP	Cell Formation Problem
CF	Cell Formation
DCA	Direct Clustering Algorithm
DP	Difference Percentage
EE	Exceptional Elements
EZCA	Extended Zahn's Clustering Algorithm
GA	Genetic Algorithms
GC	Grouping Efficacy
GT	Group Technology
IC	Intercellular
LP	Linear Programming
MPIM	Machine-Part Incidence Matrix
MST	Minimum Spanning Tree
MTO	Make-To-Order
MTS	Make-To-Stock
MU	Machine Utilization
PE	Percentage of Exceptional Elements

PFA	Production Flow Analysis
ROC	Rank Order Clustering
SA	Simulated Annealing
SCM	Similarity Coefficient Method
TS	Tabu Search
TSP	Travelling Salesman Problem
WIP	Work-In-Process

LIST OF SYMBOLS

E	Edges
M_k	Total number of machines in the *k*th cell
M	Total number of machines
N	Nodes
N	Total number of non-exceptional elements
N	Total number of parts
Q	Number of cells
P	Number of parts
P_k	Number of parts in the cell
α	Reveal the relative importance of each term
o	Number of 1's in the matrix
e	Number of exceptional elements
v	Number of voids
G	Number of machines that part type *k* needs to be processed
V_k	Production volume for part type *k*
W_{il}^{k}	Number of movement that part type *k* makes between machines i and l
w	Inconsistent edge weight
w_{ave}	Average weight of edges
σ	Standard deviation of edge weights

KAEDAH BARU PEMBENTUKAN SEL MENGAMBIL KIRA URUTAN OPERASI DAN JUMLAH PENGELUARAN

ABSTRAK

Dalam pasaran hari ini, pelanggan menuntut kepada lebih banyak produk-produk khas. Oleh sebab itu, syarikat-syarikat pembuatan terpaksa menghasilkan berbagai-bagai produk dengan pelbagai pilihan dan ciri-ciri, dalam kumpulan yang kecil. Dalam keadaan itu, perubahan rekabentuk produk, campuran produk, jumlah produk dan proses pengeluaran yang mempengaruhi susun atur pembuatan kerap berlaku. Untuk memenuhi keperluan dan bertindak balas terhadap perubahan, syarikat-syarikat perlu mengamalkan susun atur yang sesuai di bahagian pengeluaran untuk meningkatkan operasi mereka dari segi produktiviti yang lebih tinggi, kualiti yang lebih baik dan kadar tindakbalas segera terhadap kemahuan pelanggan. Susun atur selular adalah susun atur alternatif dan sesuai untuk syarikat-syarikat pembuatan yang dicirikan dengan jumlah pengeluaran yang rendah dan kepelbagaian produk yang tinggi. Susun atur selular terdiri daripada beberapa sel yang mana komponen-komponen diproses dibawah kumpulan mesin. Pengenalan mesin dan komponen-komponen di dalam setiap sel, dikenali sebagai pembentukan sel, adalah langkah teras dan kritikal dalam susun atur selular. Kajian ini, membentangkan satu algoritma untuk pembentukan sel untuk meminimumkan pergerakan antara selular. Algoritma tersebut mengambilkira dua faktor pengeluaran, iaitu urutan operasi dan jumlah pengeluaran bagi setiap komponen disamping bilangan sel yang boleh dikenal pasti terlebih dahulu. Teori graf telah digunakan dalam pembangunan algoritma ini. Ia terdiri daripada empat langkah, dengan langkah pertama

menunjukkan urutan mesin yang digunakan oleh setiap komponen dalam bentuk graf. Langkah kedua melibatkan pengiraan hubungan antara mesin-mesin berdasarkan jumlah pengeluaran bagi setiap komponen (dengan mengira berat setiap pinggir graf). Langkah ketiga adalah mengumpulkan mesin ke dalam sel-sel mengikut bilangan sel yang diperlukan. Tujuan langkah ini adalah untuk memaksimumkan jumlah pergerakan komponen-komponen di antara mesin-mesin dalam sel yang sama. Langkah terakhir dalam algoritma yang dicadangkan ialah membahagikan komponen-komponen kepada sel-sel yang tertentu. Tujuan langkah ini adalah untuk menetapkan komponen kepada bilik-bilik kecil yang terbentuk dalam langkah sebelumnya untuk mengurangkan jumlah pergerakan antara selular. Algoritma yang dibangunkan kemudiannya dikodkan didalam MATLAB dan disahkan dengan tiga contoh berangka yang diambil dari pelbagai penerbitan. Setelah itu, algoritma telah disahkan di dalam kajian kes sebenar di syarikat yang menghasilkan produk-produk elektronik dan elektrik di Malaysia. Keputusan menunjukkan bahawa kaedah ini boleh menghasilkan penyelesaian yang sama dengan kaedah-kaedah yang diikuti oleh contoh berangka. Di samping itu, algoritma yang dicadangkan telah terbukti dalam pembentuken sel-sel di syarikat pembuatan yang bersaiz kecil dan sederhana. Tambahan pula, algoritma yang dicadangkan menunjukkan fleksibiliti yang membenarkan pereka sel untuk memilih bilangan sel-sel yang diperlukan terlebih dahulu. Kesimpulannya, keputusan menunjukkan bahawa algoritma yang dicadangkan boleh mengurangkan pergerakan antarasel di bahagian pengeluran.

