MANUFACTURING SYSTEMS DESIGN FOR MASS PRODUCTION OF DISC BRAKES

By

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CERTIFICATION OF APPROVAL

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Approved:

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January 2010

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 acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or person

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KUMANAN A/L RAMAN

ABSTRACT

Disc Brake is a commonly used component in vehicles. It is used as a braking device to stop a moving vehicle. According to research, Malaysia being a car manufacturing country does not have any major disc brake manufacturing plant. Therefore, Malaysia is still depending on China and Taiwan to cater the spare part market demand for disc brakes. This project aims to theoretically apply the concepts of forecasting, process selection, modelling machining configurations, designing plant operations and modelling a quality control inspection plan to build a manufacturing system that is capable of producing certain amount of disc brakes. The manufacturing system is designed in a best possible way to cater the demand of market where a few cases of implementation have been considered. The operating systems proposed in the report can be used on a long term provided that the assumptions made are still applicable. The results of this project shows that the manufacturing systems design will be able to handle huge demands of disc brake with very few improvements. This has been proven by using the WITNESS Simulation. This project is a theoretical application and there are a lot of room for a more robust and optimum upgrades.

ACKNOWLEDGMENTS

My appreciation to my project supervisor Dr Ir Setyamartana Parman, for taking me under his wing and providing me all the necessary assets and resources, not only to accomplish this project, but to enrich my character and knowledge further. My utmost appreciation and gratitude is also extended to Dr. Ir. Mohd Amin Abd Majid, for the dedication of his time and effort, relentlessly teaching and guiding me despite his many other obligations. Many thanks to my family back home for their sacrifices coupled with their continuous encouragement and support in heading me towards the stars. Special thanks to all the members of the Mechanical Department, for establishing continuous support and backing me up, my appreciation is also extended to my friends and everyone who encouraged and supported me throughout the successful completion of this project.

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CHAPTER 1
INTRODUCTION

This chapter is dedicated for the introduction and explanations of the project entitled "Manufacturing Systems Design for Mass Production of Disc Brakes". Also included are the background study, problem statement, objectives, and finally the scope of study for the project.

1.1 Background of Study

A disc brake is a device for slowing or stopping the rotation of a wheel. It is usually made of cast iron or ceramic composite. Disc brakes was first developed and used in England in 1890's. Since then it has gone through many modifications and development to fulfill the need of consumers. This FYP topic entitled "Manufacturing Systems Design for Mass Production of Disc Brakes" was initiated by Ir. Dr. Amin B Abd Majid and it will be carried out under the supervision of Dr. Satyamartana Parman from the Mechanical Engineering Department and is to be funded by UTP. This project will be fully concentrating on the manufacturing systems design for mass production of disc brakes to cater the Malaysia's spare market demand.

1.2 Problem Statement

Disc brakes were only used in racing cars like Jaguar C-Type and Citreon DS when it was initially developed. But later on, disc brakes were also used on passenger vehicles. At the current market, almost all the cars in the market are fitted with disc brakes because it ensures a reliable and efficient braking system. Therefore, the demand for disc brakes as spare parts has increased tremendously over the years. Research shows that Malaysia is depending on China & Taiwan to fulfill more than 50% of its disc brake spare part demand [4]. This is because Malaysia does not have any mass disc brake producer. Therefore, putting up a disc brake producing plant in Malaysia could help to cater all the local disc brake demand thus reducing the need to import disc brakes from china and Taiwan. This could also indirectly reduce the currency outflow and develop our country's economy.

1.3 Objectives

The objectives of this project are:

- To do research and forecast on the disc brake demand for Malaysia's spare part market for the next 12 years.
- To model a reliable and efficient manufacturing system to produce disc brakes.

1.4 Scope of Study

The project will only focus on manufacturing 12' solid type disc brakes and the scope of study will be as follow:

- Forecasting the demand for disc brakes in Malaysia for the next 12 years.
- Selecting the manufacturing process to be used in the plant.
- Configuring the machining process for the disc brakes.
- Designing of operation systems for the manufacturing process.
- Modeling a quality control mechanism for the finished products.

CHAPTER 2

LITERATURE REVIEW

This section reviews the critical points and theories covered in this project

2.1 Disc Brake

Disc brakes are now widely been used on vehicles. It is used not only on cars but also on motorcycles, and also bicycles. The braking performance of disc brakes is proven to be more efficient and reliable than the common drum brakes. Cars nowadays are using disc brakes on all the four wheels. That provides a more confident driving. The picture of a common disc brake is used in most vehicle is shown below.

