CHAPTER 1

INTRODUCTION

1.1 Background of Study

The company will be succeeding only if they can fulfill the required number of output to their customers based on the schedule. It is important to ensure that the production capacity with the demand is balanced. Therefore, the company needs to have the proper production plan to satisfy market demand besides minimizing the cost. Without production planning, the company will face difficulty to accomplish the production capacity with the forecasted demand levels, the number of new man power to hire for upcoming months', years' or weeks' production, the inventory levels and to achieve the production goal. The strategic production plan is aggregate production plan. An aggregate plan is the process of planning an operation's total production effort to satisfy market demand (Filho, Souza, & Almeida, 2006).

The aggregate plan can be apply either in manufacturing area or services area. It is important to develop the company production rates, workforce level and inventory level based on the demand. Moreover, aggregate planning allows the managers to recognize costly plant underutilization and over utilization in the next time periods. Aggregate planning initiate with a forecast of the predictable demand for the intermediate range and followed by the general plan to meet demand obligation by setting output, employment and inventory levels. There are some significant information needs to recognize for effective aggregate planning which are available recourses over period, forecast expected demand and the policies of the company.

1.2 Problem Statement

Aggregate plan for the production is very important because the company needs to have the accurate plan to construct the master production schedule, material requirement planning systems and details work schedules. Definitely, customer satisfaction regarding on time schedule performance is critical in a highly competitive manufacturing industry. The company can lose their tender and thrust believes of the customer if the product delivered is out of schedule and bad quality product.

Occasionally the equipment in the factory can break down. This situation also will affect the productivity of the plant. So, the delivery schedule to the customer changes. To avoid it, the manager needs to decide whether the part time is used or overtime should be apply to absorb this problem. The manager also needs to consider about the cost that effect the decision. In order to reduce this problem, an appropriate planning should be made where it can minimize the cost while increase the productivity. This project concerns of the constraint work force level strategy for manufacturing of disc brake.

1.3 Objective

- To develop an aggregate planning model for manufacturing of discrete component : A case study for disc brake manufacturing

1.4 Scope of Study

- The manufacturing processes of discrete component consisting of casting and machining process
- Developing 2 types of aggregate planning strategy for the production of discrete component namely production level and constant workforce.
- The project uses the spreadsheets excel and compare with linear programming as the result of the project.
- The models uses applied to disc brake manufacturing.

1.5 The Relevance of the Project

The case study of the disc brake is significance to the scope of study which is involving casting and machining process. The aggregate planning of the disc brake is relevance to the production of car since the production of disc brake is dependent to the production of car. This project gives more understanding in production planning process and be more familiar with the linear programming which is beneficial for the future. Besides that, the author created a new standard template spreadsheet which are easier and friendly user compare to linear programming. The author also does sensitivity analysis on the incremental costs to the total production aggregate planning cost.

1.6 The Feasibility of The Project

This project need more research on understanding the strategies of aggregate planning in order to complete it. The aggregate plan also needs to be done frequently to ensure the project succeeds. This project could be complete if the work flow is according to the plan and objective can be achieved if the procedure is correct and followed thoroughly.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

As the term aggregate denotes, the aggregate plan means combining appropriate recourses into general or overall terms. Given the demand forecast, facility capacity, inventory levels, workforce size and related inputs, the engineer has to select the rate of output for future facility. A literature review was conducted to understand the process flow of manufacturing discrete component involving casting and machining process, the aggregate planning, types of forecasting, understanding on linear programming, a few revisions on disc brake and investigate the data of the production car.

2.2 Manufacturing of the discrete component involving casting and machining process.

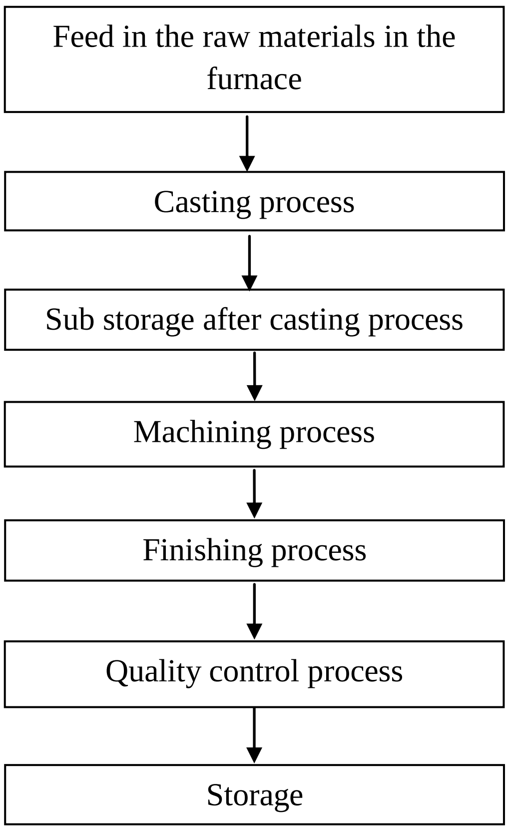

Figure 2.1: Manufacturing process flowchart of discrete components involving casting and machining process

2.3 The aggregate planning

The method necessary for the aggregate planning will be differing for each company based on the products and services provide. The company will define the new products and services that it plans to continue offer in the next year or two as well as the existing products and services that it plans to continue offering (Tripathy, 2007). Then, the forecast for new product and existing products are created. The forecast of the company will generate the product demand. Aggregate planning consists of drawing up the strategy to meet demand (Filho, Souza, & Almeida, 2006).

Basic functions of aggregate planning are (Tripathy, 2007):

1. To be the origin of the production, planning and control process to develop for the operation area
2. To be an instrument of control of the strategic plan.
3. To allow all demand to be met
4. To keep production relatively stable
5. To keep within the constraint of capacity plan
6. To meet any other specific objectives and constraints.

There are two types of aggregate planning which are the aggregate production planning and aggregate capacity planning. The aggregate production planning deals with the output side of the plan (R.B.Khanna, 2007), while for the aggregate capacity planning ensure the enough capacity to meet the demand expressed in the aggregate output plan. The aggregate product is a representative product of the product family not the specific individual product. For example, Tata Motors make different models cars like the Indica, Indigo and Safari, but at the aggregate production planning stage the target may be produce a ten thousand cars in the year where car is a representative product of the family and is assumed to consume a standard amount of resources to help the capacity requirement (R.B.Khanna, 2007). The plan is manage by the accessibility of capacity and company's overall policies for sustaining inventories, backorders, employee policies and subcontracting. On the other hand, the aggregate capacity needs to plan on how the capacity will be utilized and on how to improve the over or under capacity. 3 basic planning strategies to arrive at an acceptable aggregate plan are:

2.3.1 Chase strategies (zero inventory strategy)

The chase strategy matches demand during the planning horizon by varying either workforce level or output level (Ritzman & Krajewski, 2003). In this strategy, the production capacity change according to demand (M.Takey & A.Mesquita, 2006). It will require a high flexible production system which the inventory tends to be lower but with the higher labor costs. Varying the output rate to match the demand may cause the changes of the workforce level. Sometimes it called the utilization strategy because the timing of the workforce's utilization is change overtime and under time.

2.3.2 Constant workforce level strategies

The level strategy maintains a constant workforce level or constant during planning horizon (Ritzman & Krajewski, 2003). Opposite to the chase strategies, the level strategy hunts for a smooth production capable to accomplish total demand capacity in planning period with the constant workforce. Besides that, the expectation inventory, backorders and stock out are supplementary to the list of possible reactive alternatives. Therefore it is sometimes known as inventory strategies. The advantages of stable workforce are increase under time, overtime and inventory.

2.3.3 Mixed strategies

The mixed strategies are combination between the level strategies and chase strategies to produce the best acceptable aggregate plan. This strategy considers and implements a fuller range of hasty alternatives and goes further than a chase or level strategies. Usually the company uses overtime, temporary workforce and outsourcing for the mixed strategies.

All of the alternatives will involve directly or indirectly to the cost. So the models of the aggregate planning should have the solution to minimize the total production cost during the period of production planning. The production cost in each period time include the costs that vary according to the number of employees hired or fired, the number of units stored in the stock and the number of units produced in each of the respective production schedule. The appropriate costs are calculated as follows (J.Stevenson, 1996):

Table 2.1: Type of cost and its formula

Types of cost	**The formula**
Output cost • Regular • Overtime • Subcontract	 *Regular cost per unit × Quantity of regular output* *Overtime cost per unit × Overtime quantity* *Subcontract cost per unit × Subcontract quantity*
• Hire • Fire	*Cost per hire × Number of hired* *Cost per fire × Number of fired*
Inventory	*Carrying cost per unit × Average inventory*
Back order	*Back order cost per unit × Number of back order units*

The amount of inventory at the end of given period is (J.Stevenson, 1996):

$$\textit{Inventory at the end of period} = \textit{Inventory at the end of previous period} + \textit{Production in the current period} - \textit{Amount used to satisfy demand in current period}$$

Cost of the production plan for a given period (J.Stevenson, 1996):

$$\textit{Total cost production} = \textit{Total output cost} + \textit{Total hire/ fire cost} + \textit{Inventory cost} + \textit{Back order cost}$$

2.4 The forecasting

Forecasting is art of predicting future events which involved the historical data and extrapolative the data into the future with some sort of mathematical model. In today's market driven production system, forecasts are most important because it predict the future which will affect the profit or loss of company. The forecast is also known as future time horizon and it has 3 categories which are (Render, 2006):

- Short range forecast
  - ✓ Time span of up to 1 year but generally less than 3 months.
  - ✓ Used for planning purchasing, job scheduling, workforce levels, job assignments and production levels

- Medium range forecast
    - ✓ Time spans from 3 months to 3 years.
    - ✓ Useful in sales planning, production planning and budgeting, cash budgeting and analyzing various operating plans.
- Long range forecast
    - ✓ Time spans 3 years or more
    - ✓ Useful in planning for new product, capital expenditures, facility location and RND.

