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นางสาวน้ำพลอย พรพิบูลย์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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ปีการศึกษา 2556

APPLICATION OF CELLULAR MANUFACTURING CONCEPT IN A FURNITURE PRODUCTION COMPANY

Miss Namploy Pornpiboon

A Thesis Submitted in Partial Fulfillment of the Requirements
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น้ำพลอย พรพิบูลย์: การประยุกต์ใช้หลักการการผลิตแบบเซลลูล่าร์ในบริษัทผลิตเฟอร์นิเจอร์ (APPLICATION OF CELLULAR MANUFACTURING CONCEPT IN A FURNITURE PRODUCTION COMPANY) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ.ดร. ปารเมศ ชุติมา, 105 หน้า

งานวิจัยฉบับนี้ได้ทำการศึกษาวิเคราะห์การผลิตสินค้าเฟอร์นิเจอร์ระดับคุณภาพของบริษัท เอ ซึ่งดำเนินธุรกิจอุตสาหกรรมเฟอร์นิเจอร์ขนาดย่อม-กลาง ตั้งอยู่ในประเทศไทย ปัญหาที่หลักที่พบในปัจจุบันคือปัญหาความล่าช้าในการส่งมอบสินค้า จุดประสงค์ในการศึกษาเพื่อพัฒนาปรับปรุงผังกระบวนการผลิต (Process Layout) โดยมุ่งเน้นการนำหลักการผลิตแบบเซลลูล่าร์มาประยุกต์ใช้ในการพัฒนาการจัดวางผังกระบวนการผลิต เพื่อปรับปรุงประสิทธิภาพในการผลิต

การวิจัยเริ่มจากการรวบรวมข้อมูลและวิเคราะห์ถึงสภาพปัญหาในกระบวนการผลิต การวิเคราะห์ได้ดำเนินการเพื่อพิจารณาหามาตรการพัฒนาปรับปรุงกลยุทธ์ในการปรับเปลี่ยนโครงสร้างระบบการผลิตที่เหมาะสม จากนั้นได้ดำเนินการปรับปรุงผังกระบวนการผลิตจากผังกระบวนการผลิตแบบกระบวนการ (Functional layout) เป็นกระบวนการผลิตแบบกลุ่ม (Cellular layout) โดยประยุกต์จากหลักการผลิตแบบเซลลูล่าร์ สายการผลิตใหม่ส่งผลให้สามารถลดขั้นตอนและเวลาในการปฏิบัติงาน ลดปัญหาความล่าช้าในการผลิต ลดค่าปรับ รวมทั้งปรับปรุงคุณภาพสินค้าให้ได้มาตรฐาน ทำให้เกิดความพึงพอใจแก่ลูกค้า

ผลลัพธ์จากการปรับปรุงพัฒนา พบว่าสามารถปรับปรุงให้เกิดประสิทธิภาพขึ้น ทั้งในแง่ของการผลิตและคุณภาพ กล่าวคือ หากพิจารณาในแง่ของการผลิต ผังกระบวนการผลิตและผังโรงงานที่ถูกปรับให้เหมาะสมทำให้ระยะทางการไหลของสินค้าสั้นลง 56.64% ยังผลให้ เวลาเคลื่อนย้ายของชิ้นส่วนการผลิต(Move Time) ลดลง 57.33% กระบวนการที่ล่าช้าลดลง 68.83% ส่วนจำนวนขั้นตอนการผลิตลดลง 6.67% รวมทั้งลดเวลาที่ใช้ในกระบวนการผลิตทั้งสิ้นลง 30.99% เช่นกัน เมื่อพิจารณาในแง่ของคุณภาพ พบว่า จำนวนวัสดุเสียหายและชิ้นส่วนที่ต้องกลับไปทำใหม่ลดลง 27.55% และ 47.97% ตามลำดับ ในขณะที่ อัตราการส่งสินค้าล่าช้าลดลง 59.31% ส่วนค่าปรับจากการส่งล่าช้าลดลง 85.08% ทำให้สามารถลดข้อร้องเรียนจากลูกค้าได้ 59.77%

ภาควิชา ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต ลายมือชื่อนิสิต ....

สาขาวิชา การจัดการทางวิศวกรรม ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

ปีการศึกษา 2556

#5371617621 : MAJOR ENGINEERING MANAGEMENT
KEYWORDS : CELLULAR MANUFACTURING, FURNITURE PRODUCTION

NAMPLOY PORNPIBOON: APPLICATION OF CELLULAR MANUFACTURING CONCEPT IN A FURNITURE PRODUCTION COMPANY. ADVISOR: ASSOC. PROF. PARAMES CHUTIMA, Ph.D., 105 pp.

This thesis studies the high quality furniture production of the 'Company A', the small-to-medium sized-manufacturer, located in Thailand. The main problem is late delivery to customers. The objective of this thesis was to redesign of production process layout through application of Cellular Manufacturing concept in order to improve production efficiency.

The researching process started with data collecting and production problem assessment. The analysis was performed to select proper operational strategy for suitable production process layout. Production process layout was re-designed from functional layout to cellular layout by applying Cellular Manufacturing Concept. The new improvement by Cellular Manufacturing concept resulted to shorter travel distance and moving time, reduced work in process, reduced delay and penalty costs, including product quality improvement and finally leaded to customer satisfaction.

The results showed efficiency improvement both in production and quality. Focused on production perspective, more simplify factory and production process layout leads to reduction of product flow distance by 56.64%. Consequently, 57.33% of the total move time and 68.83% of the delay process were reduced. Likewise, the total number of work process and throughput time were reduced by 6.67% and 30.99% respectively. In terms of quality perspective, scrap and rework were reduced by 27.55% and 47.97% respectively. The reduction of 59.31% in late product delivery did not only reduce penalty cost in late delivery but also reduced customer complaints by 59.77% accordingly.

The Regional Centre for Manufacturing System Engineering Student's Signature ....
Field of Study: Engineering Management Advisor's Signature ....
Academic Year: 2013

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LIST OF ABBREVIATIONS

AEC	=	ASEAN Economics Community
AHP	=	Analytic Hierarchy Process
CM	=	Cellular Manufacturing
MRP	=	Material Requirement Planning
OEM	=	Original Equipment Manufacturer
PCC	=	Product Classification Code
PFA	=	Product Flow Analysis
PV-LF	=	Product/Volume-Layout/Flow Matrix
SLP	=	Systematic Layout Planning
SME	=	Small and Medium Enterprise
WIP	=	Work-In-Process
WS	=	Work Station

CHAPTER I
INTRODUCTION

This chapter is the introduction to the research describing background of the research, objectives, scopes, methodology, and expected benefits.

1.1 Background

Furniture industry in Thailand is rapidly growing and expanding to export markets, especially the upcoming join of ASEAN Economics Community (AEC). Thai furniture industry has high reputation in quality of works with high-skilled workers in craftsmanship. Instead of competing in price or cost leadership with China, Thai furniture companies would rather compete in quality of products. Customers demand for high quality products are increasing as well as high competition in the export markets. Companies that are able to provide variety and flawless quality of products in shorter lead time can win customer satisfactions. Therefore, to be able to increase customer satisfaction and retention, competitive advantages can be gained from not only business perspectives but also production perspectives. Ability to improve in production efficiency is also considered as one of the key success factors, especially improving on-time delivery performance.

The case study is based on a furniture production company that currently encounters problems with on-time delivery performance. The problems cause great impacts and consequences to decrease in customer satisfaction and retention. Customer orders come in lots and production starts after order placing. When orders are increasing in quantity and frequency, the current production systems is not efficient and causing delay in delivery. In order to survive in the business, the furniture manufacturers would have to redesign the production systems and layout to leverage production efficiency and to improve customer satisfaction. Therefore, Cellular Manufacturing Concept would be applied to make more productive, lower costs, and sustain competitive advantages.

1.2 Case Study Company

This case study is based on a specific furniture production company in Thailand by the name of “Company A”. The company is an Original Equipment Manufacturer (OEM) which produces fine-quality wooden furniture. It is categorised as a Small and Medium Enterprise (SME) with 60 employees located in Thailand. It is a family-owned business founded since 1992. Company A produces wooden furniture products according to customer order quantity. All products are made of Para woods. Customers can select to order a variety of products such as cupboards, tables, chairs, and stools. The company has variety design of products for customers to choose from. Product specification can be determined from customers in terms of size, set, and colours. The company does not store much inventory on hands but produces when order quantity is placing. Currently, the production system is Job Shop which allows flexible productions for high product variety in small quantity.

1.3 Statements of the Problems

Company A encounters the problems of delayed delivery of products to customers. Such problems caused impacts and consequences in terms of high penalty costs and decreased customer satisfaction. Based on historical data, the problem of long customer lead time is mainly caused by production department.

Long travel distance, long move time, and delay time in the production line are the main reason of the problem. The current production systems and layout does not support full potential to compete in time and quality. Company A analysed that having production process layout which is not suitable with nature of production causes the problem of long travel distance, long move time, and delay time, and under standard of quality products (scraps and reworks). This finally results in late product delivery to customers.

1.4 Objectives

The purpose of this thesis is to redesign of process layout for the company through application of Cellular Manufacturing concept.

1.5 Scope of Study

The development is based on the case study of the Company A, which is a medium-sized wooden furniture production company. The scope of study will focus only on production process layout in the Production Department of Company A. The process flow starts from arrival of raw materials to the production systems, work in process, until finished goods leave the production systems.

In this case study, an application of Cellular Manufacturing concept will be initially implemented in terms of production process layout improvement. This is only the initial phase of implementing full Cellular Manufacturing production systems. Familiarisation to team-based working and multi-task skill concepts are introduced to staff in order to embrace the changes of working in Cellular Manufacturing environment. In-depth study in terms of production planning & control is not included in this study.

1.6 Expected Benefits

The application of Cellular Manufacturing concept in the production process layout shall bring benefits in terms of:

(1) Reduction in travel distance, move time, and delay time

(2) Reduction in delay delivery to customers and penalty costs

(3) Reduction in rework and scrap rates

These benefits lead to shorter lead time and improve quality of products, which result to on-time delivery performance and customer satisfaction.

1.7 Methodology

1. Theory study: study literatures, theories, and tools & techniques which relates to Cellular Manufacturing, work instructions and production planning and control.
2. Data collection from workplace: the data will be directly collected, recorded, and observed through personal interviewing the owner of the factory and visiting the real site.

3. Identifying and analysing problems: analyse current situations of the production.
4. Define manufacturing strategy: defines methods and theories to be used to solve the current situation
5. Implementation: implement Cellular Manufacturing concept
6. Comparison and assessment: compare results of the proposed systems to the current systems.
7. Research conclusion and recommendation
8. Thesis report preparation and examination

CHAPTER II

THEORETICAL CONSIDERATION AND LITERATURE REVIEW

There are several theories, tools, and techniques to be used in this thesis to improve the production systems of the Company A.

2.1 Manufacturing Strategy (Miltenburg's Framework)

According to Whicker and Hartland (2005), operations strategy is the use of market requirements with operations resources to form decisions on long-term capabilities of operations for overall strategies. The objective of setting operations strategy is to satisfy customer requirements while developing and maintaining key operations resources.

In the business, the alignment between market perspectives and operations perspectives should be considered in order to formulate good operations strategies. To consider market perspectives in the operations strategy, the company decides which market to attract and which competitors to compete with. Then, competitive advantages will be established.

Miltenburg Framework is a tool for formulating manufacturing strategy by considering customers" requirement, performance of competition, manufacturing current capabilities, and manufacturing outputs (Whicker and Hartland, 2005). John Miltenburg has developed three-step process to formulate the suitable manufacturing strategy. The processes are

(1) Where am I?

(2) Where do I want to be?

(3) How will I get from where I am to where I want to be?

This first step (Where am I?) is to analyse company's current situations in terms of production systems, capabilities, and outputs.

2.1.1 Production Systems

Production systems are classified into 5 types based on different characteristics in product variety, production volume, process layout and arrangement, and flows of materials through the process. Five types of production process are Job Shop, Batch, Operator-paced Line Flow, Equipment-paced Line Flow, and Continuous production systems.

- *Job Shop*

This production system produces high variety but small volumes products. It has high process flexibility. The layout for this type of production system is functional layout with varied flows. Job Shop production system is suitable for orders in lots with high variety products.

- *Batch*

This production system produces many products in small volumes. The product variety is less than in Job Shop production system but product volume is higher. It still has process flexibility. The layout for this type of production system is cellular layout with varied flows in pattern. Batch production system is suitable for products that require similar processes but different in details.

- *Operator-Paced Line Flow*

This production system produces many products in medium volumes. The product variety is less than in Batch production system but product volume is higher. It has medium process flexibility. The layout for this type of production system is operator-paced line flow layout with mostly regular flows. Operator-pace Line Flow production system is suitable for production that requires large batch but low product differences. The production is rather based on operators than equipments and machines.

- *Equipment-Paced Line Flow*

This production system produces several products in high volumes. The product variety is less than Operator-paced Line Flow production system but product volume is higher. It has low process flexibility. The layout for this type of production system is equipment- paced line flow layout with regular flows. The production is rather based on equipments and machines than operators.

- *Continuous Line Flow Process*

This production system produces one product in very high volumes. The product variety is less than in Equipment-paced Line Flow production system but product volume is higher. It has no process flexibility. The layout for this type of process is continuous line flow layout with rigid flows. Continuous Line Flow process is suitable for single type products that require large amount production. The production mainly based on automated machines.

The illustration of PV-LF matrix in the first step to analyse company's current situations is in Figure 2-1. The differences of these types of production systems are described as follows.

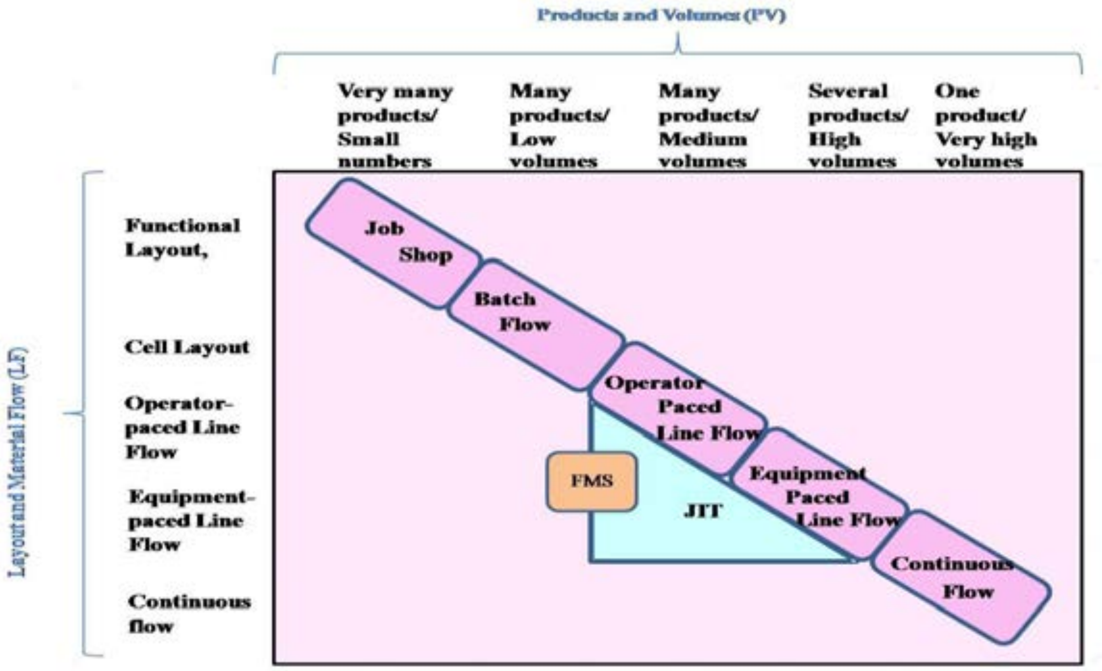


Figure 2-1: Types of Production Systems in PF-LV Matrix

2.1.2 Manufacturing Capability

- *Human Resource*

Human Resource lever refers to skill level, wage, training and promotion policy, and employment security.

- *Organisational Structure and Control*

Organisational Structure and Control refers to formal relationship among groups in the production systems.

- *Production Planning and Control*

Production Planning and Control lever refers to flows of materials, activities of line staffs, production operations, and new product introduction.

- *Sourcing*

Sourcing lever refers to vertical integration, production and distribution systems management, and relationship with suppliers.

- *Process Technology*

Process Technology lever refers to the product process, types of equipment, automation, linkages between parts of production process.

- *Facilities*

Facility lever refers to locations and sizes of the plant.

2.1.3 Manufacturing Outputs

Different production systems give different effects on manufacturing outputs. The manufacturing outputs are divided into 6 aspects:

- *Cost*

Cost refers to cost of materials, labours, resources related to the production.

- *Quality*

Quality refers to quality of products compared to customer specification and expectation.

- *Performance*

Performance refers to performance of products that gives the extra features that other products do not have.

- *Delivery time and Delivery reliability*

Delivery time refers to time duration between the product orders is taking from customers to the customers receive the products. Delivery reliability refers to on-time performance in terms of frequency and duration of late delivery.

- *Flexibility*

Flexibility refers to ability to response to changes in customer demands during the production such as increased product volumes.

- *Innovativeness*

Innovativeness refers to ability to launch new products or adjust design of products.

The relationship between the manufacturing outputs and production systems is illustrated in Figure 2-2. In the manufacturing output matrix, solid bars indicate good levels of outputs but white bars indicate poor level, while length of bars indicate degree of to the level.

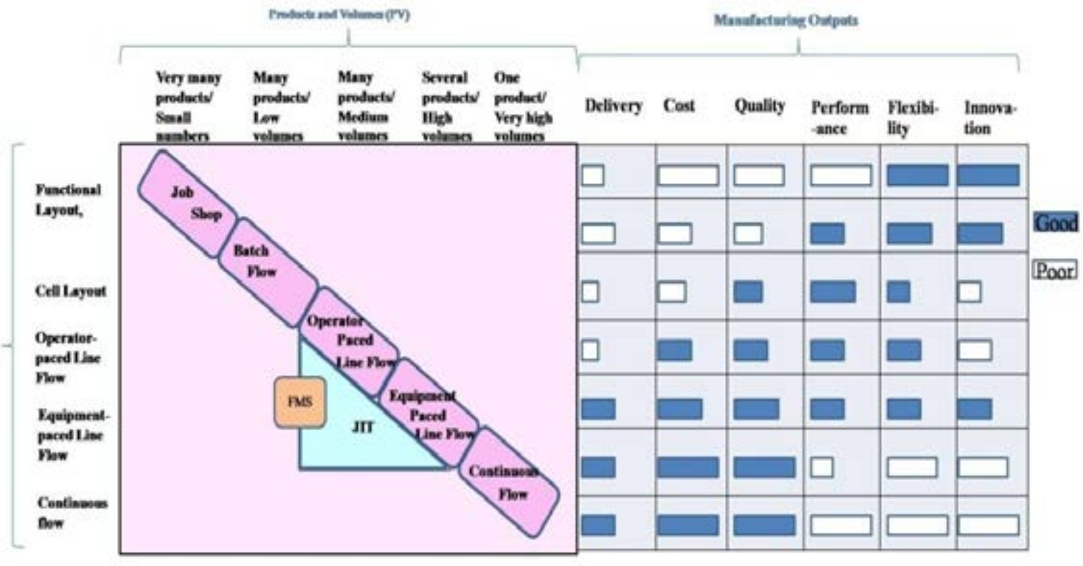


Figure 2-2: Manufacturing Outputs and Production Systems

The second step (Where do I want to be?) is to determine the desired production systems to deliver the desired manufacturing outputs. This is done by considering 2 parts: (1) competitive analysis and (2) desired production systems.

2.1.4 Product Positioning Analysis (Puttick's Grid)

Puttick‟s Grid is a tool to define product positioning of the company because it links the market, business processes, order winning criteria, and core competencies together (Puttick, 1986 in Whicker, Hartland, and Hessey, 2011). Based on product complexity and uncertainty criteria, product positioning is divided into 4 types: Super Value Goods, Fashion/ Spares, Consumer Durables, and Commodity. 'Complexity' refers to numbers of products and variants, tiers of supply chain, layers in bills of materials, purchased items, or processes. 'Uncertainty' refers to changes in factors such as specification, quality, process reliability, level of demand, fashion changes, or supply changes.

Table 2-1: Four Types of product (Puttick‟s Grid)

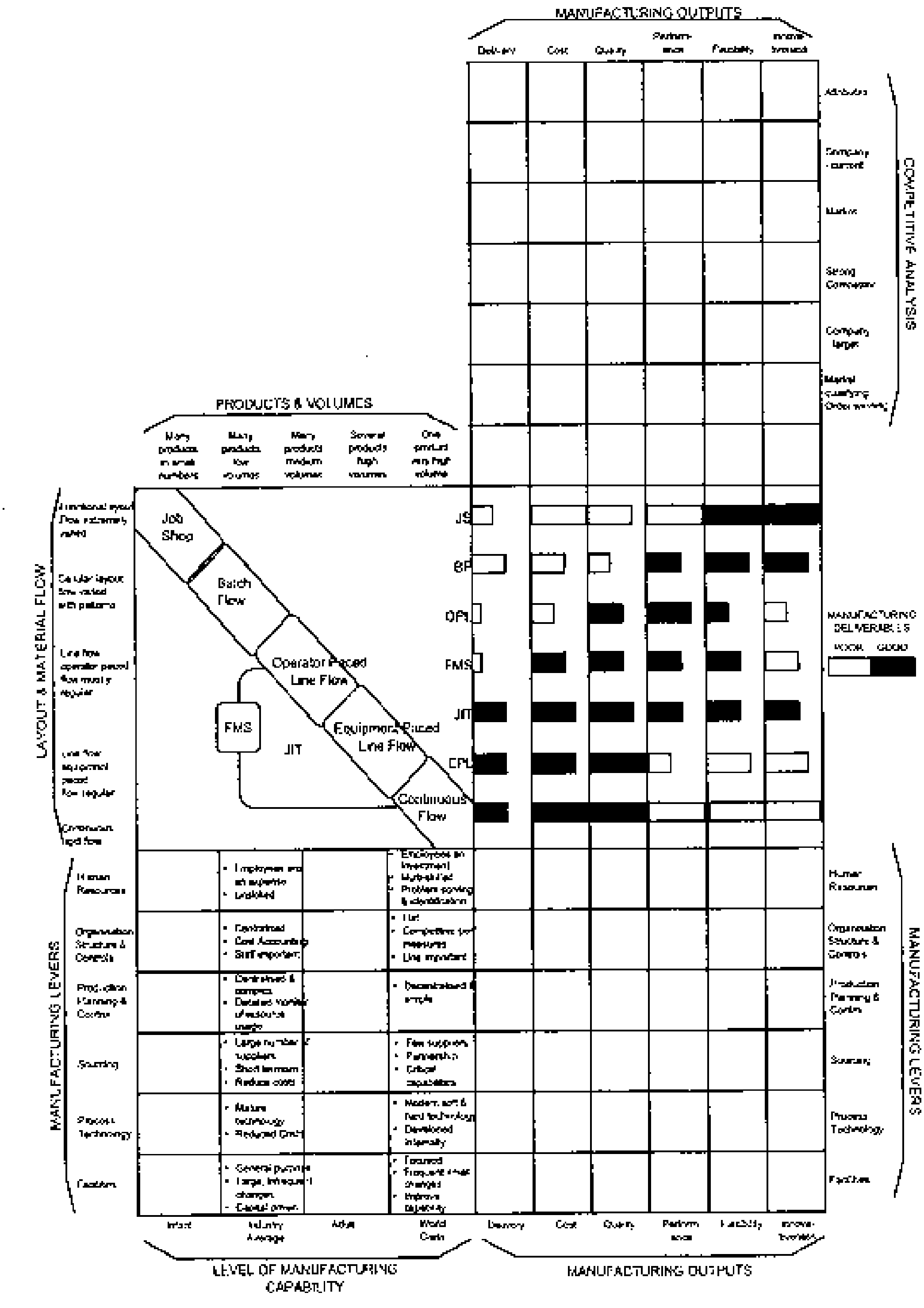
Types of products	Quadrant		Characteristics	Differentiation factors	Examples of industrial sectors
	Complexity	Uncer-tainty			
Super Value Goods	High	High	Long-term usage with upgrading	Fitness for purpose, Service support	Aerospace, Defense, Heavy equipment
Fashion/ Spares	Low	High	Suddenly high demand, Rapid depreciation, Fashion, Easily obsolescence	Time to market and Emotional appeal	Food&Drink, Cosmetic, Mobile Phones
Consumer Durables	High	Low	Medium-term usage, Demand in second hand market	Value for money, Availability	Automotives
Commodity	Low	Low	Common product	Price	Paper, Metal, Glass

2.1.5 Order Winners and Qualifiers

Order Winners and Qualifiers are tools for business analysis used to assess the products. Order Winners are the critical success factors that will affect the purchasing decision of the customers to buy our products instead of competitors. Order Qualifiers are the essential factors that the company should have in order to maintain a position in the market otherwise the customers will not purchase the product (Hill, 1993 in Whicker, Hartland, and Hessey, 2011).

