PRODUCT FAMILIES DEVELOPMENT AND SIMULATION OF WELL COMPLETION SYSTEM PRODUCTS BY USING BUSINESS SIMULATION SOFTWARE

KHAIRUZZIKRI BIN MOHD SAGI

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by

Khairuzzikri Bin Mohd Sagi

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Dissertation submitted in partial fulfillment of the requirement for the Bachelor of Engineering (Hons)

(Mechanical)

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Universiti Teknologi Petronas

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

…………………………………….

(Dr.Ainul Akmar binti Mokthar)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references, and acknowledgements, and that their original work contained herein have not been undertaken or done by unspecified sources or persons.

………………………………………….

(KHAIRUZZIKRI BIN MOHD SAGI)

ABSTRACT

Particularly, high - mix, low - volume manufacturing industries such as companies that produce Christmas Tree components are very common these days. Being in high product mix, process flow is hard to be seen when products have a multitude of options, variations in production lead times. Besides, manufacturing organizations will also be constrained on capacity issue. Resources have to be shared and it is difficult to dedicate equipment to any specific of product. Productive manufacturing industries should have a total understanding on how their production system is performed so that the right product families can be developed. Inaccurate product families might result in creating more wastes such as bottleneck which eventually a longer production lead time will be required for a product to be manufactured. This project paper is about developing a new model of product families for a manufacturer that produce Christmas Tree components. The new model of product families is expected to reduce the production lead time. Product families that have been developed will be simulated by using Business Simulation Software – WITNESS. A new model of product families will be compared with existing product families. The new model of product families will be accepted if production lead time can be improved by five percent. The methodology of forming product families will be based techniques discussed by Duggan (2012) – Creating Mixed Model Value Streams.

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LIST OF ABBREVIATIONS

WCS	Well Completion System
WAS	Well Access System
MPS	Manifold and Pipeline System
SDS	Subsea Drilling System
THB	Tubing Head Body
CVB	Composite Valve Block
PWB	Production Wing Valve Block
PSDV	Production Shutdown Valve Block
WNF	Weldneck Flange
FTEE	Flow Loop Tee Piece
AWB	Annulus Wing Valve Block
AAVB	Annulus Access Valve Block
TEB	Target Elbow Body
BEB	Block Elbow Body
IVB	Injection Valve Block
PIVB	Production Injection Valve Block
FPIPE	Flow Loop Pipe

CHAPTER 1
INTRODUCTION

1.0 Background Studies

Competitive manufacturers in a real market should understand how their production system is behaved and have a total control of all, not only some parts of processes or pieces of equipment (Hunter & Black, 2003). Failure to understand the vital process technology, will lead to failure.

There are many categories of manufacturing in a real industry. According to Duggan (2012), manufacturing can be divided into four categories which are high mix - low volume industry, high mix - high volume industry, low mix - low volume industry and low mix - high volume industry. It is very essential to comprehend the type of manufacturing categories so that further improvement concepts can later be identified and implemented.

In many subsea manufacturing organizations, they will be producing at least five main systems to meet the industry demand which each and every system has its own components;

1. Well Completion System (WCS)
2. Well Access System (WAS)
3. Manifold and Pipeline System (MPS)
4. Subsea Drilling System (SDS)

Christmas Tree is commonly produce by Well Completion System which thirteen component parts are needed to develop the system.

Below is the list of common parts required by a Christmas Tree;

1. Tubing Head Body (THB)
2. Composite Valve Block (CVB)
3. Production Wing Valve Block (PWB)
4. Production Shutdown Valve Block (PSDV)
5. Weld Neck Flange (WNF)
6. Flow loop Tee Piece (FTEE)
7. Annulus Wing Valve Block (AWB)
8. Annulus Access Valve Block (AAVB)
9. Target Elbow Body (TEB)
10. Block Elbow Body (BEB)
11. Injection Valve Block (IVB)
12. Production Injection Valve Block (PIVB)
13. Flow loop Pipe (FPIPE)

Well Completion System can be treated as high-mix – low volume industry as they have many different type of components to be produced but not in a mass production. For example, in order for a Christmas Tree to be produced, only one Production Wing Valve Block, one Composite Valve Block, three Block Elbow Body are needed and so on.

Figure 1,2 and 3 below show one of the Christmas Tree - Enhanced Vertical Deepwater Tree that is assembled by one of the big manufacturing organizations in the world.

Figure 1 : Enhanced Vertical Deepwater Tree

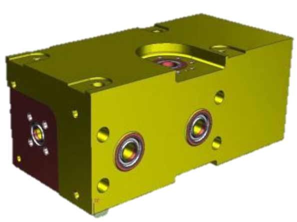

Figure 2: Production Wing Valve Block

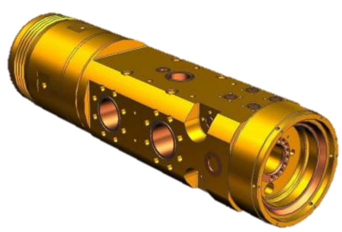

Figure 3: Tubing Head Body

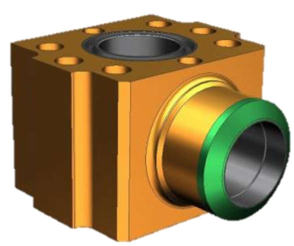

Figure 4: Block Elbow Body

Business environment is rapidly changed and manufacturers have to confront the complexities in their production management. High product variants will be quite challenging to manage as each product has its own routing to be complied. The ability of manufacturers to continuously and systematically respond to these challenges will distinguish whether they can sustain their competitiveness in the market (Sundar, Balaji, Kumar, & Sathessh, 2014).

According to the perspective of manufacturing industry, it can be acknowledged as a world class standard once it is being “lean”(Page, 2004). In another words, waste has to be minimum in the production. There are many sources of waste such as bottleneck which eventually will lead to a long production lead time.

Since all the WCS components are highly varied and more complex, effective system has to be implemented to ensure the smoothness of the production execution. Creating a right product family with a right production capacity allocation might be a good solution.

1.1 Problem Statement

Typically, a long production lead time is resulted due to the inefficiency of how production is being handled. Inefficiency of production would lead to failure in meeting the On Time Delivery (OTD). Some of the manufacturers might be very weak in allocating their production capacity. Per say, they just let the material to be flowed randomly according to any vacancy of production capacity. By all means, no milling machines, turning machines and welding machines were dedicated to any component. As the result, the production line might be resulted in a bottleneck.

This situation is absolutely very tricky to resolve as every part has its own routing and lead time. What is more, the production is subjected to limited number of machines and inspectors. Scheduling must be done perfectly in order to avoid parts from queuing at the staging area or stuck in a bottleneck again. Ultimately, a long production lead time will always be the worst case scenario whereby the resource is not being well-optimized. In return, higher cost of production will be incurred. Continuous improvement plays a very fundamental role in manufacturing industries as there is no perfect or ideal case in the real world. A lot of hiccups may be occurred which contribute to production delays.

Establishing right product families in high-mix, low-volume industry could be another lean technique which might be very helpful in reducing the problem - high production lead time. The product families have to be allocated with their own production capacity and to be executed independently - no crossover job is allowed and production is executed according to the product families. It is perhaps that production planning will be much simpler and further improvement can be done easier since manufactures are now having a smaller scope to handle. It is expected that production lead time can be reduced and thus, cost of production can also be reduced.

In early April 2014, one of subsea manufacturing organizations attempted to develop product families which later to be adapted in Value Stream Mapping (VSM) for further improvement. Due to the time constraint, the Manufacturing Engineering Team has taken only a week to do all the value stream analysis in order to form the product families. What is more, the product families have not yet been tested in any simulation software beforehand.

Product families development is very crucial as Current State Map of VSM will be based on them. Established Current State Map will then be the foundation of Future State Map whereby all the improvement strategies will be implemented. In another words, inaccurate product families could lead the manufacturer to adopt insignificant improvement.

Therefore, this project is done specifically to develop new model of product families with the use of techniques proposed by Duggan (2012). The new model will be simulated by using Business Simulation Software – Witness in order to analyze the production performance in term of production lead time.

1.2 Objectives

The main objective of this project is **to reduce the production lead time by creating a new product families model of Subsea Well Completion System products.** The new product families will later to be simulated by using business simulation software-WITNESS.