Mostly the organization use 3 major types of forecast in planning future operations are economic forecasts, technological forecast and demand forecast. There are 2 type approaches to forecasting which quantitative and qualitative forecast. There are 4 varieties qualitative techniques which are (Render, 2006):

- Jury of executive opinion
    - opinions of a group of high level expert, frequently in combination with statistical models
- Delphi method
    - 3 different types of participants which are decision makers, staff personnel and respondents.
- Sales force composite
    - Each sales person estimates what sales will be in his region. The forecasts are then reviewed to ensure that they are realistic.
- Customer market survey
    - It can help not only in preparing a forecast but also improving product design and planning for new product.

While for quantitative methods, there are 2 types of models which are time series models and associative model. Time series models predict on the assumption that the future is a function of the past. They look at the past data and use to make a forecast. Decomposition of time series has 4 components which are trend, seasonality, cycles and random variations. The methods on forecast using time series are (Render, 2006):

- Naïve approaches which assume that the demand in the next period will be equal to demand in the most recent period
- Moving averages uses a number of historical actual data values to generate a forecast. It is useful if assume that the market demands will stay fairly steady over time. The formula are:

  $$Moving\ average = \frac{\sum demand\ \ in\ previous\ \ n\ periods}{n} \quad . \quad . \quad . \qquad (1)$$

- Exponential smoothing is a sophisticated weighted moving average forecasting method that is still fairly easy to use. The basic formula is

  $$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1}) \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

  Where

  F_t = New forecast

  F_{t-1} = Previous forecast

  α = smoothing constant

  A_{t-1}= Previous period's actual demand

- Trend projections technique fits a trend line to a series of historical data points and then projects the line into future for medium to long range forecast. Several mathematical trend equations can be developed for example, exponential and quadratic.

The Associate models or known as causal models is incorporating the variables that might influence the quantity being forecast (Render, 2006). The most common model is linear regression analysis.

2.5 Linear Programming

Linear programming is a widely used mathematical technique designed to help operations managers plan and make decisions necessary to allocate resources (Render, 2006). There are 2 basic assumptions of linear programming are variables are linear and continuously divisible. Hanssman and Hess (1960) first formulated aggregate planning as a linear programming model (Daniel Sipper& Robert L.Buflin, 1998). The others example linear programming applications are production mix, production schedule and labor schedule. There are 4 types of requirements of a linear programming problem which are (Render, 2006):

- Objective function which typical firm to maximize or minimizes some quantity.
- The constraints are restrictions that limit the degree to which a manager can pursue an objective.
- There must be alternative courses of action to choose from.
- The objective and constraints in linear programming problems must be expressed in term of linear equations.

The easiest method to solve a small linear programming is the graphical solution approach. This method can be applied only when there are two decision variables. In order to know the value of each decision variable and the value of the objective is by sensitivity analysis. Sensitivity analysis is an analysis that projects how much a solution may change if there are changes in data variables or input data (Render, 2006). There are 2 approach can be done to determine the sensitivity of the data to the changes which are trial and error method and analytic post optimality method. The equations of linear programming are:

$x_{ij} = decision\ varies$

$c_{ij} = cost\ varies$

$$\max or\ min; z = \sum_{i=1}^{j} \sum_{j=1}^{n} c_{ij} x_{ij} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

Subject to;

Workforce, production, hired, lay off, inventory and subcontracting.

With;

$$x_{ij} \geq 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (4)$$

$$x_{ij} = integer \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

2.6 Disc Brake

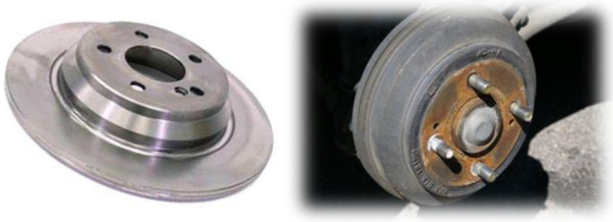

Figure 2.2: Disc brake rotor and drum brake

In early days of the automobile, drum brakes were the best types of brake which could release the water and dust. But the main problem with drum brakes is that the heat is not efficiently distributed since the drum prevents wind from drawing it away. On 1918, the invention of four wheels hydraulic brake system by Malcolm Loughead. This type of brake replaced the mechanical system brake that use at that time. However, the hydraulic brake made it difficult to stop all the wheels because it required the drivers to apply high force on brake pedal to slow the car and frequently causing loss of control. On 1950's, Chrysle was the first introduced the disc brake in cars. The system did not have much success till Studebaker reintroduce the system in 1964. The cause that disc brake were success during Studebaker was due to the development of the power braking system (M. Zaid Akop, 2007).

Disc brake is a device for slowing or stopping the rotation of a wheel. The disc brake has a grey cast iron consisting of flake graphite in a pearlitic matrix. In selecting materials for the disc brake, it is necessary to consider the coefficient of friction of the material and its thermal properties since considerable heat is generated during braking (Holme,John David,1999). The disc brake is coupled to the wheel of the car. The wheel will stop by the friction force that forms by the brake pads which mounted on the brake caliper against both sides of the disc. Disc brake has 2 styles which are solid and vented. The friction surface of solid brake disc is on the opposite's side of the solid piece of metal. The solid discs do not cool as well as the vented. While a vented disc brake has radial cooling passages cast between its friction surfaces (Rehkopf, 2006). The function of passages are allow the disc to turn as a centrifugal fan that draws cooling air into the center of disc and forces it out at the edges. Lower operating temperatures increase both disc and brake pad life and improve fade resistance (Rehkopf, 2006).

A ventilated disc is casted with mesh like assembly between two friction surfaces. The mesh emits from a center of the rotor much like vanes or fins in a fan. As the disc turns, air is drawn into the disc at its center, flows between the friction surfaces and discharged along the outer edge (Jack Erjavec (2005). The ventilated disc reduces the probability of brake fade, even during multiple hard stops.

2.7 The data for the production cars

According to Malaysia Automobile and Associate of Malaysia website, the summary of commercial vehicles registered in Malaysia for year 1980 to 2011 was increasing every year as shown in Table 2.2. The example on commercial vehicles are trucks, prime movers, pick up, panel vans and bus.

Table 2.2: Summary of vehicles registered in Malaysia for the year 1980 to 2011

Year	Passenger Cars	Commercial Vehicles	4x4 Vehicles	Total Vehicles
1980	80,420	16,842	-	97,262
1985	63,857	26,742	4,400	94,999
1990	106,454	51,420	7,987	165,861
1995	224,991	47,235	13,566	285,792
2000	282,103	33,732	27,338	343,173
2005	416,692	97,820	37,804	552,316
2006	366,738	90,471	33,559	490,768
2007	442,885	44,291	-	487,176
2008	497,459	50,656	-	548,115
2009	486,342	50,563	-	536,905
2010	543,594	61,562	-	605,156
2011	535,113	65,010	-	600,123
YTD March 2012	122,837	15,707	-	138,544

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the author will show the 2 types of methodology which are research methodology and aggregate planning methodology. The author also will explain regarding the project activity and the forecast method.