The third step (How will I get from where I am to where I want to be?) is to move from the current manufacturing levers to the desired production systems, the targeted manufacturing outputs, and the targeted level of manufacturing capabilities.

By implementing Miltenburg"s framework, manufacturing strategies are formulated based on 6 levers: human resource, organization structure and control, production planning and control, sourcing, process technology, and facility. The strategies are formulated with objectives to improve manufacturing outputs in 6 aspects: cost, quality, performance, delivery time in delivery reliability, flexibility, and innovativeness (Miltenburg, 1996). The illustration of Miltenburg's framework is in Figure 2-3.



Source: John Miltenbur, "Manufacturing Strategy", Productivity Press, Oregon, 1995
ISBN: 1-56327-071-4

Figure 2-3: Generic Miltenburg"s Framework

2.2 Production Components

There are 4 production components that are very important and related directly to production: people, machines, materials and supporting functions.

1) **People** or labours are directly involving in the production. The labour types can be classified as direct/indirect, skilled/unskilled, permanent/part-time labours. The problems that normally occur in people components are concerned in availability, ability and numbers aspects.

2) **Machine** and equipment are important in the production. Various machine types can be classified as production such as machine and equipment, auxiliary machines, maintenance and service equipment, quality control equipment etc.

3) **Material** is also important to production. This includes raw materials, direct and/or indirect materials, work in process and finished product

4) **Supporting function** would make all the processes success. This includes engineering design, production planning and control, plant engineer to install and maintain machines, finance, and inventory control etc.

2.3 Flow Charting

Flow Charting is a tool to illustrate physical and logical relationship elements of systems. This tool helps enhancing understanding of the operations of systems. It shows movement of workflow in terms of operation, decision, input/output. The difference in the movement of workflows is indicated by symbols as shown in Figure 2-4.

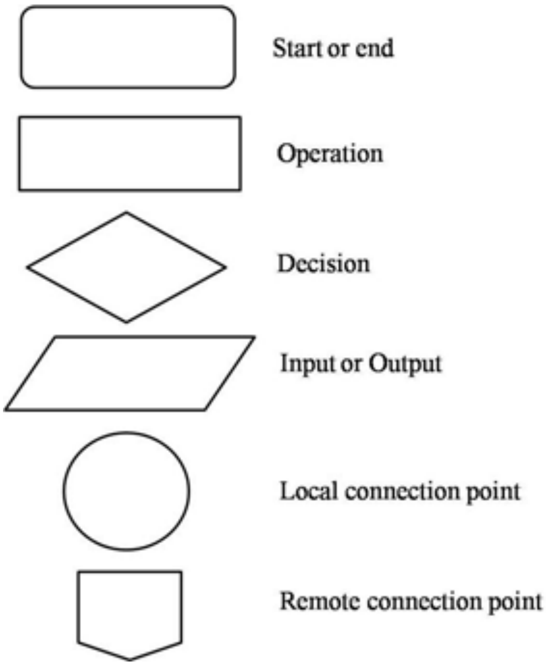


Figure 2-4: Flowcharting symbols

2.4 Flow Process Charts

Flow Process Charts are used to analyse the flows of raw materials, parts, people, equipments in the production process as well as other activities occur in the production line. Flow Process Chart is illustrated in terms of symbols. Each symbol has meaning of the activities as shown in Figure 2-5.

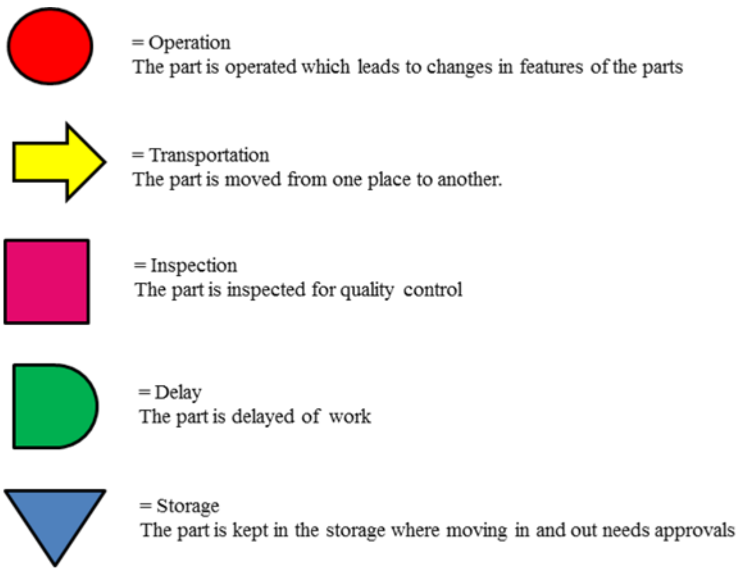


Figure 2-5: Symbols for Flow Process Chart (ASME)

According to Karnchanapunyakom (2009), flow process chart is analysed in order to reduce move time and to enhance production efficiency. In the flow process chart, process, products/parts, machines, equipment, entry and exit of production line are determined. All relevant activities are recorded in details in every process by using symbols. Moving distance, quantity of part being moved, and duration for delay are recorded and analysed in order to compare the current systems to the improved systems.

2.5 Plant Layout

According to Klomjit (2012), plant layout is divided into 4 types according to process flow of products. Advantages and disadvantages of each type are analysed.

- Process Layout

Process layout is suitable for functional production systems, where a set of similar machines is located together in the same area. The production flows is based on process.

Advantages of process layout are low machines and equipment investment and long machine operation time. Moreover, when one machine is broken down, other machines in the same area can still proceed the operations.

Disadvantages of process layout are transportation of products among process because different processes are located apart. Travel distance and time are long. And, correlation among processes is not efficient leading to bottlenecks during the production line.

- Product Layout

Product Layout is suitable for line production, where machines are arranged in the production line according to the process.

Advantages of product layout are that it is easy to control production schedule as the production process is certain. Space utilisation is more efficient. Part travel distance in the production line is short. Machine Setup time is reduced.

Disadvantages of product process are high investment in machines. If one machine is broken down, the operation of the whole production line will be terminated.

- Fixed Position Layout

Fixed Position is not widely used. Mostly, it is used with huge industry such as ship construction or aircraft.

- Group Layout

Group Layout is suitable for cellular production systems. Products with similar process are grouped together in same location.

2.6 Lead Time

Lead time is the key strategic factors to improve operational efficiency and effectiveness. Lead time is divided into 2 types: manufacturing lead time and customer lead time. Manufacturing lead time or cycle time or flow time refers to the time between order start to order completion within the production. While, customer lead time refers to the time customers place orders to customers receive ordered products. Reducing in manufacturing lead time can also help in reducing customer lead time.

Manufacturing lead time consists of 4 elements: setup time, operation time, move time, and waiting time. Setup time refers to time spent in changeovers between parts/products across workstations. Operation time refers to time spent in working on the parts/products at the workstations. Move time refers to time spent in moving the parts between workstations. And, waiting time refers to time spent for waiting for availability of resources to perform the work. It includes waiting for equipment, labour, material, and tools, waiting for inspection, and waiting for material-handling resources. According to Hyer and Wemmerlov (2002), how to reduce lead time are suggested in the Table 2-2.

Table 2-2: How to Reduce Manufacturing Lead Time

Reduce	**How to?**
Time per setup	Improve setup procedure Use alternative equipment that requires less setup time
Number of setup	Assign equipment to the product family to avoid changeover
Time per operation	Simplify the design of the products to be produced faster and easier Put skilled labours to the operations Reroute operations to faster resources Use smaller lot size
Planned number of operations	Redesign parts to eliminate operations
Time per move	Use close proximity layout Improve material-handling procedure
Number of moves	Use multi-operation machines
Time spent waiting	Provide more capacity Improve setup time, operation time, and move time

2.7 Cellular Manufacturing

Cellular Manufacturing is a cell-based manufacturing. The production systems are grouped into cells to produced similar parts. Each cell is divided to processing a specific set of part families. A manufacturing cell consists of several different machines. A part family in the same cell consists of a set of parts that required similar processing (Askin, Selim, and Vakharia, 1997).

Within a cell, equipments and people required for production of the product families are grouped and located in close areas. This strategy leads to performance improvements by shortening response time, improving production quality, and decreasing inventories and costs (Wickham Skinner, 1966).

In Cellular Manufacturing, cell operators are cross-trained on several machines and equipments and on several tasks as well as supervisors' and support tasks. The cell operators could be able to perform multi-tasks for job rotating. Moreover, cell operators should be able to understand and perform activities such as quality control, planning and scheduling, part ordering, record keeping, and trouble shooting.

According to Hyer and Wemmerlov (2002), benefits of Cellular Manufacturing are reducing in lead time, move distance, setup times, customer response time, on-time delivery, inventory, scrap and rework rates, unit costs, and use of space. Also, it is improving in employee job satisfaction, production flexibility, labour flexibility, job status visibility, operator improvement methods, and labour productivity.

2.8 Cell Formation Using Machine-Component Matrix

According to Irani (1999), in order to adjust the production from functional layout to cellular layout, the relationship between parts and machines should be identified. Finding out the part routing into machines can show the relationship of processes and parts. Knowing any part visits which machines for their production can help in cell formation. Part families and lists of machines are found. The relationships of them are shown in the machine-component matrix, which is a block diagonal matrix. Parts are indicated in the row of the matrix, while machines are indicated in the column. The visited machines by any part will be expressed by '1' to the diagonal. The inter-cell moving along the axis brings the block diagonals to the solutions of cell formation.

2.9 Part Family

Two methods of part family classification are considered in this case study in order to form the cell. Advantages and disadvantages of the classification using the two methods are compared in order to select which method to be used. The two methods of part family classification are Production Flow Analysis (PFA) and Production Flow Classification Code (PCC).

2.9.1 Production Flow Analysis (PFA)

According to Irani (1999), design for a Cellular Manufacturing is a complex task. Using Production Flow Analysis is a tool for part family classification by finding the parts and process relationship. The first step is to analyse the initial part flow routing among machines. Then, the classification is according to the flow criteria. Part flow similarity is grouped into the same cell and same groups of machines. The number of extra-cell operations, loads of machines, and inter-cell flows are minimised. Machine allocations are according to those aspects.

2.9.2 Product Classification Code (PCC)

According to Irani (1999), Product Classification Code is a tool for part/ product family classification. The method of classification is different from Production Flow Analysis (PFA) in that the Product Classification Code classifies products/ parts by attributes instead of process routing. The classification is in terms of shape, size, type, colours, etc. The code stands for attributes of the products. The products that share similarity in some attribute will be coded by the same code in the digit of the attributes.

In comparison between Production Flow Analysis (PFA) and Production Classification Code, the two methods are used to identify the part families which share something in common. The different of these two methods are that the Production Flow Analysis classifies the parts by looking at the process routing of the part, while Production Classification Code classifies by attributes. The relationship between parts and machines indicates which process that the part does visit.

On the other hand, Production Classification Code can classify products in terms of attributes.

Advantage of using the Production Flow Analysis is that the flow of production of each part is classified. The cells are divided based on process that the parts go into. Disadvantage of using the Production Flow Analysis is that the wrong analysis of part-machine relationship can lead to wrong product family classification.

Advantage of using the Production Classification Code is that it is easy to classify product family by attributes and appearance. Disadvantage is that the process of the parts being processed is not shown. The relationships of parts and machines are not mentioned.

2.10 U-shape Cell Layouts

According to Hyer and Wemmerlov (2002), U-shape layout is where the workstations are located as nearest as possible in the form of 'U' shape in order to reduce parts move distances. With this layout, there are many advantages for the production process. The advantages of U-shaped Cell Layouts are that

- It reduces move distances for operators to operate many workstations
- Operators can easily assigned to do job rotation to another workstations
- It allows parts crossing-over with short distance. When parts are needed to backtrack or skip the workstation. Parts can cross over to the opposite workstation without passing through any unnecessary workstation.

Designing of U-shape cell layouts should consider placing workstations in close proximity; operators face outward; operators stands to operate tasks; the use of conveyors is reduced; same operator will be assigned to the entry and exit workstations of the production; and operate in one-piece production.

2.11 Standard Work Instruction

According to Kanjanapunyakom (2009), Standard Work Instruction is a form for recording the standard operation of the specific work. Standard work operations, how-to operate the machines and equipments, and details of operation procedure, are notified in the Standard Work Instruction Sheet.

The objective of setting the standard work instruction to the operation is to keep every production on the same track, making sure that all products and parts are produced in the same standard. By having standard procedure for the operators to produce accordingly will help in quality control of the products.

2.12 Organisation Culture

According to Trompenaar and Hampden-Turner's corporate cultural diversity theory, the corporate culture is divided into 4 types: Power-oriented, Role-oriented, Project-oriented, and Fulfilment-oriented. The corporate culture model is illustrated in Figure 2-6 (Trompenaar and Hampden-Turner, 1999 in Hartland, 2011).

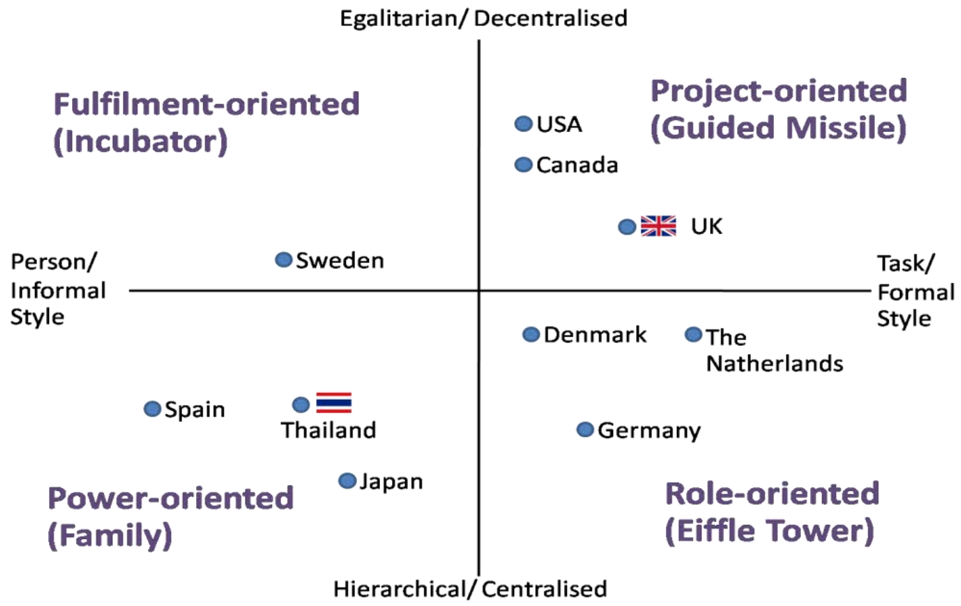


Figure 2-6: Corporate Culture Model

- *Power-oriented (Family)*

It refers to the „family‟ corporate culture which supervisors and subordinates develop personal relationship. However, there is a hierarchical sense in the relationship. The power and status of the leader are recognised. The leader in the project-oriented corporate culture focuses on caring, moral, and social, rather than focus on financial and legal.

- *Role-oriented (Eiffel Tower)*

It refers to the „bureaucratic‟ corporate culture which the hierarchy is determined by roles and functions. The subordinates obey the supervisors in every aspect because of roles and tasks.

- *Project-oriented (Guided Missile)*

It refers to the corporate culture which focuses on tasks and goal achievement done by team. Normally, it is used in group projects. The corporate culture is decentralised.

- *Fulfilment-oriented (Incubator)*

It refers to the corporate culture which focuses on self-fulfilment. It has no structure but emphasising on individuals. Normally, it is used in consultant Company and legal company.

2.13 Literature Review

The literatures in the field of Cellular Manufacturing are various as they are widely used in many industries for improving production systems. These literature reviews present some published documents that are related to this thesis.

Ngampak and Phruksaphanrat (2011) present the case of Cellular Manufacturing layout design and selection for an electronic manufacturing service plant. The paper shows the best practice of using Cellular Manufacturing layout design based on Systematic Layout Planning (SLP) and selection of the layout design by using Analytic Hierarchy Process (AHP). The current production system of the manufacturing plant is process layout, which is not suitable for the nature of the industry of having high volume and high variety. Therefore, the concept of Cellular Manufacturing is proposed. Systematic Layout Planning (SLP) is used to analysed and design possible cellular layout. Then the Analytic Hierarchy Process (AHP) is used as a performance measurement tools to select the best cellular layout design from the proposed designs based on selected quantitative and qualitative criteria.

Bhat (2008) presents Cellular Manufacturing in a small-scaled industry. It is used in small-to-medium sized batches of large variety of part types, which can be produced in flow line of different manufacturing cells. This case is to apply the production of part family with similar manufacturing processes. The objectives of application of Cellular Manufacturing concept in the industry is to reduce costs and lead time, improve quality, and improve delivery performance. The concept groups the similar products into families which can be processed in the same processes and equipments. A cell is a group of work stations and machines and equipment. Within a cell, a product is processed progressively from one station to another station without waiting for a batch to be completed. The objectives of applying the concept of Cellular Manufacturing are to improve work-in-process (WIP), space utilisation, lead time reduction, productivity improvement, quality improvement, enhanced teamwork and communication, and enhanced flexibility and visibility.

Parashar and Kamath (2004) present an integrated approach for Cellular Manufacturing design. Formation of machines cells, part family, processes of components, layout design are considered systematically. This paper also considered workload on each machine and cost before duplication. The result of applying the concept of Cellular Manufacturing is 58% reduction in material handling, work-in-process inventory, set-up time, etc.

Zayko, Broughman, and Hancock (1997) present a Cellular Manufacturing for a small manufacturer of membrane filtering products. The company has several problems such as poor delivery performance, high inventory, heavy reliance in inspection and testing, high scrap rates, supplier quality problems, and machine downtime. After the Cellular Manufacturing concept is applied, employees are cross-trained to perform different tasks in the cells. The training involves about quality improving, waste reducing, layout planning, setup time reducing, bottlenecks solving, one-piece flow implementing, and team working. The Cellular Manufacturing concept in the case study is successfully implemented. Reorganising workplace into cells and workforce into cell team is the key of success.

Maria and Lopez (1997) present a design and implementation of Cellular Manufacturing in a Job Shop environment. The case study is for Boeing's Defense and Space group who produces airplane for commercials and military. The researchers introduced the application of Cellular Manufacturing concept to the current production systems which is Job Shop. The concept is applied to produce part families with similar production process and stable demand. The case study describes cellular manufacturing assessment, cell planning phase, and cell implementation and performance measurement phase for application of Cellular

Manufacturing concept. The result of the thesis are reducing lead time and costs as well as improving quality and delivery performance.

Ekapach Sithitriwat (2007) presents Shop Floor Control improvement for a music instrument factory. The thesis is focused on solving the problems for the Conga Drum production line in terms of organisation management and relationship, production, expenses, and delivery date. Theories, tools, and concepts for shop floor control are applied such as follow up tools, built-in quality concept, and factory re-layout. The result of the thesis shows that delivery performance and labour productivity are improved and production costs and defects are reduced.

Udomrat Laichuthai (2002) presents a case study on using production scheduling systems to improve delivery performance. The existing problems of production planning are in terms of production capacity and poor planning scheduling. Related tools and techniques as well as database are used to improve the production planning. The results of thesis show improvement in reducing overtime and improving delivery performance.

Kantachart Krungsumlucksme (1998) presents a case study on study of cellular manufacturing and incentive plan for cutting die process. The current system has problems in long production time, high overtime, and unskilled labours. The Cellular Manufacturing concept is applied to improve production systems in order to reduce lead time and improve labour skills. Also, incentive plan is applied to improve productivity and employee satisfaction.

Punjaporn Chinchanachokchai (2010) presents a case study of Shop Floor Control and production planning of a medium-sized restaurant. The thesis is to improve the production systems and operations. Various tools and techniques related to the production planning and operation are used. Fishbone Diagram is used for problem assessment. Material Requirement Planning (MRP) is implemented for purchasing plan improving. The results of the thesis is reducing products run-out for 100%, increase customer's and employee's satisfaction, and reduce monthly operation costs.

Piyapong Pankeaw (2009) presents a case study of designing production planning systems for a plastic packaging factory. The current production planning has caused problems in terms of late delivery time. This case study is to develop the FPPS production planning systems to improve delivery performance. The thesis describes implementation methods for production planning systems from data collection to implementation of the designed systems. The result of the thesis shows that there are significant improvements in production planning and scheduling performance. On-time shipment performance and production efficiency are increased.

CHAPTER III
MANUFACTURING STRATEGY

In this chapter, overall information and current situations and problems of the Company A, which is used as the case study, is discussed. The discussion includes the topic of organisation, products, production process, machines and resources, manpower, plant layout, delivery, and problems. The objective of this chapter is for understanding the current situation, manufacturing capability, and problem awareness; defining goals the company desires to achieve, and methods to achieve such goals.

3.1 Case Study Company

Company A is a Small-Medium Enterprise (SME) wooden furniture production company located in Thailand. It plays in a role of Original Equipment Manufacturer (OEM). Customers of Company A are both domestic and international furniture companies. The market is 80% domestic market and 20% exported market to Vietnam and Laos. The company aims to increase sales in exported market within 3 years.

Company A produces wooden furniture products according to customer order quantity. All products are made of Para woods. Customers can select to order a variety of products such as cupboards, tables, chairs, and stools. The company has design of products for customers to choose from. Product specification can be determined from customers in terms of size, set, and colours. The company does not store much inventory on hands but produces when order quantity is placing. Currently, the production system is Job Shop which allows flexible productions for high product variety in small quantity.

3.2 Problem Analysis

The Company A encounters a problem of delayed delivery of products to customers. Effects of delayed delivery of products to customers are penalty costs due to late delivery, sales loss to competitors, and decreasing in customer satisfaction and retention.

The problem of long customer lead time is mainly caused by production department. Long travel distance, long move time, and delay time in the production line are the main reason of the problem. The current production systems and layout does not support full potential to compete in time and quality. Company A analysed that having production process layout which is not suitable with nature of production causes the problem of long production time and under standard of quality products (scraps and reworks). This finally results in late product delivery to customers.

3.3 Manufacturing Strategy

Manufacturing Strategy of Company A will be formulated by using Miltenburg‟s framework. Miltenburge‟s framework is selected to be a suitable tool for Company A. Because, this framework takes customer requirements, performance of competitors, current capability of manufacturing, possible options available to manufacturing and detailed outputs into considerations.

According to Miltenburg (1996), there are 3 main steps to formulate the Miltenburg framework, which are as follows.

Step 1: Where am I?

Step 2: Where do I want to be?

Step 3: How will I get from where I am to where I want to be?