1.3 Scope of Studies

The research will be focused on Well Completion System products that are in-house manufactured. On top of that, some of the techniques in VSM will be used throughout this project in order for the product families to be used. To be more specific, only product family development methods will be captured in this project. Moreover, product families that are to be developed will be based on the pull of demand in 2014 and 2015.

CHAPTER 2

LITERATURE REVIEW

Waste is the enemy of any manufacturing industries. It is an activity that has no add value which product can be transformed in such a way that customer is willing to pay for it (Duggan, 2012). In other words, resources are consumed by waste activity but no value is delivered to the customer. Thus, waste reduction should be in the highest priority of manufacturing strategies (Page, 2004). Page (2004) also emphasized seven wastes which are defects in products, overproduction, Work in Progress (WIP) queues, unnecessary processing, unnecessary movement, excessive transport of parts and waiting people which they are all intangible material issues. What is more, it is quite complex for manufacturer to visualize the source of wastes due to the manufacturing complexities.

Too many of systems and their interactions with manufacturing operations have made the manufacturing systems more complex (Anthony, 2007). Frizelle and Woodcock (1995) discussed that manufacturing complexity can be categorized into two categories – static and dynamic complexities. Dynamic complexities are more about unpredictable events such as machine breakdowns or quality failures. On the other hand, static complexities is merely about the factory structure or design such as the variety of products, the routing patterns and number of machines.

Research done by Anthony (2007) has shown that a lower level of static manufacturing complexity lead to a better manufacturing performance. However, the market nowadays is demanding for a high variety of products with lower prices (Bahns, Gebhardt, & Krause , 2014). The increment of product variety will then result in higher complexity of the production (Bahns, Gebhardt, & Krause , 2014).

Numerous manufactures are nowadays evolving towards mass customization in order to stay competitive (Liu & Hsiao, 2014). This global competition somehow will be resulting in cost pressure as higher cost of production might be incurred due to the increasing of manufacturing complexities (Bahns, Gebhardt, & Krause , 2014). Product family development might be one of the best methods in dealing with such cases. According to Johannes, Adriana and Wim (2003), many companies are practicing product families and platform-based product development to increase variety, shorten lead times and reduce costs.

Typically a product family is a group of products that have passed through similar processes or equipment (Duggan, 2012). The book of Lean Thinking[1] discussed that there are few principles of lean technique that might be helpful in reducing wastes. One of the points is to create a right value flow. Thus, developing a right product family could lead to a correct value flow which eventually wastes could be reduced.

Brunt. et al. (2012) has taken few examples in explaining the concept of product family. Per say, a car platform of Ford and Mercury which are produced in an assembly plant can be a product family in the auto industry. There might be a component supplied to auto assemblers such as an alternator which using the same design architecture and assembled in a cell, but with different power output for different vehicles.

Many researchers have done studies about product family development. There are multiple of approaches that can be implemented to create product family. Sony, Black and Decker and Hewlett Packard are industrial examples that have developed products family with platform-based (Liu & Hsiao, 2014).

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[1] Lean Thinking. James P Womack and Daniel T.Jones. Simon & Schuster,1996, p.10.

Liu and Hsiao (2014) have extensively discussed few decision support systems in designing product family such as Analytic Network Process (ANP) and Goal Programming approach. ANP is first carried out to calculate the relative importance of components based on customer requirements. The Goal Programming approach will be conducted based on ANP result to determine the platform.

Deepak, Wei and Timothy (2008) have explained another approach in designing the product family which is Market-Driven Product Family Design (MPFD). What is more, MPFD offers a comprehensive strategy to confront with the product family design problems such as product line positioning, commonality and optimal configuration of design variable for each member of product family.

On the other hand, Nicolas, Tammo and Dieter (2014) explained that product families can be developed in modular mode by using Integrated PKT – Approach and Module Interface Graph (MIG). The development of modular product family is aimed to handle the high product variety which to reduce process complexity.

Product families are also have been introduced in Reconfigurable Manufacturing System (RMS) (Galan et al., 2007). Products which a system configuration is required each are to be grouped into families. The system is configured in order to develop the first product family. Once the first product family has been established, the system is again to be reconfigured to produce the second methodology for grouping the next product family. Hence, the effectiveness of RMS is based on the development of the best set of product families. There are a lot of steps throughout the product families development which comprised of product requirement calculation and a matrix that captures the similarities between pairs of product. Next, a unique matrix has to be obtained by using AHP methodology which later to be applied with Average Linkage Clustering algorithm in order to determine the various sets of product families that may be developed.

On the other hand, Creating Mixed Model Value Streams[2] is a an extension to the book of Learning to See[3] whereby Duggan (2012) recognized product family development as one of the prerequisites for any of further lean steps that are to be conducted. The author has chosen Electro-Motion Control (EMC) Supply Company is taken by Duggan (2002) to explain the concept of product families development in complex manufacturing environment.

Duggan (2012) suggested that product family matrix is to be used in identifying the product families. The product family matrix is simply a grid whereby products are to be listed in the row and processing steps are to be listed in the columns. Note that all the listed processing steps are regardless of their sequence. At this point, products that have eighty percent of similar processing steps will be grouped into product families. The product families are later to be refined by checking their work content criteria. In order for the product families to be established, each member of product family should be within thirty percent of each other. If the work content criteria of a product is beyond the range of thirty percent, the product is might belong to the next most similar product family. Equation 1 below shows how the work content criteria is calculated;

$$\text{Work content criteria} = \frac{\text{Highest cycle time} - \text{Lowest cycle time}}{\text{Highest cycle time}} \qquad [1]$$

Once the product families have been established, production capacity such as number of equipment will be allocated with respective to the product families. Equation 2 below shows how the production capacity such us number of equipment is calculated;

$$\text{Equipment required} = \frac{\text{Sum (Cycle time x Demand)}}{\text{Effective working time}} \qquad [2]$$

Note that the number of labors can also be calculated by using the same equation above.

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[2] Creating Mixed Model Value Streams – Practical Lean Techniques for Building to Demand. Kevin J.Duggan, Productivity Press, 2002.

[3] Learning to See. Mike Rother and John Shook. The Lean Enterprise Institute, 1998.

The development of mixed model value streams is to be continued by drawing a current state map. Current state map is a practical lean technique which to identify any potential waste in every product family. Analyzing the complexity of the product variants within the same product family is more preferable as sources of the complexity are easier to be tracked under the same scenario (Park & Gul, 2015). Finally, future state map will be designed based on the established current state map but with some improvements in the production.

CHAPTER 3

METHODOLOGY

The methodology of this project will be divided into two phases. In the first phase, simulation will be done for the existing product family by using WITNESS software. This simulation has to be done in order to ensure the feasibility of the software in mimicking the actual production. If the simulation results are approximately the same as the actual production lead time, the software will be further used to test the new product families that will be developed.

In the second phase, a new product family will be developed and will be simulated by using the same software. The production lead time produced will be compared with the actual production lead time and later to be justified whether a significant improvement has been produced.

In both simulations, only one input will be simulated for each component in product families. The total production lead time produced will later to be assumed as the flow rate of the production.

3.0 Methodology for the first phase

This phase is basically to verify whether the simulation is feasible to be used in the project. Below are the data that have to be gathered and several concerns that need to be taken during the simulation process;

1. **Actual production lead time data is gathered**

   Data is gathered about the actual of production lead time of previous product family and the average of production lead time is calculated.

2. **Product routing information is gathered**

   Product routing data is to be gathered which comprised of the process sequence and cycle time for each process. The data can be retrieved by using SAP system software and later to be manually recorded into spreadsheet.

3. Product families simulation

The cycle time used during the simulation is as per routing gathered. Existing model of product families is to be simulated which production capacity such as number of machinery and labors are according to the current practice on the shop floor. Only one input is simulated for every component. For example, one THB and one CVB in Product Family A will be simulated and the production lead time produced will be recorded. Table 1 shows the existing production capacity;

Table 1: Existing machinery and inspection capacity

<table>
<tr><th rowspan="2">PRODUCT FAMILY</th><th colspan="6">NUMBER OF MACHINES OR INSPECTOR</th></tr>
<tr><th>MILLING MACHINE</th><th>TURNING MACHINE</th><th>WELDING MACHINE</th><th>QC</th><th>NDE</th><th>WI</th></tr>
<tr><td>A</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td rowspan="3">2</td></tr>
<tr><td>B</td><td>1</td><td rowspan="2">1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>C</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table>

Some assumptions have to be taken into account due to the insufficient of data. Therefore, the result of the simulation might be varied as compared to the actual data.