A NEW CELL FORMATION METHOD CONSIDERING OPERATION SEQUENCES AND PRODUCTION VOLUMES

ABSTRACT

In today's market, customers are demanding more customized products. Hence, manufacturing companies are forced to produce a variety of products with various options and features in small batches. Under such circumstance, frequent changes take places in product design, product mix, product volume and production process affecting the manufacturing layout. To fulfill these requirements and respond to the changes, companies need to adopt appropriate shop floor layout to improve their operations in terms of higher productivity, better quality and customer responsiveness. Cellular layout is an alternative layout and is suitable for manufacturing companies which are characterized by low volume and high product variety. Cellular layout is composed of cells that ideally act as independent entities. Also, each cell is composed of a group of machines that can process a family of parts. Identification of machines and parts in each cell, known as cell formation, is the core and critical step component of cellular layout. This research, presents an algorithm for cell formation to minimize intercellular movements. The algorithm considers two production factors, operation sequences and production volumes of each part as well as the number of cells can be identified in advance. The graph theory was employed to develop the algorithm. It consists of four stages that the first one shows the sequences of machines that are used by each part in a graph. The second stage calculate the relationships between machines based on the production volume of each part (calculate the weight of each edge of the graph). The

third stage groups machines into cells according to the required number of cells. The aim of this stage is to maximize the total moves of parts between machines within the same cells. The last stage of the developed algorithm assigns parts to cells. The aim of this stage is to assign parts to the cell formed in previous stage to minimize the total intercellular movement. The developed algorithm is coded in MATLAB and is verified with three numerical examples taken from the literatures. Furthermore, the developed algorithm is validated in a real case study producing electronic and electrical parts in Malaysia. The results indicate that the developed algorithm can produce reasonable results. In addition, the developed algorithm enables to form cells for small and medium-sized manufacturing companies. Furthermore, the proposed algorithm showed the flexibility to allow the cell designer to select the required number of cells in advance. In conclusion, the outputs indicate that the proposed algorithm enables to reduce the intercellular movements on the shop floor.

CHAPTER 1

INTRODUCTION

1.1 Background

Industry consists of enterprises and organizations that produce and/or supply goods and/or services. Industries can be classified as primary, secondary and tertiary (Groover, 2008). The primary industries are those that cultivate and exploit natural resources such as agriculture and mining. The secondary known as manufacturing industries convert the outputs of the primary industries into goods and the tertiary well known as service industries provide services rather than goods.

Manufacturing can be defined as the application of physical and chemical processes to change the geometry, properties and form of raw material to make products. The processes that carry out manufacturing for producing products involve a combination of machines, tools and labors. These processes usually take place on the shop floor.

To produce products, manufacturing carries out three functions that comprise marketing, finance and operations (Heizer and Render, 1996). The marketing is in charge for assessing customer needs and keep a responsive working relationship with customers. The finance performs activities to gain funds for the company and guide it to utilize of financial resources and the operations is responsible for quick response to customers order and producing products on the shop floor.

The operations function is important as compared to other two functions since this function should satisfied customers in terms of delivery time and quality of products and it is performed by the greatest number of people who are responsible for producing products on the shop floor.

In order to maintain a successful manufacturing company in today's competitive world, it is necessary for a manufacturing company to have a strategy to increase the efficiency of operations.

1.2 Operation Strategy

In general, the “operation” is the activity of managing resources and processes that produce products on the shop floor (Slack and Lewis, 2008). Therefore, it is necessary for a shop floor‘s manager to make strategic decisions about their operations (operations strategy). In other words, the role of operations strategy is to present a plan for the operations function to make the best use of resources. The operations strategy can involve strategies for production, process and technology, capacity, layout, human resources and quality. One of the most important areas of the operation strategy is production strategy which describes the manner of producing operations in each manufacturing company.

1.2.1 Production Strategy

Proper production strategy can significantly impact competitive strength and performance of the company. In general, the production strategy can be divided into two types, Make-to-stock (MTS) and Make-to-order (MTO) (Soman et al., 2004).

Make-to-stock (MTS) is a strategy that production is completed before the customer's order is received. A problem in such companies is that customers are not involved in customizing and changing the design and features of product (Kingsman et al., 1996). Consequently, customers will lose the ability to customize the product but gain speed of delivery. This strategy is feasible for standardized products with high production volumes, for example soft drinks and standard automotive parts.

Make-to-order (MTO) is a strategy where products are designed, produced, and delivered to customer specifications in response to customer orders, and the delivery time is long (Kaminsky and Kaya, 2009). In other words, they don't produce finished products until they receive an order from customers. This strategy is appropriate for high product variety (high-mix) and low production volumes.

In addition, in today's competitive market some changes such as short product life cycle, variable customer demand and reducing product volume have taken place in production system. To survive in today's competitive world, a production systems should have the ability to response customer orders quickly, as well as offer a large variety of products. Hence, producing to stock becomes costly and unpractical when the variety of products is high and it is also risky when demand is stochastic (Gupta and Benjaafar, 2004). Therefore, a significant increase in product variety meant shifting from MTS to MTO. Given these facts, many production systems gradually are moving to MTO production strategy due to increasing needs of customers that wants the products tailored to their particular needs.