3.2 Research Methodology

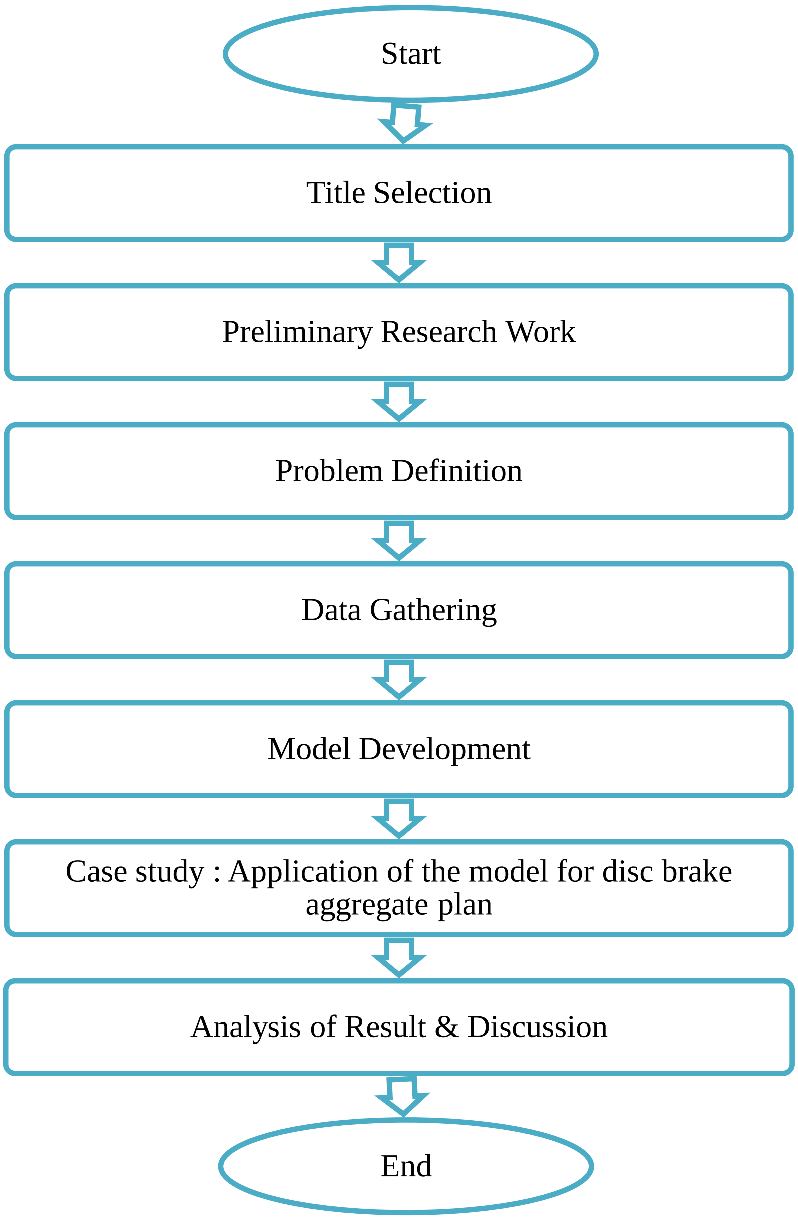

Figure 3.1: Flowchart of research methodology

3.3 Aggregate planning process

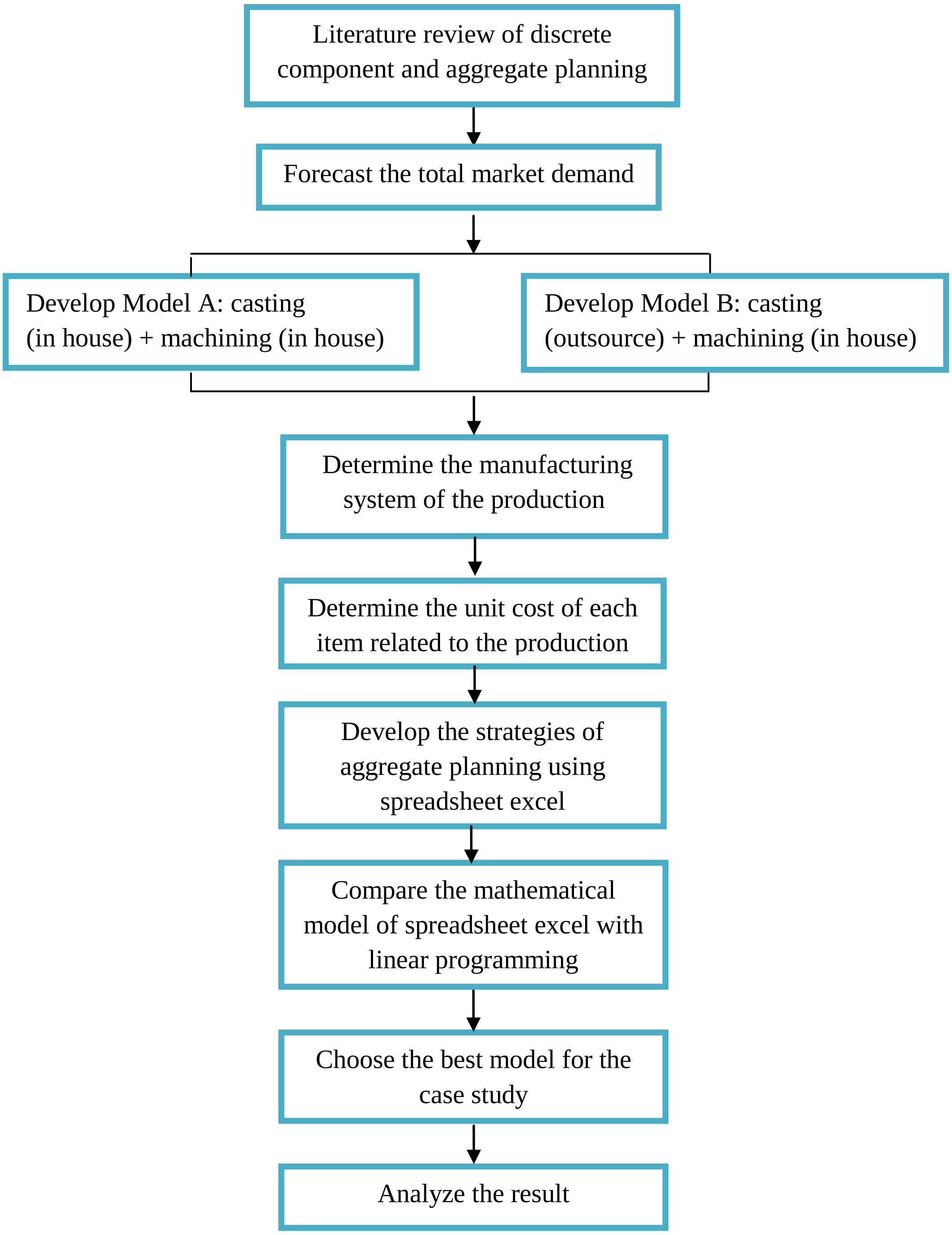

Figure 3.2: Flowchart of aggregate planning process for discrete component

3.4 Details on aggregate planning procedure

- Develop the 2 models of planning which are
  - ✓ operate the casting and machining in the factory = model A
  - ✓ subcontract the casting process and operate the machining process in the factory = model B
- Develop the forecast model of the disc brake to determine the quantity and timing of the production.
- Determine the costs related to the production of the discrete component.
- Compare the model A and model B and select the least costly and preferable by using spreadsheet excel approaches for aggregate planning
- Linear programming is used to ensure the optimum results

3.5 Details on the spreadsheet excel study

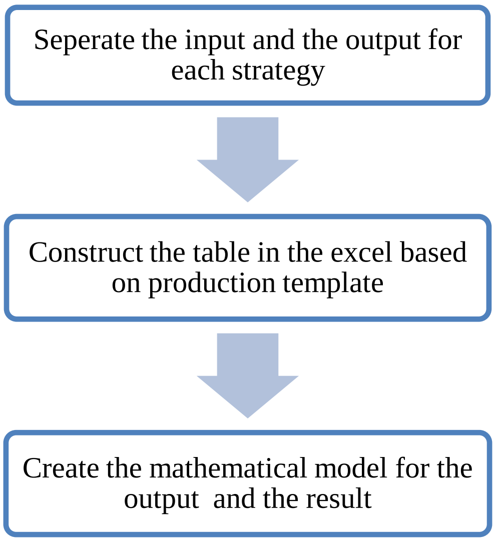

Figure 3.3: Flowchart of development aggregate planning by using excel

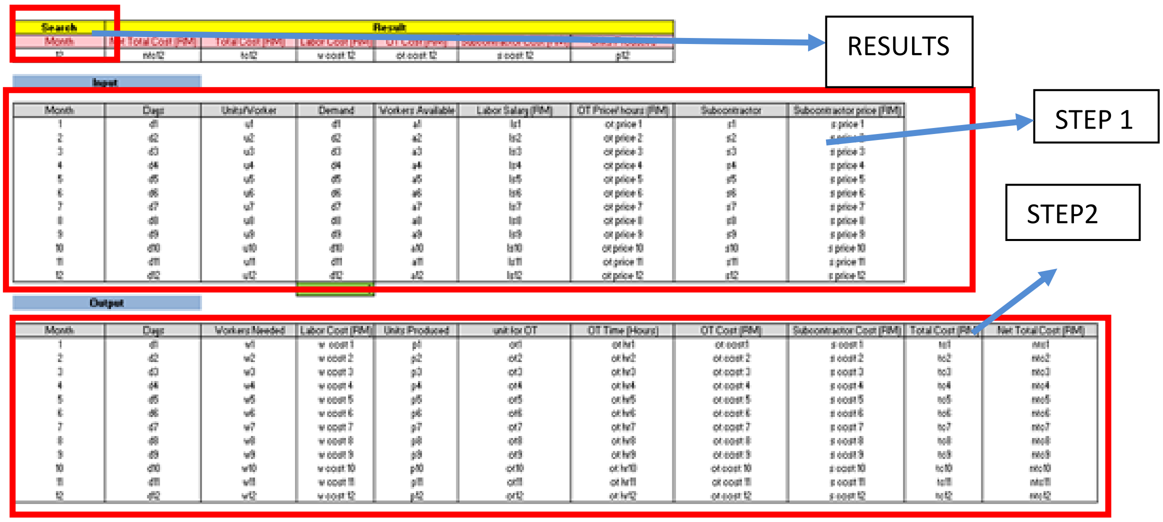

Figure 3.4: Methodology to get the result from excel

- Step 1: Key in the input data. The result will appear at the output.
- Step 2: Key in the mathematical model in the output box.