Simulation model assumptions;

a) The sequence of components entering the production line is to be done at random since there is no specific sequence is being practice at the host company. Besides, it is almost impossible for the previous sequence to be tracked again.

b) The duration of component being moved, absence of labors, duration of machine break-down and setup time are excluded from this simulation.

c) Simulation is subject to ten percent of potential rework at every inspection point which different rework process and cycle times are required for different type of components. Potential rework process and cycle times are assumed to be the same at every inspection point. Once rework has been done, the component has to start from the beginning of the routing again. Table 2 below shows the rework routing per component;

Table 2: Rework hours for every component

COMPONENT	ROUTING (HOURS)					
	Turning	Large Milling	Milling	Deburr	NDE inspection	QC inspection
CVB	59	137	32	4	4	5
THB	59	137		1	4	5
AAVB			32.5	1	2	3
AWB			40.2	1	2	3
IVB			26	1		
PIVB			107.7	2.5	2	3
PSDV			46.9	1	2	3
PWB			51	1	2	3
TEB					1	1
WNF	5		4	1	1	1
BEB1			18	1	2	3
BEB2			21	1	2	3
FTEE	14		24	1	2	3

If the simulation result is not within the ten percent of actual production, simulation has to be checked again. It has to be ensured that there are no skipped routing and cycle time have to be inserted correctly into the simulation. If the result produced is still more than ten percent, other simulation software might need to be acquired.

Justification regarding the high range of simulation result;

Ten percent range of difference between simulation result and the actual production lead time has to be considered due to many assumptions that have to be done.

a) The sequence of components entering the production line can be too random and might be totally different from the actual production.

b) The probability of machine break-down and absence of labors has never been evaluated in the company. Moreover, the setup time for every component might be different and hardly being specified.

c) As per discussion with the production manager, the production is subject to 10 percent of potential rework at every inspection point. However, it is just a rough probability and has not yet been proven statistically.

   On top of that, defect might be varied at each inspection point. Thus, different rework and rework cycle time is needed. However, it is very hard to anticipate the type of defect and rework needed at every inspection point. Hence, the rework process and cycle time will be assumed to be just the same.

The figure 5 below shows the flowchart for the first phase of methodology;

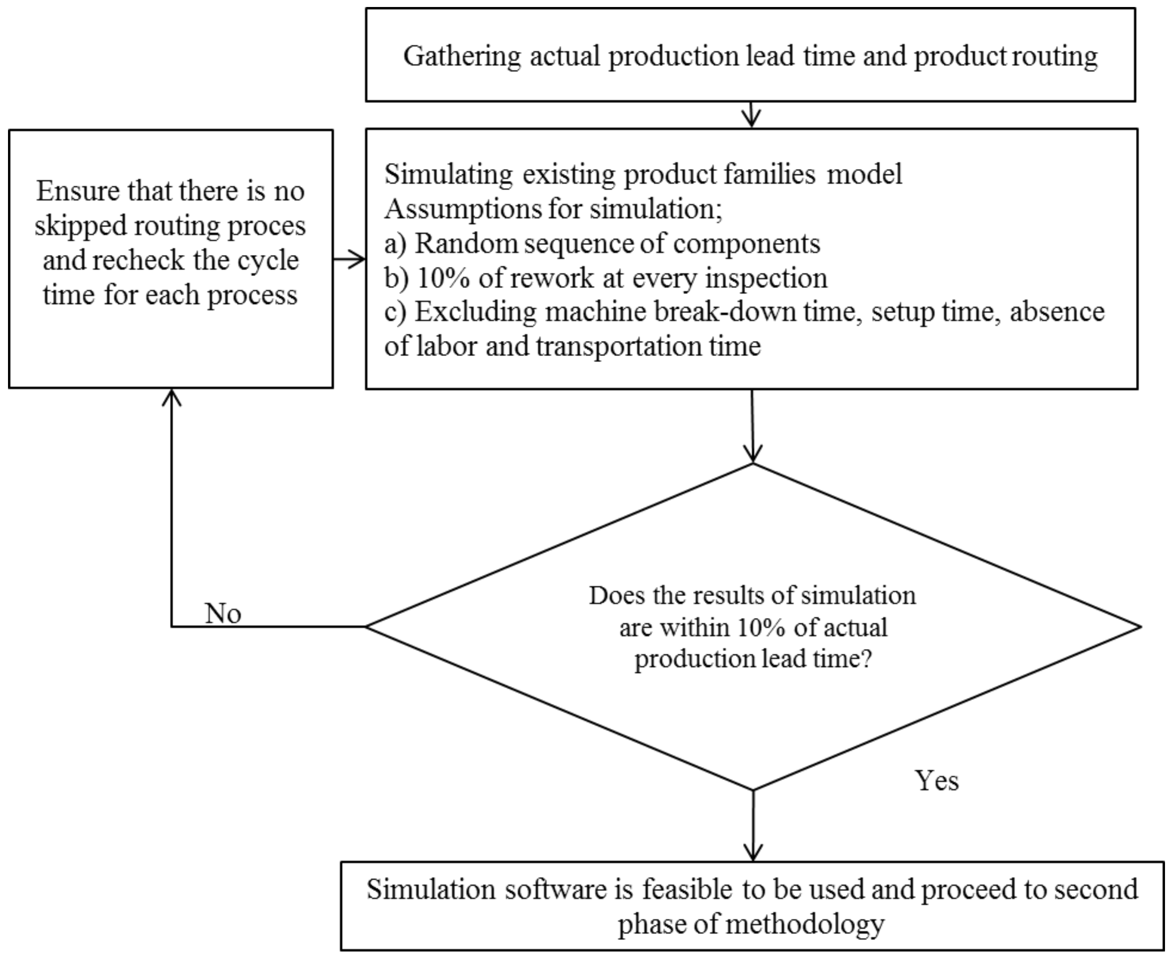


Figure 5: First phase of methodology

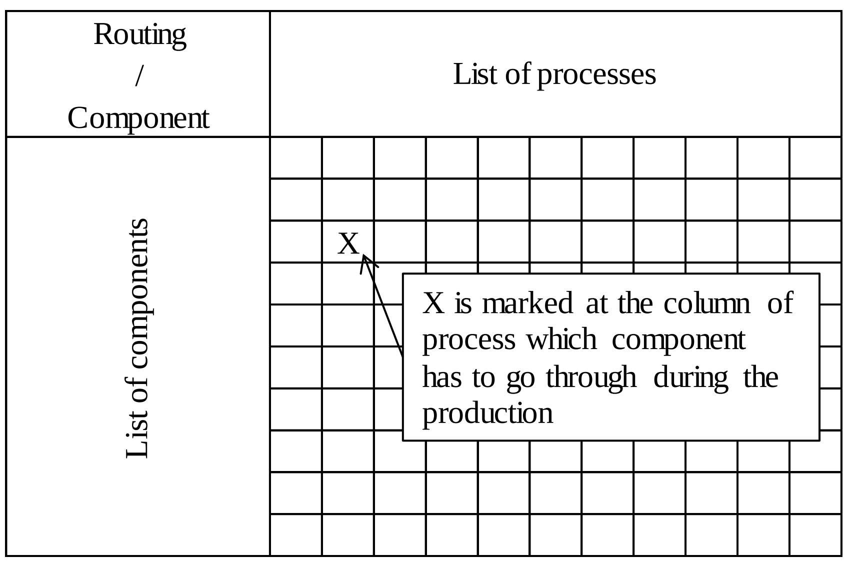
3.1 Methodology for the Second Phase

This phase is basically to develop new model of product family once the first phase of methodology has been passed. Below are the steps that have to be done in product family model development;

1. **Product family matrix**

   The purpose of forming a product family matrix is to identify which components will have similar processes. Components that have about eighty percent of the same processing steps will be grouped into product families (Duggan, 2012). However, these product families are not permanent yet as they have to be further refined in the next step. The product family matrix is basically a grid that has a list of processes in the columns and a list of components in the rows. The lists of processes are not necessarily to be arranged in a correct order. Table 3 below illustrates the layout of the product family matrix;

Table 3 : Layout of the product family matrix



2. **Product families refinement**

   Product families can be further refined by using a work content criteria determination. The work content criteria can be referred as equation [1] in the literature review. As a general rule, the total work content of the processing steps for each part in the product family should be within thirty percent of each other

(Duggan, 2012). The reason of this step is that, while components might pass through the same processing steps, the cycle time might be vastly different. If these components are still to be put in the same families, irregular or "choppy" flow will be resulted.