MTO production strategy can become inefficient when operation consume too much time, space or labor on the shop floor. Thus, the next step for MTO production strategy is the allocation of orders to the production line and making an adequate assignment of the available machines (a satisfactory layout) on the shop floor. Truly, proper layouts have an impact on productivity of shop floor.

1.2.2 Layout Strategy

The selection of an efficient layout on the shop floor is a strategic problem. Layout is the arrangement of physical resources within the shop floor. Layout design is the process to devise a good, workable and effective arrangement of the resources on the shop floor and is a very important issue of the production systems (Wang and Edgar, 2009).

Layout design have significant effect on the shop floor such as facilitate the flow of materials, increasing the efficient utilization of labor and equipment, reducing hazards to workers, improving employee morale and communication.

The shop floor layout can be classified into four types, including fixed product layout, flow line layout, job shop layout, and cellular layout (Hassan, 1995). Fixed product layout is commonly used when the product is too large to move throughout the various processing steps. Thus, the product stays at one location and the equipment required for products is moved to the product, for instance shipbuilding industry, aircraft industry. Flow line layout is based on the processing sequence for the parts being produced on the line. Materials typically flow from one workstation directly to the next adjacent one. Drira et al.(2007) stated that the flow line layout was used for systems with high production volumes and a low-variety of products. Job shop layout groups similar machines together in department or work-centre according to the process or functions. This layout is appropriate for a system with high product variety and low production volume (Hasan et al., 2011).

In order to maximize the utilization of job shop and flow line layout, cellular layout have been developed as the new types of layout for production systems. Cellular layout is according to the grouping of machines into cells to process the family of similar parts. In this layout, the processing sequence is generally the basis for forming families of parts and hence cells. In other words, the main concern of this layout is to divide all parts and machines into dependent cells. Cellular layout tries to combine the advantages of flow line layout and the job shop layout.

As mentioned previously, customers are forcing manufacturing companies to produce variety of product in a smaller lot sizes and shorter lead time. Hence, the company that adopt traditional layout is facing challenges. In other words, traditional layouts do not have the ability to respond to changes to product mix (Suresh, 1992). Consequently, cellular layout is an alternative for the traditional layout that has been proved effective to most manufacturers (Albadawi et al., 2005).

1.3 Problem Statement

In recent years, manufacturing companies have been unable to cope with an increasingly fast changing market. Customers are demanding products that are tailored to their unique specifications. Product life cycle tend to be much shorter than in the past. Hence, customized products with short product life-cycles and variable demand have gradually made the manufacturing companies shift from high production volume to high mix and low production volume (HMLV) (Arıkan and Güngör, 2009). The major difficulty in these manufacturing companies is due to high level of product variety. The effects of these product variations in manufacturing is high investment in equipment, high tooling costs, difficult scheduling, high quality control costs and high setup time and costs. For that reason, shop floor's manager recognized the need for an appropriate layout which can handle future changes and reduces product costs. Thus, the development of an appropriate layout is a critical issue for managers to response effectively to the requirements.

In order to cope with the customer needs, manufacturing companies are attracted towards implementing cellular layout (Shiyas and Pillai, 2012). In other words, adopting cellular layout becomes even more pressing in today's competitive environment. One of the most important problems faced in practice with cellular layout is to select and group machines and parts with similar features into cells; this process is called cell formation (Pailla et al., 2010). This primary step can influence all other decisions involved in the design of cellular layout in which similar parts are clustered into part families and dissimilar machines are allocated into cells (Saxena and Jain, 2011). Therefore, it seems that there is a need of a development of an algorithm to form a cell. The algorithm should not only be reliable theoretically, but also has high potentials of portability into practice and real life applications.

1.4 Objectives

The objectives of this research can be enumerated as follows:

1. To develop an algorithm to design new cellular layout.
2. To verify the developed algorithm with numerical examples.
3. To validate the developed algorithm using a case study company.

1.5 Research Scope

The layout algorithm in this study is developed based on the following considerations and constraints which are:

1. In this study, since the proposed algorithm is for industrial application, validation of frame work should be done practically. Thus, it requires a case study to form layout of shop floor.
2. Two production factors, including operation sequences and production volume, are considered throughout this context.
3. The manufacturing company is small and medium-sized. Thus, large-sized manufacturing company is neglected.

1.6 Thesis Outline

The overview of this thesis is as follows; Chapter 2 provides a literature review of the related subjects. Chapter 3 then deals with the developed algorithm. The algorithm is verified by three numerical examples taken from the literatures and validated in a case study carried out at an electrical and electronic company in Malaysia discussed in Chapter 4. Chapter 5 presents the overall discussion and algorithm verification and validation and Chapter 6 finally addresses the conclusion and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses briefly on the introduction of layout design and the related impacts on the shop floor. A general explanation on classification of shop floor layout is also presented. As known, there are three types of layout for shop floor, namely; job shop, flow line and cellular layout. In this research, cellular layout will be the focus of discussion because of its commonly implementation on the shop floor layout.