3.3.1 Step 1: Where am I?

3.3.1.1Manufacturing‟s Current Production Systems

The Company A's current production systems is *Job Shop*. The Company A builds parts for several products in small numbers. The production process is the same for all products. The functional-layout equipments/machines of the same functions are located together as a group. Functional layout is benefit for flexibility.

On the other hand, products/parts travel distances is all over the factory, causing high throughput time. Batching work-in-process (WIPs) are waiting in the production line as bottlenecks before moving to the next workstation. When WIPs are long waiting in the line, they tend to have quality problems and defects occur since they are all made of Para wood. That causes reworks and scraps at the end of production. This problem also leads to late delivery of products to customers. When the number of products is increased, production scheduling becomes more complex. Many change-over of production for different parts/products consume high setup time and setup costs.

Determining the manufacturing"s current production systems is using the Product/Volume-Layout/Flow (PV-LF) matrix in Figure 3-1.

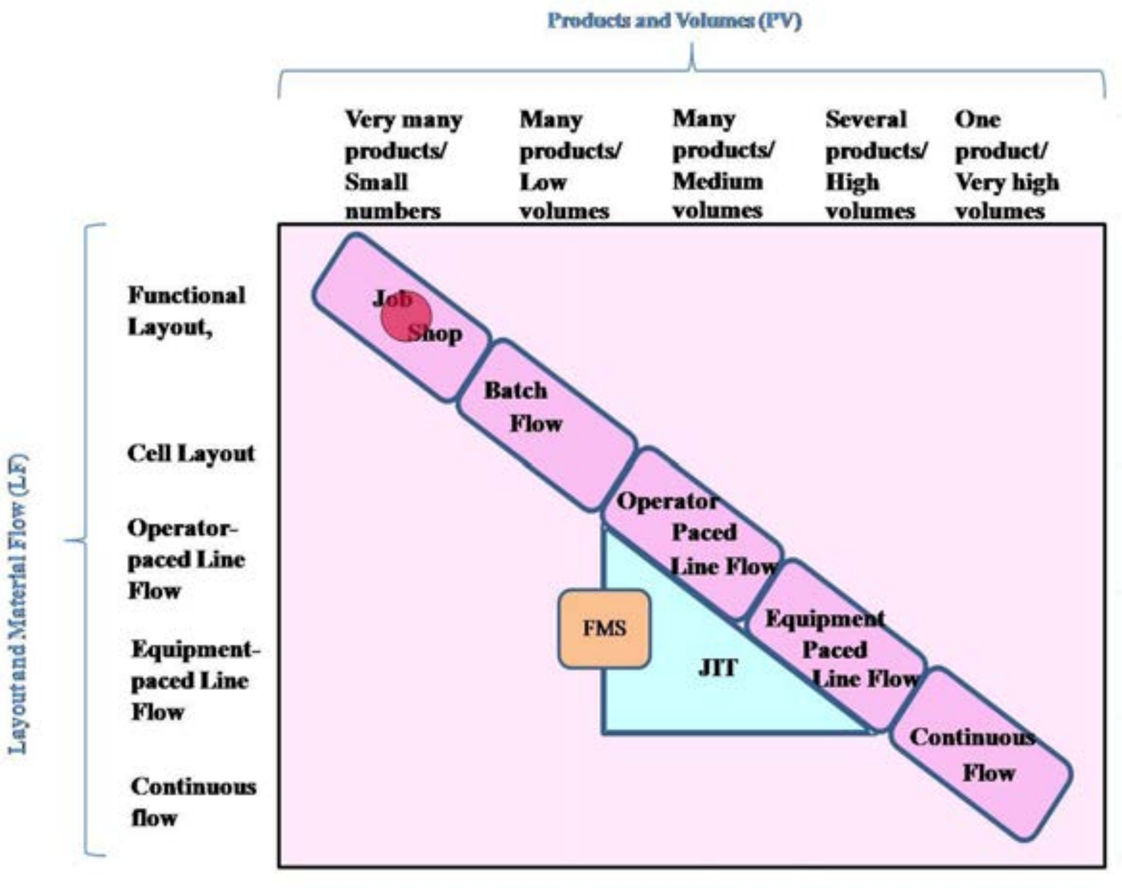


Figure 3-1: Company A Product/Volume-Layout/Flow (PV-LF) matrix

3.3.1.2 Current Level of Manufacturing Capability

3.3.1.2.1 Human Resource

Company A has 60 staffs in 2 types classified by payment: Office Employees and Operation Workers.

Table 3-1: Company A Number of Staff

Office Employees		**Operation Workers**	
Factory Manager	1	Production Supervisors	3
Operation Planning & Control	2	Production Workers	42
Procurement	2	Labourers	3
Human Resource	2		
Warehouse	1		
Quality Control	1		
Financial	1		
Production	2		
Total	**12**		**48**
Grand Total = 60			

- *Office Employees*

There are 12 office employees working for office works. They earn monthly payment in the form of salary. The salary is varied upon position and experiences. Their working days are 5 days/week (Monday-Friday). Their working hours are 8 hours/day (8.00 am - 5.00 pm, lunch break for 1 hour at noon).

- *Operation Workers*

There are 48 operation workers for production works. These people consist of production supervisors, production workers (skilled workers), and labourers (unskilled workers). They earn daily payment in the form of wage. Their working days are 5 days/week (Monday-Friday). Their working hours are 8 hours/day (8.00 am - 5.00 pm, lunch break for 1 hour at noon).

3.3.1.2.2 Organisational Structure and Control

As Company A is only a small organisation, it applies a flat organisation structure. The factory manager is the head of organisation who commands directly to every department. The company has 7 departments: Operation Planning & Control, Procurement, Human Resource, Warehouse, Quality Control, Financial, and Production. The organisation chart for Company A is illustrated in Figure 3-2.

Figure 3-2: Company A Organisation Chart

- *Operation Planning & Control department*

There are 2 persons in this department taking responsibility for inventory control and sales forecasts.

- *Procurement department*

There are 2 persons in this department taking responsibility for purchasing and sourcing.

- *Human Resource department*

There are 2 persons in this department taking responsibility for administration and personnel recruitment.

- *Warehouse department*

There is 1 person in this department taking responsibility for store keeping and inventory checking.

- *Quality Control department*

There is 1 person in this department taking responsibility for quality inspection before products are delivered to customers.

- *Financial department*

There is 1 person in this department taking responsibility for accountants and financial control.

- *Production department*

Unlike other departments, this department has 2 office staffs and 45 operation staffs. The two office staffs are taking responsibility for the paper work of the production. The rests are operation staff working in the production systems.

3.3.1.2.3 Process Technology

Overall Production Process of Production Department

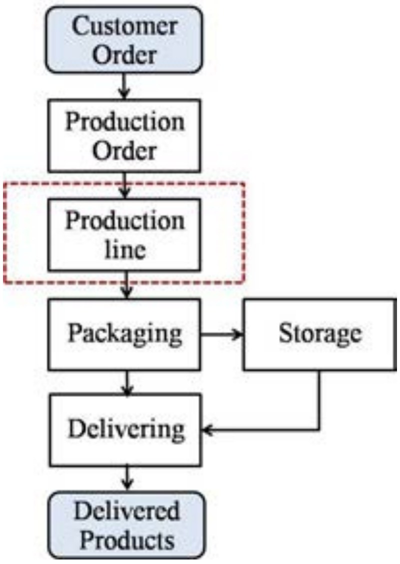


Figure 3-3: Overall Process of Production Department

Customers determine product specification and quantity of orders. After receiving the customer orders, production department places production orders to production lines to produce the products accordingly. Finished goods then go to packaging process. Then, the finished products are delivered to customers or stored in the inventory waiting for delivering process. The illustration of overall process of Production Department is in Figure 3-3.

In this thesis, the scope of study is focused only on the production line. The production line starts from raw materials entering the production line until finished goods exiting the production line.

<u>Production Process in the Production Line</u>

The production line has 8 main processes: Sizing, Smoothening, Cutting, Edging, Drilling, Colour Processing, Holder Attachment, and Assembly. Every product goes into the same process.

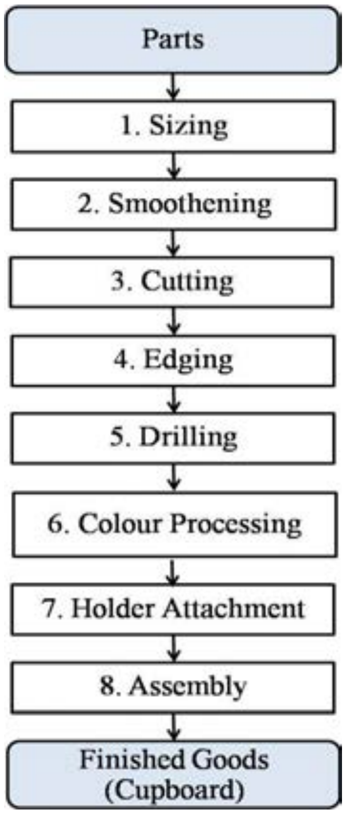


Figure 3-4: Production Process in the Production Line

(1) Sizing

Sizing process is the process where pieces of wood are shaped into proper size that will possibly fit with the smoothening machine in the next process (smoothening process).

Figure 3-5: Sizing

(2) Smoothening

Smoothening process is the pieces of proper size piece of wood are smoothened and polished into fine surface. The process is done through the smoothening & polishing machines.

Figure 3-6: Smoothening

(3) Cutting

Cutting process is where the pieces of wood are cut into particular parts of the final products.

(4) Edging

Edging process is the process of making edges onto the parts according to the design of products.

(5) Drilling

Drilling process is the process of making holes in the parts.

Figure 3-7: Drilling and Edging

(6) Colour Processing

Colour Processing is where the parts are painted with colours and dried up.

Figure 3-8: Colour Processing

(7) Holder Attachments

Holder attachment process is the process of attaching the holders, hinges, and/or wheels to particular parts before assembly all pieces together.

Figure 3-9: Holder Attachment

(7) Assembly Processes is where pieces of parts are assembled together as a finished product.

Figure 3-10: Assembly

3.3.1.2.4 Facility

Factory

Company A locates the small-sized factory in Samutprakarn province, Thailand. Plant site has an area of 1,200 square meters, where office, production area, and storages are located together. The location of factory is convenience for transportation and logistics of all products to be exported by ships from the piers.

Problems: Long Travel Distances

Workstations are located in functional layout in which machines, labours, and facilities are grouped into process similarity. When parts need to pass through all the processes to be produced as one product, they need to travel long distance all over the factory to complete all processes. Delay occurs due to bottlenecks. That affects production lead time to be increased.

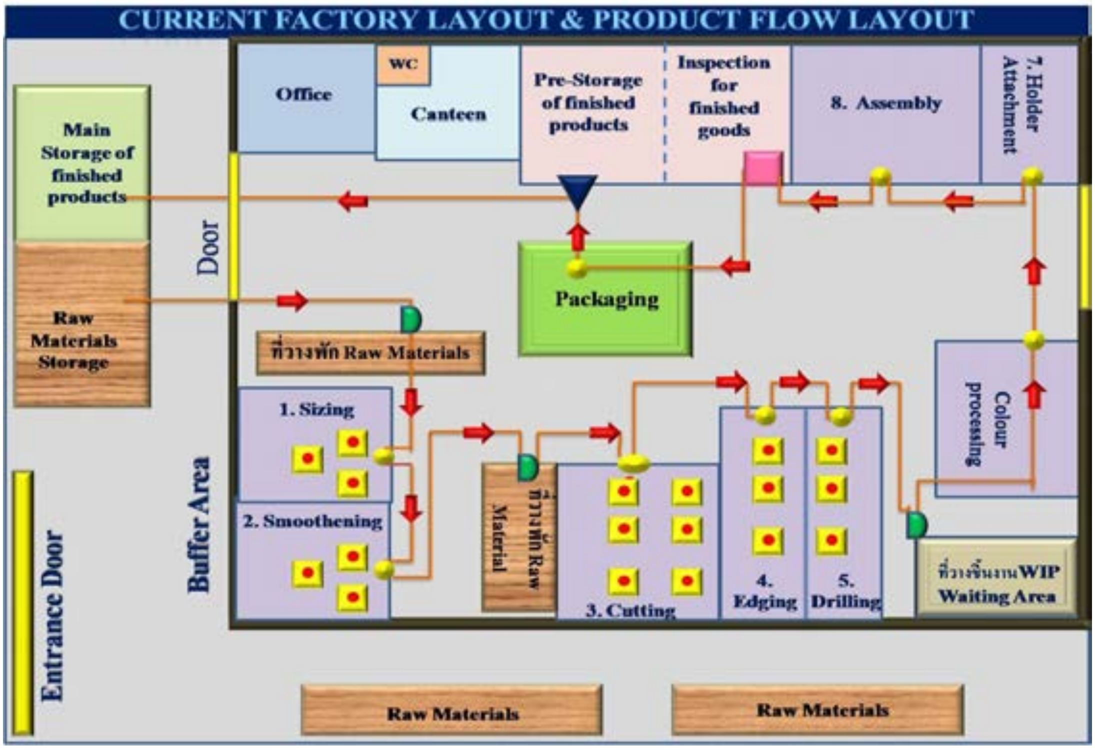


Figure 3-11: Current Plant Layout and Product Flows

Production Process Record Chart

Chart No._1_ Page_1_ of_2_
Product / Material / Staff

Activity: Production Process
Process of wooden dining table production
Work method: Current / Improve
Place: Company A Furniture Production Factory
Recorded by:
Approved by: Date:

Summary									
Activity		Current (Pre-Avg.)		Improved (CM)		Reduce			
						Variance		Rate of reduction	
		QTY	Time	QTY	Time	QTY	Time	QTY	Time
Set up		0	7.08						
Operate		9	116.36						
Move		15	35.68						
Delay		3	64.17						
Inspect		1	-						
Keep		2	-						
Throuhput tim		-	223						
TTL Distance		119	-						
Work process		30	-						

Pre= Before improvement, Post-CM= After improvement with cullular manifactures concept, Avg. = Average

	Task description	Pre Distance (metre)	Pre Time	Post-CM Distance (metre)	Post-CM Time (min.)	Symbol: Operate	Symbol: Move	Symbol: Delay	Symbol: Inspect	Symbol: Keep	Note
	Machine Set up										
	Set up sizing machine at workstation 1	-	0.44								
	Set up smoothening machine at workstation 2	-	1.12								
	Set up cutting machine at workstation 3	-	1.13								
	Set up edging machine at workstation 4	-	1.14								
	Set up drilling machine at workstation 5	-	1.12								
	Set up colour processing machine at workstation 6	-	2.13								
	Production process										
1	Move parts from Storage to the factory	25	7.38								
2	Delayed in the part waiting area for production processed		6.06								
3	Move parts to Work Station 1 for sizing	6	1.77								
4	Operate sizing		5.35								
5	Move sized parts to Work Station 2 for smoothening	7	2.07								
6	Operate smoothening		5.35								
7	Move smoothened parts to waiting area	10	2.95								
8	Delay in the part waiting area for cutting process		25.20								
9	Move the smoothened parts to Work Station 3 for cutti	12	3.54								
10	Operate cutting		10.50								
11	Move cut parts to Work Station 4 for edging	10	2.95								
12	Operate edging		10.43								
11	Move parts to Work Station 5 for drilling	8	2.49								
12	Operate drilling		5.12								
13	Move the parts to waiting area	10	2.51								
14	Delay in the part waiting area for colour processing		32.91								
15	Move parts to Work Station 6 for colour processing	7	3.30								
16	Operate colour processing		60.00								
17	Move parts to fitting workstaion 7 for holder attachment	10	2.95								
18	Operate holder attachment		3.35								
19	Move the parts to workstation 8 for assembly process	7	1.71								
20	Operate furniture assembly		16.26								
21	Move Finished goods to Q.C.process	7	2.07								
	Process under responsibility of other departments										
22	*Operate product inspection*										
23	*Move qualified goods to packaging process*										
24	*Operate packing*	Other Departments' activities									
25	*Move Finished goods to Pre-Storage*										
26	*Keep in Pre Storage*										
	Move Finished goods to Main Storage										
	Keep in Main Storage										
	Total	**119**	**223**								Total
	Total quantified number of work process (Pre-improve)					9	15	3	1	2	30
	Total quantified number of work process (Post-improved by CM concept)										

Figure 3-12: Current Product Flows

3.3.1.2.5 Production Planning and Control

There are 8 workstations in the production line based on the production process: 1) Sizing, 2) Smoothening, 3) Cutting, 4) Edging, 5) Drilling, 6) Colour Processing, 7) Holder Attachment, and 8) Assembly. The product flows are illustrated in Figure 3-12.

Problems: Defects

Defects occur to the products. When there are many parts waiting in the production line, workers seem to be rush and lack of efficiency in work. As well, defects occur during long waiting without noticed or taken for granted. That affects product quality. When the products do not pass quality inspection, they are returned to the production line to fix the defects or are considered as scraps.

Resources Allocation --Machines and Manpower

Resource allocation of each process in the current production systems is in Table 3-2.

Table 3-2: Company A Resource Allocation

Processes	**Resource Allocation**			
	Machines	**Capacity**	**Operators**	**Capacity**
			Supervisor	3
Sizing	Sizer Machines	3	Sizers	3
Smoothening	Smoothing Machines	3	Smoothener	3
Cutting	Cutting Machines	6	Cutters	6
Edging	Edging Machines	6	Edgers	3
Drilling	Drilling Machines		Drillers	3
Colour Processing	Colour Processing Machines	3	Colour Processor	9
Holder Attachment	-		Attacher	3
Assembly	-		Assembler	12
			Labourers	3
Total				**48**

Order Systems

As customer orders come in lots and production starts after order placing. Sequence of production is done for one order at a time. The next coming orders will be waiting for the first one to finish production. When orders are increasing in quantity and frequency, the current production systems is not efficient enough and finally causing delayed delivery date.

Problems: Poor Delivery performance

Products delivery is done through trucks or shipments depending on quantity of delivered products and haste in delivery. For many times, late delivery occurs when many orders come at the same period of time. According to historical data and site visits, two main reasons for late delivery that can be detected are problems in production systems and problem in quality of products. Problems caused by other departments related to late delivery are not significant.

3.3.1.2.6 Sourcing

Company A has been in the furniture business for many years, relationship with suppliers is very good. Raw materials of Company A come from local suppliers in Thailand. Para wood is popular used for furniture industry. Therefore, there are many local suppliers available. Problem of supply shortage has never been occurred.

According to Miltenburg (1996), Assessment of Company A's current level of capability for manufacturing lever is using the Manufacturing Capacity matrix as shown in Figure3-12.Manufacturing levers refer to the elements of manufacturing strategy. There are six manufacturing levers, which are Human Resource, Organisational Structure and Control, Sourcing, Production Planning and Control, Process Technology, and Facilities. While, there are four levels of manufacturing capability, which are Infant, Average, Adult, and World Class. The Company A defines the current level of capability based on each manufacturing levers.

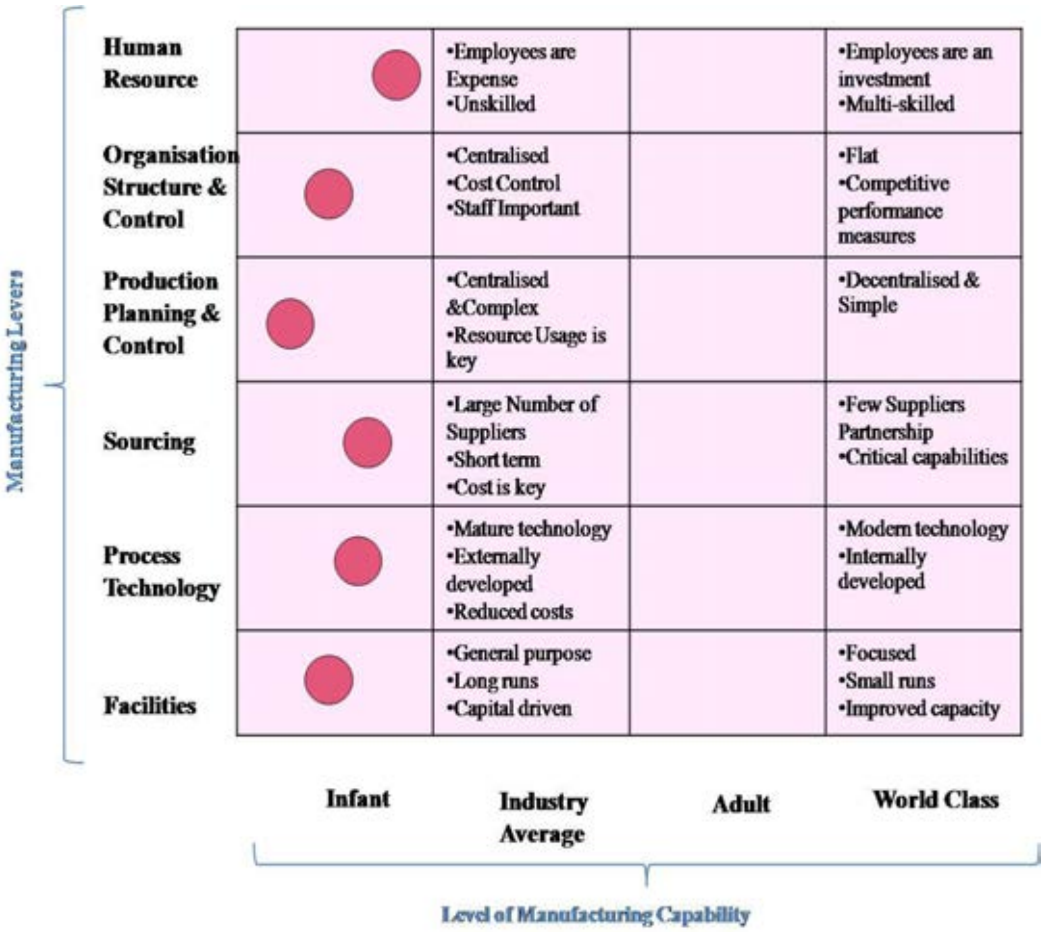


Figure 3-13: Company A Manufacturing Capability matrix

Source: Adapted from Miltenburg (1996) in Whicker and Hartland (2011)

3.3.2 Step 2: Where do I want to be?

This step is to determine the production system that is most suitable for delivering the required manufacturing outputs. This is done by considering two aspects, which are (1) Competitive analysis and (2) The Desired Production Systems

3.3.2.1 Competitive Analysis

According to Miltenburg, the competitive analysis compares the manufacturing outputs with the target levels such as company‟s products, competitors‟ products, customer needs and expectation. The manufacturing outputs are Delivery, Cost, Quality, Performance, Flexibility, and Innovativeness.

3.3.2.1.1 Product Positioning (Puttick's Grid)

In applying the Puttick‟s grid to the products of Company A, its product positioning falls into the *Consumer Durables* product family. Products of the Company A are furniture products such as chairs, stools, tables, and cupboards. These products are considered to be high complexity but low uncertainty. The products are having high complexity in product variation, processes, and tiers of suppliers, while having low uncertainty in changes of specification, quality, and process reliable. Furniture products are medium-term usage, demanded in second hand market, and differentiated from competitors by value-for-money and availability factors.

Figure 3-14: John Puttick Market Segmentation Grid

Source: Adapted from Puttick (1986) in Whicker, Hartland, and Hessey (2011)

3.3.2.1.2 Order Winners and Order Qualifiers

Order Winners

To create competitive advantages for furniture products which are „consumer durables‟ products, value-for-money and availability are significant differentiation factors.

- Value-for-money

Value-for-money is described in terms of price that customers spend to purchase the products compared to value and quality that the customers acquire from the purchased products. Customers will be willing to pay the higher-than-market price if the products present greater value and differentiation. To make the products outstanding from competitors', the Company A should add value by superior design, craftsmanship, and innovation.