If there are components that have work content of more than 30 percent difference from each other, the components might need to be placed into the next most similar product family.

3. **Product families simulation**

   Based on the product routing information and new product families that have just been developed, simulation will be repeated again but with an additional assumption.

   Additional simulation model assumption on production capacity;

   The new model of product family might be almost the same as existing model or could be a totally different from the existing model. Therefore, the production capacity may need or may not need to be reallocated. However, due to the time constraint, the production capacity is assumed to be the same as existing model of product family due to the time constraint.

   If the production lead time produced has more than five percent of improvement as compared to the actual production lead time, the new model will be accepted.

   Figure below shows the flow chart of the second phase of the methodology;

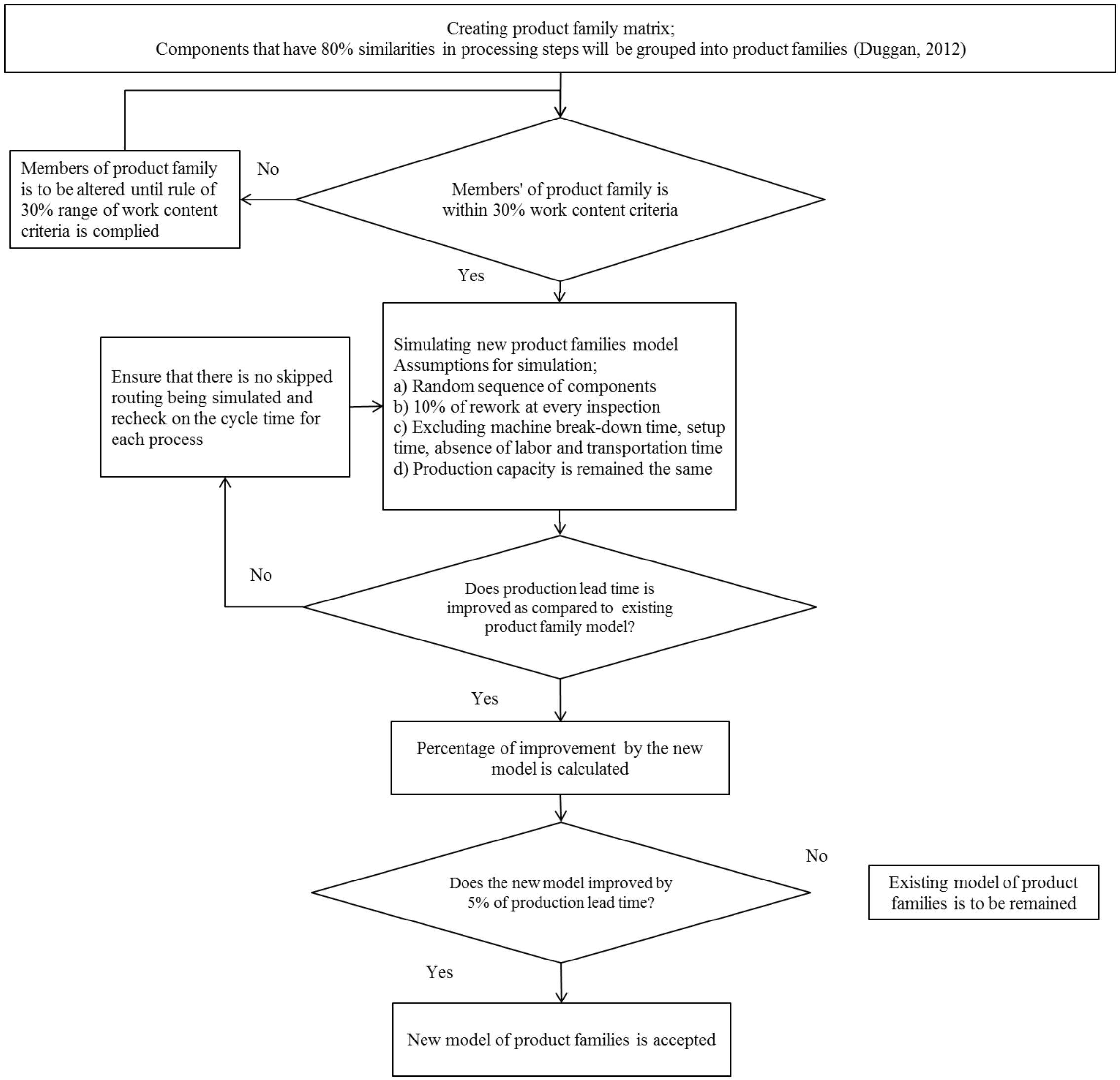


Figure 6: New product families development and simulation

3.3 Gantt Chart and Key Milestones

Table 4 below shows the weekly project planning. This project is conducted chapter by chapter.

Table 4 : Weekly Project Planning

Descriptions	Week																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Identifying how does the production work					◆																							
Determining the major problem in the production																												
Deciding appropriate way to solve the major problem																												
Identifying the scope of study					◆																							
Conducting literature review about techniques in developing product families												◆																
Developing a research methodology									◆																			
Gathering actual production lead time and routing																	◆											
Simulating the existing product families																												
Developing Product Family Matrix																												
Refining product family based on Product Family Matrix																					◆							
Simulating the new model of product families																												
Analysing the result of simulation																								◆				

CHAPTER 4
RESULT AND DISCUSSION

4.0 Result on the First Phase of Methodology

1. Actual production lead time data

Table 5, 6 and 7 below demonstrate the data collection on the actual lead time per component. Components are to be arranged with respect to the existing product families and average of actual lead time is to be calculated.

Table 5: Average of actual lead time of existing Product Family A

PRODUCT FAMILY	COMPONENT	ACTUAL LEAD TIME (DAYS)	AVERAGE OF ACTUAL LEAD TIME	
			DAYS	HOURS
A	CVB	100	93	2232
	CVB	90		
	CVB	95		
	CVB	90		
	CVB	95		
	THB	92		
	THB	88		
	THB	95		
	THB	90		
	THB	95		

Table 6: Average of actual lead time of existing Product Family B

PRODUCT FAMILY	COMPONENT	ACTUAL LEAD TIME (DAYS)	AVERAGE OF ACTUAL LEAD TIME	
			DAYS	HOURS
B	AAVB	124	78	1890
	AAVB	104		
	AAVB	104		
	AAVB	104		
	AAVB	103		
	AWB	37		
	AWB	35		
	AWB	33		
	AWB	30		
	AWB	42		
	IVB	98		
	IVB	98		
	IVB	99		
	IVB	98		
	PIVB	67		
	PIVB	64		
	PIVB	87		
	PIVB	87		
	PIVB	67		
	PSDV	71		
	PSDV	77		
	PSDV	71		
	PSDV	77		
	PSDV	78		
	PWB	78		
	PWB	94		
	PWB	94		
	PWB	85		
	PWB	78		

Table 7: Average of actual lead time of existing Product Family C

PRODUCT FAMILY	COMPONENT	ACTUAL LEAD TIME (DAYS)	AVERAGE OF ACTUAL LEAD TIME	
			DAYS	HOURS
C	BEB	115	63	1525
	BEB	119		
	BEB	119		
	BEB	116		
	BEB	107		
	FTEE	95		
	FTEE	84		
	FTEE	73		
	FTEE	95		
	FTEE	73		
	TEB	21		
	TEB	23		
	TEB	23		
	TEB	26		
	TEB	27		
	WNF	40		
	WNF	30		
	WNF	29		
	WNF	26		
	WNF	30		

2. Product routing information

Component routing data is gathered which comprised of the routing or process sequence, and processing time. Table 8 below shows the routing for each of the component;