A fundamental step in cellular layout is the determination of machine cells and part families. This step is known as cell formation that is chosen as a main scope of literature. The cell formation methods employed to form cells are explained in details. Some performance measures are introduced to evaluate the quality of final solution. This research deals with two kinds of cell formation. The first is for binary information, while the second one is various production factors. Approaches that have been developed with binary data and production data for cell formation will be the main focus in this chapter. Finally, findings from the literatures will be discussed at the end of this chapter.

2.2 Shop Floor Layouts

Nowadays, manufacturing companies are facing short product life cycle and increased demand from their customers for quick response and product customization. This has resulting in enhancing the complexity and diversification of the production processes and manufacturing systems in the companies. Since the complexity and diversity of the production has intensified, companies are shifting to high mix and low volume (HMLV) environment (Zhang and Tseng, 2009). In order to survive and compete, manufacturing companies have to retain its flexibility. A flexible manufacturing system can be viewed as a requirement to attain success because it determines the company's capability in satisfying customers in terms of cost, delivery time and product quality (Filho and Tiberti, 2006). In addition, companies have to rearrange the shop floor layout in order to accommodate the changes. The location and arrangement of machines and workstations on the shop floor can be considered as a typical shop floor layout (Ulutas and Kulturel-Konak, 2011). Shop floor layout has profound effects on the complexity of the companies' production processes and flexibility of their manufacturing systems. As a result, designing the shop floor layout for the manufacturing companies is one of the most recognized and critical problem in industrial engineering with considerable research have been done in this area (Meller and Gau, 1996).

In general, the research relating to the shop floor layout is focusing in determining the optimal arrangement of machines and workstations on the production floor (Mckendall Jr and Hakobyan, 2010). Optimal arrangement means, that no other arrangement can be better with regard to the chosen criteria. Other arrangement may be equally good, but none of them is better (Solimanpur and Jafari, 2008). Hence, the problem of a shop floor layout design beside deciding on the optimal arrangement of machines and workstations, the other imperative aim are; to achieve smooth flow of workers and material, reducing material handling cost, reducing lead time, increases the throughput, enhance shop floor's efficiency and productivity, utilizing the available space effectively and efficiently, and increase employee morale (Yaman and Balibek, 1999; El-Baz, 2004; Maniya and Bhatt, 2011). Inappropriate shop floor layout will result in poor productivity, increased work-in-process (WIP) and inefficient material handling (Chiang and Chiang, 1998;Wang et al., 1998).

Given these facts, shop floor layout design is an essential issue and decision makers always face the difficulties to choose optimal shop floor layout. Hence, to address this issue the selection of optimal layout design procedure will be elaborated. Beforehand it is necessary to understand various types of shop floor layouts that were adopted by the manufacturing companies.

2.2.1 Types of Shop Floor Layout

Traditionally, the shop floor layout can be classified into two that is job shop and flow line. However, the emergence of group technology has added a new type of layout under the named as cellular layout (Al-Mubarak et al., 2003; Drira et al., 2007). These layouts allocate machines, and equipment on a shop floor based on different criteria. Therefore, each of them has advantages and disadvantages. Each of these shop floor layouts will be further discussed as follows.

- **Job Shop Layout**

Job shop is a layout that has the arrangement of machines, equipment and tooling based on their functional capabilities (Gupta and Leelaket, 1993). It is also known as process layout because it groups similar activities such as processes and functions into one department. For instance some functions such as, cutting, drilling, and polishing are located almost close to each other in order to increase machine utilization and production flexibility (Huang, 2003). This layout is suitable when there are a wide variety of products and low production volume (Montreuil, 1999). The schematic illustration of the job shop layout can be seen in Figure 2.1.

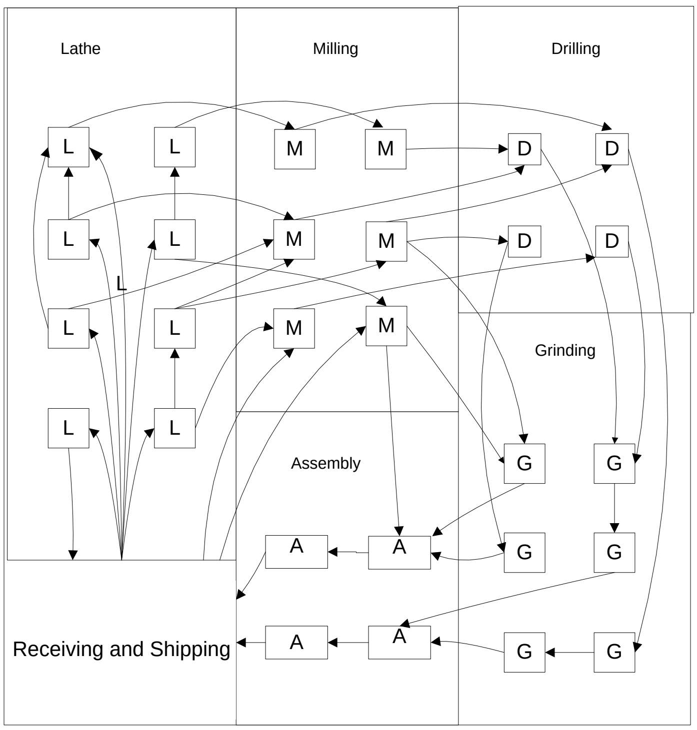

Figure 2.1: Job Shop Layout (Heragu, 2008)

Job shop layout is composed of general machines, while departments are formed by grouping machines that perform similar operations. Therefore, job shop is flexible enough to produce many different parts with different production sequences.

the advantages of job shop is the ability to produce a high variety of parts in small lots (Jaramillo, 2007).