Figure 1 Common disc brake

The main components of a disc brake are as below where every part can be replaced individually.

i. Brake pads
ii. Brake caliper
iii. Disc (rotor)

2.2 Mechanism of Disc Brake

The working mechanism of a disc brake is a lot like the breaks on a bicycle.Bicycle brakes have a caliper,which squeezes the brake pads against the wheels. In a disc brake,the brake pads squeezes the rotor instead of the wheels and the force is transmitted hydraulically instead of through a cable.Friction between pads and the disc slows the disc down . A moving car has a certain amount of kinetic energy and the brakes remove this energy from the car in order to stop it. Each time you stop the car, the brakes convert the kinetic energy of the car to heat generated by the friction between the pads and the disc.Some brakes are vented to be able to dissipate the heat faster. The diagram below shows the mechanism of a common disc brake.

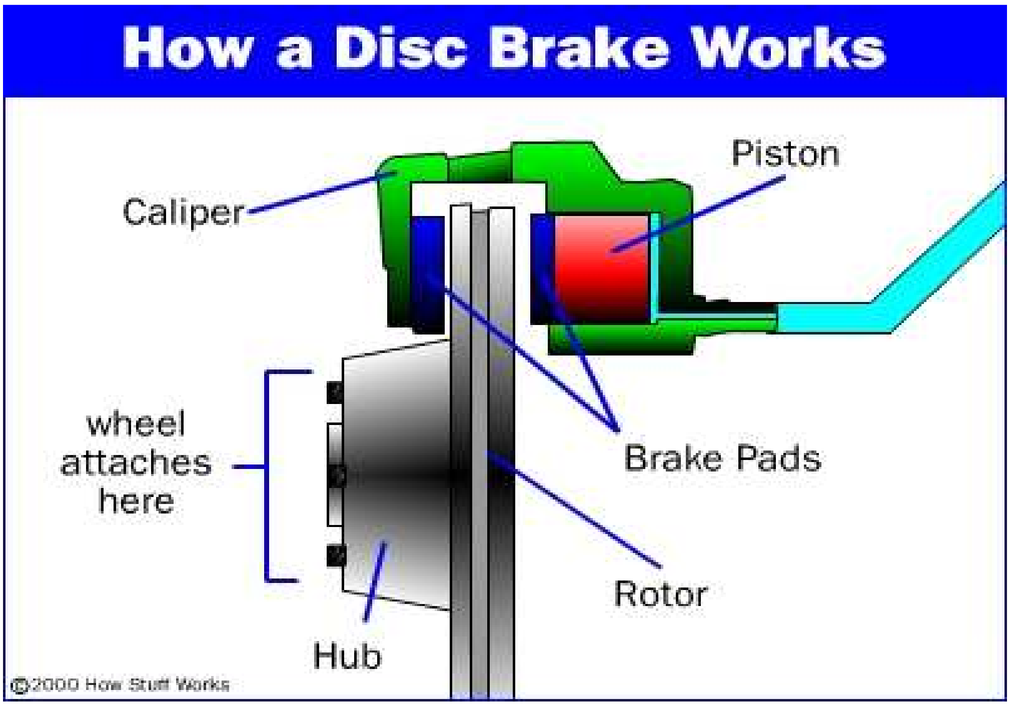

Figure 2 Mechanism of disc brake (single piston floating calliper)

The disc brake also has a self-adjusting /self centering capability where caliper is able to slide from side to side so it will move to the center each time the brakes are applied. Also, since there is no spring to pull the pads away from the disc, the pads always stay in light contact with the rotor (the rubber piston seal and any wobble in the rotor may actually pull the pads a small distance away from the rotor). This is important because the pistons in the brakes are much larger in diameter than the ones in the master cylinder. If the brake pistons retracted into their cylinders, it might take several applications of the brake pedal to pump enough fluid into the brake cylinder to engage the brake pads. Older cars had dual or four-piston fixed-caliper designs. A piston (or two) on each side of the rotor pushes the pad to that side [1]. This design has been largely eliminated because single-piston designs are cheaper and more reliable.

There are a few types of disc brakes in the market. The types of disc brakes are shown below.