Table 8: Component routing and the process time

	COMPONENTS / CYCLE TIME (HOURS)													
ROUTING	CVB	THB	AWB	PWB	PSDV	AAVB	IVB	PIVB	FPIPE	TEB	WNF	BEB 1	BEB 2	FTEE
WELDING INSPECTION	1	5	1	1	1	1		1	1	1	1	1	1	1
WELD	254	233	66	112	81	37		146	15	28	15	36	36	9
WELDING INSPECTION	1	1	1	1	1	1		1	1	1	1	1	1	1
TURNING									5		3			
MILLING										12		7	7	11
DEBURR									1	1	1	1	1	1
NDE INSPECTION									6	4	4	4	4	4
TURNING									9		9			
MILLING				8						7		7	7	11
DEBURR				4					1	1	1	1	1	1
QC INSPECTION				4					1	1	1	1	1	3
NDE				4					1	1	1	1	1	
WELDING INSPECTION				1					1	1	1	1	1	1
WELD				60					17	54	17	54	54	61
WELDING INSPECTION				1					1	1	1	1	1	1
PWHT	120	120	48	48	48	48		48	48	48	48	48	48	48
QC INSPECTION	4	4	4	4	4	4		4	1	1	1	1	1	1
TURNING FOR NDE	6	6												
NDE INSPECTION	4	4									9			
TURNING FINISH	142	142							16				28	21
MILLING FINISH	339	339	103	152	73	51		160	4	30	4	33	33	26
TURNING FINISH					23									
DEBURR	5	5	3	3	3	3	1	3	1	1	1	1	1	1
QC INSPECTION	8	8	4	4	4	4	4	4	8	1	8	8	8	8
NDE	8	8	4	4	4	4		4	8	2	8	8	8	8
NDE UT RT				4	4	4	5	4	5	4	5	5	5	5
COATING 1	144	144	144	144	144	144	144	144	144	144	144	144	144	144
COATING 2	144	144	144	144	144	144	144	144	144	144	144	144	144	144
FINAL INSPECTION	4	4	4	4	4	4	4	4	4	1	4	4	4	4

3. Product families Simulation.

Figure 7 below is the snapshot of simulation for the existing model of product families which consist of Family A, Family B and Family C by using WITNESS simulation software;

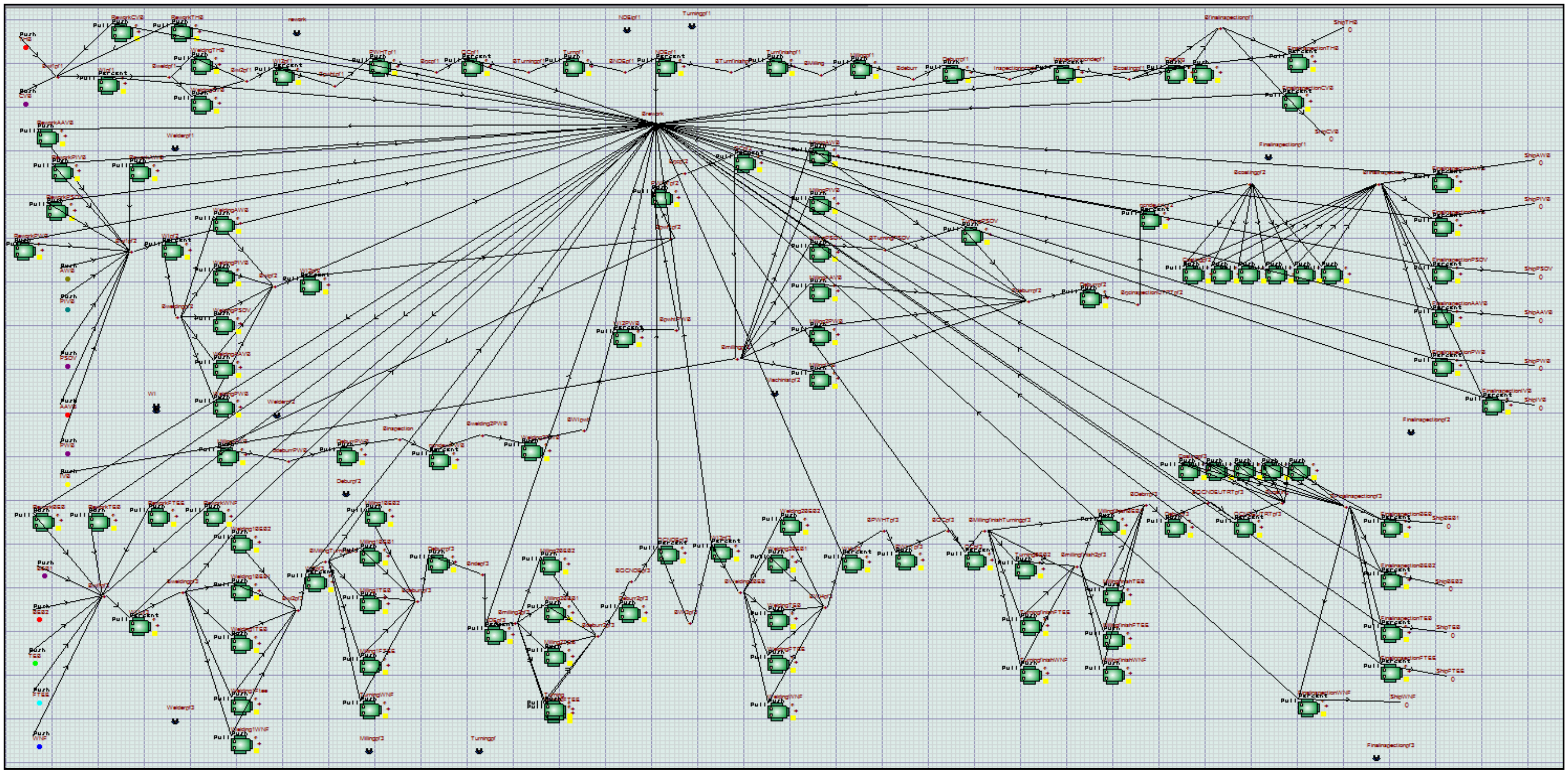


Figure 7: Existing model of product families simulation

Table 9 below shows the result of the simulation for existing model of product families which to be compared with the average of actual production lead time;

Table 9: Comparison between the result of existing model simulation and actual production lead time

PRODUCT FAMILY	COMPONENT	SIMULATION PRODUCTION LEAD TIME OF EXISTING MODEL OF PRODUCT FAMILIES (HOURS)				AVERAGE OF ACTUAL PRODUCTION LEAD TIME (HOURS)	PERCENTAGE OF DIFFERENCE (%)
		FIRST TRIAL	SECOND TRIAL	THIRD TRIAL	AVERAGE OF PRODUCTION LEAD TIME		
A	CVB THB	1996	1943	1943	1961	2232	12
B	AWB PIVB PSDV PWB	1750	1700	1800	1750	1890	7
C	BEB FTEE TEB WNF AAVB IVB	1400	1450	1416	1416	1525	7

Based on the simulation results, it can be seen that almost all the product families are within the ten percent of difference between simulation and actual production lead time. However, Product Family A has exceeded the percentage of difference by two percent. Since there are many assumptions that have been made throughout the simulation, twelve percent of difference could be considered as acceptable value. Therefore, the simulation software is feasible to be further used in this project.

4.0 Result for the Second Phase of Methodology

Below is the result for the data collection and simulation;

1. Product family matrix

The product family matrix created below is based on the product routing information gathered. At this stage, components that have about eighty percent of the same processing steps are to be grouped into product families. Table 10 below shows the product family matrix that has been created based on the actual routing;

Table 10: Initial stage of grouping the product family

COMPONENTS/ ROUTING	DEBURR	QC	COATING	COATING	FINAL QC	NDE	WI	WELDING	WI	PWHT	QC	M.FINISH	NDE UT RT	DEBURR	QC	WI	WELDING	WI	DEBURR	NDE	NDE	MILLING	TURNING	T.FINISH	T.S.NDE	M.S.NDE	EXISTING PRODUCT FAMILY	NEW PRODUCT FAMILY
FPIPE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		C	3
WNF	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		C	3
BEB2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	C	3
BEB1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	C	3
TEB	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	C	3
FTEE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X		X	C	3
PWB	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X					C	3
PSDV	X	X	X	X	X	X	X	X	X	X	X	X	X											X			B	2
AWB	X	X	X	X	X	X	X	X	X	X	X	X	X														B	2
AAVB	X	X	X	X	X	X	X	X	X	X	X	X	X														B	2
PIVB	X	X	X	X	X	X	X	X	X	X	X	X	X														B	2
CVB	X	X	X	X	X	X	X	X	X	X	X										X	X	X	X			A	1
THB	X	X	X	X	X	X	X	X	X	X	X										X	X	X	X			A	1
IVB	X	X	X	X	X								X														C	4

Based on the product family matrix, there are roughly four product families might be produced at the end of this project – Product Family 1, Product Family 2, Product Family 3and Product Family 4.