For model A and model B is using the same mathematical models and same spreadsheet tables because the different between both models are the number of workers and number of unit per worker. The value of subcontract will be directly calculated in the total cost column.

3.6 Details on the linear programming study

- In this project, the author will like to minimize the total cost of production.

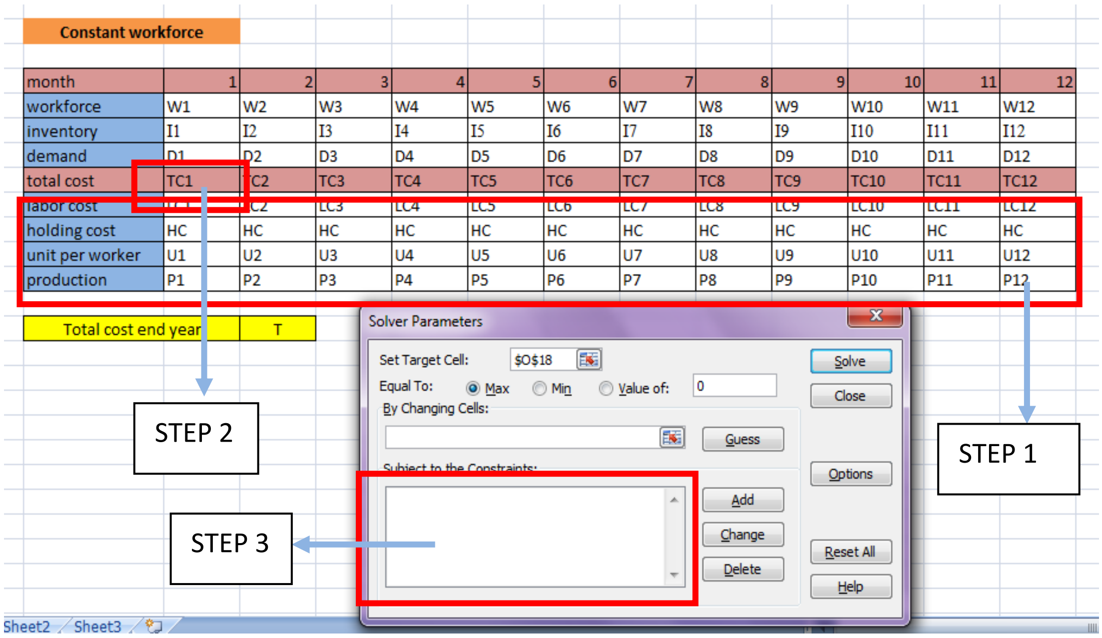

Figure 3.5: Methodology to construct the aggregate planning

- Step 1: Key in the costs needed for the variable
- Step 2: Propose the mathematical model for the objective
- Step 3: Put the constraints in the solver box

3.7 Case study: Details of disc brake

The product for the case study must have 2 types of manufacturing process which are casting and machining process. In this report, the author uses the disc brake as her case study on the aggregate planning.

- The disc brake rotor manufacturing process is:

    a) Casting process which not required high technology at production level.

    b) Then, the disc brake undergoes machining process such as grinding, drilling or pierced.

    c) Finishing process is needed to ensure the disc brake under quality control.

- Recognize the type of the machine whether automatic, semi automatic or manually use in manufacture the disc brake

- Identify the total number of workers need to operate on each machine and each process

- Make some assumptions to calculate the manufacturing system of the disc brake such as the plant capacity and production rate.

- Aggregate the production planning by using spreadsheet excel and linear programming

- Analyze the results of the disc brake.

3.8 Gantt Chart

Table 3.1: Gantt chart of FYP 1 and FYP 2

Activity	FYP 1				FYP 2			
	Feb	March	April	May	June	July	Aug	Sept
Title Awarded	X							
Research on aggregate planning and the manufacturing process of brake rotor.	X	X	X					
Calculate all the required parameters			X					
Draft the schedule for each strategy.				X				
Develop the models using spreadsheet excel				X	X			
Develop the models using linear programming						X		
Report Completion							X	X

3.9 Key Milestone on FYP 2

Table 3.2: Key Milestones

Detail	Week
Develop the models using spreadsheet excel	1
Develop the models using linear programming	4
Poster presentation	10
Submission of dissertation	13
Submission of technical paper	13
Oral presentation	15

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In the results and discussion chapter, the author will show the mathematical model for manufacturing system, the spreadsheet excel and linear programming. In this session, the result for the mathematical model for linear programming and spreadsheet will be shown. All the result will be discuss in the last sub title.

4.2 Template spreadsheet excel for discrete component

The symbols in the tables below show the rows in the spreadsheet excel. The details of the formula for each strategy will be including in the output tables. For the results, the author creates a new table to facilitate the user to find the details per month. The user just need to put the required month and then the details will appear in the table.

X = number of rows of variable

Y = X + 16 rows from X

- *Constant workforce level*

Table 4.1: Details of spreadsheet excel for constant workforce level

Input	Symbols
• Days	D
• Units/ worker	E
• Demand	F
• Worker available	G
• Labor salary (RM)	H
• Holding price (RM)	I
• Subcontractor	J
• Subcontractor price (RM)	K
• Material cost (RM)	L
Output	
Labor cost (RM)	= PRODUCT(G_X,H_X)
Unit produce	= PRODUCT(E_X,G_X)

Inventory	$= F_Y – F_X$
Net inventory	$= G_Y$
Holding cost	$= \text{PRODUCT}(I_X,H_Y)$
Subcontractor cost	$= J_X + K_X$
Total cost	$= I_Y + E_Y + J_Y + (L_X * F_Y)$
Net total cost	$= K_Y + K_{Y-1}$
Results	
Month	= C
Net total cost (RM)	= LOOKUP(C7,C12:C23,L28:L39)
Total cost (RM)	= LOOKUP(C7,C12:C23,K28:K39)
Holding cost (RM)	= LOOKUP(C7,C12:C23,I28:I39)
Labor cost (RM)	= LOOKUP(C7,C12:C23,E28:E39)
Subcontractor cost (RM)	= LOOKUP(C7,C12:C23,J28:J39)
Unit produced	= LOOKUP(C7,C12:C23,F28:F39)

❖ *Production level*

Table 4.2: Details of spreadsheet excel for production level

Input	Symbols
• Units/ worker	D
• Demand	E
• Hiring price (RM)	F
• Layoff price (RM)	G
• Labor salary (RM)	H
• Subcontractor	I
• Subcontractor price (RM)	J
• Material cost (RM)	K
Output	
Worker needed	$= \text{ROUND}(E_X/D_{X,}\ 0)$
Worker available	$= D_{X-1}$

Worker hired	= IF(E_X>D_Y, D_Y – E_X,0)
Hiring cost (RM)	= F_X*F_Y
Worker laid off	= IF(D_Y<E_X, D_Y – E_X,0)
Lay off cost (RM)	= ABS(H_Y,G_X)
Labor cost (RM)	= PRODUCT(D_Y,I_X)
Subcontractor cost(RM)	= I_X*J_X
Unit produce	= PRODUCT(D_X,D_Y)
Total cost	= G_Y + I_Y + J_Y + K_Y + (K_X*L_Y)
Net total cost	= N_Y + O_{Y-1}
Results	
Month	= B
Net total cost (RM)	= LOOKUP(B7,B12:B23,O28:O39)
Total cost (RM)	= LOOKUP(B7,B12:B23,N28:N39)
Hiring cost (RM)	= LOOKUP(B7,B12:B23,G28:G39)
Lay off cost (RM)	= LOOKUP(B7,B12:B23,I28:I39)
Subcontractor cost (RM)	= LOOKUP(B7,B12:B23,K28:K39)
Labor cost (RM)	= LOOKUP(B7,B12:B23,J28:J39)
Unit produced	= LOOKUP(B7,B12:B23,L28:L39)

4.3 Template of linear programming for discrete component

W_t = workforce size for the month t

H_t = number of workers hired at month t

F_t = number of workers fired at month t

C_t = number of unit subcontracted for month t

B_t = number of units backorder at end of month t

I_t = inventory at end of month t

P_t = Production in month t

D_t = demand of month t

x_1 = the labor cost

x_2 = the inventory cost

x_3 = the hiring cost

x_4 = the layoff cost

x_5 = the material cost

x_6 = the subcontractor cost

4.3.1 Model A

Table 4.3: Objectives of linear programming for model A

Types of strategy	Objective
Constant workforce	Min = $\sum x_1 W_t + x_2 I_t + x_5 P_t$
Production level	Min =$\sum x_3 H_t + x_4 L_t + x_1 W_t + x_5 P_t$

Table 4.4: Constrains of linear programming for model A

Types of strategy	Constraints
Constant workforce	▪ $W_t, I_t \geq 0$ ▪ $P_t = U_t * W_t$ ▪ $W_t = W_{t-1}$ ▪ $W_t = integer$ ▪ $I_t = P_t - D_t$
Production level	▪ $W_t, L_t, H_t \geq 0$ ▪ $W_t, L_t, H_t = integer$ ▪ $L_t = WA_t - W_t$ ▪ $H_t = W_t - WA_t$ ▪ $P_t = U_t * W_t$ ▪ $W_t = W_{t-1}$

4.3.2 Model B

Table 4.5: Objectives of linear programming for model B

Types of strategy	Objective
Constant workforce	Min = $\sum x_1 W_t + x_2 I_t + x_6 S_t + x_5 P_t$
Production level	Min =$\sum x_3 H_t + x_4 L_t + x_1 W_t + x_5 P_t + x_6 S_t$

Table 4.6: Constrains of linear programming for model B

Types of strategy	Constraints
Constant workforce	▪ $W_t, I_t, S_t \geq 0$ ▪ $P_t = U_t * W_t$ ▪ $W_t = W_{t-1}$ ▪ $W_t = integer$ ▪ $I_t = P_t - D_t$
Production level	▪ $W_t, L_t, H_t, S_t \geq 0$ ▪ $W_t, L_t, H_t, S_t = integer$ ▪ $L_t = WA_t - W_t$ ▪ $H_t = W_t - WA_t$ ▪ $P_t = U_t * W_t$ ▪ $W_t = W_{t-1}$

4.4 Case study: Disc brake

4.4.1 Forecasting

Based on the literature review, the author uses the production cars data from MAA to forecast the demand by using average method because the data is not constant increasing. Table and graph below show the trend of the production passenger cars in Malaysia.