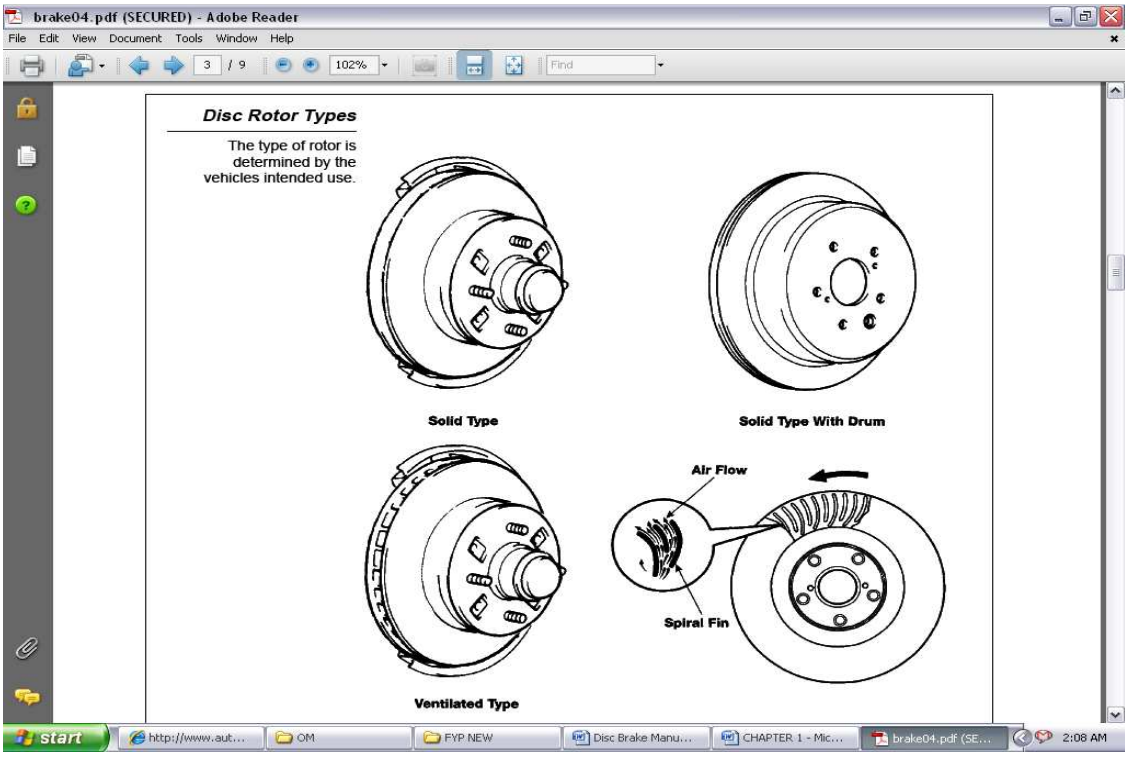

Figure 3 Types of disc brakes [2]

Most Malaysian cars use the solid type disc brakes. According to the Malaysian Automotive Association, the number of cars in Malaysia is increasing tremendously. The increase in the number of cars manufactured in Malaysia is growing very fast over the years. Therefore, the needs for disc brakes as spare parts are almost increasing. The table below shows the figure on the total vehicles manufactured in Malaysia

2.3 Historical Data on Number of Cars Assembled In Malaysia

There are many car assembling plants operating in Malaysia. There are both continental car and local car assembling plant in Malaysia. Continental car assembling plant includes Mercedes Benz and Honda while local cars assembling plant is Proton and Perodua. The table below shows the number of cars been assembled in Malaysia from year 1981 to 2008.

Year	Passenger Vehicles
1981	87,822
1982	85,321
1983	100,226
1984	96,357
1985	69,769
1986	41,896
1987	33,878
1988	74,144
1989	86,148
1990	116,526
1991	135,479
1992	116,965
1993	120,864
1994	147,351
1995	231,280
1996	280,222
1997	337,717
1998	143,756
1999	257,607
2000	295,318
2001	355,863
2002	350,050
2003	355,450
2004	364,852
2005	372,225

2006	377,952
2007	403,245
2008	484,512

Figure 4 Summary of total vehicles assembled in Malaysia (1981 -2009) [4]

Research shows that 70% of the total passenger cars assembled in Malaysia are Malaysian cars [4]. The life time for a disc brake is approximated to be maximum of 5 years under standard operating conditions (well maintained).

2.4 Forecasting

Forecasting is a process of predicting a future event. Forecasting is the underlying basis of all business decisions. For example, production forecasting, Inventory forecasting, personnel forecasting and also facilities forecasting. In the case of modelling a manufacturing system to manufacture disc brakes, the disc brake demand for the future must be forecasted to determine the production volume of the plant. The forecasting can be done by using the historical data of the number of passenger vehicles assembled in Malaysia [6].