2. Product family refinement

Based on the product family matrix, range of work content criteria is now tested for Product Family 3;

Table 11: Product Family 3 refinement

COMPONENT/ ROUTING	WI	WELD	WI	T. NDE	M. NDE	DEBURR	QC	NDE	TURNING	MILLING	DEBURR	QC	NDE	WI	WELD	WI	PWHT	QC	T. FINISH	M. FINISH	MILLING	DEBURR	QC	NDE	NDE UT RT	COATING	COATING	F. INSPECTION	TOTAL CYCLE TIME	RANGE OF WORK CONTENT
FPIPE	1	15	1	5		1		6	9		1	1	1	1	17	1	48	1	16	4		1	8	8	5	144	144	4	443	37
WNF	1	15	1	3		1		4	9		1	1	1	1	17	1	48	1	9	4		1	8	8	5	144	144	4	432	39
BEB1	1	36	1		7	1		4		7	1	1	1	1	54	1	48	1		33		1	8	8	5	144	144	4	512	28
BEB2	1	36	1		7	1		4		7	1	1	1	1	54	1	48	1	28	33		1	8	8	5	144	144	4	540	24
TEB	1	28	1		12	1		4		7	1	1	1	1	54	1	48	1		30		1	8	8	5	144	144	4	506	28
FTEE	1	9	1		11	1		4		11	1	3		1	61	1	48	1	21	26		1	8	8	5	144	144	4	515	27
PWB	1	112	1		8	4	4	4						1	60	1	48	4			152	3	4	4	4	144	144	4	707	0

Based on the table 11 above, FPIPE and WNF are not within the thirty percent criteria. In order to maintain the right work content, a component with the highest total cycle time might need to be removed from the family.

Therefore, PWB will be taken out from the product family and to be placed in the most other similar product family – product family 2. The work content is now to be checked again.

Table 12: Product Family 3 of second refinement

COMPONENT/ ROUTING	WI	WELD	WI	T. NDE	M. NDE	DEBURR	QC	NDE	TURNING	MILLING	DEBURR	QC	NDE	WI	WELD	WI	PWHT	QC	T. FINISH	M. FINISH	MILLING	DEBURR	QC	NDE	NDE UT RT	COATING	COATING	F. INSPECTION	TOTAL CYCLE TIME	RANGE OF WORK CONTENT
FPIPE	1	15	1	5		1		6	9		1	1	1	1	17	1	48	1	16	4		1	8	8	5	144	144	4	443	18
WNF	1	15	1	3		1		4	9		1	1	1	1	17	1	48	1	9	4		1	8	8	5	144	144	4	432	20
BEB1	1	36	1		7	1		4		7	1	1	1	1	54	1	48	1		33		1	8	8	5	144	144	4	512	5
BEB2	1	36	1		7	1		4		7	1	1	1	1	54	1	48	1	28	33		1	8	8	5	144	144	4	540	0
TEB	1	28	1		12	1		4		7	1	1	1	1	54	1	48	1		30		1	8	8	5	144	144	4	506	6
FTEE	1	9	1		11	1		4		11	1	3		1	61	1	48	1	21	26		1	8	8	5	144	144	4	515	5

Based on the table 12 above, all members of Product Family 3 are within the thirty work content criteria. Thus, Product Family 3 can be established as one product family.

Product family refinement is prolonged for the Product Family 2 with new additional member – PWB.

Table 13: Product Family 2 refinement

COMPONENT/ ROUTING	WI	WELD	WI	MILLING	DEBURR	QC	NDE	WI	WELD	WI	PWHT	QC	MILLING	T. FINISH	MILLING	DEBURR	QC	NDE	NDE YT RT	COATING	COATING	FINAL INSPECTION	TOTAL CYCLE TIME	RANGE OF WORK CONTENT
PWB	1	112	1	8	4	4	4	1	60	1	48	4			152	3	4	4	4	144	144	4	707	0
PSDV	1	81	1								48	4	73	23		3	4	4	4	144	144	4	538	24
AWB	1	66	1								48	4	103.3			3	4	4	4	144	144	4	530.3	25
AAVB	1	37	1								48	4	51			3	4	4	4	144	144	4	449	36
PIVB	1	146.2	1								48	4	160			3	4	4	4	144	144	4	667.2	6

Based on the table 13 above, it can be seen that AAVB is not complied with the thirty percent of work content criteria. Since its cycle time is too low while the other members of family are on average merely the same, AAVB might need to be replaced into the other most similar product family – Product Family 1. The work content is now to be checked again.

Table 14: Product Family 2 of second refinement

COMPONENT/ ROUTING	WI	WELD	WI	MILLING	DEBURR	QC	NDE	WI	WELD	WI	PWHT	QC	MILLING	T. FINISH	MILLING	DEBURR	QC	NDE	NDE YT RT	COATING	COATING	FINAL INSPECTION	TOTAL CYCLE TIME	RANGE OF WORK CONTENT
PWB	1	112	1	8	4	4	4	1	60	1	48	4			152	3	4	4	4	144	144	4	707	0
AWB	1	66	1								48	4	103.3			3	4	4	4	144	144	4	530.3	25
PIVB	1	146.2	1								48	4	160			3	4	4	4	144	144	4	667.2	6
PSDV	1	81	1								48	4	73	23		3	4	4	4	144	144	4	538	24

Based on the table 14 above, all members of Product Family 2 are within the thirty percent of work content criteria. Thus, Product Family 2 can be established as one product family.

Product family refinement is to be continued for the Product Family 1 with new additional member – AAVB.

Table 15: Product Family 1 refinement

COMPONENT/ ROUTING	WI	WELDING	WI	PWHT	QC	MILLING	DEBURR	QC	NDE	UT RT	COATING	COATING	F. INSPECTION	TOTAL CYCLE TIME	RANGE OF WORK CONTENT
AAVB	1	37	1	48	4	51	3	4	4	4	144	144	4	449	56
CVB	1	254	1	120	4	339	5	8	8		144	144	4	1032	0
THB	1	233	1	120	4	339	5	8	8		144	144	4	1011	2

Based on the table 15 above, it can be seen that AAVB is still not complied with the thirty work content criteria although it has been replaced into the next most similar product family. Therefore, AAVB has now to be replaced into the product family that has merely the same total cycle time – Product Family 3. The work content is now to be checked again.

Table 16: Product Family 1 of second refinement

COMPONENT/ ROUTING	WI	WELDING	WI	PWHT	QC	MILLING	DEBURR	QC	NDE	UT RT	COATING	COATING	F. INSPECTION	TOTAL CYCLE TIME	RANGE OF WORK CONTENT
CVB	1	254	1	120	4	339	5	8	8		144	144	4	1032	0
THB	1	233	1	120	4	339	5	8	8		144	144	4	1011	2

Based on the table 16 above, all members of Product Family 2 are within the thirty work content criteria. Thus, Product Family 1 can be established as one product family.

Product Family 3 is again to be refined with the new additional product member – AAVB;

Table 17: Product Family 3 of third refinement

COMPONENT/ ROUTING	WI	WELDING	WI	T. NDE	M. NDE	DEBURR	NDE	TURNING	MILLING	DEBURR	QC	NDE	WI	WELDING	WI	PWHT	QC	MILLING	T. FINISH	MILLING	DEBURR	QC	NDE	UT RT	COATING	COATING	F. INSPECTION	TOTAL CYCLE TIME	RANGE OF WORK CONTENT
AAVB	1	37	1													48	4	51			3	4	4	4	144	144	4	449	17
FPIPE	1	15	1	5		1	6	9		1	1	1	1	17	1	48	1	16	4		1	8	8	5	144	144	4	443	18
WNF	1	15	1	3		1	4	9		1	1	1	1	17	1	48	1	9	4		1	8	8	5	144	144	4	432	20
BEB1	1	36	1		7	1	4		7	1	1	1	1	54	1	48	1		33		1	8	8	5	144	144	4	512	5
BEB2	1	36	1		7	1	4		7	1	1	1	1	54	1	48	1	28	33		1	8	8	5	144	144	4	540	0
TEB	1	28	1		12	1	4		7	1	1	1	1	54	1	48	1		30		1	8	8	5	144	144	4	506	6
FTEE	1	9	1		11	1	4		11	1	3		1	61	1	48	1	21	26		1	8	8	5	144	144	4	515	5

Based on the table 17 above, it can be explained that all the product members are complied with thirty percent of work content criteria and so can be established as one product family.