Table 4.7: Production passenger cars in Malaysia

Year	No of cars
2005	416,692
2006	366,738
2007	442,885
2008	497,459
2009	486,342
2010	543,594
2011	535,113
total	**3,288,823**

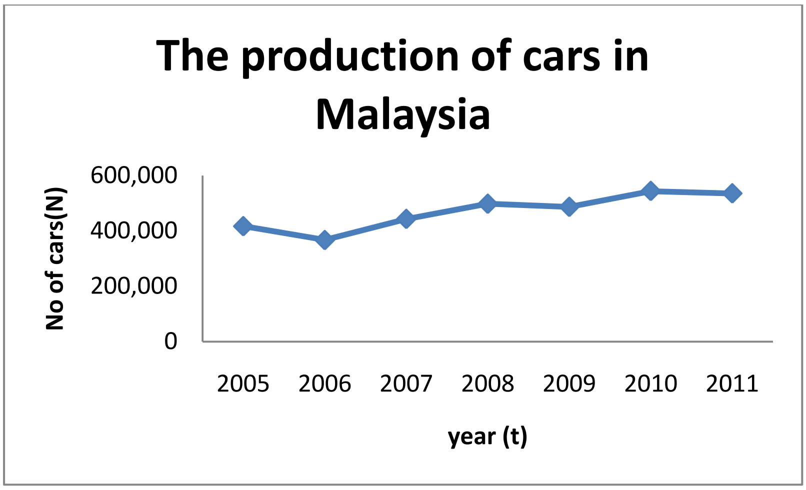

Figure 4.1: Production passenger cars in Malaysia shows in graph

- The total production cars are 3288,823 since 2005 until 2011.
- To find the demand for the forecast:

$$Forecast = \frac{\sum N}{t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

Where

$\sum N$ = Number of cars

t = Number of years

$$Forecast = \frac{3{,}288{,}823}{7}$$

$$= \mathbf{469,832}$$

In this project, the author assumes that the production cars in Malaysia use 2 disc brakes for each car. So the total number of the disc brake need to produce for the next year is **939664 of disc brake.**

4.4.2 Manufacturing system

Assumption made:

- This manufacturing system is semi automatic.
- No defect rate
- Availability of the machine is 100%
- The cycle time for the casting process is 5 minutes while machining process is 7 minutes.

- One machine for one worker.
- 4 weeks per month
- The company has 3 shifts per day and 7 hours per shift.

The total disc brake produce per year is 939,664. So demand forecast **per month is 78,305 units. The availability time is 525 hours per month.**

Production rate (R_p) is:

$$R_p = \frac{60}{T_c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

Workload of the production per month (WL) is:

$$WL = QT_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

Number of machine (n) is:

$$n = \frac{WL}{AT} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (9)$$

Plant capacity of the plant:

$$PC = nS_W H_{sh} R_p \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (10)$$

Where

$n = number\ of\ machine$

$S_w = shift\ per\ month$

$H_{sh} = total\ hours\ per\ shift\ per\ month$

Table 4.8: Manufacturing system for the disc brake

Process	Workload (WL)	Number of machine (n)	Utilization of the machine (%)	Plant capacity per month
Casting	6525.4	12.4~13	95.4	81,900
Machining	9135.6	17.4~18	96.7	81,000

a) So, for the model A the total machine use is 31 machines. Based on the assumption, the minimum numbers of workers needed are 31 workers. Each worker need to produce 2,526 units per month.

b) While for model B, the total numbers of workers are 18 workers. Each worker need to produce 4,351 units per month.

This numbers of worker will be used in the constant workforce level strategy and as the worker available for first month of the year for production level strategy.

4.4.3 Spreadsheet excel

Below are the lists of cost estimation:

- → Hiring cost = RM 300 per person
- → Firing cost = RM 500 per person
- → Labor cost = RM 800 per person per month
- → Inventory cost = RM 1 per unit
- → Subcontractor cost = RM 45 per unit
- → Material cost for model A = RM 30 per unit
- → Material cost for model B = RM 10 per unit

Table 4.9: Results aggregate planning by using excel

Models	Constant workforce (RM)	Production level (RM)
A	28,593,923	28,494,160
B	51,961,776	51,856,720

Constant Workforce Level

Search	Result				
Month	Net Total Cost (RM)	Total Cost (RM)	Holding cost (RM)	Labor Cost (RM)	Units Produced
12	28593923	2384424	10114	24800	78306

Input

Month	Days	Units/Worker	Demand	Workers Available	Labor Salary (RM)	Holding Price (RM)	Material cost (RM)
1	25	2526	78,305	31	800	1	30
2	20	2526	70,727	31	800	1	30
3	25	2526	78,305	31	800	1	30
4	25	2526	75,779	31	800	1	30
5	25	2526	78,305	31	800	1	30
6	25	2526	78,305	31	800	1	30
7	25	2526	88,409	31	800	1	30
8	25	2526	78,305	31	800	1	30
9	25	2526	78,305	31	800	1	30
10	25	2526	78,305	31	800	1	30
11	25	2526	78,305	31	800	1	30
12	25	2526	78,317	31	800	1	30
			939,672				

Output

Month	Days	Labor Cost (RM)	Units Produced	Inventory	Net Inventory	Holding Cost (RM)	Total Cost (RM)	Net Total Cost (RM)
1	25	24800	78306	1	1	1	2373951	2373951
2	20	24800	78306	7579	7580	7580	2154190	4528141
3	25	24800	78306	1	7581	7581	2381531	6909672
4	25	24800	78306	2527	10108	10108	2308278	9217950
5	25	24800	78306	1	10109	10109	2384059	11602009
6	25	24800	78306	1	10110	10110	2384060	13986069
7	25	24800	78306	0	10110	10110	2687180	16673249
8	25	24800	78306	1	10111	10111	2384061	19057310
9	25	24800	78306	1	10112	10112	2384062	21441372
10	25	24800	78306	1	10113	10113	2384063	23825435
11	25	24800	78306	1	10114	10114	2384064	26209499
12	25	24800	78306	0	10114	10114	2384424	28593923

Figure 4.2: Results excel constant workforce level model A

Production Level

Search	Result					
Month	Jet Total Cost (RM	Total Cost (RM)	Hiring cost (RM)	Lay off Cost (RM)	Labor Cost (RM)	Units Produced
12	28494160	2373980	0	0	0	78306

Input

Month	Days	Units/Worker	Demand	Hiring Price (RM)	Lay off Price (RM)	Labor Salary (RM)	Subcontractor (unit)	Subcontractor price(RM)	Material cost (RM)
1	25	2526	78,305	300	500	800			30
2	20	2526	70,727	300	500	800			30
3	25	2526	78,305	300	500	800			30
4	25	2526	75,779	300	500	800			30
5	25	2526	78,305	300	500	800			30
6	25	2526	78,305	300	500	800			30
7	25	2526	88,409	300	500	800			30
8	25	2526	78,305	300	500	800			30
9	25	2526	78,305	300	500	800			30
10	25	2526	78,305	300	500	800			30
11	25	2526	78,305	300	500	800			30
12	25	2526	78,317	300	500	800			30
			939,672						

Output

Month	Days	Workers Needed	Workers Available	Workers Hired	Hiring Cost (RM)	Workers Laid Off	Lay Off Cost (RM)	Labor Cost (RM)	Subcontractor Cost (RM)	Units Produced	Extra production	Total Cost (RM)	Net Total Cost (RM)
1	25	31	31	0	0	0	0	24800		78306	1	2373980	2373980
2	20	28	31	0	0	-3	1500	22400		70728	1	2145740	4519720
3	25	31	28	3	900	0	0	24800		78306	1	2374880	6894600
4	25	30	31	0	0	-1	500	24000		75780	1	2297900	9192500
5	25	31	30	1	300	0	0	24800		78306	1	2374280	11566780
6	25	31	31	0	0	0	0	24800		78306	1	2373980	13940760
7	25	35	31	4	1200	0	0	28000		88410	1	2681500	16622260
8	25	31	35	0	0	-4	2000	24800		78306	1	2375980	18998240
9	25	31	31	0	0	0	0	24800		78306	1	2373980	21372220
10	25	31	31	0	0	0	0	24800		78306	1	2373980	23746200
11	25	31	31	0	0	0	0	24800		78306	1	2373980	26120180
12	25	31	31	0	0	0	0	24800		78306	0	2373980	28494160