- Availability

As furniture industry is competitive, availability of products is important for customers' purchasing decisions. No one wants to wait long time for the products. If the products from this supplier are not available, the customers will change another supplier easily if the products are not different. Apart from managing availability of the existing ordered products, Company A should also leverage ability to increase production flexibility in order to acquire business opportunity from high-variety orders or unexpected orders grabbed from availability failure of competitors.

- Quality and Reliability

Quality and Reliability is mainly focused on quality and reliability of products and processes to follow the order specifications and reliable delivery in terms of time and quality.

<u>Order Qualifiers</u>

- Quality

Quality of products and processes are expected from customers and consumers of furniture products as their durable usage term is medium to long. Especially, if customers pay higher price, they will also expect superior quality. Therefore, Company A should focus on quality control of products and processes.

- Fitness of Purpose

Company A should consider fitness of purpose for both customers and consumers. Since Company A's customers are trader companies and brand companies, fitness of purpose is focused on specification in relations to numbers of parts, size, materials, and colours.

- Brand Image

As Company A is OEM, reputation for Company A is mainly from delivery reliability and quality of products. In highly competitive market, Company A need to compete in reputation and retention in order to maintain existing customers and also gain new customers.

According to Miltenburg (1996), Assessment of Company A competitive analysis is using the matrix as shown in Figure 3-14.

Manufacturing Outputs

5 = Poor
1= Good

	Delivery	Cost	Quality	Performance	Flexibility	Innovation
Attributes	1.Time	Factory Cost	1.Defects	1.Reliability 2.Specification	1. Machine 2. Process	1. Design 2. Craftmanship
Company - Current	4	3	4	4	3	2
Market	3	3	3	3	3	3
Strong Competitors	1	2	2	2	3	3
Company-Target	1	2	1	2	2	2
Market Qualifiers, Order Winners	M	M	M	O	O	O

Competitive Analysis

Figure 3-15: Company A Competitive Analysis

After assessing of competitive analysis, the Company A would rather want to improve strongly on delivery time, cost, quality, and performance in order to be able to compete with competitors. However, company's competitive advantage in terms of flexibility is needed to be maintained.

3.3.2.2 The Desired Production Systems

After the competitive analysis is analysed, the company realises that delivery time, cost, and quality are needed to be improved. Batch Flow or Cellular

Manufacturing system is the desired production systems. Cellular Manufacturing allows combination of product flow efficiency with flexibility of functional layout.

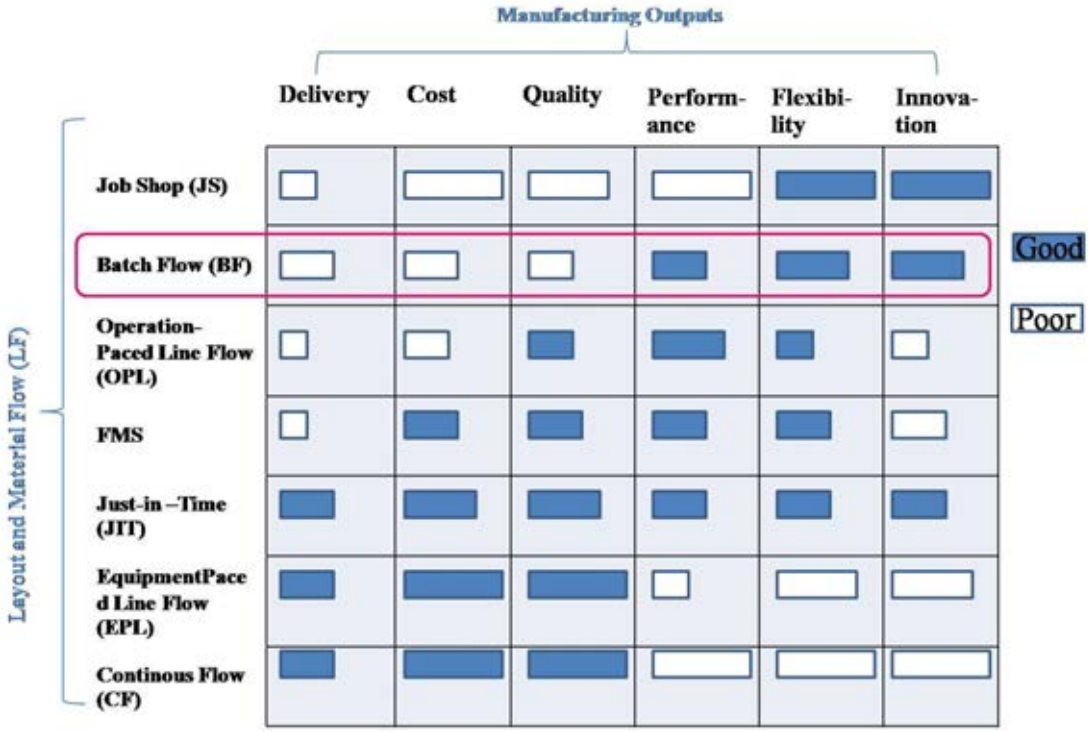


Figure 3-16: Company A Desired Production Systems

Source: Adapted from Miltenburg (1996) in Whicker and Hartland (2011)

In Cellular Manufacturing, products that required similar process will be grouped into product family and manufactured in a cell. The cell is consisted of different workstations, machines, and equipments that are required to produce one product.

Benefits from Cellular Manufacturing

- Increasing process flow continuity for parts to be produced.
- Reducing in throughput time
- Improving quality of products
- Reducing setup time and move time
- Less work-in-process
- Less complexity in production scheduling

As a result of increasing production efficiency, manufacturing outputs will be improved, especially in terms of delivery, cost, and quality.

3.3.3 Step 3: How will I get from where I am to where I want to be?

The manufacturing strategies are proposed to improve in the manufacturing levers in order to improve manufacturing output.

In this thesis, only production department is focused. Therefore, Company A considers applying Cellular Manufacturing concept as the main strategy to improve Production Planning & Control, Process Technology levers. Other supporting strategies are to be improved as by products are in Human Resource, Organisation Structure & Control and Facilities levers.

Production Planning & Control and Process Technology

- Cellular Manufacturing Concept

Facilities

- Improve Plant Layout

  This is to change from functional layout into U-shaped cell layout

Organisation Structure & Control

- Built-in Quality Control by Empowerment

  Changing from having QC staff to inspect finished goods at the end of the production to having self quality control is done within the Cell.

- Organisation Culture Management

  Organisation Culture Management is to set creative, learning, and innovative cultures. This is to motivate employees' best competency and performance. Creating a relaxed working environment will enable people to be creative, to learn new things, and to be passionate in the works.

Project-oriented Organisation Structure

This is to change from power-oriented organisation structure to project-oriented organisation structure. As the production process will be changed from line-flow production to batch flow production. The concept of teamwork will be emphasised instead of the concept of tasks and roles. The target will be achieved in a name of the team called 'Cell'.

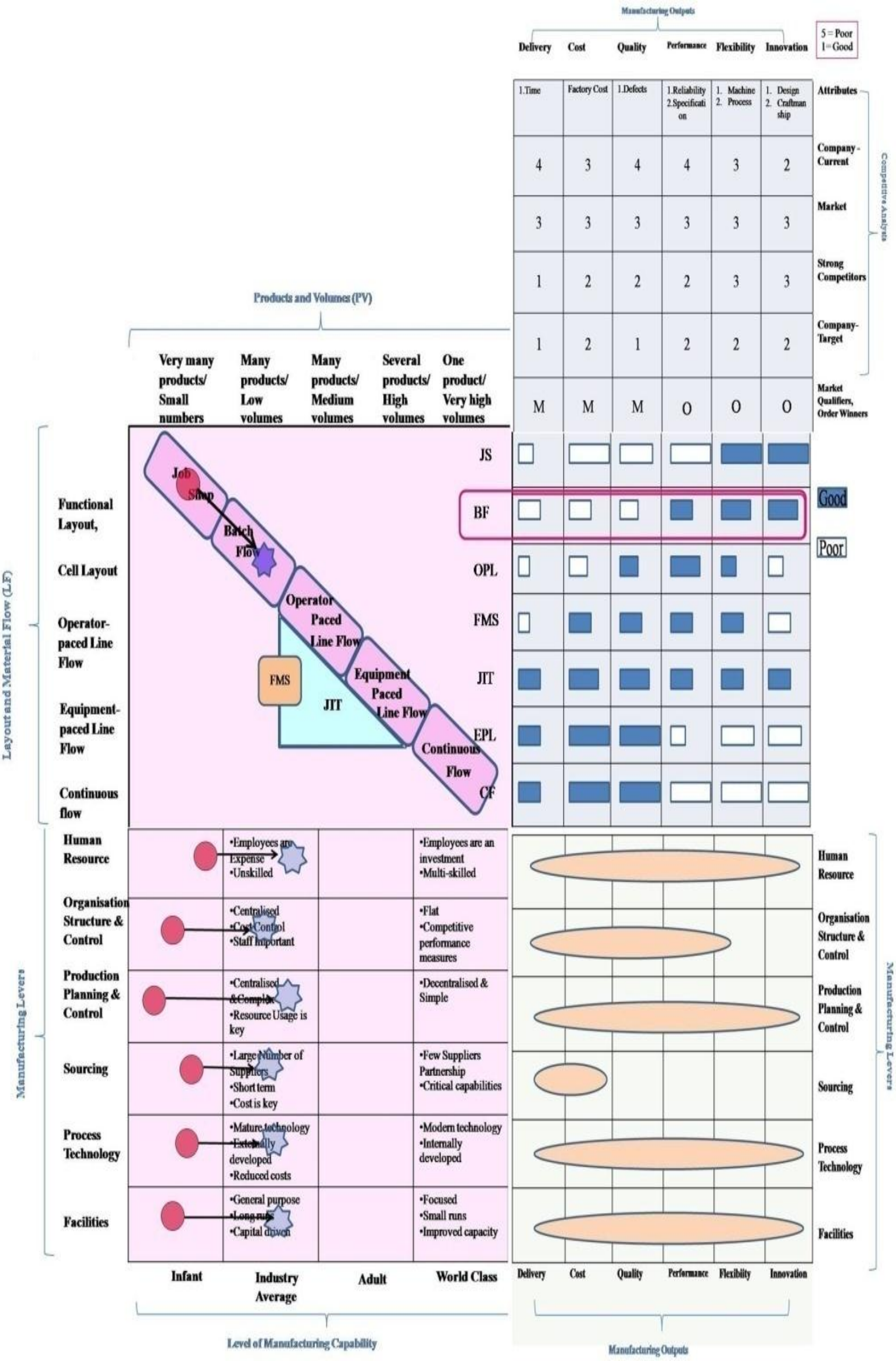
Human Resource

- Develop personnel competencies and professionalism

  Company A will arrange on-the-job training and coaching for the employees and workers to build their skills for work. This is to help them to enhance their competencies, functional knowledge, and team-based skills.

- Standard Work Instruction

  The Standard Work Instruction is a tool to share know-how of work instruction within the production line and to transfer tacit and explicit knowledge among people. This is to enhance people competency, skills, and performance.



	Delivery	Cost	Quality	Performance	Flexibility	Innovation
Attributes	1.Time	Factory Cost	1.Defects	1.Reliability 2.Specification	1. Machine 2. Process	1. Design 2. Craftmanship
Company - Current	4	3	4	4	3	2
Market	3	3	3	3	3	3
Strong Competitors	1	2	2	2	3	3
Company- Target	1	2	1	2	2	2
Market Qualifiers, Order Winners	M	M	M	O	O	O

Figure 3-17: Adjustment of Levers

CHAPTER IV

CELLULAR MANUFACTURING IMPLEMENTATION AND RESULTS

This chapter explains the application of Cellular Manufacturing (CM) concept for production department of Company A to replace the current Job Shop production.

4.1 Design for Cellular Manufacturing

4.1.1 Defining Parts Families

Grouping the products that similarity are found. Two techniques of defining the product families are Product Classifying Code and Product Flow Analysis (PFA). There are some differences between these two techniques. Product Classification Code is classifying the products by similarity of attributes of the products. While, Product Flow Analysis (PFA) technique is classifying the parts by similarity of processes and operations. In this case study, the two methods are using.

By using Product Classification Code, part family methods are not complicated. Raw materials, which are considered as parts, are wood boards and bars. The differences of the parts are only type, thickness, and size. The part families are defined by 3 characteristics: type, size, and thickness. Each digit of the code stands for characteristics of the part.

- First digit stand for Type of parts: Board (A) or Bar (B).
- Second digit stand for Size of parts: Size: Small (S), Medium (M), and Large (L).
- Third digit stand for Thickness parts Thickness: 20 mm (3), 25 mm (4), 30 mm (6), and 45 mm (9).

For example, 'AM3' is a medium-sized wood board with 20mm thickness.

By using Product Flow Analysis (PFA), similarity of sequences of the process that the parts go into can indicate the parts family. By consider the nature of furniture production, all the parts are needed to go through every process and every kind of machine. However, different part families may go to different machines.

The relationships between part families are identified by routing of operations sequence that parts go through machines. The use of Machine-Parts Matrix is used to visualise the relationship of those two aspects. The lists of machines in the systems and part family routing are identified.

(1) List of Machines

There are 21 numbers of machines in 6 types. Each type of machines is identical in appearance but actually there is a difference in the setting of machine based on thickness and size of parts. For example, there are 6 cutting machines. Each one is setup with different size of blades and size of machines for different part thickness and size. However, with the capability of machines, they can be flexible to serve all thickness.

Table 4-1: List of Machines

Machine Number	Machine Type
S1	Sizing Machine
S2	Sizing Machine
S3	Sizing Machine
M1	Smoothening Machine
M2	Smoothening Machine
M3	Smoothening Machine
C1	Cutting Machine
C2	Cutting Machine
C3	Cutting Machine
C4	Cutting Machine
C5	Cutting Machine
C6	Cutting Machine
E1	Edging Machine
E2	Edging Machine
E3	Edging Machine
D1	Drilling Machine
D2	Drilling Machine
D3	Drilling Machine
P1	Colour Processing Machine
P2	Colour Processing Machine
P3	Colour Processing Machine

(2) Part Family Routing

This is to analyse of parts flow routing in the production systems. The sequence of processes that the parts go through is defined by the operated machines. In this case study, there are 15 parts families based to thickness, size, and types.

Table 4-2: Part Family Routing

Part Family	**Machine Sequence**
AS3	S1-M1-C1-E1-D1-P1
AS4	S1-M1-C1-E1-D1-P1
AS6	S2-M2-C2-E2-D2-P2
AS9	S3-M3-C2-E3-D3-P3
AM3	S1-M1-C3-E1-D1-P1
AM4	S1-M1-C3-E1-D1-P1
AM6	S2-M2-C4-E2-D2-P2
AM9	S3-M3-C4-E3-D3-P3
AL3	S1-M1-C5-E1-D1-P1
AL4	S1-M1-C5-E1-D1-P1
AL6	S2-M2-C6-E2-D2-P2
AL9	S3-M3-C6-E3-D3-P3
BL3	S1-M1-C1-E1-D1-P1
BL6	S2-M2-C3-E2-D2-P2
BL9	S3-M3-C6-E3-D3-P3

(3) Define part family and machine grouping

Machine-Part Matrix is used to visualise the relationship between machine and part. In this matrix, row represents part families and column represents machine numbers. When a part family goes into a machine, '1' is put in the matrix to show the relationship as shown in Table 4-3.

Table 4-3: Part Family and Machine Grouping Matrix

Machine Code	Part Family														
	AS3	AS4	AS6	AS9	AM3	AM4	AM6	AM9	AL3	AL4	AL6	AL9	BL3	BL6	BL9
S1	1	1			1	1			1	1			1		
S2			1				1				1			1	
S3				1				1				1			1
M1	1	1			1	1			1	1			1		
M2			1				1				1			1	
M3				1				1				1			1
C1	1	1											1		
C2			1	1											
C3					1	1								1	
C4							1	1							
C5									1	1					
C6											1	1			1
E1	1	1			1	1			1	1			1		
E2			1				1				1			1	
E3				1				1				1			1
D1	1	1			1	1			1	1			1		
D2			1				1				1			1	
D3				1				1				1			
P1	1	1			1	1			1	1			1		
P2			1				1				1			1	
P3				1				1				1			1

Table 4-4: Part Family and Machine Grouping

Machine Code	Part Family														
	BL3	AS3	AS4	AM3	AM4	AL3	AL4	BL6	AS6	AM6	AL6	AS9	AM9	AL9	BL9
S1	1	1	1	1	1	1	1								
M1	1	1	1	1	1	1	1								
E1	1	1	1	1	1	1	1								
P1	1	1	1	1	1	1	1								
D1	1	1	1	1	1	1	1								
C1	1	1	1												
C3				1	1			1							
C5						1	1								
S2								1	1	1	1				
M2								1	1	1	1				
E2								1	1	1	1				
D2								1	1	1	1				
P2								1	1	1	1				
C2									1			1			
C4										1			1		
C6											1			1	1
S3												1	1	1	1
M3												1	1	1	1
E3												1	1	1	1
D3												1	1	1	1
P3												1	1	1	1

Then, the matrix is sorted by moving the inter-cell until the matrix in the Table 4-4 is derived. However, there are still some problems in grouping occur. There is a problem of out-group inter-cell. The problem is on cutting machines. To solve them, some parts sequence are needed to be changed. However, it must be based on machine capacity and suitability. In this case, the out-groups appear in part family AM9, AL6, AS9, and B16.

Table 4-5: Part Family Routing Adjustment

Part Family	Former Part Route	New Part Route
AM9	S3-M3-**C4**-E3-D3-P3	S3-M3-**C6**-E3-D3-P3
AL6	S2-M2-**C6**-E2-D2-P2	S2-M2-**C4**-E2-D2-P2
AS9	S3-M3-**C2**-E3-D3-P3	S3-M3-**C6**-E3-D3-P3
BL6	S2-M2-**C3**-E2-D2-P2	S2-M2-**C2**-E2-D2-P2

As mentioned earlier, the machines can be flexible and a change in routing of the part family can be possible. Then, 3 machine-part distinct groups are derived as shown in Table 4-6.

Table 4-6: Part Family and Machine Grouping Result

Machine Code	Part Family														
	B13	AS3	AS4	AM3	AM4	AL3	AL4	B16	AS6	AM6	AL6	AS9	AM9	AL9	B19
S1	1	1	1	1	1	1	1								
M1	1	1	1	1	1	1	1								
E1	1	1	1	1	1	1	1								
P1	1	1	1	1	1	1	1								
D1	1	1	1	1	1	1	1								
C1	1	1	1												
C3				1	1										
C5						1	1								
S2								1	1	1	1				
M2								1	1	1	1				
E2								1	1	1	1				
D2								1	1	1	1				
P2								1	1	1	1				
C2								1	1						
C4										1	1				
C6												1	1	1	1
S3												1	1	1	1
M3												1	1	1	1
E3												1	1	1	1
D3												1	1	1	1
P3												1	1	1	1

4.1.2 Defining Cell Process

The derived 3 distinct groups indicate 3 cells in for cellular manufacturing. The relationship of the parts and machines in each cells are analysed.

The first cell in the matrix consisted on part family B13, AS3, AS4, AM3, AM4, AL3, and AL4 to be operated in machines S1-M1-C1-C3-C5-E1-D1-P. The relationship of them is the thickness of parts. The parts with 20 to 25 mm are compatible to be operated in the machines that are set for their thickness. This range of thickness can indicate the type of products to be produced. The parts with 20 to 25 mm are used to produce chairs and stools. Therefore, this cell is classified as 'Chair' cells.

The second cell in the matrix consisted on part family B16, AS6, AM6, AL6 to be operated in machines S2-M2-C2-C4- E2-D2-P2. The relationship of them is the thickness of parts. The parts with 30 mm are compatible to be operated in the machines that are set for their thickness. This range of thickness can indicate the type of products to be produced. The parts with 30 mm are used to produce cupboards. Therefore, this cell is classified as 'Cupboard' cells.

The third cell in the matrix consisted on part family B19, AS9, AM9, AL9 to be operated in machines S3-M3-C6-E3-D3-P3. The relationship of them is the thickness of parts. The parts with 45 mm are compatible to be operated in the machines that are set for their thickness. This range of thickness can indicate the type of products to be produced. The parts with 45 mm are used to produce tables. Therefore, this cell is classified as 'Table' cells.

4.1.3 Finalise the Conceptual design of Cells

Three manufacturing cells are classified as 'Chair', 'Cupboard', and 'Table'. However, the flows of process are slightly different for different product family. The illustration of production process of 3 families of products is in Figure 4-1.

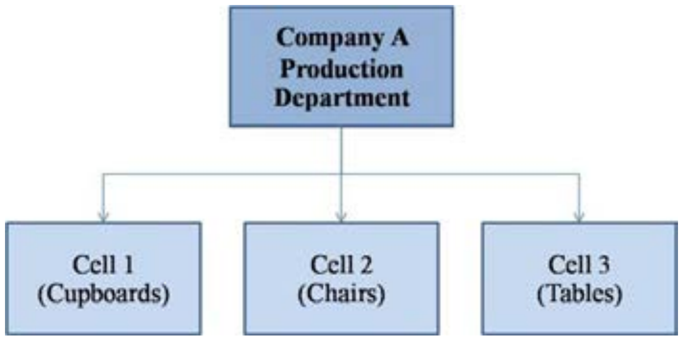


Figure 4-1: Three Manufacturing Cells

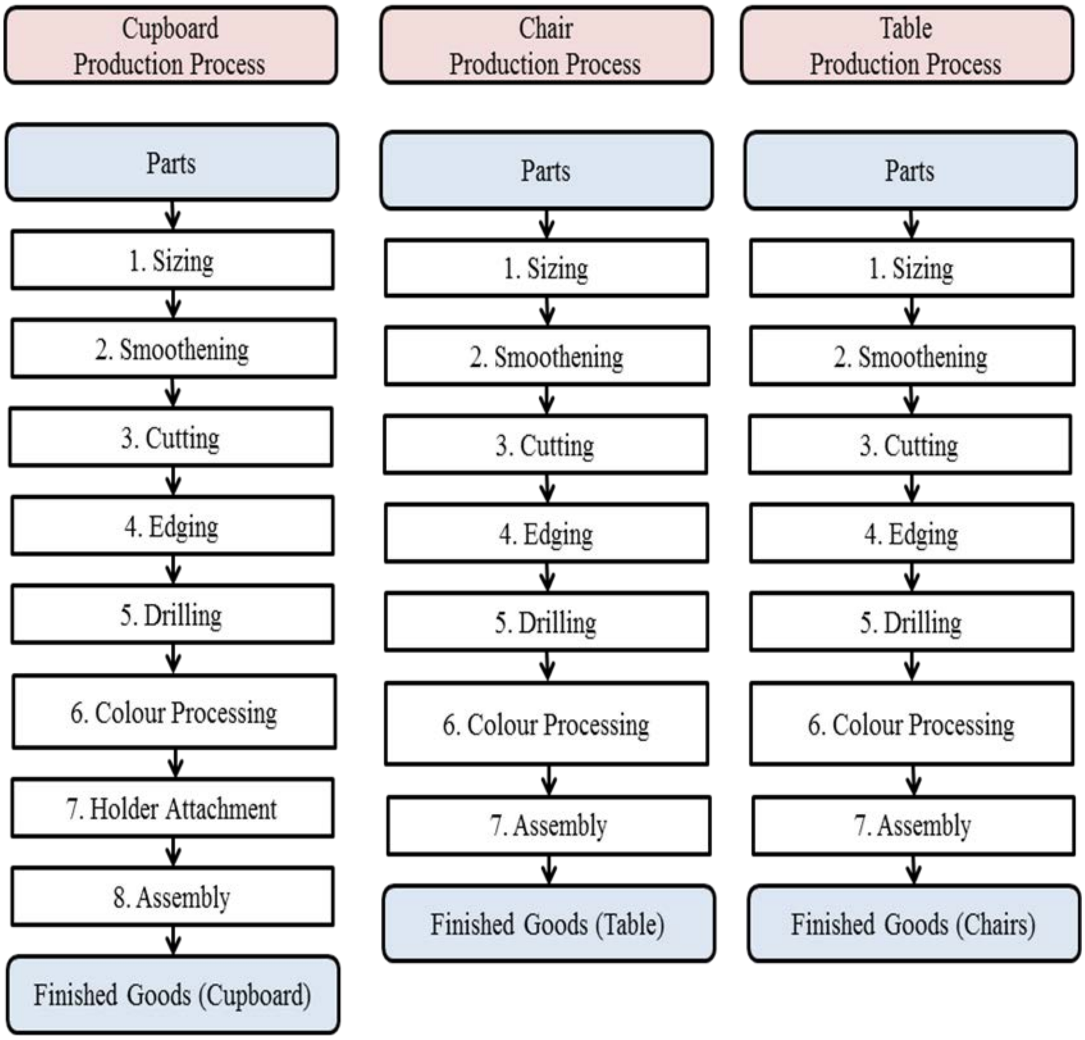


Figure 4-2: Three Cell Processes

In Chair and Table cells, the holder attachment process is skipped as they do not have holders and hinge. After the Colour Processing is finished the parts will go directly to Assembly process.