Since IVB has the least processing steps and a stand-alone product family in the product family matrix, it will be then to be put into product family that has almost the same total cycle time – Product Family 3. Moreover, it is not really feasible if there are too many product families developed as they are subjected to limited production capacity.

Table 18: Product Family 3 of fourth refinement

COMPONENT/ ROUTING	WI	WELDING	WI	T. NDE	M. NDE	DEBURR	NDE	TURNING	MILLING	DEBURR	QC	NDE	WI	WELDING	WI	PWHT	QC	MILLING	T. FINISH	MILLING	DEBURR	QC	NDE	UT RT	COATING	COATING	F. INSPECTION	TOTAL CYCLE TIME	RANGE OF WORK CONTENT
IVB																				50	3	8	8		144	144	4	361	33
AAVB	1	37	1													48	4	51			3	4	4	4	144	144	4	449	17
FPIPE	1	15	1	5		1	6	9		1	1	1	1	17	1	48	1	16	4		1	8	8	5	144	144	4	443	18
WNF	1	15	1	3		1	4	9		1	1	1	1	17	1	48	1	9	4		1	8	8	5	144	144	4	432	20
BEB1	1	36	1		7	1	4		7	1	1	1	1	54	1	48	1		33		1	8	8	5	144	144	4	512	5
BEB2	1	36	1		7	1	4		7	1	1	1	1	54	1	48	1	28	33		1	8	8	5	144	144	4	540	0
TEB	1	28	1		12	1	4		7	1	1	1	1	54	1	48	1		30		1	8	8	5	144	144	4	506	6
FTEE	1	9	1		11	1	4		11	1	3		1	61	1	48	1	21	26		1	8	8	5	144	144	4	515	5

Based on the table 18 above, IVB is still not within the thirty percent of work content criteria. However, the range is almost at the border line. Thus, it is assumed to be fit into this product family.

All product families refinement are now completed. Therefore, a new model of product families can be established. Table below shows the comparison between existing and new model of product families.

Table 19: Product families comparison

EXISTING MODEL		NEW MODEL	
PRODUCT FAMILY	COMPONENT	PRODUCT FAMILY	COMPONENT
A	THB CVB	1	THB CVB
B	PWB AWB PSDV PIVB AAVB IVB	2	PWB AWB PSDV PIVB
C	BEB TEB FTEE WNF	3	BEB TEB FTEE WNF AAVB IVB

According to the table 19 above, it can be explained that Product Family A-1, Product Family B-2, and Product Family C-3 are almost similar to each other. Product family A and 1 have the same component members. On the other hand, Product Family B-2 and Product Family C-3 are both differed by only two components.

Since, the new model of product families will be assumed to have the same production capacity, the production capacity will be allocated such that Product Family 1 has the same production capacity as Product Family A, Product Family 2 has the same production capacity as Product Family B and Product Family 3 has the same production capacity as Product Family C. Table 20 below shows the finalized production capacity that will be simulated – number of machines or inspectors with respect to new model of the product families.

Table 20: Production capacity for the new model of product families

<table>
<tr><th rowspan="2">PRODUCT FAMILY</th><th colspan="6">NUMBER OF MACHINES OR INSPECTOR</th></tr>
<tr><th>MILLING MACHINE</th><th>TURNING MACHINE</th><th>WELDING MACHINE</th><th>QC</th><th>NDE</th><th>WI</th></tr>
<tr><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td rowspan="3">1</td></tr>
<tr><td>2</td><td>1</td><td rowspan="2">1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>3</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table>

3. Product families simulation

Figure 8 below is the simulation result of new model of product families which consist of Family 1, Family 2 and Family 3 by using WITNESS simulation software;

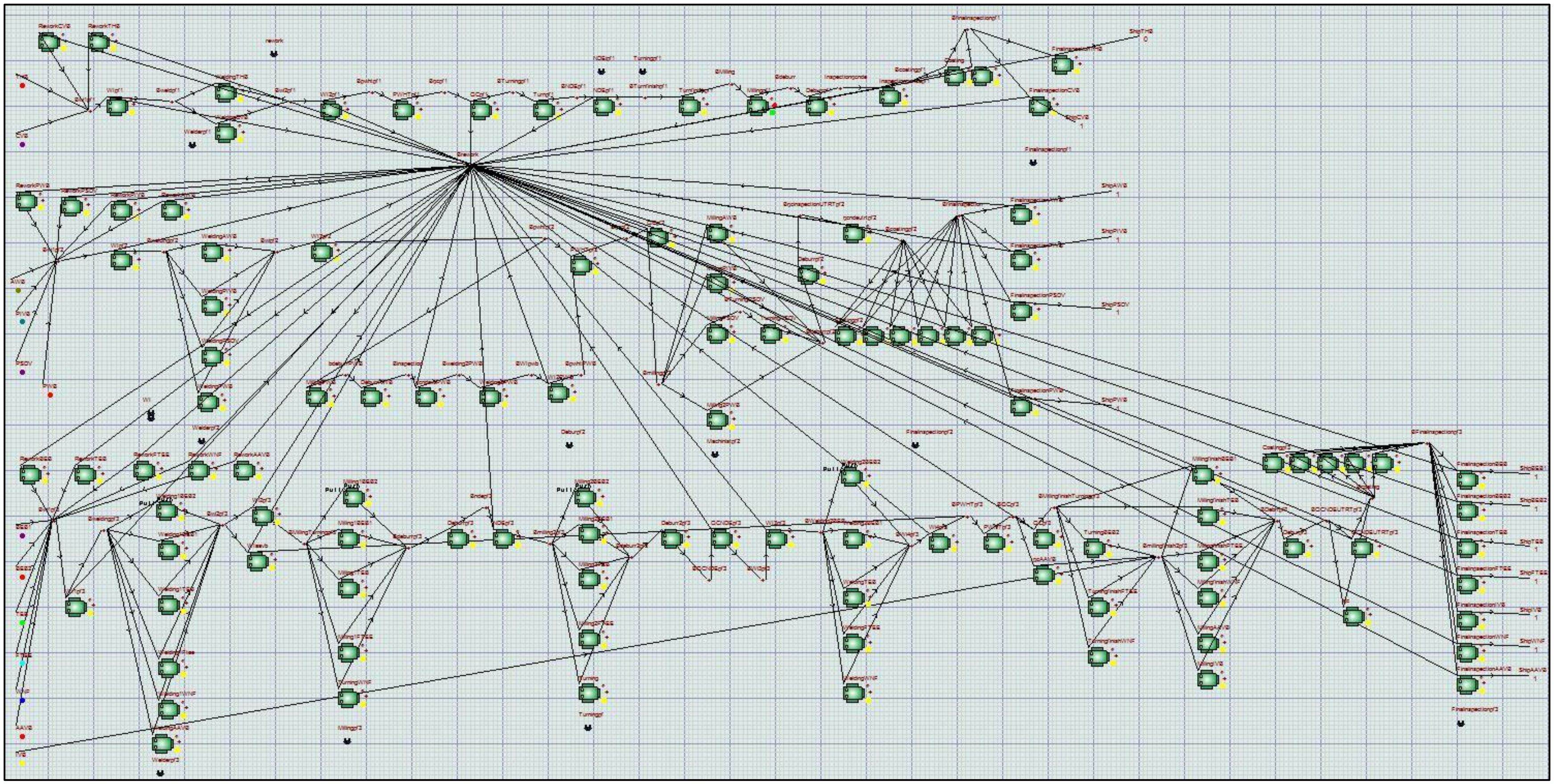


Figure 8: New model of product families simulation

Table 21 below shows the result of the simulation for new model of product families which to be compared with the average of actual production lead time;

Table 21: Comparison between the result of existing model simulation and actual production lead time

PRODUCT FAMILY	COMPONENT	SIMULATION PRODUCTION LEAD TIME OF NEW MODEL OF PRODUCT FAMILIES(HOURS)				AVERAGE OF ACTUAL PRODUCTION LEAD TIME (HOURS)	PERCENTAGE OF IMPROVEMENT (%)
		FIRST TRIAL	SECOND TRIAL	THIRD TRIAL	AVERAGE OF PRODUCTION LEAD TIME		
1	CVB	1960	1880	1957	1932	2232	13
	THB						
2	AWB	1600	1656	1599	1618	1890	14
	PIVB						
	PSDV						
	PWB						
3	BEB	1440	1450	1420	1437	1525	5
	FTEE						
	TEB						
	WNF						
	AAVB						
	IVB						

Based on the table 21 above, it can be seen that the new model of product families have brought a good improvement which at least 5 percent of reduction in production lead time. This is just another way to say that slight changes in product families might affect the production performance. The reduction of production lead time is also showing that the new model of product families is more effective in term of process flow.