Since in job shop layout, machines are distributed based on their function thus during processing some products may have to travel throughout the shop floor. It may lead to a congestion on the shop floor (Heragu, 2008). In addition, products are moved through the shop floor in batches that cause longer throughput time and high level of work-in-process (WIP) and high material handling cost (Wang et al., 2010). This results in an increase in the cost of production and a decrease in the rate of production. In general, job shop layout is usually inefficient due to high work-in-process and high material handling requirements.

- **Flow Line Layout**

Flow line layout is designed base on the sequences of processes required to produce a product. Accordingly, machines and workstations are arranged within a line in a sequence and part move from one work center directly to the next one (Irani and Huang, 1998). Thus, each flow line is fully dedicated to produce a particular product. Figure 2.2 illustrates the schematic illustration of flow line layout.

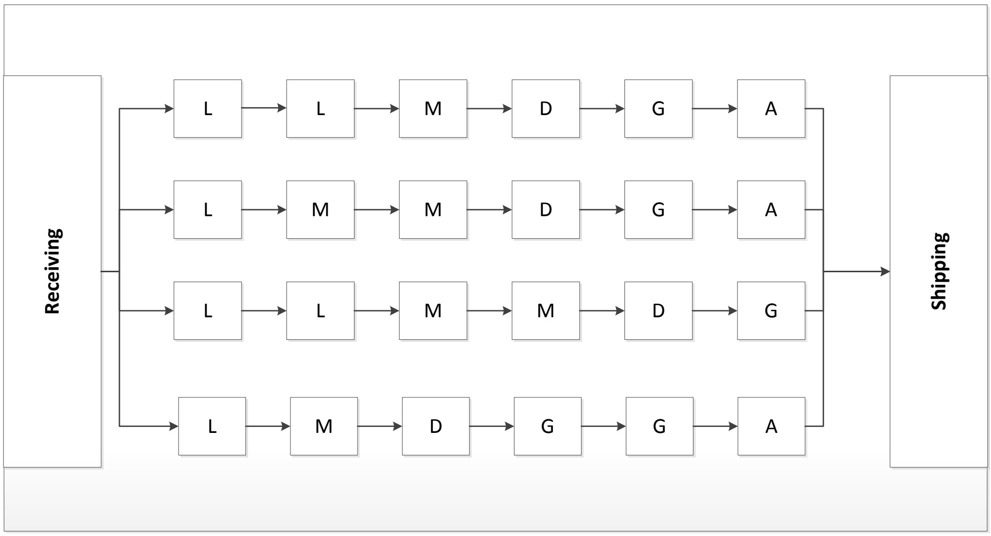

Figure 2.2: Flow Line Layout (Heragu, 2008)

Flow line layout is usually designed to produce high production volume and standardized product. In other words, flow line layout is appropriate for manufacturing companies operating high production volume and low product variety (Hasan et al., 2011). A major limitation of flow lines is the lack of flexibility to produce products which are not designed. The main reason is that specialized machines, which are expensive, are setup to perform limited operations (Mungwattana, 2000).

- **Cellular Layout**

From the previous sections, a conclusion can be made that job shop and flow line layout cannot meet today's production requirement which include constant changes in product design and demand. With increase in order quantity and variety of the products, many manufacturers have adopted the cellular layout in their shop floor system configuration (Tang and Abdel-Malek, 1996; Modrák et al., 2006). As a result, cellular layout has emerged as new types of shop floor layouts.

The cellular layout comes from the application of group technology (GT) concepts to reconfiguration the manufacturing companies and shop floor layout design (Irani, 1999). Group technology was first proposed by Mitrofanov in the late 1950's (Hachicha et al., 2007). GT can be defined as a manufacturing philosophy, identifying similar parts and grouping them together to take the advantage of their similarities in manufacturing and design characteristics.

Cellular layout is composed of cells that ideally act as independent entity. Furthermore, each cell is composed of a group of machines that can process a family of parts. A part family is a set of parts which are similar either because of geometric shape and size or similar processing steps required in their manufacture (Won and Currie, 2006). Cellular layout is designed in a way that minimizing the inter-cellular movements and maximizing the utilization of machines (Solimanpur et al., 2004). In other words, an ideal cell manufacturing system has no flow among cells.

The tenet of cellular layout is to divide a shop floor into several groups of machines (cells), each being dedicated to the processing of a part family. Therefore, each part type is ideally produced in a single cell. Consequently, flow of material is reduced and simplified and the scheduling will become easier (Mungwattana, 2000).