Figure 4.3: Results excel production level model A

Constant Workforce Level

Search	Result					
Month	Net Total Cost (RM)	Total Cost (RM)	Holding cost (RM)	Sub cost (RM)	Labor Cost (RM)	Units Produced
12	51961776	4332070	10235	3524265	14400	78318

Input

Month	Days	Units/Worker	Demand	Workers Available	Labor Salary (RM)	Holding Price (RM)	Subcontractor	Subcontractor price (RM)	Material cost/Unit (RM)
1	25	4,351	78,305	18	800	1	78,305	45	10
2	20	4,351	70,727	18	800	1	70,727	45	10
3	25	4,351	78,305	18	800	1	78,305	45	10
4	25	4,351	75,779	18	800	1	75,779	45	10
5	25	4,351	78,305	18	800	1	78,305	45	10
6	25	4,351	78,305	18	800	1	78,305	45	10
7	25	4,351	88,409	18	800	1	88,409	45	10
8	25	4,351	78,305	18	800	1	78,305	45	10
9	25	4,351	78,305	18	800	1	78,305	45	10
10	25	4,351	78,305	18	800	1	78,305	45	10
11	25	4,351	78,305	18	800	1	78,305	45	10
12	25	4,351	78,317	18	800	1	78,317	45	10

Output

Month	Days	Labor Cost (RM)	Units Produced	Inventory	Net Inventory	Holding Cost (RM)	Subcontractor cost (RM)	Total Cost (RM)	Net Total Cost (RM)
1	25	14400	78318	13	13	13	3523725	4321188	4321188
2	20	14400	78318	7591	7604	7604	3182715	3911989	8233177
3	25	14400	78318	13	7617	7617	3523725	4328792	12561969
4	25	14400	78318	2539	10156	10156	3410055	4192401	16754370
5	25	14400	78318	13	10169	10169	3523725	4331344	21085714
6	25	14400	78318	13	10182	10182	3523725	4331357	25417071
7	25	14400	78318	0	10182	10182	3978405	4887077	30304148
8	25	14400	78318	13	10195	10195	3523725	4331370	34635518
9	25	14400	78318	13	10208	10208	3523725	4331383	38966901
10	25	14400	78318	13	10221	10221	3523725	4331396	43298297
11	25	14400	78318	13	10234	10234	3523725	4331409	47629706
12	25	14400	78318	1	10235	10235	3524265	4332070	51961776

Figure 4.4: Results excel constant workforce level model B

Production Level

Search	Result						
Month	Net Total Cost (RM)	Total Cost (RM)	Hiring cost (RM)	Lay off Cost (RM)	Sub cost (RM)	Labor Cost (RM)	Units Produced
12	51856720	4316390	0	0	3519810	14400	78318

Input

Month	Days	Units/Worker	Demand	Hiring Price (RM)	Lay off Price (RM)	Labor Salary (RM)	Subcontractor	Subcontractor price (RM)	Material cost/Unit (RM)
1	25	4351	73,900	300	500	800	73,900	45	10
2	20	4351	73,900	300	500	800	73,900	45	10
3	25	4351	82,550	300	500	800	82,550	45	10
4	25	4351	78,195	300	500	800	78,195	45	10
5	25	4351	78,207	300	500	800	78,207	45	10
6	25	4351	78,218	300	500	800	78,218	45	10
7	25	4351	82,467	300	500	800	82,467	45	10
8	25	4351	78,218	300	500	800	78,218	45	10
9	25	4351	79,218	300	500	800	79,218	45	10
10	25	4351	78,300	300	500	800	78,300	45	10
11	25	4351	78,273	300	500	800	78,273	45	10
12	25	4351	78,218	300	500	800	78,218	45	10
			939,664						

Output

Month	Days	Workers Needed	Workers Available	Workers Hired	Hiring Cost (RM)	Workers Laid Off	Lay Off Cost (RM)	Labor Cost (RM)	Subcontractor price (RM)	Units Produced	Net extra production	Total Cost (RM)	Net Total Cost (RM)
1	25	17	18	0	0	-1	500	13600	3325500	73,967	67	4078600	4078600
2	20	17	17	0	0	0	0	13600	3325500	73,967	67	4078100	8156700
3	25	19	17	2	600	0	0	15200	3714750	82,669	119	4556050	12712750
4	25	18	19	0	0	-1	500	14400	3518775	78,318	123	4315625	17028375
5	25	18	18	0	0	0	0	14400	3519315	78,318	111	4315785	21344160
6	25	18	18	0	0	0	0	14400	3519810	78,318	100	4316390	25660550
7	25	19	18	1	300	0	0	15200	3711015	82,669	202	4551185	30211735
8	25	18	19	0	0	-1	500	14400	3519810	78,318	100	4316890	34528625
9	25	18	18	0	0	0	0	14400	3564810	78,318	0	4371390	38900015
10	25	18	18	0	0	0	0	14400	3523500	78,318	18	4320900	43220915
11	25	18	18	0	0	0	0	14400	3522285	78,318	45	4319415	47540330
12	25	18	18	0	0	0	0	14400	3519810	78,318	100	4316390	51856720

Figure 4.5: Results excel production level model B

4.4.4 Linear programming

Tables below show the objectives for each model that being use in the case study. The constraints are same with the table 4.4 and 4.6.

Table 4.10: Objectives of linear programming for model A

Types of strategy	Objective
Constant workforce	Min = $\sum 800W_t + I_t + 30P_t$
Production level	Min =$\sum 300H_t + 500L_t + 800W_t + 30P_t$

Table 4.11: Objectives of linear programming for model B

Types of strategy	Objective
Constant workforce	Min = $\sum 800W_t + I_t + 45S_t + 10P_t$
Production level	Min =$\sum 300H_t + 500L_t + 800W_t + 10P_t + 45S_t$

Table 4.12 shows the results of aggregate planning and the figures below prove the results gained.

Table 4.12: Results aggregate planning by using linear programming

Models	Constant workforce (RM)	Production level (RM)
A	28,593,923	28,493,561
B	51,961,776	51,857,372

Constant workforce

month	1	2	3	4	5	6	7	8	9	10	11	12
workforce	31	31	31	31	31	31	31	31	31	31	31	31
inventory	1	7579	1	2527	1	1	0	1	1	1	1	0
Net inventory	1	7580	7581	10108	10109	10110	10110	10111	10112	10113	10114	10114
demand	78,305	70,727	78,305	75,779	78,305	78,305	88,409	78,305	78,305	78,305	78,305	78,317
total cost	2373951	2154190	2381531	2308278	2384059	2384060	2687180	2384061	2384062	2384063	2384064	2384424
labor cost	800	800	800	800	800	800	800	800	800	800	800	800
material cost	30	30	30	30	30	30	30	30	30	30	30	30
holding cost	1	1	1	1	1	1	1	1	1	1	1	1
unit per worker	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526
production	78,306	78,306	78,306	78,306	78,306	78,306	78,306	78,306	78,306	78,306	78,306	78,306

Total cost end year	28593923

Figure 4.6: Results linear programming constant workforce model A

Production level

month	1	2	3	4	5	6	7	8	9	10	11	12
worker available	31	31	27.9996	30.9996	29.9996	30.9996	30.9996	34.9996	30.9996	30.9996	30.9996	30.9996
worker lay off	0	3.000396	0.000397	1	0	0	0	4	0	0	0	0
workforce	31	27.9996	30.9996	29.9996	30.9996	30.9996	34.9996	30.9996	30.9996	30.9996	30.9996	30.9996
worker hiring	0	0	0	0	1.0001	0	5.011862	0	0	0	0	0
demand	78,305	70,727	78,305	75,779	78,305	78,305	88,409	78,305	78,305	78,305	78,305	78,317
total cost	2373950	2145710	2373950	2297870	2374250	2373950	2681773	2375950	2373950	2373950	2373950	2374310
labor cost	800	800	800	800	800	800	800	800	800	800	800	800
lay off cost	500	500	500	500	500	500	500	500	500	500	500	500
hiring cost	300	300	300	300	300	300	300	300	300	300	300	300
material cost	30	30	30	30	30	30	30	30	30	30	30	30
unit per worker	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526
production	78,305	70,727	78,305	75,779	78,305	78,305	88,409	78,305	78,305	78,305	78,305	78,317

Total cost end year	28493561

Figure 4.7: Results linear programming production level model A

Constant workforce

month	1	2	3	4	5	6	7	8	9	10	11	12
workforce	18	18	18	18	18	18	18	18	18	18	18	18
inventory	13	7591	13	2539	13	13	0	13	13	13	13	1
Net inventory	13	7604	7617	10156	10169	10182	10182	10195	10208	10221	10234	10235
demand	78,305	70,727	78,305	75,779	78,305	78,305	88,409	78,305	78,305	78,305	78,305	78,317
total cost	4321188	3911989	4328792	4192401	4331344	4331357	4887077	4331370	4331383	4331396	4331409	4332070
labor cost	800	800	800	800	800	800	800	800	800	800	800	800
material cost	10	10	10	10	10	10	10	10	10	10	10	10
subcontract cost	45	45	45	45	45	45	45	45	45	45	45	45
holding cost	1	1	1	1	1	1	1	1	1	1	1	1
unit per worker	4,351	4,351	4,351	4,351	4,351	4,351	4,351	4,351	4,351	4,351	4,351	4,351
production	78,318	78,318	78,318	78,318	78,318	78,318	78,318	78,318	78,318	78,318	78,318	78,318