4.1.4 Resource Allocation

Apart from process sequence are slightly different, the resource allocation of each cell are different in terms of number of machines and manpower.

The resource allocation is determined by setup time and operating time of all cells for each part obtained from historical data and existing manufacturing plan. This part is important for accuracy for capacity balance between workload and resource capacity. Another aspect to be concerned is parts demand from historical data. The orders of production for 6 month historical data are obtained. Then the two aspects, which are set up & operating times and order of production, are combined to calculate resources required for the cell.

By applying Cellular Manufacturing concept to replace the existing Job Shop concept, multi-task team concept will be introduced to the operation line. In this case study, 21 machines and 48 operators are classified into 3 cells. Number of machines and number of operator are relevant. The machines must be operated with operators throughout the process since they are not fully-automated machines. Each cell team consists of team leader, team member, and labour working together.

The resource allocation in terms of machines and manpower for each cell team are illustrated in Table 4-7, 4-8, and 4-9.

Table 4-7: Cell 1 (Cupboards) Resource Allocation

Workstations	**Resource Allocation (Cell 1)**			
	Machines	**Capacity**	**Cell Team**	**Member**
			Team Leader	1
Sizing	Sizer Machines	1	Team Members	14
Smoothening	Smoothing Machines	1		
Cutting	Cutting Machines	2		
Edging	Edging Machines	1		
Drilling	Drilling Machines	1		
Colour Processing	Colour Processing	1		
Holder Attachment	-			
Assembly	-			
			Labourer	1
Total		**7**		**16**

Table 4-8: Cell 2 (Tables) Resource Allocation

Workstations	Resource Allocation (Cell 2)			
	Machines	Capacity	Cell Team	Member
			Team Leader	1
Sizing	Sizer Machines	1	Team Members	11
Smoothening	Smoothing Machines	1		
Cutting	Cutting Machines	1		
Edging	Edging Machines	1		
Drilling	Drilling Machines	1		
Colour Processing	Colour Processing Machines	1		
Holder Attachment	-			
Assembly	-			
			Labourer	1
Total		**6**		**13**

Table 4-9: Cell 3 (Chairs) Resource Allocation

Workstations	Resource Allocation (Cell 3)			
	Machines	Capacity	Cell Team	Member
			Team Leader	1
Sizing	Sizer Machines	1	Team Members	17
Smoothening	Smoothing Machines	1		
Cutting	Cutting Machines	3		
Edging	Edging Machines	1		
Drilling	Drilling Machines	1		
Colour Processing	Colour Processing Machines	1		
Holder Attachment	-			
Assembly	-			
			Labourer	1
Total		**8**		**19**

Each workstation can have flexible workforce within the same cell. Everyone in the team can perform every task. One operator is not fixed to one station or one machine. Workforce in the team can be rotated and transferred from one workstation to another. When there is a bottleneck or idle in any workstation, the team workforce can be transferred among each other to solve the problem. For example, a bottleneck happens at Cutting station where 2 workers are busy working but an idle happens at

Assembly station where 4 workers are idle working. One worker from Assembly station will be transferred to help in Cutting station. As everyone in the cell team can do every task within the cell, workforce can be flexible.

4.2 Implementation for Cellular Manufacturing

4.2.1 Form Cellular Manufacturing Team

Cellular Management is a concept which a set of workers are working as a team within a cell called 'Cell Team'. A cell team consists of a leader and team workers. The cell team will be working to accomplish the job target together. Everyone in the team has multi-skill for production. It means that everyone can perform every task within the cell. The good point of it is that the bottleneck of any task in the production process will be minimised.

Successful cell team involves good leadership, team involvement, and empowerment. In order to pull out the best of team's ability, good team management is very important.

- *Good Leadership,*

The team leader is the key person to direct, assign, and support the team toward the target accomplishment. The leader will be selected to be an authorised person who is in-charge and take responsibility on any results of the team performance. The leader of the cell team will be selected based on experiences and work performance.

- *Team Involvement*

The team workers will be working as a team by involving in the decision making and brainstorming together with the team leader and management. After the consensus is made in the team, everyone is involved. They will direct to the same goal and help each other to accomplish it.

- *Empowerment*

Creating sense of teamwork with relaxed working environment can motivate empowerment. Empowerment involves in encouraging team to express opinions, enabling decision making without asking seniors all the time, and involving in the results of the team.

In the initial phase of implementation of Cellular manufacturing, every cell will be allocated with at least 1 experienced worker of each required process. A cell team is consisted of experienced workers of every process to make sure that every process will be done properly.

4.2.2 Manufacturing Cell Layout

The production department is divided into 3 cells. Cell 1 (Cupboards) contains 8 workstations: Sizing, Smoothening, Cutting, Edging, Drilling, Colour Processing, Holder Attachment, and Assembly. While, Cell 2 (Chairs) and Cell 3 (Tables) each contain 7 workstations: Sizing, Smoothening, Cutting, Edging, Drilling, Colour Processing, and Assembly.

The manufacturing cell layout is designed in U-shape arrangement, where the workstations are located in close proximity. This helps decreasing move time among workstations. Operators can transfer entities to another workstation easily with less travel distance.

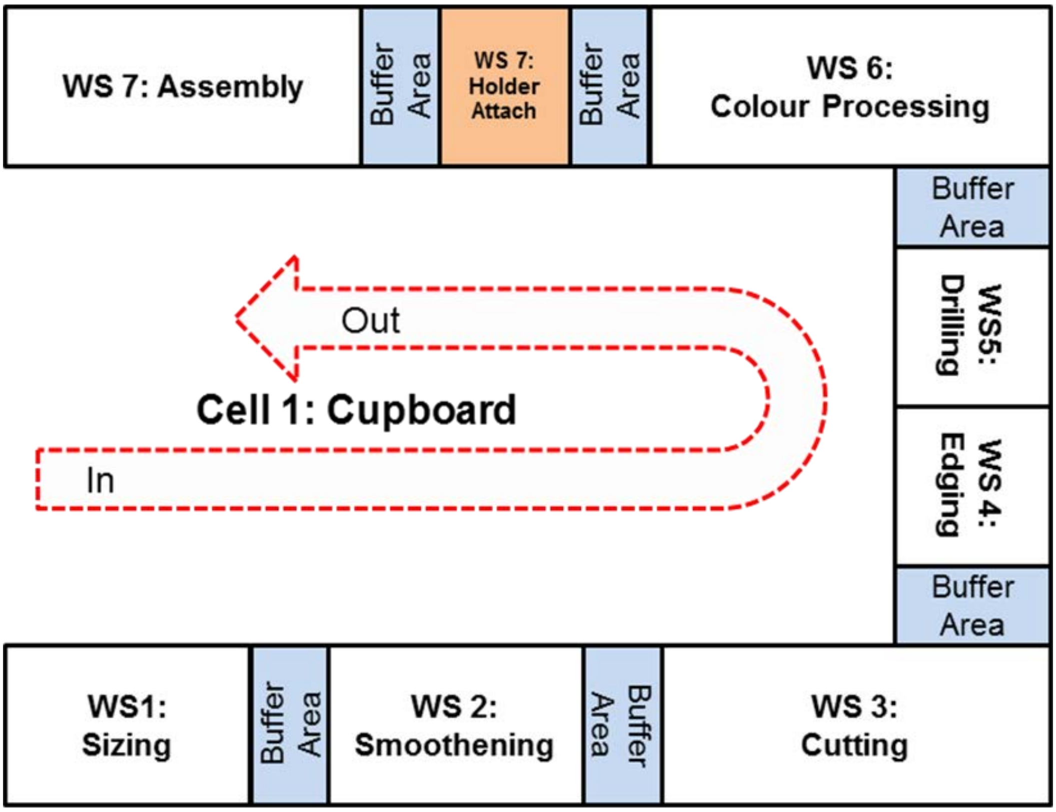


Figure 4-3: Cell 1 (Cupboards) Cell Layout

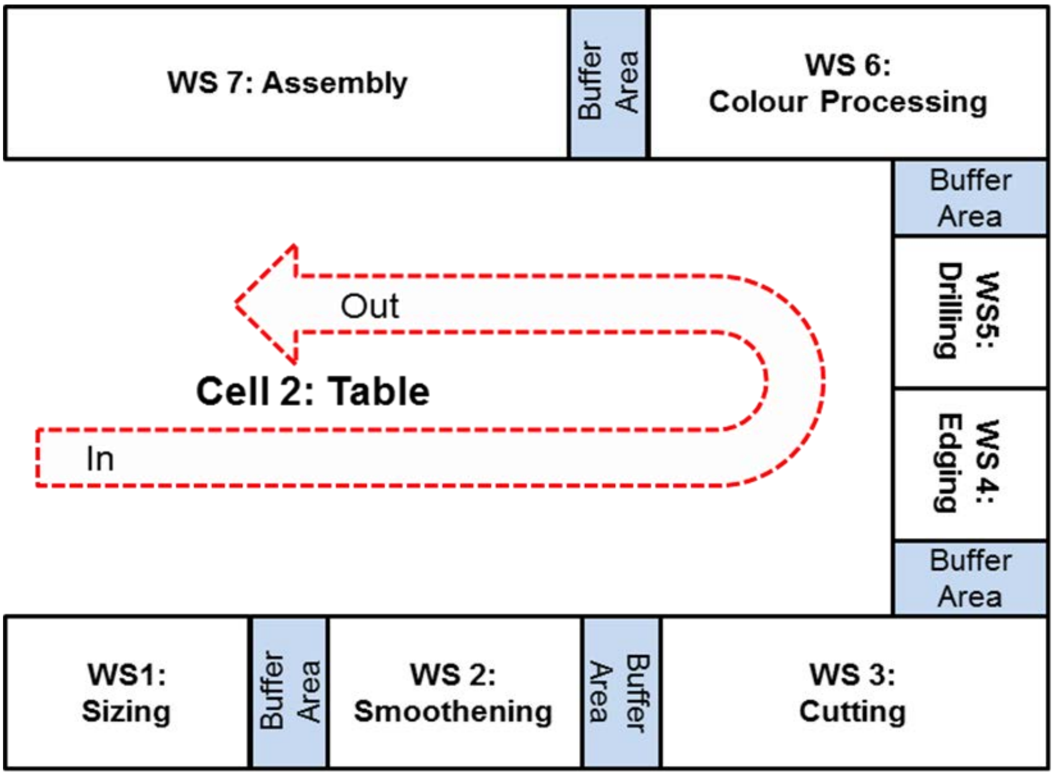


Figure 4-4: Cell 2 (Table) Cell Layout

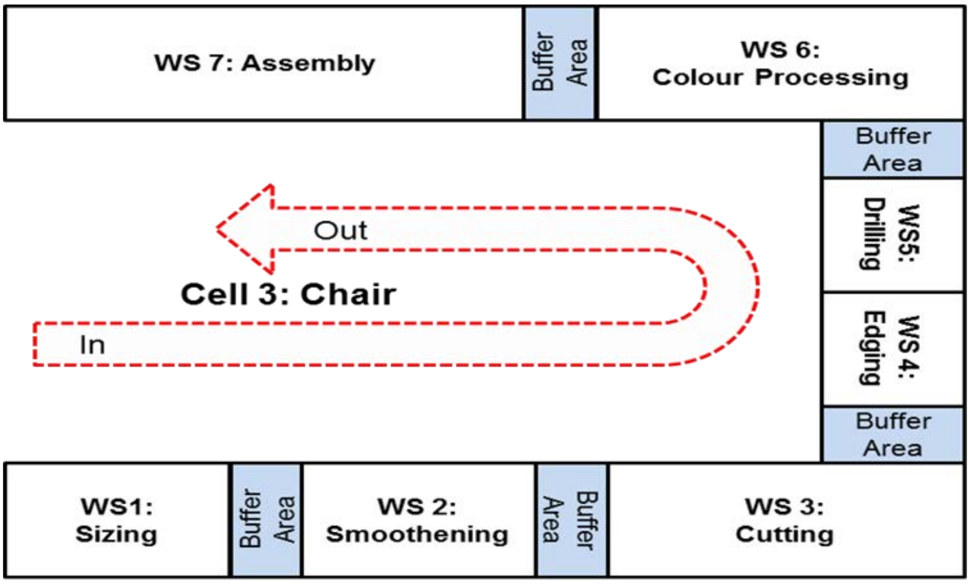


Figure 4-5: Cell 3 (Chair) Cell Layout

4.2.3. Proposed Plant Layout

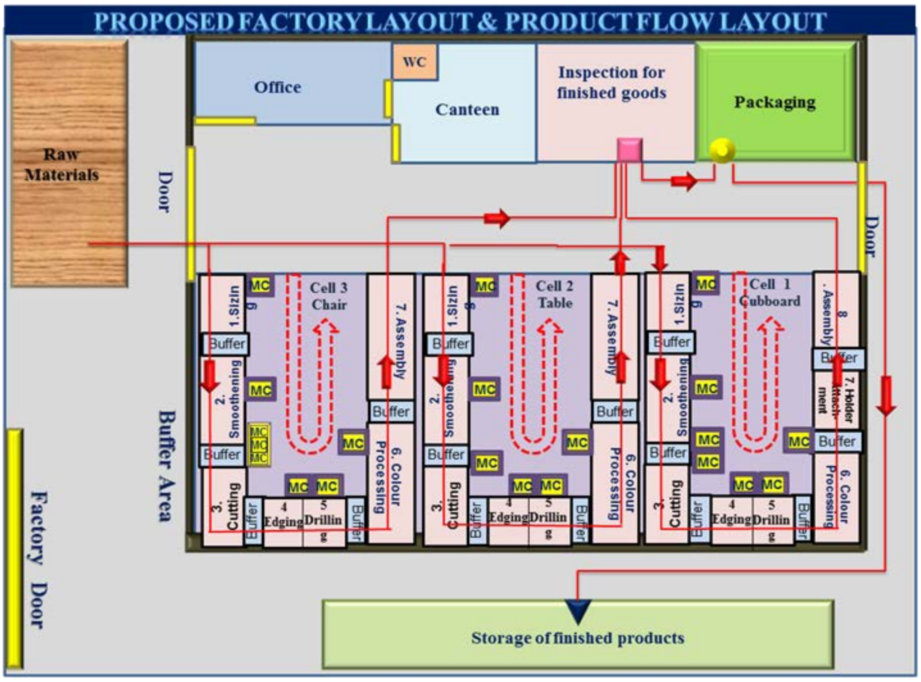


Figure 4-6: Proposed Plant Layout

4.2.4 Other Improvements

4.2.4.1 Standard Work Instruction

As the production systems and layout change, one worker can perform every task in every workstation. To set the same level of standard working, the Standard Work Instruction should be used as a tool to control working standard of each workstation.

In this case study, a tool for Standard Working Instruction concept is applied through the Standard Work Instruction sheet. The sheet is illustrated in Table 4-10. It consists of process/station name, machine number/tools, materials, work instruction, and remark. This tool makes it clear to the workers to perform tasks correctly by follow the instruction. The tables will be attached to every workstation.

Table 4-10: Work Instruction Table

<table>
<tr><th colspan="6">Company A (Production Department)</th></tr>
<tr><td>Work Sheet:</td><td colspan="3">Standard Work Instruction</td><td>Sheet no.</td><td></td></tr>
<tr><td rowspan="2">Workstation/
Cell:</td><td rowspan="2"></td><td>Products
/ Parts</td><td></td><td>Date:</td><td></td></tr>
<tr><td>Code</td><td></td><td>Approved by</td><td></td></tr>
<tr><td colspan="4">Illustrations</td><td colspan="2">Standard Work Instruction</td></tr>
<tr><td colspan="4" rowspan="7"></td><td colspan="2"></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="4">Parts</td><td colspan="2">Standard</td></tr>
<tr><td>Part No.</td><td>Name</td><td>Code</td><td>Quantit</td><td>Part Standard:</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Equipments/
Machines</td><td></td><td></td><td></td><td>Products
Standard:</td><td></td></tr>
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This is done to create awareness for performance standard to workers. Performance standard for every worker should be ensured in that everyone follows the same work instruction when performing the particular tasks. So, the outputs will be standard as well.

Apart from being used in the production line, the Standard Work Instruction is also used for training and on-the-job training. New workers can practice and perform the tasks according to the written instruction. This will prevent errors in machine operations, which possibly cause machine breakdown.

4.2.4.2 Develop Personnel Competencies and Professionalism

In applying Cellular Manufacturing Concept, skilled workers are very essential because everyone must be able to perform every task within the cell. Therefore, training is important.

Initially, every cell is allocated with at least 1 experienced worker of each required process. A cell team is consisted of experienced workers of every process. Training session is arranged by the cell team to teach each other how to perform tasks in each process. The Standard Work Instruction sheet for every process is provided as a training document for everyone to learn and practice. On-the-job training also needed to practice the real tasks during training. However, the team leader is responsible to check and coach workers on the training.

New workers are needed to be practiced in one by one process first in order to be familiar with each process and practice skills for every process. Also, new workers are always be coached by the team leader or senior workers. However, the Standard Work Instruction sheets that attached on every workstation can remind the new workers of the work instruction. This is to enhance workers' competencies, functional knowledge, and team-based skills.

4.2.4.3 Build-in Quality

In terms of quality control, Build-in Quality concept is applied. Through this concept, quality inspection of products is done during WIP is in the production line. The WIP will be inspected in the workstation before moving to the next workstation. Everyone in the team will perform inspection during production.

In this case study, a tool for Build-in Quality concept is applied through the Process Input/output chart. The chart is illustrated in Table 4-11. The chart consists of process name, pictures table for good and bad input/output. This tool makes it clear to the workers to visualise examples of good and bad WIPs in order to inspect their input/output WIP accordingly. The charts will be attached to every workstation together with the Standard Work Instruction sheet.

Table 4-11: Process Input/output Chart

Process Name:	
Good Input	**Good Output**
Picture	Picture
Bad Output	**Bad Output**
Picture	Picture

This is done to create quality-concerned awareness for workers. Quality standard for every piece of WIP should be ensured before being forwarded to the next workstation. Build-in Quality helps in reducing defects on WIPs and finished goods. It leads to reworks and scraps reduction. Also, each team leader who is supervisor can check production quality during production and after production is done.

4.3 Comparison and Assessment

The results of the current functional layout and the proposed cellular layout are compared. The implementation of Cellular Manufacturing layout starts in July 2012. The timeframe to be compared is 6 months. The data of currents production systems are collected in during January - June 2012 to be compared with the data of proposed production systems in July - December 2012.

After the initial implementation of Cellular Manufacturing concept is applied to the Company A, there are performance improvements in several dimensions.

4.3.1 Reduction in Move Time

Application of cellular manufacturing concept in furniture production results to significant reduction in move time by 57.33% of the current production systems within 6 months due to shorten product flow distance and less work in process. Operating time is reduced by 3.94% while 68.83% of delay process is also reduced but set up time remains unchanged. As a result, the average reduction of throughput time had reduced by 30.99% of the current production systems within 6 months (Illustrated in Figure 4-7).

4.3.2 Reduction in Product Flow Distance and Work Process

Based on cellular manufacturing concept, redesign of process layout to be U-Shape cell can shorten production flow distance and simplifies production process flow and lead to reduction of product flow distance by 56.64% while 6.67% of the total number of work process was also reduced.

4.3.3 Reduction in the Delay time of Work-in-process

The delay of work in process was reduced by 68.83% because 2 processes of delay in waiting areas for further process are eliminated.

Production Process Assessment and Comparison Chart

Chart No._1_ Page_1_ of_2_

Product / Material / Staff

Activity: Production Process

Process of wooden dining table production

Work method: Current / Improve

Place: Company A Furniture Production Factory

Recorded by:

Approved by: Date:

Summary									
Activity		Current (Pre-Avg.)		Improved (CM)		Reduce			
						Variance		Rate of reduction%	
		QTY	Time	QTY	Time	QTY	Time	QTY	Time
Set up		0	7.08	0	7.08	0	0.00	-	0.00%
Operate		9	116.36	9	111.78	0	4.58	-	3.94%
Move		15	35.68	14	15.22	1	20.45	6.67%	57.33%
Delay		3	64.17	1	20.00	2	44.17	66.67%	68.83%
Inspect		1	-	1	-	0	-	0.00%	-
Keep		2	-	1	-	1	-	50.00%	-
Throuhput tim		-	223	-	154.08	-	69.20	-	30.99%
TTL Distance		119	-	51.6	-	67	-	56.64%	-
Work process		30	223	28	154.08	2	69.20	6.67%	30.99%

Pre= Before improvement, Post-CM= After improvement with cullular manifactures concept, Avg. = Average

	Task description	Pre Distance (metre)	Pre Time	Post-CM Distance (metre)	Post-CM Time (min.)	Symbol: Operate	Move	Delay	Inspect	Keep	Note
	Machine Set up										
	Set up sizing machine at workstation 1	-	0.44	-	0.44						
	Set up smoothening machine at workstation 2	-	1.12	-	1.12						
	Set up cutting machine at workstation 3	-	1.13	-	1.13						
	Set up edging machine at workstation 4	-	1.14	-	1.14						
	Set up drilling machine at workstation 5	-	1.12	-	1.12						
	Set up colour processing machine at workstation 6	-	2.13	-	2.13						
	Production process										
1	Move parts from Storage to the factory	25	7.38								
2	Delayed in the part waiting area for production processed		6.06								
3	Move parts to Work Station 1 for sizing	6	1.77	20	5.9						
4	Operate sizing		5.35		5.35						
5	Move sized parts to Work Station 2 for smoothening	7	2.07	3.6	1.06						
6	Operate smoothening		5.35		5.36						
7	Move smoothened parts to waiting area	10	2.95		0.00						
8	Delay in the part waiting area for cutting process		25.20		0.00						
9	Move the smoothened parts to Work Station 3 for cu	12	3.54	3.5	1.03						
10	Operate cutting		10.50		5.53						
11	Move cut parts to Work Station 4 for edging	10	2.95	3.5	1.03						
12	Operate edging		10.43		5.30						
13	Move parts to Work Station 5 for drilling	8	2.49		0.00						
14	Operate drilling		5.12		5.12						
15	Move the parts to waiting area	10	2.51	3.5	1.03						
16	Delay in the part waiting area for colour processing		32.91		20.00						
17	Move parts to Work Station 6 for colour processing	7	3.30	3.5	1.03						
18	Operate colour processing		60.00		60.00						
19	Move parts to fitting workstaion 7 for holder attachment	10	2.95	3.5	1.03						
20	Operate holder attachment		3.35		5.12						
21	Move the parts to workstation 8 for assembly process	7	1.71	3.5	1.03						
22	Operate furniture assembly		16.26		20.00						
23	Move Finished goods to Q.C.process	7	2.07	7	2.07						
24	**Process under responsibility of other departments**										
25	*Operate product inspection*										
26	*Move qualified goods to packaging process*										
27	*Operate packing*	Other Departments' activities									
28	*Move Finished goods to Pre-Storage*										
29	*Keep in Pre Storage*										
30	*Move Finished goods to Main Storage*										
31	*Keep in Main Storage*										
	Total	**119**	**223**	**51.6**	**154**						Total
	Total quantified number of work process (Pre-improve)					**9**	**15**	**3**	**1**	**2**	**30**
	Total quantified number of work process (Post-improved by CM concept)					**9**	**14**	**3**	**1**	**1**	**28**

Figure 4-7: Production Process Assessment and Comparison Chart

4.3.4 Reduction in Late Delivery Time

After applying Cellular Manufacturing Concept to the production line, it results in improving on-time efficiency for delivery. Even though, late delivery cannot be totally removed from the production, however, customer complaints for late delivery and penalty costs are significantly reduced.