The reduction of production lead time can have a significant impact on the cost such as working cost. A series of table below will explain how working cost is calculated and how much working cost can be reduced.

Economic justification

Each product family has different number of operators. Three shifts are scheduled per day which one shift is eight hours long. An operator will cost the manufacturer for RM13 per hour. The total working cost required with respective to the product families are first to be calculated and can be shown in the table 22 below;

Table 22: Working cost per hour with respect to product family for every shift

PRODUCT FAMILY	NUMBER OF OPERATORS PER SHIFT						TOTAL NUMBER OF OPERATORS	TOTAL WORKING COST PER HOUR (RM) (TOTAL NUMBER OF OPERATOR X RM13)
	MILLING MACHINE	TURNING MACHINE	WELDING MACHINE	QC	NDE	WI		
A/1	1	1	1	1	1	0.3	5.3	69.3
B/2	1	0.5	1	1	1	0.3	4.8	62.8
C/3	1	0.5	1	1	1	0.3	4.8	62.8

The total working cost for the existing model of product families are now to be calculated and later to be compared with the new model of product families.

Table 23: Comparison of total working cost between existing and new model of product families

PRODUCT FAMILY	WORKING COST PER HOUR (RM)	ACTUAL PRODUCTION LEAD TIME (HOUR)	TOTAL WORKING COST (RM) (WORKING COST PER HOUR X ACTUAL PRODUCTION LEAD TIME)	NEW MODEL PRODUCTION LEAD TIME (HOUR)	TOTAL WORKING COST (RM) (WORKING COST PER HOUR X NEW MODEL PRODUCTION LEAD TIME)
A / 1	69.3	2232	154 752	1932	133 952
B / 2	62.8	1890	118 755	1618	101 664
C / 3	62.8	1525	95 821	1437	90 292
		TOTAL	369 328	TOTAL	325 908

Based on the table 23 above, the cost reduction can be calculated as per below;

$$\text{Cost reduction} = \text{Total working cost of existing model} - \text{Total working cost of new model}$$

$$\text{Cost reduction} = \text{RM369 328} - \text{RM325 908}$$

$$= \text{RM 43 420}$$

Therefore, the manufacturer could save up to RM43420 if the new model of product families is considered to be implemented. Note that the total working cost calculated in the table above is meant only for one input for every component. Per year, every component is expected to be produced at minimum quantity of four components. Therefore, the company might get RM 173 680.

CHAPTER 5

CONCLUSION AND RECCOMENDATIONS

Based on the research study above, Witness Simulation software is feasible to be used throughout the whole project. The study has well-explained that there is a strong relationship between the product family model and the production lead time. Even a slight difference in the model may result in a good or poor production lead time.

The comparison between the existing model and the new model of product families has shown that they are only varied by two components in their product families. However, this slight variation has brought a significant improvement towards production lead time up to fourteen percent. As per estimation, the improvement produced by the new model of product families worth RM43420 of saving.

Since the new model of product families have more than five percent of improvement, the **new model of product families are to be accepted**. What is more, the new model has been validated by using work content criteria and being simulated by using WITNESS software. In short, the new model developed is more reliable as compared to the existing model of product families.

All in all, the objective of this project is achieved as **production lead time could be reduced by the new model of product families**.

There are many assumptions that have been taken throughout the simulation. In the future research study, it is perhaps that the simulation is based on the same sequence of input. Besides, statistical study has to be done regarding the probabilities of components having rework and machine to break-down. On top of that, actual number of demand per component has to be collected and to be simulated rather than simulating only one unit per product. This is because simulating more units per product could give better picture of potential bottleneck. Moreover, the production capacity has to be calculated for each product family before simulation is done.

In a real case of industry, it might be hard to simply increase the number of production capacity like purchasing more machines as capital revenue of a company will be affected. However, a right production capacity allocation will at least reduce the possibility of having bottleneck in the production lines. On the other hand, farming out more processes might be helpful to overcome the short of production capacity.

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APPENDICES

Sample of Product Matrix System by using spreadsheet written by Duggan (2002):

Step 1: Name of part is to be inserted in the row header and routing process is to be filled into respective column header. X is to be mark in the space if the product has to undergo the process stated in the column header.

Table 24: Step 1 of Product Family Matrix

	A	B	C	D	E	F	G
Product 1	X		X	X		X	X
Product 2		X		X		X	
Product 3	X			X		X	X
Product 4			X	X		X	X
Product 5	X	X		X	X		X
Product 6	X			X			X
Product 7		X			X		X
Product 8		X		X		X	
Product 9		X		X		X	
Product 10	X	X		X	X		X
Product 11		X		X		X	
Product 12	X			X		X	X
Product 13		X			X		X
Product 14	X		X	X		X	X
Product 15		X		X	X		X
Product 16		X		X		X	
Product 17	X		X	X		X	X
Product 18	X	X		X	X		X
Product 19	X			X		X	X
Product 20		X		X		X	

Step 2: A row with “power of 2” is developed and 2 to the power of 0, 1,2, 3, etc are assigned for each process (column), and every X is converted to 1.

Table 25: Step 2 of Product Family Matrix

	1	2	4	8	16	32	64
	A	B	C	D	E	F	G
Product 1	1		1	1		1	1
Product 2		1		1		1	
Product 3	1			1		1	1
Product 4			1	1		1	1
Product 5	1	1		1	1		1
Product 6	1			1			1
Product 7		1			1		1
Product 8		1		1		1	
Product 9		1		1		1	
Product 10	1	1		1	1		1
Product 11		1		1		1	
Product 12	1			1		1	1
Product 13		1			1		1
Product 14	1		1	1		1	1
Product 15		1		1	1		1
Product 16		1		1		1	
Product 17	1		1	1		1	1
Product 18	1	1		1	1		1
Product 19	1			1		1	1
Product 20		1		1		1	

Step 3: Each column from step 2 is multiplied by “power of 2” row value. “Sum” column is added and so value for each row is also to be added.

Table 26: Step 3 of Product Family Matrix

	1	2	4	8	16	32	64	
	A	B	C	D	E	F	G	SUM
Product 1	1	0	4	8	0	32	64	109
Product 2	0	2	0	8	0	32	0	42
Product 3	1	0	0	8	0	32	64	105
Product 4	0	0	4	8	0	32	64	108
Product 5	1	2	0	8	16	0	64	91
Product 6	1	0	0	8	0	0	64	73
Product 7	0	2	0	0	16	0	64	82
Product 8	0	2	0	8	0	32	0	42

Product 9	**0**	**2**	**0**	**8**	**0**	**32**	**0**	**42**
Product 10	**1**	**2**	**0**	**8**	**16**	**0**	**64**	**91**
Product 11	**0**	**2**	**0**	**8**	**0**	**32**	**0**	**42**
Product 12	**1**	**0**	**0**	**8**	**0**	**32**	**64**	**105**
Product 13	**0**	**2**	**0**	**0**	**16**	**0**	**64**	**82**
Product 14	**1**	**0**	**4**	**8**	**0**	**32**	**64**	**109**
Product 15	**0**	**2**	**0**	**8**	**16**	**0**	**64**	**90**
Product 16	**0**	**2**	**0**	**8**	**0**	**32**	**0**	**42**
Product 17	**1**	**0**	**4**	**8**	**0**	**32**	**64**	**109**
Product 18	**1**	**2**	**0**	**8**	**16**	**0**	**64**	**91**
Product 19	**1**	**0**	**0**	**8**	**0**	**32**	**64**	**105**
Product 20	**0**	**2**	**0**	**8**	**0**	**32**	**0**	**42**

Step 4: Sum column is sorted in descending order. “Power of 2” column is then created. Power values are assigned to rows.