The main difference between a job shop layout and a cellular layout is in the grouping and layout of machines. The job shop layout in Figure 2.1 is converted into a cellular layout as shown in Figure 2.3. Obvious benefits gained from the conversion of the layout are less travel distance for parts, less space required, and fewer machines needed.

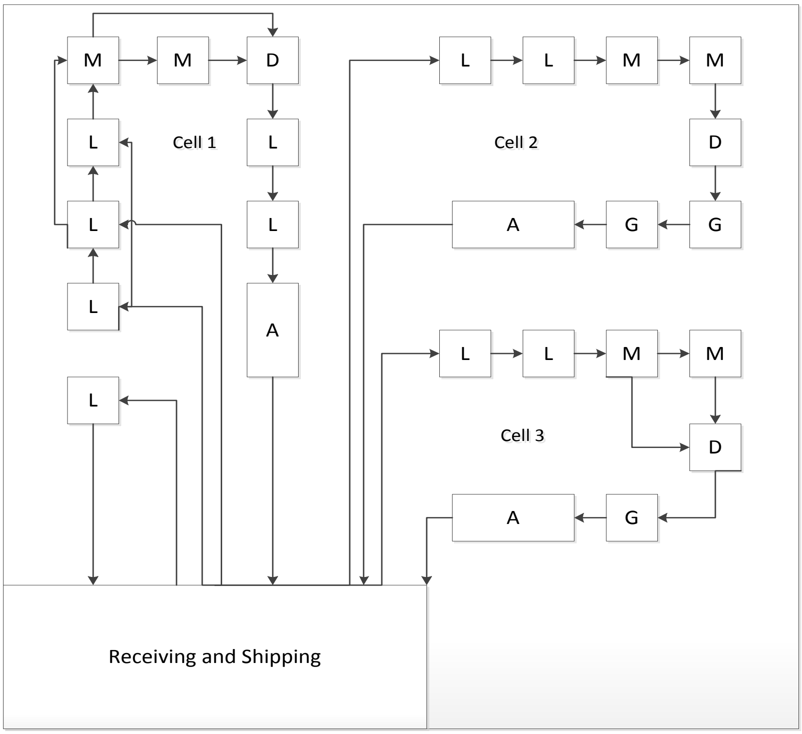

Figure 2.3: Cellular Layout (Heragu, 2008)

Cellular layout has many advantages over the other two types of layouts. Cellular layout major advantages, including reduction in lead time and work-in-process inventories and reduction of set up time due to similarities of part type, reduction in material handling cost, better quality and production control, increment in flexibility, simplified flow of parts and tools and increase workers satisfaction (Asokan et al., 2001; Ariafar and Ismail, 2009). Traffic congestion, material handling cost, WIP inventory, production lead time and other forms of waste are significantly reduced in a cellular layout because the parts in a family are processed almost entirely in their respective cell. In other words, the cellular layout combines the advantages of the job shop's flexibility and the flow line's efficiency (Balakrishnan and Cheng, 2007). Given these facts, many manufacturing companies have recently selected cellular layout in order to achieve flexibility and efficiency which are essential for survival in today's competitive environment.

The design for cellular layout involves three following stages (Tavakkoli-Moghaddam et al., 2007):

1. Formation of machine cells and part families.
2. Layout of machines within each cell (i.e. intra-cell layout).
3. Layout of the cells within the shop floor (i.e. inter-cell layout).

The primary step in implementing cellular layout is grouping machines into cells and parts into families. In other words, cell formation is a major step in the cellular layout.

2.3 Cell Formation under the Cellular Layout

The aim of cellular layout is to group machines into cells and parts into families based on the similarities in their design and manufacturing attributes. Thus, the process of determination of machine cells and their corresponding part families is known as cell formation (Jeon and Leep, 2006). In general cell formation procedure has three main decisions (Selim et al., 1998):

1. Identification of part families

2. Identification of machine cells

3. Allocation of families to cells or vice versa

These three decisions are interrelated and can be regarded as sub problem for cell formation and should be note that the above steps are not necessarily performed in the above order or even sequentially. It is depending on the procedure that uses to make cell formation.

In recent years many research has been done on cell formation and a large number of procedures have been developed based on diverse methodologies for cell formation (Mahesh and Srinivasan, 2002). These methods will be discussed in the following section.

2.4 Classification of Cell Formation Methods

As mentioned before, the primary step for implementation of cellular layout is the cell formation (CF). Cell formation consists of identifying part families and machine cells. In the last three decades, many attempts have been made to seek for effective methods for the cell formation problem. Hence, various methods have been developed to solve the cell formation problem. Three general methods for grouping machines into cells and parts into families are as follows (Papaioannou and Wilson, 2010):

1. visual inspection method
2. classification and coding methods
3. production flow analysis methods (PFA)

These methods are different in terms of information requirements and final design. Each method with its importance is discussed. Figure 2.4 demonstrates cell formation methods in details.