Table 4-12: Late Product Delivery

Reduction in Late Product Delivery				
Production Systems	**Months**	**Order Quantity (Units)**	**Number of Days for Late Delivery (Days)**	**Average no. of days**
Current Production Systems	Jan-12	750	20	17.6
	Feb-12	750	21	
	Mar-12	760	18	
	Apr-12	780	15	
	May-12	800	15	
	Jun-12	800	17	
CM Production Systems	Jul-12	800	9	7.16
	Aug-12	800	10	
	Sep-12	840	8	
	Oct-12	850	5	
	Nov-12	850	5	
	Dec-12	870	6	
Average reduction in late product delivery				10.44

The average number of days for late delivery had significantly reduced by 10.44 days within 6 months which reduced from 17.6 to 7.16days or equivalent to the reduction by 59.31% from the current production systems

4.3.5 Reduction of Rework and Scrap Rates

Improvement in terms of production quality indicates by reduction in rework rates. Rework rates is reduced from 4.94% to 2.57% of order quantity. The average reduction in number of reworks had significantly reduced by 2.37% within 6 months or equivalent to the reduction by 47.97% of the current production systems.

Table 4-13: Reduction in Number of Reworks

Reworks					
Production Systems	**Months**	**Order Quantity (Units)**	**Number of Reworks (Units)**	**Rework Rate (%)**	**Average Rework Rates (%)**
Current Production Systems	Jan-12	750	38	5.07	**4.94%**
	Feb-12	750	38	5.07	
	Mar-12	760	44	5.79	
	Apr-12	780	29	3.72	
	May-12	800	38	4.75	
	Jun-12	800	42	5.25	
CM Production Systems	Jul-12	800	29	3.63	**2.57%**
	Aug-12	800	22	2.75	
	Sep-12	840	19	2.26	
	Oct-12	850	20	2.35	
	Nov-12	850	19	2.24	
	Dec-12	870	19	2.18	
The average reduction in number of reworks					**2.37%**

Scrap rates is reduced from 2.54% to 1.84% of order quantity. The average reduction in scrap rates is reduced by 0.70% within 6 months or equivalent to the reduction by 27.55% of the current production systems.

Table 4-14: Reduction in Number of Scraps

Scraps					
Production Systems	**Months**	**Order Quantity (Units)**	**Number of Scraps (Units)**	**Scrap Rate (%)**	**Average Scrap Rates (%)**
Current Production Systems	Jan-12	750	22	2.93	**2.54%**
	Feb-12	750	18	2.40	
	Mar-12	760	15	1.97	
	Apr-12	780	23	2.95	
	May-12	800	22	2.75	
	Jun-12	800	18	2.25	
CM Production Systems	Jul-12	800	18	2.25	**1.84%**
	Aug-12	800	16	2.00	
	Sep-12	840	17	2.02	
	Oct-12	850	13	1.53	
	Nov-12	850	15	1.76	
	Dec-12	870	13	1.49	
Average reduction in scrap rates					**0.70%**

4.3.6 Reduction in Customer Complaints on Late Delivery

Customer complaints, specifically on late product delivery are significantly reduced by changing in production systems. This results in higher customer satisfaction and retention.

Table 4-15 Reduction in Number of Customer Complaints on Late Delivery

Number of Customer Complaints on Late Delivery			
Production Systems	**Months**	**Number of Complaints**	**Average Number of complaints**
Current Production Systems	Jan-12	17	16.16
	Feb-12	18	
	Mar-12	15	
	Apr-12	17	
	May-12	16	
	Jun-12	14	
CM Production Systems	Jul-12	9	6.5
	Aug-12	6	
	Sep-12	6	
	Oct-12	7	
	Nov-12	6	
	Dec-12	5	
Average reduction in number of complaints			9.66

In summary, the average number of complaints had significantly reduced by 9.66 complaints which down from 16.16 to 6.5 complaints or equivalent to the reduction by 59.77% of the current production systems within 6 months.

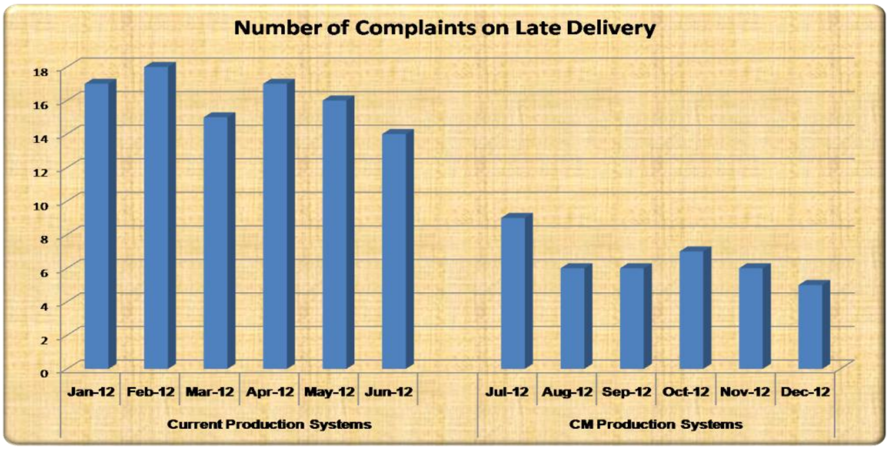

Figure 4-8: Number of Customer Complaints

4.3.7 Penalty Costs due to Late Delivery

Penalty costs that the company A signs contract with customers are in increased rate. The 1st-5th day of late deliveryis charged at 10 Baht/day/unit. The 6th-10th day of late delivery is 12 Baht/day/unit. The 11th-15th day of late delivery is 15 Baht/day/unit. The 16th-20th day of late delivery is 18 Baht/day/unit. The 21th-25th day of late delivery is 20 Baht/day/unit. Therefore, the longer the late delivery, the higher in penalty cost. More details are available in Appendix B.

After applying Cellular Manufacturing Concept to the production line, it results in high reduction in penalty costs due to late delivery from 40,116 Baht in 6 months (from January 2012 to June 2012) to 5,982 Baht in 6 months later (from July 2012 to December 2012). In summary, the total reduction in penalty costs had significantly reduced by Baht 34,134 or equivalent to the cost saving by 85.08% of the current production systems within 6 months.

Table 4-16: Total Reduction in Penalty Costs due to Late Delivery

Reduction in Penalty Costs due to Late Delivery						
Production Systems	**Months**	**Late Delivery (Days)**	***Penalty Costs/unit (Baht)**	**Late Delivered Products**	**Penalty Costs (Baht)**	**Total Penalty Costs (Baht)**
Current Production Systems	Jan-12	20	275	30	8,250	40,116
	Feb-12	21	295	41	12,095	
	Mar-12	18	239	30	7,170	
	Apr-12	15	185	28	5,180	
	May-12	15	221	16	3,885	
	Jun-12	17	98	15	3,536	
CM Production Systems	Jul-12	9	98	15	1,470	5,982
	Aug-12	10	110	16	1,760	
	Sep-12	8	86	12	1,032	
	Oct-12	5	50	12	600	
	Nov-12	5	50	10	500	
	Dec-12	6	62	10	620	
Reduction in penalty cost						34,134

4.4 Total Production Improvement Results

In summary, the result of applying cellular manufacturing concept in cellular layout compared to the current functional production layout within 6 months reflects to the successful result of significant improvement in terms of both production and quality dimensions.

Production improvement result

- The average move time is reduced by 57.33% of the current production.
- Product flow distance is reduced by 56.64% of the current production.
- The total number of work process is reduced by 6.67% % of the current production.
- Delay time of work process is reduced by 68.83% of the current production.
- The average number of late delivery of product had significantly reduced by 59.31% from the current production.

Quality improvement result

- Average rework rates is reduced by 47.97% of the current production.
- Average scrap rates is reduced by 27.55% of the current production.
- Average number of customer complaints is reduced by 59.77% of the current production.
- Total penalty cost is reduced by 85.08% of the current production.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions for the case study in the topic of 'Application of Cellular Manufacturing Concept in a Furniture Production Company' are presented as well as recommendations for further study and improvement.

5.1 Conclusions

The application of Cellular Manufacturing concept is initially implemented in Production Department of Company A in terms of production process layout. The current functional layout is redesigned to be cellular layout by applying the concept of Cellular Manufacturing. This is done to initially improve the production of Company A and to solve the current problems.

Long travel distance, long move time, and delay time in the production line are the main reason of the long customer lead time problem. The current production systems and layout does not support full potential to compete in time and quality. Company A analysed that having production process layout which is not suitable with nature of production causes the problem of long travel distance, long move time, and delay time, and under standard of quality products (scraps and reworks). This finally results in late product delivery to customers.

In this case study, an application of Cellular Manufacturing concept is initially implemented in terms of production process layout. This is only the initial phase of implementing full Cellular Manufacturing production systems. Familiarisation to team-based working and multi-task skill concepts are introduced to staff in order to embrace the changes of working in Cellular Manufacturing environment and be ready for further implementation of the systems in the future.

However, apart from production improvement, applying the concept of Cellular Manufacturing also leads to improvement in other aspects as well.

After analysing the company's current situations, the manufacturing strategies are formulated in order to improve the situation. The strategy of applying Cellular Manufacturing Concept to the production process layout is selected to be the main strategy. After implementing the concept, there are significant improvement in terms of Production and Process, Organisation Structure & Control, Human Resources, and Facility.

In terms of *Production and Process*, the production process layout is changed from functional layout in Job Shop production systems to cellular layout in Cellular Manufacturing systems. Before, there is a single production line based on production process. All products are using the same production line. Production orders are produced one at a time. When there is any production delay for the first order, the second order is also affected. After Cellular Manufacturing concept is applied, production for cupboards and tables can be produced at the same time by different production cells.

Through the part of changing to the Cellular Manufacturing concept, the design and implementation of Cellular Manufacturing Concept are described. During the design process, part family is classified by using two methods: Product Classification Code (PCC) and Product Flow Analysis (PFA). Then, the relationship between part family routing and machines are found by using machine-part matrix. The group of machines and part families are related in terms of thickness of the part family. There is a relationship between thickness and product types. There are the 3 derived cell groups which are classified by product types. Resource allocation for the cells is set according to the historical data on operating time and production orders.

After the manufacturing cells are designed, the implementation is according to it. Cell teams are identified to work in the group with a team leader. The Cell layout is implemented in U-shape to have all people in the cell team working together as a group and working flexibly in the cell. After the implementation of the Cell Manufacturing is launched to the production systems, the results of operation are assessed and compare to the former Job Shop production systems.

The results show improvements in terms of shorter travel distance, move time, delay time, and work process as well as reducing scraps and reworks rates, late delivery, number of customer complaints, and penalty cost for late delivery.

In terms of *Organisation Structure and Control*, by adopting Cell Team concept, the organisation culture within the production department is changed from power-oriented culture to project-oriented culture. Before, the management style is centralised to the management and supervisors. After Cellular Manufacturing concept is applied, the management style is more decentralised to the operation workers. In Cellular Manufacturing concept, workers are grouped into cell teams in order to work together within the Cell. Everyone in the team will be working toward the same goal and will be responsible for the results of the team either good or bad. Therefore, the team opinions, ideas, and discussion will be counted. The supervisors are no longer the boss but instead the leaders. This changes the organisation culture in the Production department to be relaxed environment. Goal and achievements of the work are mainly focused.

In terms of Human Resources, operation workers improve working skills. Before one worker can only perform one task. It leads to fatigues and boredom. After Cellular Manufacturing concept is applied, they are improving their skills though training. One worker can perform multi tasks. It leads to more job satisfaction. Moreover, improving in work standard by having standard work instruction is helping the workers to perform tasks easier while having accuracy on production. The cell workers are not performing only on production but quality control as well. Inspection process is empowered to the operation workers. The built-in quality is applied to allow cell team to inspect the parts along the production within cells.

In terms of Facility, the plant layout is reorganised to be suitable for Cellular Manufacturing concept. Before, the current plant layout is unorganised and leads to waste in travel time of WIP from process to process. After Cellular Manufacturing concept is applied, the layout of the production line is adjusted into U-shape, where the workstations are placed in close proximity. Apart from reducing WIP travel time, having the U-shape production line makes it easier for the cell team to perform tasks together. As everyone in the cell can perform every task within the cell, the cell team will be moving around among workstations to help each other in the cell.

The result of the study shows efficiency improvement both in production and quality. Focused on production perspective, more simplify factory and production process layout leads to reduction of product flow distance by 56.64%. Consequently, 57.33% of the total move time and 68.83% of the delay process were reduced. Likewise, the total number of work processes and throughput time were reduced by 6.67% and 30.99% respectively. In terms of quality perspective, scrap and rework were reduced by 27.55% and 47.97% respectively while 59.31% of product delivery.

5.2 Recommendations

Further study and improvement for this case study is recommended in terms of in-depth implementation of Cellular Manufacturing systems in the production planning and control by considering the production demands and operating time. Moreover, lean manufacturing should also be studied. The using of tools and techniques for lean manufacturing should be applied to the case study. Cellular Manufacturing concept can be further improved for lean manufacturing as a continuous improvement. The tools such as Kaizen, 5Ss, and Kanban can be applied to the improvement of production efficiency. Moreover, the study of using Cellular Manufacturing to improve other aspects in relations to costs, sales, and employees are also recommended.

Another aspect to be recommended for further study is management of change. After the change of the whole shop floor from functional layout in Job Shop systems to cellular layout in Cellular Manufacturing, there are many changes occurred during the planning stage. Resistance to changes from employees and workers are important that restrict the success in changes. Management of change is also one of the most interesting studies for further improvement after the application of Cellular Manufacturing Concept.

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APPENDICES

APPENDIX A

(Process data)

Data analysis of throughput time before improvement (Jan-Jun 2012)							
Jan-12							
	Loop	Setup Time (Min)	Operating Time (min)	Move Time	Delay Time	Total Time/Unit	Amount/ 8hours (Unit)
WS1 sizing	1	0.45	5.20	3.22	5.11	13.98	34.33
	2	0.44	5.60	3.65	6.40	16.09	29.83
	3	0.45	5.70	3.35	5.30	14.80	32.43
	4	0.43	5.00	3.45	5.70	14.58	32.92
	5	0.43	5.50	3.60	7.60	17.13	28.02
	6	0.44	5.60	3.65	7.40	17.09	28.09
	7	0.45	5.30	3.66	5.40	14.81	32.41
	8	0.45	5.40	3.75	5.50	15.10	31.79
	Total Average	0.44	5.41	3.54	6.05	15.45	31.23
WS2 smoothening	1	1.12	5.50	2.60		9.22	52.06
	2	1.13	5.60	2.40		9.13	52.57
	3	1.12	5.20	2.30		8.62	55.68
	4	1.11	5.30	2.40		8.81	54.48
	5	1.13	5.10	2.53		8.76	54.79
	6	1.13	5.40	2.52		9.05	53.04
	7	1.14	5.60	2.50		9.24	51.95
	8	1.12	5.50	2.40		9.02	53.22
	Total Average	1.13	5.40	2.46		8.98	53.47
WS3 cutting	1	1.13	25.30	3.55		29.98	16.01
	2	1.14	24.10	3.52		28.76	16.69
	3	1.12	25.30	3.51		29.93	16.04
	4	1.12	25.20	3.53		29.85	16.08
	5	1.15	24.30	3.55		29.00	16.55
	6	1.12	25.80	3.54		30.46	15.76
	7	1.13	25.70	3.56		30.39	15.79
	8	1.11	25.90	3.56		30.57	15.70
	Total Average	1.13	25.20	3.54		29.87	16.08
WS4 Edging	1	1.15	10.30	2.30	10.05	23.80	20.17
	2	1.12	10.50	2.20	12.40	26.22	18.31
	3	1.12	10.20	2.40	13.30	27.02	17.76
	4	1.12	10.60	2.15	10.50	24.37	19.70
	5	1.15	10.30	2.30	9.40	23.15	20.73
	6	1.10	10.70	2.20	10.40	24.40	19.67
	7	1.13	10.20	2.50	10.50	24.33	19.73
	8	1.13	10.50	2.80	10.70	25.13	19.10

	Total Average	1.13	10.41	2.36	10.91	24.80	19.40
WS5 Drilling	1	1.11	5.11	3.20		9.42	50.96
	2	1.12	5.12	3.10		9.34	51.39
	3	1.12	5.11	3.20		9.43	50.90
	4	1.11	5.13	3.22		9.46	50.74
	5	1.12	5.12	3.40		9.64	49.79
	6	1.11	5.14	3.10		9.35	51.34
	7	1.13	5.14	3.32		9.59	50.05
	8	1.12	5.12	3.35		9.59	50.05
	Total Average	1.12	5.12	3.24		9.48	50.65
WS6 Spray & Bake	1	2.12	30.40	3.20	32.10	67.82	7.08
	2	2.13	30.60	3.10	33.40	69.23	6.93
	3	2.14	30.20	3.20	34.00	69.54	6.90
	4	2.16	30.10	3.22	33.00	68.48	7.01
	5	2.13	30.60	3.40	32.50	68.63	6.99
	6	2.14	30.60	3.10	33.60	69.44	6.91
	7	2.14	30.30	3.32	33.40	69.16	6.94
	8	2.15	30.30	3.35	34.50	70.30	6.83
	Total Average	2.14	30.39	3.24	33.31	69.08	6.95
WS7 Holder attachment	1		3.45	1.60		5.05	95.05
	2		3.20	1.60		4.80	100.00
	3		3.20	1.60		4.80	100.00
	4		3.35	1.59		4.94	97.17
	5		3.40	1.65		5.05	95.05
	6		3.50	2.00		5.50	87.27
	7		3.45	1.59		5.04	95.24
	8		3.45	2.00		5.45	88.07
	Total Average		3.38	1.70		5.08	94.73
WS8 Assembly	1		15.30	1.58		16.88	28.44
	2		17.40	1.64		19.04	25.21
	3		15.40	1.68		17.08	28.10
	4		16.30	1.60		17.90	26.82
	5		17.20	1.65		18.85	25.46
	6		16.20	1.80		18.00	26.67
	7		15.70	1.62		17.32	27.71
	8		16.30	2.00		18.30	26.23
	Total Average		16.23	1.70		17.92	26.83
	Grand Total	7.08	101.54	21.77	50.27	180.65	2.66

Feb-12							
	Loop	**Setup Time (Min)**	**Operating Time (min)**	**Move Time**	**Delay Time**	**Total Time/Unit**	**Amount/ 8hours (Unit)**
WS1 sizing	1	0.45	5.30	3.34	5.30	14.39	33.36
	2	0.44	5.50	3.71	6.20	15.85	30.28
	3	0.46	5.70	3.45	5.30	14.91	32.19
	4	0.43	5.10	3.61	6.10	15.24	31.50
	5	0.42	5.50	3.77	7.60	17.29	27.76
	6	0.44	5.50	3.65	7.40	16.99	28.25
	7	0.46	5.30	3.63	5.20	14.59	32.90
	8	0.45	5.40	3.75	5.50	15.10	31.79
	Total Average	0.44	5.41	3.61	6.08	15.55	31.00
WS2 smoothening	1	1.13	5.40	2.50		9.03	53.16
	2	1.12	5.60	2.35		9.07	52.92
	3	1.12	5.20	2.30		8.62	55.68
	4	1.10	5.30	2.42		8.82	54.42
	5	1.13	5.20	2.61		8.94	53.69
	6	1.12	5.40	2.52		9.04	53.10
	7	1.13	5.50	2.48		9.11	52.69
	8	1.12	5.60	2.32		9.04	53.10
	Total Average	1.12	5.40	2.44		8.96	53.59
WS3 cutting	1	1.13	25.40	3.43		29.96	16.02
	2	1.14	24.20	3.62		28.96	16.57
	3	1.13	25.30	3.65		30.08	15.96
	4	1.12	25.10	3.52		29.74	16.14
	5	1.15	24.30	3.41		28.86	16.63
	6	1.12	25.70	3.66		30.48	15.75
	7	1.12	25.80	3.38		30.30	15.84
	8	1.10	25.90	3.56		30.56	15.71
	Total Average	1.13	25.21	3.53		29.87	16.08
WS4 Edging	1	1.16	10.30	2.40	10.05	23.91	20.08
	2	1.13	10.40	2.30	12.40	26.23	18.30
	3	1.12	10.20	2.40	12.30	26.02	18.45
	4	1.13	10.50	2.15	10.50	24.28	19.77
	5	1.16	10.40	2.40	9.40	23.36	20.55
	6	1.10	10.70	2.20	11.40	25.40	18.90
	7	1.14	10.20	2.60	10.50	24.44	19.64
	8	1.13	10.60	2.70	10.60	25.03	19.18
	Total Average	1.13	10.41	2.39	10.89	24.83	19.36

WS5 Drilling	1	1.10	5.11	3.48		9.69	49.54
	2	1.12	5.13	3.23		9.48	50.63
	3	1.13	5.12	3.20		9.45	50.79
	4	1.11	5.13	3.36		9.60	50.00
	5	1.12	5.11	3.40		9.63	49.84
	6	1.10	5.14	3.23		9.47	50.69
	7	1.13	5.13	3.32		9.58	50.10
	8	1.11	5.12	3.52		9.75	49.23
	Total Average	1.12	5.12	3.34		9.58	50.10
WS6 Spray & Bake	1	2.11	30.50	3.35	33.40	69.36	6.92
	2	2.13	30.60	3.22	32.50	68.45	7.01
	3	2.15	30.30	3.20	34.00	69.65	6.89
	4	2.16	30.20	3.45	33.10	68.91	6.97
	5	2.12	30.60	3.40	32.50	68.62	7.00
	6	2.14	30.50	3.10	33.60	69.34	6.92
	7	2.13	30.30	3.51	32.40	68.34	7.02
	8	2.16	30.20	3.35	34.50	70.21	6.84
	Total Average	2.14	30.40	3.32	33.25	69.11	6.95
WS7 Holder attachment	1		3.45	1.59		5.04	95.24
	2		3.10	1.60		4.70	102.13
	3		3.20	1.65		4.85	98.97
	4		3.35	1.59		4.94	97.17
	5		3.40	1.65		5.05	95.05
	6		3.60	2.00		5.60	85.71
	7		3.45	1.60		5.05	95.05
	8		3.45	2.00		5.45	88.07
	Total Average		3.38	1.71		5.09	94.67
WS8 Assembly	1		15.20	1.62		16.82	28.54
	2		17.40	1.60		19.00	25.26
	3		15.50	1.68		17.18	27.94
	4		16.40	1.65		18.05	26.59
	5		17.20	1.60		18.80	25.53
	6		16.10	1.80		17.90	26.82
	7		15.60	1.65		17.25	27.83
	8		16.40	2.00		18.40	26.09
	Total Average		16.23	1.70		17.93	26.82
	Grand Total	7.08	101.56	22.05	50.22	180.91	2.65