Total cost end year	51961776

Figure 4.8: Results linear programming constant workforce model B

Production level

month	1	2	3	4	5	6	7	8	9	10	11	12
worker available	18	16.9846	16.9846	18.97265	18.97265	17.97449	17.97702	18.95357	17.97702	18.20685	17.99586	17.99585
worker lay off	1.015399	0	0	1.000919	0.998161	0	0	0.976557	0	0.210986	0	0
workforce	16.9846	16.9846	18.97265	17.97173	17.97449	17.97702	18.95357	17.97702	18.20685	17.99586	17.99585	17.99584
worker hiring	0	0	1.98805	0	0	0.002528	0.976567	0	0.229832	0	0	0
demand	73,900	73,900	82,550	78,195	78,207	78,218	82,467	78,218	79,218	78,300	78,273	78,218
total cost	4078595	4078088	4556025	4315603	4316264	4316372	4551141	4316860	4371624	4321002	4319412	4316387
labor cost	800	800	800	800	800	800	800	800	800	800	800	800
lay off cost	500	500	500	500	500	500	500	500	500	500	500	500
hiring cost	300	300	300	300	300	300	300	300	300	300	300	300
subcontractor cost	45	45	45	45	45	45	45	45	45	45	45	45
material cost	10	10	10	10	10	10	10	10	10	10	10	10
unit per worker	4,351	4,351	4,351	4,351	4,351	4,351	4,351	4,351	4,351	4,351	4,351	4,351
production	73,900	73,900	82,550	78,195	78,207	78,218	82,467	78,218	79,218	78,300	78,273	78,218

Total cost end year	51857372

Figure 4.9: Results linear programming production level model B

4.5 Discussion

The difference between the results obtained using linear programming and spreadsheet excel is very small, which the author can say that the mathematical model of spreadsheet were accurate. The differentiation occurred due to the some non integer value. This standard spreadsheet excel that the author create can be used in any types of manufacturing production planning. The users just need to follow the instruction to get the result. The diverse between linear programming and spreadsheet is the linear programming need high skill in mathematical to create every moment to construct the aggregate planning. The author found this complexity while doing the linear programming. Sometime, the linear programming gives the odd result although the formula for February is same with the March. The author needs to rewrite the formula until get the logic result. Thus it took time to construct the linear programming to ensure get the right result. There is a lacking in the spreadsheet excel for the production level strategy. Supposedly, the net inventory at end of the year must be zero units, but the result occurred is 100 units.

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Table 4.13: Differentiation between linear programming and spreadsheet excel

Models	Constant workforce (RM)	Production level (RM)
A	0	2.1022×10^{-5}
B	0	1.2573×10^{-5}

Table 4.14: Results round off linear programming production level model A

Month	Worker needed	Workers available	Workers hiring	Workers laid off	Total cost
1	31	31	0	0	2373950
2	28	31	0	3	2145710
3	31	28	3	0	2373950
4	30	31	0	1	2297870
5	31	30	1	0	2374250
6	31	31	0	0	2373950
7	35	31	4	0	2681770
8	31	35	0	4	2375950
9	31	31	0	0	2373950
10	31	31	0	0	2373950
11	31	31	0	0	2373950
12	31	31	0	0	2373950
				Net total cost	28493200

Table 4.15: Results round off linear programming production level model B

Month	Worker needed	Workers available	Workers hiring	Workers laid off	Total cost
1	17	18	0	1	4078600
2	17	17	0	0	4078100
3	19	17	2	0	4556050
4	18	19	0	1	4315625
5	18	18	0	0	4316285
6	18	18	0	0	4316390
7	19	18	1	0	4551185
8	18	19	0	1	4316890
9	19	18	1	0	4372490
10	18	19	0	1	4321400
11	18	18	0	0	4319415
12	18	18	0	0	4316390
				Net total cost	51858820

Table 4.14 and 4.15, show the results from round off the linear programming result especially their workforce level value. Based on the results, the differential between model A production level non integer value of linear programming with round off value is 1.267×10^{-5} while for model B is 2.9793×10^{-3} Linear programming produce the optimization results but sometimes it need to be corrected in the normal spreadsheet excel.

The author uses the average forecasting due to the inconstant demand of the production car in seven years from 2005 until 2011. Based on the results from spreadsheet excel and linear programming above, it shows that production level strategy produce least cost compare to constant workforce strategy for both models which is RM 28,494,160 per year; model A and RM 51,856,720 per year; model B. This is because the cost of net inventory per month is higher compared to hire or lay off the worker. For example in July for model A, the net cost of inventory is RM 10,110 while the hiring and lay off costs is RM 1,200. The constant workforce strategy produces a constant production every month which sometimes the value of production is higher compared to the demand. Whereas the production level strategy produces the disc brake same with the demand. In this strategy, the number of workers will vary depends on the demand.

The model B has higher production cost per year compared to the model A. This is due to the high cost of subcontracting casting process. The author assumes the cost per unit subcontracting disc brake is RM45. So, it is quite expensive for each unit. If the author considers the investment cost for the machining machine, casting machine and area of the factory, possibly the cost of model A will increase because the casting machine is expensive and it required the large area of the factory.

Based on the cost analysis in figure 4.10, shows that increasing the value of material cost give more affect to the total production cost for model A while in figure 4.11 for model B the incremental of subcontracting cost more sensitive to the total production of disc brake. From this analysis, the author can reduce the total production cost by decrease the value of material cost for model A and subcontracting cost for model B. The incremental of material cost and the holding cost do not influence much the total production cost. The result for the cost analysis for labor cost, holding cost, hiring cost and lay off cost shows less impact to the total production cost.