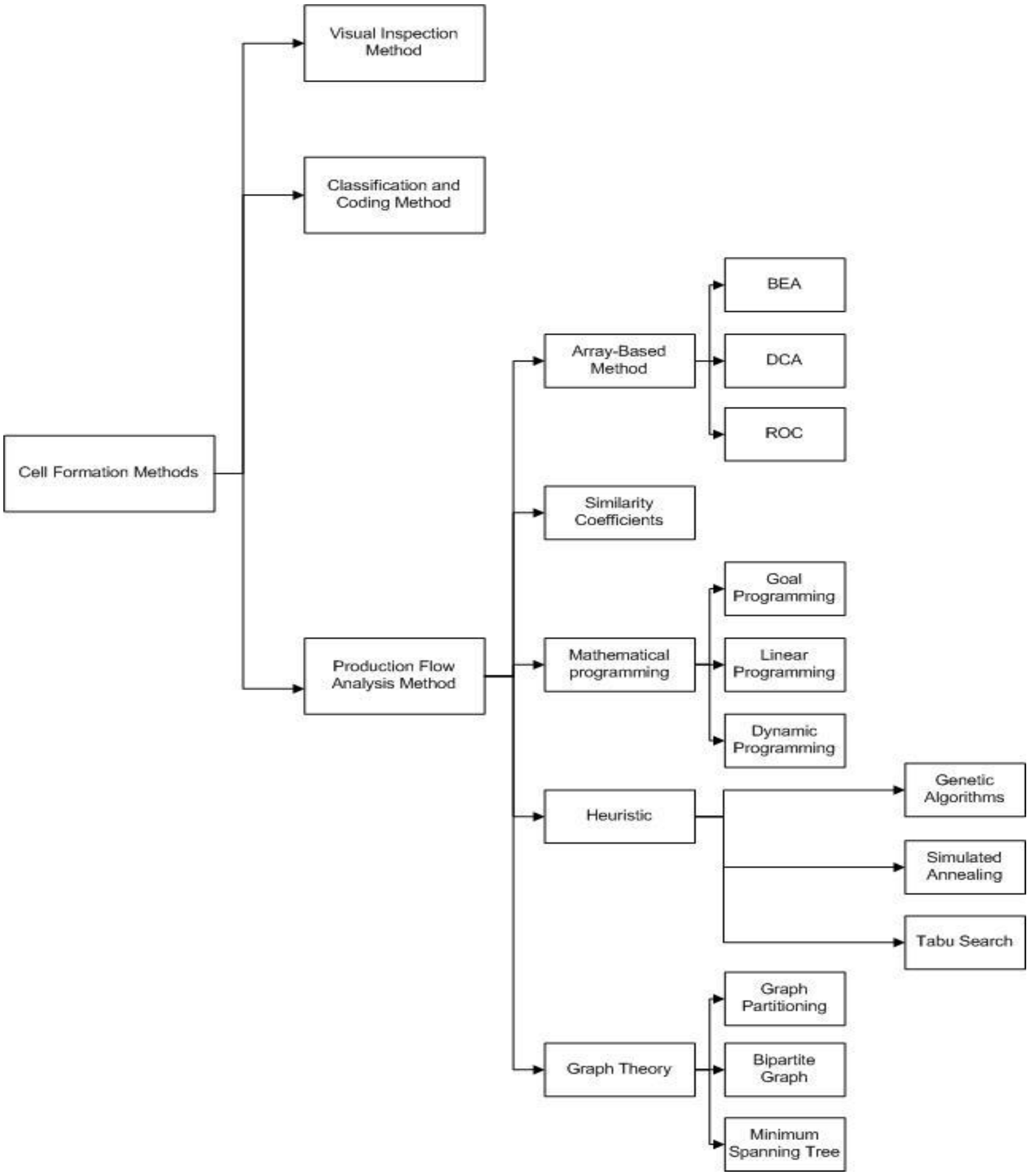

Figure 2.4: Classification of Cell Formation Methods

Referring to Figure 2.4, the visual inspection method classifies parts into part families by visualizing part geometries and arranging them into groups based on general criteria. A human expert is needed to perform inspections, assign part families and related machines groups (Chan et al., 1999). The analyst simply inspects the parts to determine proper groups. It success is highly dependent on experience and knowledge of the analyst even in small problem cases (Murugan and Selladurai, 2007). This method is the least sophisticated, relatively inexpensive, and the least accurate when compared with other methods. It is not a systematic method and cannot be applied if the number of parts is great (Liu et al., 2010). For example, in the case of more than hundred parts, it would be impossible to realize which part goes with which family via this method. Therefore, this method is less common and least applicable in grouping process due to many constraints on it. Besides that, an inaccurately result occurred due to certain human and environment errors.

Classification and coding methods are the traditional tools used to implement cellular layout. In these methods, each part is assigned a code according to its shape, size, or production requirements. Based on the similarity of these codes, parts can be grouped into part families. These methods only form the part families (Liu et al., 2009). In the coding methods, parts can be classified on the basis of the following features:

- Geometric shape and complexity
- Dimensions
- Type of material
- Shape of raw material
- Required the accuracy of the finished parts

The drawbacks of a classification and coding methods are that it is expensive and needs significant effort to design and implement. Furthermore, it requires spending a lot of time to code parts. In addition parts of similar size, shape, and function may not use the same set of machines and other resources (Cheng et al., 1995). Because of these limitations, many techniques have been developed to solve the cell formation problem based on production flow analysis (PFA).