Mar-12							
	Loop	**Setup Time (Min)**	**Operating Time (min)**	**Move Time**	**Delay Time**	**Total Time/Unit**	**Amount/ 8hours (Unit)**
WS1 sizing	1	0.44	5.30	3.46	5.40	14.60	32.88
	2	0.43	5.50	3.60	6.30	15.83	30.32
	3	0.46	5.60	3.45	5.30	14.81	32.41
	4	0.43	5.10	3.61	6.10	15.24	31.50
	5	0.42	5.50	3.78	7.50	17.20	27.91
	6	0.45	5.40	3.65	6.40	15.90	30.19
	7	0.46	5.30	3.63	5.20	14.59	32.90
	8	0.45	5.40	3.75	5.60	15.20	31.58
	Total Average	0.44	5.39	3.62	5.98	15.42	31.21
WS2 smoothening	1	1.14	5.40	2.56		9.10	52.75
	2	1.12	5.50	2.30		8.92	53.81
	3	1.11	5.20	2.10		8.41	57.07
	4	1.10	5.40	2.42		8.92	53.81
	5	1.13	5.20	2.61		8.94	53.69
	6	1.11	5.30	2.63		9.04	53.10
	7	1.13	5.50	2.48		9.11	52.69
	8	1.13	5.60	2.32		9.05	53.04
	Total Average	1.12	5.39	2.43		8.94	53.75
WS3 cutting	1	1.12	25.30	3.54		29.96	16.02
	2	1.15	24.20	3.62		28.97	16.57
	3	1.13	25.40	3.67		30.20	15.89
	4	1.12	25.20	3.52		29.84	16.09
	5	1.14	24.30	3.41		28.85	16.64
	6	1.12	25.60	3.66		30.38	15.80
	7	1.13	25.70	3.40		30.23	15.88
	8	1.10	25.90	3.52		30.52	15.73
	Total Average	1.13	25.20	3.54		29.87	16.08
WS4 Edging	1	1.17	10.30	2.30	10.15	23.92	20.07
	2	1.14	10.50	2.20	12.40	26.24	18.29
	3	1.12	10.10	2.40	13.30	26.92	17.83
	4	1.12	10.50	2.20	10.40	24.22	19.82
	5	1.15	10.40	2.30	9.30	23.15	20.73
	6	1.11	10.60	2.25	10.40	24.36	19.70
	7	1.14	10.20	2.60	11.50	25.44	18.87
	8	1.13	10.70	2.70	10.50	25.03	19.18
	Total Average	1.14	10.41	2.37	10.99	24.91	19.31

WS5 Drilling	1	1.10	5.12	3.52		9.74	49.28
	2	1.11	5.13	3.23		9.47	50.69
	3	1.13	5.11	3.32		9.56	50.21
	4	1.10	5.13	3.36		9.59	50.05
	5	1.10	5.11	3.41		9.62	49.90
	6	1.10	5.15	3.23		9.48	50.63
	7	1.12	5.13	3.30		9.55	50.26
	8	1.11	5.11	3.52		9.74	49.28
	Total Average	1.11	5.12	3.36		9.59	50.04
WS6 Spray & Bake	1	2.11	30.50	3.41	32.40	68.42	7.02
	2	2.12	30.60	3.22	33.20	69.14	6.94
	3	2.14	30.40	3.20	34.00	69.74	6.88
	4	2.16	30.20	3.43	33.10	68.89	6.97
	5	2.13	30.40	3.40	32.60	68.53	7.00
	6	2.14	30.60	3.15	33.60	69.49	6.91
	7	2.12	30.30	3.51	34.40	70.33	6.82
	8	2.15	30.10	3.35	34.00	69.60	6.90
	Total Average	2.13	30.39	3.33	33.41	69.27	6.93
WS7 Holder attachment	1		3.45	1.60		5.05	95.05
	2		3.20	1.60		4.80	100.00
	3		3.20	1.65		4.85	98.97
	4		3.45	1.59		5.04	95.24
	5		3.40	1.65		5.05	95.05
	6		3.60	2.00		5.60	85.71
	7		3.45	1.65		5.10	94.12
	8		3.40	2.00		5.40	88.89
	Total Average		3.39	1.72		5.11	94.13
WS8 Assembly	1		15.30	1.68		16.98	28.27
	2		17.40	1.60		19.00	25.26
	3		15.50	1.80		17.30	27.75
	4		16.30	1.65		17.95	26.74
	5		17.20	1.60		18.80	25.53
	6		16.10	1.80		17.90	26.82
	7		15.60	1.65		17.25	27.83
	8		16.40	2.00		18.40	26.09
	Total Average		16.23	1.72		17.95	26.78
	Grand Total	7.07	101.52	22.09	50.38	181.06	2.65

Apr-12							
	Loop	Setup Time (Min)	Operating Time (min)	Move Time	Delay Time	Total Time/Unit	Amount/ 8hours (Unit)
WS1 sizing	1	0.45	5.20	3.36	5.20	14.21	33.78
	2	0.42	5.40	3.52	6.20	15.54	30.89
	3	0.46	5.60	3.45	5.30	14.81	32.41
	4	0.43	5.20	3.61	6.10	15.34	31.29
	5	0.41	5.40	3.70	6.30	15.81	30.36
	6	0.45	5.50	3.65	7.30	16.90	28.40
	7	0.46	5.40	3.59	6.50	15.95	30.09
	8	0.44	5.30	3.75	5.60	15.09	31.81
	Total Average	0.44	5.38	3.58	6.06	15.46	31.13
WS2 smoothening	1	1.14	5.40	2.47		9.01	53.27
	2	1.13	5.50	2.30		8.93	53.75
	3	1.10	5.10	2.20		8.40	57.14
	4	1.11	5.40	2.42		8.93	53.75
	5	1.13	5.20	2.59		8.92	53.81
	6	1.12	5.30	2.63		9.05	53.04
	7	1.12	5.40	2.48		9.00	53.33
	8	1.13	5.60	2.34		9.07	52.92
	Total Average	1.12	5.36	2.43		8.91	53.88
WS3 cutting	1	1.12	25.40	3.60		30.12	15.94
	2	1.14	24.20	3.58		28.92	16.60
	3	1.13	25.40	3.70		30.23	15.88
	4	1.12	25.10	3.52		29.74	16.14
	5	1.15	24.40	3.41		28.96	16.57
	6	1.12	25.50	3.65		30.27	15.86
	7	1.13	25.70	3.40		30.23	15.88
	8	1.11	25.80	3.53		30.44	15.77
	Total Average	1.13	25.19	3.55		29.86	16.08
WS4 Edging	1	1.16	10.30	2.40	10.15	24.01	19.99
	2	1.14	10.40	2.30	12.40	26.24	18.29
	3	1.13	10.20	2.40	13.30	27.03	17.76
	4	1.12	10.50	2.20	10.40	24.22	19.82
	5	1.15	10.30	2.40	9.30	23.15	20.73
	6	1.12	10.70	2.25	11.40	25.47	18.85
	7	1.14	10.20	2.70	10.60	24.64	19.48
	8	1.13	10.60	2.60	10.50	24.83	19.33
	Total Average	1.14	10.40	2.41	11.01	24.95	19.28

WS5 Drilling	1	1.10	5.11	3.52		9.73	49.33
	2	1.12	5.15	3.23		9.50	50.53
	3	1.13	5.11	3.32		9.56	50.21
	4	1.11	5.13	3.36		9.60	50.00
	5	1.10	5.11	3.41		9.62	49.90
	6	1.11	5.13	3.23		9.47	50.69
	7	1.13	5.13	3.30		9.56	50.21
	8	1.11	5.11	3.52		9.74	49.28
	Total Average	1.11	5.12	3.36		9.60	50.02
WS6 Spray & Bake	1	2.10	30.40	3.41	32.40	68.31	7.03
	2	2.11	30.60	3.22	33.10	69.03	6.95
	3	2.14	30.40	3.20	34.00	69.74	6.88
	4	2.16	30.20	3.43	32.10	67.89	7.07
	5	2.13	30.30	3.40	32.60	68.43	7.01
	6	2.15	30.60	3.15	33.30	69.20	6.94
	7	2.12	30.40	3.51	34.40	70.43	6.82
	8	2.14	30.10	3.35	33.40	68.99	6.96
	Total Average	2.13	30.38	3.33	33.16	69.00	6.96
WS7 Holder attachment	1		3.40	1.60		5.00	96.00
	2		3.20	1.60		4.80	100.00
	3		3.40	1.65		5.05	95.05
	4		3.45	1.59		5.04	95.24
	5		3.20	1.65		4.85	98.97
	6		3.60	2.00		5.60	85.71
	7		3.45	1.65		5.10	94.12
	8		3.45	2.00		5.45	88.07
	Total Average		3.39	1.72		5.11	94.15
WS8 Assembly	1		15.20	1.68		16.88	28.44
	2		17.50	1.60		19.10	25.13
	3		15.30	1.80		17.10	28.07
	4		16.30	1.65		17.95	26.74
	5		17.20	1.60		18.80	25.53
	6		16.20	1.80		18.00	26.67
	7		15.60	1.65		17.25	27.83
	8		16.40	2.00		18.40	26.09
	Total Average		16.21	1.72		17.94	26.81
	Grand Total	7.07	101.43	22.10	50.23	180.83	2.65

May-12							
	Loop	**Setup Time (Min)**	**Operating Time (min)**	**Move Time**	**Delay Time**	**Total Time/Unit**	**Amount/ 8hours (Unit)**
WS1 sizing	1	0.44	5.20	3.40	5.30	14.34	33.47
	2	0.43	5.40	3.52	6.20	15.55	30.87
	3	0.46	5.50	3.50	5.40	14.86	32.30
	4	0.43	5.20	3.61	7.10	16.34	29.38
	5	0.42	5.40	3.46	6.60	15.88	30.23
	6	0.45	5.60	3.65	7.40	17.10	28.07
	7	0.46	5.40	3.59	5.20	14.65	32.76
	8	0.45	5.20	3.75	5.60	15.00	32.00
	Total Average	0.44	5.36	3.56	6.10	15.47	31.13
WS2 smoothening	1	1.15	5.30	2.52		8.97	53.51
	2	1.12	5.50	2.30		8.92	53.81
	3	1.10	5.20	2.20		8.50	56.47
	4	1.11	5.50	2.40		9.01	53.27
	5	1.13	5.30	2.55		8.98	53.45
	6	1.11	5.40	2.63		9.14	52.52
	7	1.12	5.40	2.48		9.00	53.33
	8	1.14	5.50	2.34		8.98	53.45
	Total Average	1.12	5.39	2.43		8.94	53.73
WS3 cutting	1	1.11	25.40	3.49		30.00	16.00
	2	1.14	24.30	3.42		28.86	16.63
	3	1.13	25.40	3.55		30.08	15.96
	4	1.13	25.20	3.52		29.85	16.08
	5	1.15	24.30	3.41		28.86	16.63
	6	1.13	25.50	3.65		30.28	15.85
	7	1.12	25.70	3.45		30.27	15.86
	8	1.11	25.70	3.53		30.34	15.82
	Total Average	1.13	25.19	3.50		29.82	16.10
WS4 Edging	1	1.15	10.20	2.30	10.40	24.05	19.96
	2	1.15	10.50	2.30	12.40	26.35	18.22
	3	1.12	10.20	2.45	12.15	25.92	18.52
	4	1.13	10.40	2.20	10.40	24.13	19.89
	5	1.15	10.30	2.30	9.30	23.05	20.82
	6	1.12	10.70	2.50	11.40	25.72	18.66
	7	1.15	10.30	2.70	9.60	23.75	20.21
	8	1.14	10.60	2.60	11.40	25.74	18.65
	Total Average	1.14	10.40	2.42	10.88	24.84	19.37

WS5 Drilling	1	1.11	5.12	3.24		9.47	50.69
	2	1.12	5.15	3.33		9.60	50.00
	3	1.14	5.11	3.32		9.57	50.16
	4	1.11	5.14	3.36		9.61	49.95
	5	1.11	5.11	3.41		9.63	49.84
	6	1.12	5.12	3.23		9.47	50.69
	7	1.13	5.13	3.30		9.56	50.21
	8	1.12	5.11	3.42		9.65	49.74
	Total Average	1.12	5.12	3.33		9.57	50.16
WS6 Spray & Bake	1	2.11	30.20	3.55	33.10	68.96	6.96
	2	2.11	30.60	3.25	32.40	68.36	7.02
	3	2.15	30.40	3.20	34.00	69.75	6.88
	4	2.16	30.10	3.32	32.10	67.68	7.09
	5	2.14	30.30	3.40	32.60	68.44	7.01
	6	2.15	30.60	3.23	33.30	69.28	6.93
	7	2.12	30.40	3.36	34.40	70.28	6.83
	8	2.13	30.10	3.35	33.30	68.88	6.97
	Total Average	2.13	30.34	3.33	33.15	68.95	6.96
WS7 Holder attachment	1		3.40	1.62		5.02	95.62
	2		3.20	1.60		4.80	100.00
	3		3.35	1.65		5.00	96.00
	4		3.45	1.60		5.05	95.05
	5		3.20	1.65		4.85	98.97
	6		3.60	1.59		5.19	92.49
	7		3.40	1.65		5.05	95.05
	8		3.45	2.00		5.45	88.07
	Total Average		3.38	1.67		5.05	95.16
WS8 Assembly	1		15.30	1.68		16.98	28.27
	2		17.50	1.58		19.08	25.16
	3		15.30	1.80		17.10	28.07
	4		16.20	1.64		17.84	26.91
	5		17.20	1.60		18.80	25.53
	6		16.30	2.00		18.30	26.23
	7		15.70	1.65		17.35	27.67
	8		16.40	2.00		18.40	26.09
	Total Average		16.24	1.74		17.98	26.74
	Grand Total	7.09	101.42	21.98	50.13	180.62	2.66

Jun-12							
	Loop	**Setup Time (Min)**	**Operating Time (min)**	**Move Time**	**Delay Time**	**Total Time/Unit**	**Amount/ 8hours (Unit)**
WS1 sizing	1	0.43	5.30	3.64	5.60	14.97	32.06
	2	0.44	5.30	3.33	5.50	14.57	32.94
	3	0.45	5.40	3.50	6.00	15.35	31.27
	4	0.43	5.20	3.61	5.70	14.94	32.13
	5	0.42	5.30	3.75	6.30	15.77	30.44
	6	0.44	5.60	3.65	7.40	17.09	28.09
	7	0.46	5.50	3.42	6.40	15.78	30.42
	8	0.46	5.20	3.75	5.60	15.01	31.98
	Total Average	0.44	5.35	3.58	6.06	15.44	31.17
WS2 smoothening	1	1.14	5.20	2.38		8.72	55.05
	2	1.12	5.50	2.40		9.02	53.22
	3	1.10	5.30	2.35		8.75	54.86
	4	1.12	5.40	2.30		8.82	54.42
	5	1.13	5.30	2.55		8.98	53.45
	6	1.11	5.40	2.63		9.14	52.52
	7	1.11	5.30	2.40		8.81	54.48
	8	1.14	5.40	2.34		8.88	54.05
	Total Average	1.12	5.35	2.42		8.89	54.01
WS3 cutting	1	1.12	25.30	3.54		29.96	16.02
	2	1.14	24.40	3.42		28.96	16.57
	3	1.14	25.40	3.49		30.03	15.98
	4	1.12	25.20	3.52		29.84	16.09
	5	1.15	24.40	3.53		29.08	16.51
	6	1.13	25.50	3.65		30.28	15.85
	7	1.12	25.60	3.40		30.12	15.94
	8	1.10	25.80	3.53		30.43	15.77
	Total Average	1.13	25.20	3.51		29.84	16.09
WS4 Edging	1	1.14	10.30	2.40	10.20	24.04	19.97
	2	1.15	10.60	2.60	11.05	25.40	18.90
	3	1.11	10.10	2.45	11.15	24.81	19.35
	4	1.13	10.30	2.30	10.40	24.13	19.89
	5	1.15	10.40	2.30	9.30	23.15	20.73
	6	1.12	10.70	2.50	10.40	24.72	19.42
	7	1.14	10.30	2.80	11.60	25.84	18.58
	8	1.15	10.70	2.60	10.15	24.60	19.51
	Total Average	1.14	10.43	2.49	10.53	24.59	19.54

WS5 Drilling	1	1.10	5.11	3.24		9.45	50.79
	2	1.13	5.14	3.33		9.60	50.00
	3	1.13	5.12	3.32		9.57	50.16
	4	1.11	5.14	3.25		9.50	50.53
	5	1.12	5.11	3.35		9.58	50.10
	6	1.11	5.13	3.23		9.47	50.69
	7	1.12	5.13	3.28		9.53	50.37
	8	1.11	5.11	3.40		9.62	49.90
	Total Average	1.12	5.12	3.30		9.54	50.32
WS6 Spray & Bake	1	2.12	30.20	3.56	32.60	68.48	7.01
	2	2.11	30.50	3.30	32.40	68.31	7.03
	3	2.14	30.50	3.20	33.10	68.94	6.96
	4	2.15	30.10	3.32	32.10	67.67	7.09
	5	2.14	30.20	3.45	33.00	68.79	6.98
	6	2.14	30.60	3.23	34.10	70.07	6.85
	7	2.11	30.50	3.40	33.60	69.61	6.90
	8	2.13	30.20	3.35	32.40	68.08	7.05
	Total Average	2.13	30.35	3.35	32.91	68.74	6.98
WS7 Holder attachment	1		3.30	1.65		4.95	96.97
	2		3.20	1.60		4.80	100.00
	3		3.35	1.60		4.95	96.97
	4		3.40	1.59		4.99	96.19
	5		3.20	1.65		4.85	98.97
	6		3.60	2.00		5.60	85.71
	7		3.30	1.60		4.90	97.96
	8		3.45	2.00		5.45	88.07
	Total Average		3.35	1.71		5.06	95.11
WS8 Assembly	1		15.40	1.62		17.02	28.20
	2		17.50	1.58		19.08	25.16
	3		15.30	1.60		16.90	28.40
	4		16.40	1.64		18.04	26.61
	5		17.20	1.80		19.00	25.26
	6		16.30	2.00		18.30	26.23
	7		15.60	1.65		17.25	27.83
	8		16.40	1.59		17.99	26.68
	Total Average		16.26	1.69		17.95	26.80
	Grand Total	7.07	101.41	22.05	49.51	180.04	2.67

Data analysis of throughput time after improvement (Jul-Dec 2012)							
Jul-12							
	Loop	**Setup Time (Min)**	**Operating Time (min)**	**Move Time**	**Delay Time**	**Total Time/Unit**	**Amount/ 8hours (Unit)**
WS1 sizing	1	0.32	5.30	1.04		6.66	72.07
	2	0.30	5.70	1.05		7.05	68.09
	3	0.33	5.60	1.10		7.03	68.28
	4	0.32	5.00	1.08		6.40	75.00
	5	0.34	5.40	1.06		6.80	70.59
	6	0.31	5.60	1.06		6.97	68.87
	7	0.30	5.30	1.05		6.65	72.18
	8	0.32	5.40	1.07		6.79	70.69
	Total Average	0.32	5.41	1.06		6.79	70.72
WS2 smoothening	1	0.94	5.40	1.02		7.36	65.22
	2	0.95	5.60	1.00		7.55	63.58
	3	0.94	5.30	1.01		7.25	66.21
	4	0.95	5.20	1.01		7.16	67.04
	5	0.94	5.10	1.02		7.06	67.99
	6	0.96	5.30	1.02		7.28	65.93
	7	0.94	5.60	1.00		7.54	63.66
	8	0.96	5.40	1.01		7.37	65.13
	Total Average	0.95	5.36	1.01		7.32	65.59
WS3 cutting	1	0.94	25.20	1.02		27.16	17.67
	2	0.96	24.20	1.02		26.18	18.33
	3	0.94	25.40	1.00		27.34	17.56
	4	0.95	25.20	1.01		27.16	17.67
	5	0.96	24.30	1.01		26.27	18.27
	6	0.95	25.60	1.00		27.55	17.42
	7	0.95	25.60	1.02		27.57	17.41
	8	0.94	25.80	1.00		27.74	17.30
	Total Average	0.95	25.16	1.01		27.12	17.71
WS4 Edging	1	0.51	10.40	1.00		11.91	40.30
	2	0.50	10.40	1.02		11.92	40.27
	3	0.50	10.30	1.02		11.82	40.61
	4	0.49	10.50	1.01		12.00	40.00
	5	0.49	10.30	1.00		11.79	40.71
	6	0.51	10.60	1.01		12.12	39.60
	7	0.50	10.20	1.01		11.71	40.99
	8	0.51	10.40	1.03		11.94	40.20

	Total Average	0.50	10.39	1.01		11.90	40.34
WS5 Drilling	1	0.49	5.12	1.01		6.62	72.51
	2	0.51	5.12	1.01		6.64	72.29
	3	0.51	5.11	1.00		6.62	72.51
	4	0.49	5.13	1.00		6.62	72.51
	5	0.50	5.12	1.03		6.65	72.18
	6	0.51	5.11	1.02		6.64	72.29
	7	0.50	5.14	1.02		6.66	72.07
	8	0.49	5.13	1.01		6.63	72.40
	Total Average	0.50	5.12	1.01		6.64	72.34
WS6 Spray & Bake	1	2.11	30.30	1.03		33.44	14.35
	2	2.13	30.50	1.03		33.66	14.26
	3	2.14	30.20	1.01		33.35	14.39
	4	2.15	30.10	1.00		33.25	14.44
	5	2.13	30.50	1.02		33.65	14.26
	6	2.14	30.60	1.01		33.75	14.22
	7	2.14	30.40	1.02		33.56	14.30
	8	2.16	30.30	1.02		33.48	14.34
	Total Average	2.14	30.36	1.02		33.52	14.32
WS7 Holder attachment	1		3.35	1.00		4.35	110.34
	2		3.30	1.02		4.32	111.11
	3		3.20	1.01		4.21	114.01
	4		3.35	1.01		4.36	110.09
	5		3.30	1.03		4.33	110.85
	6		3.50	1.02		4.52	106.19
	7		3.40	1.02		4.42	108.60
	8		3.45	1.01		4.46	107.62
	Total Average		3.36	1.02		4.37	109.85
WS8 Assembly	1		15.20	1.02		16.22	29.59
	2		17.30	1.00		18.30	26.23
	3		15.60	1.01		16.61	28.90
	4		16.20	1.01		17.21	27.89
	5		17.20	1.03		18.23	26.33
	6		16.20	1.02		17.22	27.87
	7		15.60	1.02		16.62	28.88
	8		16.30	1.03		17.33	27.70
	Total Average		16.20	1.02		17.22	27.92
	Grand Total	5.35	101.37	8.16		114.88	4.18

Aug-12							
	Loop	**Setup Time (Min)**	**Operating Time (min)**	**Move Time**	**Delay Time**	**Total Time/Unit**	**Amount/ 8hours (Unit)**
WS1 sizing	1	0.33	5.20	1.03		6.56	73.17
	2	0.31	5.80	1.06		7.17	66.95
	3	0.32	5.50	1.05		6.87	69.87
	4	0.31	5.00	1.08		6.39	75.12
	5	0.33	5.40	1.06		6.79	70.69
	6	0.32	5.50	1.06		6.88	69.77
	7	0.30	5.40	1.05		6.75	71.11
	8	0.32	5.40	1.10		6.82	70.38
	Total Average	0.32	5.40	1.06		6.78	70.88
WS2 smoothening	1	0.94	5.30	1.03		7.27	66.02
	2	0.95	5.60	1.01		7.56	63.49
	3	0.93	5.40	1.00		7.33	65.48
	4	0.95	5.20	1.01		7.16	67.04
	5	0.94	5.20	1.02		7.16	67.04
	6	0.96	5.30	1.01		7.27	66.02
	7	0.95	5.50	1.00		7.45	64.43
	8	0.96	5.30	1.02		7.28	65.93
	Total Average	0.95	5.35	1.01		7.31	65.68
WS3 cutting	1	0.93	25.30	1.01		27.24	17.62
	2	0.95	24.20	1.02		26.17	18.34
	3	0.94	25.40	1.00		27.34	17.56
	4	0.95	25.10	1.00		27.05	17.74
	5	0.95	24.30	1.01		26.26	18.28
	6	0.94	25.50	1.01		27.45	17.49
	7	0.95	25.60	1.02		27.57	17.41
	8	0.93	25.80	1.01		27.74	17.30
	Total Average	0.94	25.15	1.01		27.10	17.72
WS4 Edging	1	0.50	10.40	1.01		11.91	40.30
	2	0.51	10.30	1.02		11.83	40.57
	3	0.50	10.20	1.02		11.72	40.96
	4	0.50	10.50	1.01		12.01	39.97
	5	0.49	10.30	1.00		11.79	40.71
	6	0.52	10.70	1.02		12.24	39.22
	7	0.49	10.30	1.01		11.80	40.68
	8	0.51	10.40	1.02		11.93	40.23
	Total Average	0.50	10.39	1.01		11.90	40.33