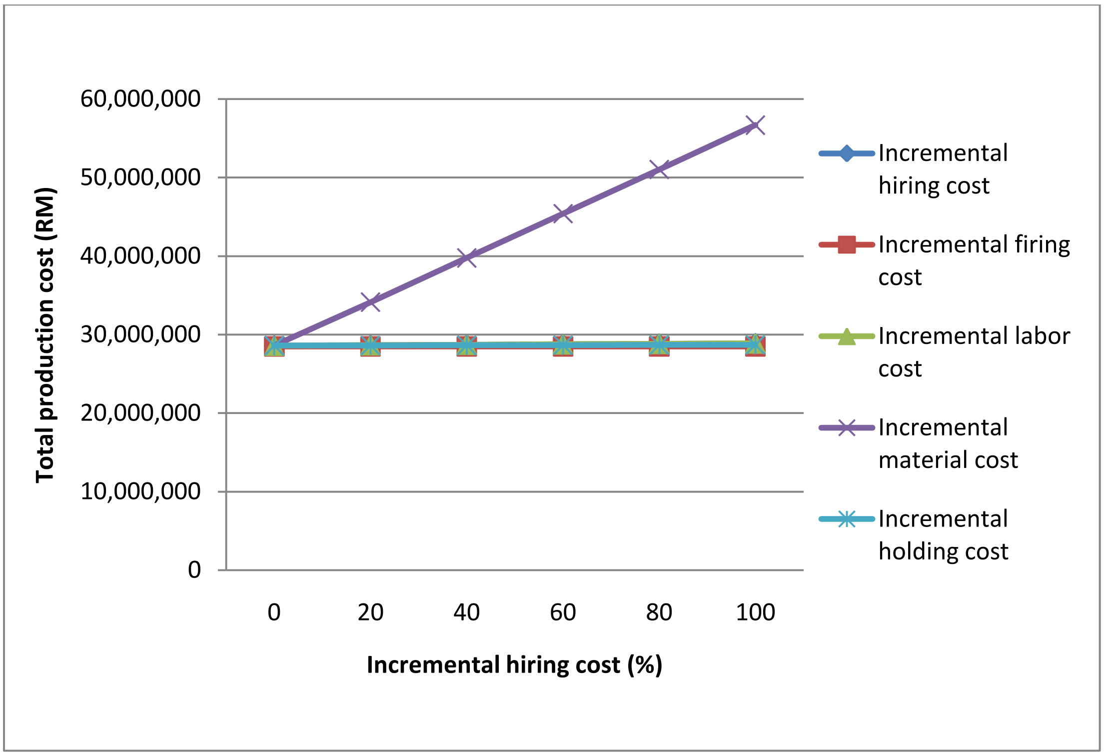

Figure 4.10: Graph of cost analysis for model A

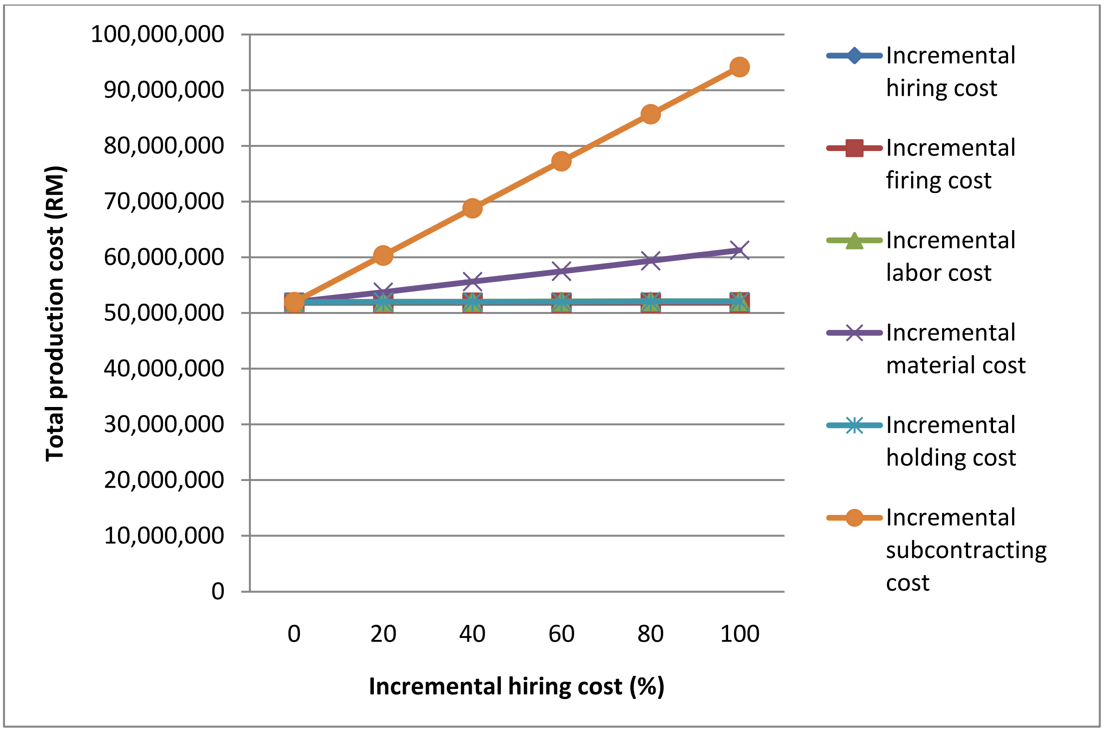

Figure 4.11: Graph of cost analysis for model B

Since the author assumes disc brake production is semi automatic, so one worker will operate one machine. The number of worker for model A is 31 workers while for model B is 18 workers. This is because in the model A, the author only need 18 workers to operate the machining process while model B, required additional 13 workers to operate casting process.

According to the manufacturing system result, the theoretical plant capacity per week is larger, compared to the production forecast per month which is 78,306 units. Otherwise, the author can reduce the number of machine to get the lower theoretical plant capacity, so that it is equivalent to the production forecast per week. Production performance can be increase by introducing that following activities by:

- ✓ Create the overtime per week
- ✓ Increase the efficiency of the machines
- ✓ Increase the number of units per worker which is 2,613 units per worker for model A and 4500 units per worker for model B.
- ✓ Use the multi cavity mold for the casting process
- ✓ Use the automatic machine for machining process

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The study shows that aggregate planning can be done by using spreadsheets excel and linear programming. Based on the literature reviews, most researches use the linear programming to conduct the production planning. So the author uses the different method to create the production planning which using spreadsheets excel. The author create the standard template table in spreadsheets excel for production planning that has machining and casting process. The total results can be compared by using the Microsoft solver. It shows that, the result for spreadsheets excel nearly same with the linear programming. From the author opinion, by construct the standard spreadsheets excel is more user friendly compare to the linear programming to get the aggregate planning.

There were six types of costs that the author considers to develop the mathematical model for spreadsheets excel which is labor cost, material cost, hiring cost, lay off cost, subcontracting cost and the inventory cost. Referring to the assumption, one worker for one machine, the total number of worker for model A is 31 workers whereas model B is 18 workers. It can be conclude during this moment that, the model B or subcontracting the casting process will produce higher production cost per year compare to the model A which is in house the process. The production level is the best strategy to get the lowest production cost of disc brake.

For further study, the author suggests that to create other standard spreadsheets excel for mix strategy which contain overtime and so on. Besides that, the author also will like to recommend creating the mathematical model for the manufacturing systems in the spreadsheet excel. Thus it can make easier for the user to create the production planning without need to calculate it.

REFERENCES

1. Filho, A. T., Souza, F. M., & Almeida, A. T. (2006). A Multicriteria Decision Model for Aggregate Planning Based on the Manufacturing Strategy. *Third International Conference on Production Research(ICPR).* Americas' Region 2006.

2. Takey, M., F. & Mesquita A. M. (2006). Aggregate Planning for a Large Food Manufacturer with High Seasonal Demand. *Brazilian Journal of Operations & Production Management* , Vol 3, No 1, pp 5-20.

3. Khanna, R.B. (2007). *Production and Operation Management.* New Delhi: Prentice' Hall of India.

4. Rehkopf, J. (2006). *Automative Brake Systems.* New Jersey: Pearson Education, Inc.

5. Ritzman, L. P., & Krajewski, L. J. (2003). *Foundations Of Operations Management.* New Jersey: Pearson Education, Inc

6. Tripathy, S. (2007). *Production and Operations Management.* Scitech Publications (India) PVT LTD.

7. Heizer J., & Render, B. (2001). *Operations Management.* New Jersey: Prentice Hall

8. Brauer, K. (2000), SYNC.SAY THE WORD. *Brakes: Drum vs. Disc*. Retrieved on 1st April 2012 from http://www.edmunds.com/car-technology/brakes-drum-vs-disc.html?articleid=43857

9. Buxey, G. (2005). Aggregate planning for seasonal:Reconciling theory with practice. *International Journal Operations & Management* , Vol 25, No 11, pp 1083-1100.

10. Erjavec, J. (2005). *Automotive Technology, A systems approach 4th Edition*, Thomson,Delmar Learning

11. Sipper, D. , Robert, L. & Bulfin, JR (1998).*PRODUCTION,Planning,Control and Integration*.Singapore: McGraw-Hill Book Co

12. Malaysia Automotive Association. *Malaysia Automotive Info: Summary of Sales & Production Data*. Retrieved on 15th April 2012 from http://www.maa.org.my/info_summary.htm

13. Akop M. A. (2007). Manufacturing System Engineering. *An Investigation of Disc Brake Rotor by Finite Element Analysis (FEA)*

14. Heizer J. & Render B. (2006).*Operations Management* New Jersey: Prentice hall

15. Derek, L. W. (2002). *Operation management, A supply chain approach* Italy: International Thomson

APPENDICES

Appendix 1 : Tables of cost analysis for model A

Incremental (%)	Hiring cost (RM)	Total production cost (RM)
0	300	28,593,923
20	360	28,653,443
40	420	28,712,963
60	480	28,772,483
80	540	28,832,003
100	600	28,891,523

Incremental (%)	Firing cost (RM)	Total production cost (RM)
0	500	28,494,160
20	600	28,494,960
40	700	28,495,760
60	800	28,496,560
80	900	28,497,360
100	1000	28,498,160

Incremental (%)	Labor cost (RM)	Total production cost (RM)
0	800	28,593,923
20	960	28,653,443
40	1120	28,712,963
60	1280	28,772,483
80	1440	28,832,003
100	1600	28,891,523

Incremental (%)	Inventory cost (RM)	Total production cost (RM)
0	1	28,593,923
20	1.2	28,615,156

40	1.4	28,636,388
60	1.6	28,657,621
80	1.8	28,678,853
100	2	28,700,086

Incremental (%)	Material cost (RM)	Total production cost (RM)
0	30	28,593,923
20	36	34,132,192
40	42	39,770,224
60	48	45,408,256
80	54	51,046,288
100	60	56,684,320

Appendix 2 : Tables of cost analysis for model B

Incremental (%)	Hiring cost (RM)	Total production cost (RM)
0	300	51,856,720
20	360	51,856,900
40	420	51,857,080
60	480	51,857,260
80	540	51,857,440
100	600	51,857,620

Incremental (%)	Firing cost (RM)	Total production cost (RM)
0	500	51,856,720
20	600	51,857,020
40	700	51,857,320
60	800	51,857,620
80	900	51,857,920
100	1000	51,859,120

Incremental (%)	Labor cost (RM)	Total production cost (RM)
0	800	51,961,776
20	960	51,996,336
40	1120	52,030,896
60	1280	52,065,456
80	1440	52,100,016
100	1600	52,134,576

Incremental (%)	Inventory cost (RM)	Total production cost (RM)
0	1	51,961,776
20	1.2	51,983,179

40	1.4	52,004,582
60	1.6	52,025,986
80	1.8	52,047,389
100	2	52,068,792

Incremental (%)	Material cost (RM)	Total production cost (RM)
0	10	51,961,776
20	12	53,736,048
40	14	55,615,376
60	16	57,494,704
80	18	59,374,032
100	20	61,253,360

Incremental (%)	Subcontractor cost (RM)	Total production cost (RM)
0	45	51,961,776
20	54	60,313,696
40	63	68,770,672
60	72	77,227,648
80	81	85,684,624
100	90	94,141,600