Production flow analysis is a method for identifying part families and machine cells. It was first introduced by Burbidge (1963). Production flow analysis, analyze the production process data listed in the operation route sheets, including, machine/workstations, operations, operation sequences, etc. Parts with similar routings are classified into part families. These families can then be used to form machine cells in a cellular layout. Production flow analysis methods are the most commonly used tools to group parts and machines into cellular layout. In this method, the machine route data for each part is shown into a machine-part incidence matrix (MPIM). This matrix provides the main data for the formation of part families and machine cells (Mahesh and Srinivasan, 2002).

2.5 Production Flow Analysis (PFA) Based Methods

The core of cell formation methods falls under the category of production flow analysis (PFA) based methods. The production based methods analyze the manufacturing sequence and workloads for parts and machines and groups parts with similar processing requirements and/or machines that process similar parts (Dimopoulos and Mort, 2001).

By virtue of the routing information, this method is quick and adequately accurate for a company to rearrange the shop floor into independent manufacturing cells (Murugan and Selladurai, 2007). Hence, in recent years, several PFA-based methods have been proposed for solving part families and machine cells formation. These methods can broadly be classified as:

- Array-based methods
- Mathematical programming methods
- Heuristic methods
- Similarity coefficient methods
- Graph theoretic methods

2.5.1 Array-Based Methods

Array-based method is one of the simplest classification of PFA-based methods for cell formation problem (Ahi et al., 2007). The array-based methods attempt to assign machines to groups and parts to their related families by appropriately rearranging the order of rows and columns to find a block diagonal matrix (Selim et al., 1998). In array-based methods a machine-part incidence matrix is constructed as shown in Figure 2.5. Referring to Figure 2.5, the rows and columns of the matrix correspond to machines and parts, respectively. The matrix consists of 0, 1 entries where an entry 1 in the (i , j) location means that machine i is used to process part j, and an entry 0 means that machine i is not used to process part j (Papaioannou and Wilson, 2010).

Machines \ Parts	1	2	3	4	5	6	7
1	0	1	0	0	1	0	0
2	1	0	0	0	0	0	1
3	0	0	1	1	0	1	0
4	0	0	1	1	0	1	0
5	1	0	0	0	0	0	1
6	0	0	1	1	0	1	0
7	0	1	0	0	1	0	0

(a) Initial Matrix

Machines \ Parts	1	7	3	4	6	2	5
2	1	1	0	0	0	0	0
5	1	1	0	0	0	0	0
3	0	0	1	1	1	0	0
4	0	0	1	1	1	0	0
6	0	0	1	1	1	0	0
1	0	0	0	0	0	1	1
7	0	0	0	0	0	1	1

(b) Clustering Matrix

Figure 2.5: Initial Matrix and Clustering Matrix (Joines et al., 1996)

Well-known array-based clustering methods are bond energy algorithm (BEA), rank order clustering method (ROC), and direct clustering algorithm (DCA). Bond energy algorithm (BEA) involves the evaluation of “bond energy” in the machine-part incidence matrix. The BEA method proposes that a bond exists between each pair of adjacent row and column elements and the bond energy is used to measure how strong the relationships are (Chan et al., 1999). The value of the bond is equal to summation of the product of any two adjacent elements. The first step of this algorithm is to select arbitrarily columns and rows. It then places that row with the highest total bond energy beside the assigned rows or columns. The procedure repeats for all the rows and columns and tries to find a matrix containing the highest total bond energy (Chu and Tsai, 1990). Since the first step of this algorithm is arbitrary, many possible solutions can be generated (Albadawi et al., 2005). Details procedure of this method can be referred to Heragu (2008).

Rank order clustering (ROC) algorithm first assigns a binary value for each row and column of machine-part incidence matrix. The rows and columns are then alternately ranked in descending order of their binary values in order to obtain block diagonal form (Berardi et al., 1999). Although ROC is simple to use in designing part families and machine groups, it has some disadvantages. One of the disadvantages of ROC is that the final solution depends on the arrangement of rows and columns on the initial order of machine-part matrix. The other disadvantages of ROC is that the binary values used for the rearrangement, limits the size of the problem (Selim et al., 2003). For further reference to have detail perceptive of the method can refers to Parashar (2009).

Direct clustering algorithm (DCA) rearranges the rows with the left-most positive $(a_{ij} = 1)$ cells to the top and the columns with the top-most positive cells to the left of the machine-part matrix (Chan and Milner, 1982). After several iterations, all the positive cells will form diagonal block from the top-left corner to the bottom-right corner of the matrix. In order to have further understanding of the procedure Chan and Milner (1982) and Parashar (2009) can provide a complete discussion on this method.

All the above algorithms consider only the binary incidence matrix and identify the clusters along the matrix's diagonal. Hence, the vital shortcoming of these methods is that grouping machines and parts without consideration of the realistic aspect of cell formation. In the cell formation problem there are many realistic production factors that can be taken into consideration, such as machining time, machine capacities, production volume, operation sequences, production cost, inventory, which may significantly influence cell formation (Ahi et al., 2009). Because of complexity of the cell formation problem it is impossible to consider all the aforementioned factors in one algorithm.