WS5 Drilling	1	0.50	5.11	1.02		6.63	72.40
	2	0.50	5.13	1.01		6.64	72.29
	3	0.52	5.11	1.00		6.63	72.40
	4	0.49	5.14	1.01		6.64	72.29
	5	0.50	5.12	1.03		6.65	72.18
	6	0.52	5.10	1.02		6.64	72.29
	7	0.50	5.13	1.01		6.64	72.29
	8	0.50	5.14	1.02		6.66	72.07
	Total Average	0.50	5.12	1.02		6.64	72.28
WS6 Spray & Bake	1	2.12	30.40	1.02		33.54	14.31
	2	2.12	30.50	1.03		33.65	14.26
	3	2.14	30.30	1.01		33.45	14.35
	4	2.15	30.10	1.01		33.26	14.43
	5	2.13	30.60	1.02		33.75	14.22
	6	2.13	30.50	1.02		33.65	14.26
	7	2.15	30.40	1.02		33.57	14.30
	8	2.16	30.30	1.01		33.47	14.34
	Total Average	2.14	30.39	1.02		33.54	14.31
WS7 Holder attachment	1		3.30	1.01		4.31	111.37
	2		3.35	1.02		4.37	109.84
	3		3.20	1.01		4.21	114.01
	4		3.35	1.02		4.37	109.84
	5		3.30	1.03		4.33	110.85
	6		3.45	1.02		4.47	107.38
	7		3.50	1.01		4.51	106.43
	8		3.45	1.01		4.46	107.62
	Total Average		3.36	1.02		4.38	109.67
WS8 Assembly	1		15.30	1.03		16.33	29.39
	2		17.20	1.01		18.21	26.36
	3		15.60	1.01		16.61	28.90
	4		16.30	1.02		17.32	27.71
	5		17.20	1.02		18.22	26.34
	6		16.20	1.01		17.21	27.89
	7		15.60	1.02		16.62	28.88
	8		16.30	1.03		17.33	27.70
	Total Average		16.21	1.02		17.23	27.90
	Grand Total	5.35	101.37	8.17	0.00	114.89	4.18

Sep-12							
	Loop	**Setup Time (Min)**	**Operating Time (min)**	**Move Time**	**Delay Time**	**Total Time/Unit**	**Amount/ 8hours (Unit)**
WS1 sizing	1	0.32	5.30	1.02		6.64	72.29
	2	0.30	5.70	1.05		7.05	68.09
	3	0.32	5.60	1.04		6.96	68.97
	4	0.31	5.10	1.08		6.49	73.96
	5	0.32	5.40	1.06		6.78	70.80
	6	0.32	5.50	1.07		6.89	69.67
	7	0.30	5.30	1.05		6.65	72.18
	8	0.33	5.40	1.09		6.82	70.38
	Total Average	0.32	5.41	1.06		6.79	70.79
WS2 smoothening	1	0.93	5.20	1.04		7.17	66.95
	2	0.96	5.60	1.01		7.57	63.41
	3	0.92	5.30	1.01		7.23	66.39
	4	0.95	5.20	1.02		7.17	66.95
	5	0.94	5.10	1.02		7.06	67.99
	6	0.95	5.30	1.01		7.26	66.12
	7	0.95	5.50	1.01		7.46	64.34
	8	0.96	5.20	1.02		7.18	66.85
	Total Average	0.95	5.30	1.02		7.26	66.12
WS3 cutting	1	0.93	25.40	1.02		27.35	17.55
	2	0.95	24.10	1.01		26.06	18.42
	3	0.95	25.30	1.00		27.25	17.61
	4	0.95	25.20	1.01		27.16	17.67
	5	0.94	24.30	1.01		26.25	18.29
	6	0.94	25.50	1.02		27.46	17.48
	7	0.95	25.50	1.02		27.47	17.47
	8	0.94	25.70	1.01		27.65	17.36
	Total Average	0.94	25.13	1.01		27.08	17.73
WS4 Edging	1	0.49	10.50	1.00		11.99	40.03
	2	0.50	10.30	1.02		11.82	40.61
	3	0.51	10.30	1.01		11.82	40.61
	4	0.50	10.40	1.02		11.92	40.27
	5	0.49	10.30	1.00		11.79	40.71
	6	0.51	10.60	1.02		12.13	39.57
	7	0.49	10.30	1.02		11.81	40.64
	8	0.52	10.50	1.01		12.03	39.90
	Total Average	0.50	10.40	1.01		11.91	40.29

WS5 Drilling	1	0.51	5.12	1.01		6.64	72.29
	2	0.50	5.13	1.02		6.65	72.18
	3	0.52	5.10	1.01		6.63	72.40
	4	0.49	5.13	1.00		6.62	72.51
	5	0.51	5.12	1.02		6.65	72.18
	6	0.51	5.11	1.02		6.64	72.29
	7	0.50	5.13	1.02		6.65	72.18
	8	0.51	5.13	1.03		6.67	71.96
	Total Average	0.51	5.12	1.02		6.64	72.25
WS6 Spray & Bake	1	2.11	30.30	1.03		33.44	14.35
	2	2.12	30.60	1.02		33.74	14.23
	3	2.14	30.30	1.01		33.45	14.35
	4	2.16	30.10	1.00		33.26	14.43
	5	2.13	30.50	1.02		33.65	14.26
	6	2.12	30.50	1.02		33.64	14.27
	7	2.15	30.30	1.01		33.46	14.35
	8	2.15	30.30	1.02		33.47	14.34
	Total Average	2.14	30.36	1.02		33.51	14.32
WS7 Holder attachment	1		3.20	1.00		4.20	114.29
	2		3.35	1.02		4.37	109.84
	3		3.10	1.02		4.12	116.50
	4		3.35	1.02		4.37	109.84
	5		3.40	1.03		4.43	108.35
	6		3.45	1.02		4.47	107.38
	7		3.50	1.02		4.52	106.19
	8		3.50	1.01		4.51	106.43
	Total Average		3.36	1.02		4.37	109.85
WS8 Assembly	1		15.40	1.02		16.42	29.23
	2		17.10	1.01		18.11	26.50
	3		15.50	1.02		16.52	29.06
	4		16.40	1.02		17.42	27.55
	5		17.20	1.01		18.21	26.36
	6		16.30	1.01		17.31	27.73
	7		15.60	1.02		16.62	28.88
	8		16.30	1.02		17.32	27.71
	Total Average		16.23	1.02		17.24	27.88
	Grand Total	5.35	101.30	8.17		114.82	4.18

Oct-12							
	Loop	Setup Time (Min)	Operating Time (min)	Move Time	Delay Time	Total Time/Unit	Amount/ 8hours (Unit)
WS1 sizing	1	0.31	5.20	1.03		6.54	73.39
	2	0.30	5.70	1.04		7.04	68.18
	3	0.32	5.50	1.04		6.86	69.97
	4	0.32	5.20	1.07		6.59	72.84
	5	0.32	5.50	1.06		6.88	69.77
	6	0.31	5.40	1.06		6.77	70.90
	7	0.30	5.20	1.04		6.54	73.39
	8	0.32	5.40	1.09		6.81	70.48
	Total Average	0.31	5.39	1.05		6.75	71.12
WS2 smoothening	1	0.92	5.10	1.03		7.05	68.09
	2	0.95	5.50	1.01		7.46	64.34
	3	0.93	5.30	1.02		7.25	66.21
	4	0.95	5.20	1.02		7.17	66.95
	5	0.94	5.20	1.01		7.15	67.13
	6	0.94	5.30	1.01		7.25	66.21
	7	0.95	5.60	1.00		7.55	63.58
	8	0.95	5.10	1.02		7.07	67.89
	Total Average	0.94	5.29	1.02		7.24	66.30
WS3 cutting	1	0.94	25.50	1.01		27.45	17.49
	2	0.95	24.20	1.01		26.16	18.35
	3	0.95	25.30	1.01		27.26	17.61
	4	0.94	25.10	1.01		27.05	17.74
	5	0.93	24.30	1.02		26.25	18.29
	6	0.94	25.40	1.02		27.36	17.54
	7	0.95	25.50	1.03		27.48	17.47
	8	0.93	25.60	1.01		27.54	17.43
	Total Average	0.94	25.11	1.02		27.07	17.74
WS4 Edging	1	0.50	10.40	1.01		11.91	40.30
	2	0.51	10.30	1.02		11.83	40.57
	3	0.50	10.20	1.02		11.72	40.96
	4	0.49	10.40	1.01		11.90	40.34
	5	0.49	10.30	1.00		11.79	40.71
	6	0.50	10.50	1.02		12.02	39.93
	7	0.49	10.30	1.01		11.80	40.68
	8	0.51	10.60	1.03		12.14	39.54
	Total Average	0.50	10.38	1.02		11.89	40.38

WS5 Drilling	1	0.52	5.11	1.02		6.65	72.18
	2	0.50	5.12	1.02		6.64	72.29
	3	0.52	5.10	1.01		6.63	72.40
	4	0.49	5.13	1.01		6.63	72.40
	5	0.50	5.13	1.02		6.65	72.18
	6	0.51	5.11	1.01		6.63	72.40
	7	0.50	5.12	1.02		6.64	72.29
	8	0.50	5.13	1.02		6.65	72.18
	Total Average	0.51	5.12	1.02		6.64	72.29
WS6 Spray & Bake	1	2.12	30.40	1.02		33.54	14.31
	2	2.12	30.50	1.02		33.64	14.27
	3	2.13	30.30	1.02		33.45	14.35
	4	2.15	30.20	1.01		33.36	14.39
	5	2.13	30.50	1.02		33.65	14.26
	6	2.12	30.40	1.01		33.53	14.32
	7	2.16	30.30	1.01		33.47	14.34
	8	2.15	30.20	1.02		33.37	14.38
	Total Average	2.14	30.35	1.02		33.50	14.33
WS7 Holder attachment	1		3.30	1.01		4.31	111.37
	2		3.35	1.02		4.37	109.84
	3		3.10	1.01		4.11	116.79
	4		3.40	1.02		4.42	108.60
	5		3.30	1.02		4.32	111.11
	6		3.45	1.02		4.47	107.38
	7		3.50	1.03		4.53	105.96
	8		3.45	1.01		4.46	107.62
	Total Average		3.36	1.02		4.37	109.83
WS8 Assembly	1		15.30	1.03		16.33	29.39
	2		17.20	1.00		18.20	26.37
	3		15.50	1.02		16.52	29.06
	4		16.30	1.01		17.31	27.73
	5		17.20	1.01		18.21	26.36
	6		16.30	1.02		17.32	27.71
	7		15.50	1.02		16.52	29.06
	8		16.20	1.01		17.21	27.89
	Total Average		16.19	1.02		17.20	27.95
	Grand Total	5.33	101.18	8.16		114.67	4.19

Nov-12							
	Loop	**Setup Time (Min)**	**Operating Time (min)**	**Move Time**	**Delay Time**	**Total Time/Unit**	**Amount/ 8hours (Unit)**
WS1 sizing	1	0.30	5.30	1.04		6.64	72.29
	2	0.31	5.60	1.03		6.94	69.16
	3	0.31	5.50	1.04		6.85	70.07
	4	0.32	5.20	1.06		6.58	72.95
	5	0.32	5.40	1.06		6.78	70.80
	6	0.32	5.40	1.06		6.78	70.80
	7	0.30	5.10	1.05		6.45	74.42
	8	0.32	5.30	1.08		6.70	71.64
	Total Average	0.31	5.35	1.05		6.72	71.52
WS2 smoothening	1	0.93	5.20	1.02		7.15	67.13
	2	0.95	5.40	1.00		7.35	65.31
	3	0.93	5.30	1.01		7.24	66.30
	4	0.95	5.20	1.02		7.17	66.95
	5	0.93	5.10	1.02		7.05	68.09
	6	0.94	5.30	1.01		7.25	66.21
	7	0.93	5.60	1.01		7.54	63.66
	8	0.95	5.20	1.02		7.17	66.95
	Total Average	0.94	5.29	1.01		7.24	66.32
WS3 cutting	1	0.95	25.50	1.02		27.47	17.47
	2	0.95	24.30	1.01		26.26	18.28
	3	0.94	25.20	1.02		27.16	17.67
	4	0.93	25.10	1.01		27.04	17.75
	5	0.93	24.30	1.02		26.25	18.29
	6	0.95	25.30	1.01		27.26	17.61
	7	0.94	25.40	1.02		27.36	17.54
	8	0.93	25.60	1.01		27.54	17.43
	Total Average	0.94	25.09	1.02		27.04	17.76
WS4 Edging	1	0.51	10.50	1.02		12.03	39.90
	2	0.52	10.30	1.02		11.84	40.54
	3	0.50	10.30	1.02		11.82	40.61
	4	0.49	10.40	1.01		11.90	40.34
	5	0.49	10.30	1.01		11.80	40.68
	6	0.50	10.40	1.02		11.92	40.27
	7	0.49	10.30	1.00		11.79	40.71
	8	0.50	10.50	1.02		12.02	39.93

	Total Average	0.50	10.38	1.02		11.89	40.37
WS5 Drilling	1	0.51	5.12	1.01		6.64	72.29
	2	0.50	5.13	1.02		6.65	72.18
	3	0.51	5.10	1.02		6.63	72.40
	4	0.49	5.12	1.01		6.62	72.51
	5	0.49	5.13	1.02		6.64	72.29
	6	0.51	5.10	1.02		6.63	72.40
	7	0.51	5.12	1.02		6.65	72.18
	8	0.49	5.12	1.01		6.62	72.51
	Total Average	0.50	5.12	1.02		6.64	72.34
WS6 Spray & Bake	1	2.13	30.30	1.01		33.44	14.35
	2	2.12	30.40	1.02		33.54	14.31
	3	2.13	30.40	1.01		33.54	14.31
	4	2.14	30.30	1.00		33.44	14.35
	5	2.13	30.50	1.03		33.66	14.26
	6	2.12	30.50	1.01		33.63	14.27
	7	2.15	30.20	1.02		33.37	14.38
	8	2.15	30.20	1.02		33.37	14.38
	Total Average	2.13	30.35	1.02		33.50	14.33
WS7 Holder attachment	1		3.20	1.02		4.22	113.74
	2		3.35	1.02		4.37	109.84
	3		3.15	1.00		4.15	115.66
	4		3.40	1.02		4.42	108.60
	5		3.35	1.01		4.36	110.09
	6		3.45	1.02		4.47	107.38
	7		3.50	1.02		4.52	106.19
	8		3.40	1.02		4.42	108.60
	Total Average		3.35	1.02		4.37	110.01
WS8 Assembly	1		15.40	1.02		16.42	29.23
	2		17.30	1.01		18.31	26.22
	3		15.60	1.03		16.63	28.86
	4		16.20	1.01		17.21	27.89
	5		17.30	1.01		18.31	26.22
	6		16.30	1.02		17.32	27.71
	7		15.60	1.02		16.62	28.88
	8		16.20	1.00		17.20	27.91
	Total Average		16.24	1.02		17.25	27.86
	Grand Total	5.33	101.16	8.16		114.64	4.19

Dec-12							
	Loop	Setup Time (Min)	Operating Time (min)	Move Time	Delay Time	Total Time/Unit	Amount/ 8hours (Unit)
WS1 sizing	1	0.31	5.40	1.04		6.75	71.11
	2	0.30	5.50	1.02		6.82	70.38
	3	0.31	5.50	1.04		6.85	70.07
	4	0.31	5.20	1.06		6.57	73.06
	5	0.32	5.30	1.07		6.69	71.75
	6	0.32	5.40	1.06		6.78	70.80
	7	0.31	5.10	1.05		6.46	74.30
	8	0.32	5.20	1.07		6.59	72.84
	Total Average	0.31	5.33	1.05		6.69	71.79
WS2 smoothening	1	0.94	5.30	1.02		7.26	66.12
	2	0.95	5.40	1.01		7.36	65.22
	3	0.92	5.20	1.01		7.13	67.32
	4	0.95	5.20	1.02		7.17	66.95
	5	0.92	5.20	1.02		7.14	67.23
	6	0.94	5.30	1.01		7.25	66.21
	7	0.94	5.50	1.02		7.46	64.34
	8	0.95	5.30	1.02		7.27	66.02
	Total Average	0.94	5.30	1.02		7.26	66.18
WS3 cutting	1	0.94	25.40	1.03		27.37	17.54
	2	0.95	24.20	1.01		26.16	18.35
	3	0.95	25.30	1.02		27.27	17.60
	4	0.93	25.10	1.01		27.04	17.75
	5	0.94	24.30	1.02		26.26	18.28
	6	0.95	25.20	1.00		27.15	17.68
	7	0.93	25.40	1.02		27.35	17.55
	8	0.94	25.50	1.02		27.46	17.48
	Total Average	0.94	25.05	1.02		27.01	17.78
WS4 Edging	1	0.50	10.60	1.02		12.12	39.60
	2	0.51	10.40	1.03		11.94	40.20
	3	0.50	10.30	1.02		11.82	40.61
	4	0.49	10.50	1.00		11.99	40.03
	5	0.49	10.30	1.01		11.80	40.68
	6	0.50	10.40	1.02		11.92	40.27
	7	0.49	10.20	1.01		11.70	41.03
	8	0.49	10.40	1.01		11.90	40.34
	Total Average	0.50	10.39	1.02		11.90	40.34

WS5 Drilling	1	0.50	5.13	1.02		6.65	72.18
	2	0.50	5.13	1.03		6.66	72.07
	3	0.51	5.11	1.02		6.64	72.29
	4	0.50	5.12	1.00		6.62	72.51
	5	0.49	5.12	1.02		6.63	72.40
	6	0.50	5.10	1.01		6.61	72.62
	7	0.51	5.12	1.02		6.65	72.18
	8	0.49	5.13	1.02		6.64	72.29
	Total Average	0.50	5.12	1.02		6.64	72.32
WS6 Spray & Bake	1	2.12	30.20	1.02		33.34	14.40
	2	2.13	30.30	1.02		33.45	14.35
	3	2.13	30.40	1.00		33.53	14.32
	4	2.15	30.30	1.00		33.45	14.35
	5	2.13	30.40	1.03		33.56	14.30
	6	2.12	30.50	1.01		33.63	14.27
	7	2.15	30.20	1.03		33.38	14.38
	8	2.14	30.30	1.01		33.45	14.35
	Total Average	2.13	30.33	1.02		33.47	14.34
WS7 Holder attachment	1		3.30	1.01		4.31	111.37
	2		3.30	1.02		4.32	111.11
	3		3.20	1.01		4.21	114.01
	4		3.45	1.02		4.47	107.38
	5		3.35	1.00		4.35	110.34
	6		3.45	1.03		4.48	107.14
	7		3.50	1.02		4.52	106.19
	8		3.45	1.01		4.46	107.62
	Total Average		3.38	1.02		4.39	109.40
WS8 Assembly	1		15.50	1.02		16.52	29.06
	2		17.30	1.01		18.31	26.22
	3		15.50	1.02		16.52	29.06
	4		16.20	1.01		17.21	27.89
	5		17.30	1.02		18.32	26.20
	6		16.40	1.02		17.42	27.55
	7		15.60	1.01		16.61	28.90
	8		16.30	1.01		17.31	27.73
	Total Average		16.26	1.02		17.28	27.83
	Grand Total	5.32	101.15	8.16	0.00	114.63	4.19

APPENDIX B

(Penalty Costs for Late Product Delivery)

Penalty Costs for Late Product Delivery										
Production Systems	**Months**	**Total Amount of Late Days (Days)**	**Day**	**Penalty Costs/day/unit (Baht)**	**Amount of Late days (Days)**	**Penalty Costs/unit (Baht)**	**Penalty Costs/unit (Baht)**	**Amount of Late Delivered Products**	**Total Penalty Costs (Baht)**	**Total Penalty Costs (Baht)**
Current Production Systems	Jan-12	20	1st-5th	10	5	50	275	30	8,250	**40,116.00**
			6th-10th	12	5	60				
			11th-15th	15	5	75				
			16th-20th	18	5	90				
			21th-25th	20	0	0				
	Feb-12	21	1st-5th	10	5	50	295	41	12,095	
			6th-10th	12	5	60				
			11th-15th	15	5	75				
			16th-20th	18	5	90				
			21th-25th	20	1	20				
	Mar-12	18	1st-5th	10	5	50	239	30	7,170	
			6th-10th	12	5	60				
			11th-15th	15	5	75				
			16th-20th	18	3	54				
			21th-25th	20	0	0				
	Apr-12	15	1st-5th	10	5	50	185	28	5,180	
			6th-10th	12	5	60				
			11th-15th	15	5	75				
			16th-20th	18	0	0				
			21th-25th	20	0	0				
	May-12	15	1st-5th	10	5	50	185	21	3,885	
			6th-10th	12	5	60				
			11th-15th	15	5	75				
			16th-20th	18	0	0				
			21th-25th	20	0	0				
	Jun-12	17	1st-5th	10	5	50	221	16	3,536	
			6th-10th	12	5	60				
			11th-15th	15	5	75				
			16th-20th	18	2	36				
			21th-25th	20	0	0				
CM Production Systems	Jul-12	9	1st-5th	10	5	50	98	15	1,470	**5,982**
			6th-10th	12	4	48				
			11th-15th	15	0	0				
			16th-20th	18	0	0				
			21th-25th	20	0	0				
	Aug-12	10	1st-5th	10	5	50	110	16	1,760	
			6th-10th	12	5	60				
			11th-15th	15	0	0				
			16th-20th	18	0	0				
			21th-25th	20	0	0				
	Sep-12	8	1st-5th	10	5	50	86	12	1,032	
			6th-10th	12	3	36				
			11th-15th	15	0	0				
			16th-20th	18	0	0				
			21th-25th	20	0	0				
	Oct-12	5	1st-5th	10	5	50	50	12	600	
			6th-10th	12	0	0				
			11th-15th	15	0	0				
			16th-20th	18	0	0				
			21th-25th	20	0	0				
	Nov-12	5	1st-5th	10	5	50	50	10	500	
			6th-10th	12	0	0				
			11th-15th	15	0	0				
			16th-20th	18	0	0				
			21th-25th	20	0	0				
	Dec-12	6	1st-5th	10	5	50	62	10	620	
			6th-10th	12	1	12				
			11th-15th	15	0	0				
			16th-20th	18	0	0				
			21th-25th	20	0	0				

BIOGRAPHY

Namploy Pornpiboon was born on 23rd December 1984 in Bangkok, Thailand. She obtained a Bachelor of Science (First Class Honour, Gold Medal) in Management Technology from Sirindhorn International Institute of Technology, Thammasat University in 2007. After graduated, she started her career with Thai Airways International Public Company Limited. She continued Master Degree in Engineering Business Management at Chulalongkorn University (Thailand), in cooperated with University of Warwick (United Kingdom).