Before forecasting is done, we have to be aware that there are a few types of forecasting models available. Forecasting can be broke in to 2 major groups, Quantitative and Qualitative method. Qualitative method is a method which uses expertise's intuition to predict the future. The most famous method is the Delphi method. A group of expertise will discuss the factors and all related methods before concluding their predictions. Usually no calculations or analysis is involved [6].

Meanwhile, Quantitative method is more analytical. This method has 2 sub groups, Time Series Model and Associative Model. Associative Model includes Trend Projection .It takes into account the variables or factors that might influence the quantity being forecasted. However, the Time Series Model predicts on the assumption that the future is a function of the past. In other words, they look at what has happened over a period of time and use a series of past data to make a forecast. Time Series Model can be expanded into few other models like, Naïve Approach, Moving Averages and Exponential Smoothing.

Naïve approach is assumed as the demand in the next period will be equal to the demand in the most recent period. This model is the most cost-effective and efficient objective forecasting model [6].

Moving Averages model uses a number of historical data values to generate a forecast. Moving averages are useful if we can assume that market demands will stay fairly steady over time. When a detectable trend or pattern is present, weights can be used to place emphasis on recent values. This makes the forecasting technique more responsive to changes because more recent periods may be more heavily weighted. Below is a example of the moving average and weighted moving average calculations.

$$\text{Moving average} = \frac{\sum \text{demand in previous n periods}}{n}$$

$$\text{Weighted moving average} = \frac{\sum (\text{weight for period } n) \times (\text{demand in period } n)}{\sum \text{weights}}$$

$$\text{New forecast} = \text{Last period's forecast} + \alpha\,(\text{Last period's actual demand} - \text{Last period's forecast})$$

Trend projection fits a trend line to a series of historical data points and then projects the line into the future for medium to long range forecasts. Least-square method can be used to develop a linear trend line by a precise statistical method. This approach results in a straight line that minimises the sum of the squares of the vertical differences from the line to each of the actual observations. A least-square line is described in terms of its y-intercept. If y-intercept and slope can be computed, the line can be expressed with equation:

$$y = a + bx$$

The slope b is found by: $b = (\sum xy - n\chi\gamma)/(\sum x2 - n\chi 2)$

There are seven important steps that need to be taken in account before a forecast is done. The steps are shown below [6].

1. Determine the use of the forecast
2. Select the items to be forecasted
3. Determine the time horizon of the forecast
4. Select forecasting models
5. Gather data
6. Make the forecast
7. Validate & implement results

2.5 Design Selection

Product design is a crucial matter in manufacturing industry. Every product that is to be manufactured must have a design. Design can be created by using software like AutoCAD or Solid Works. Product design specifies the measurement and shape of the actual product to be manufactured. It is a guide for the operators on how a completed product will look like after going through the machining process. Below is the design of the disc brake that will be manufactured. The final dimensions and shape is shown in detail.

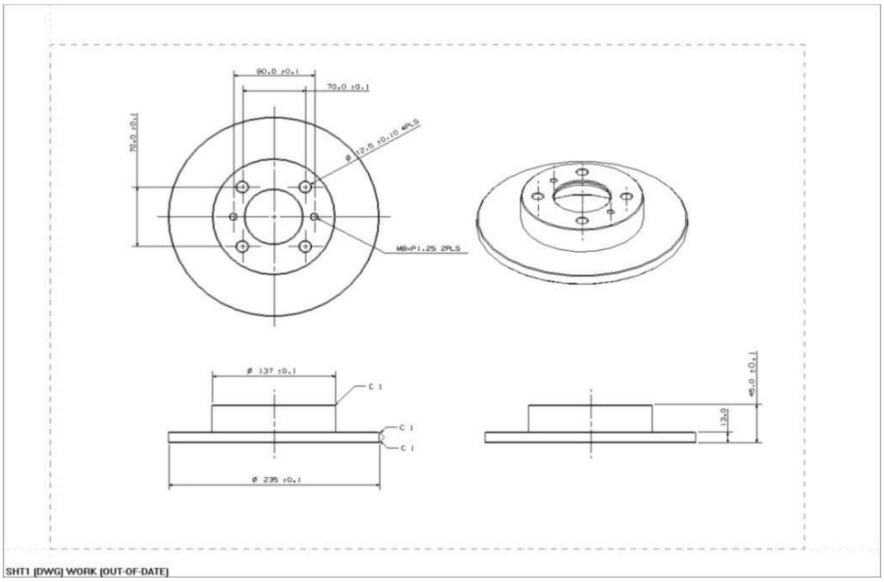

Figure 5 AUTOCAD design for the disc brake

2.6 Machining Process

Common machining process used in producing round shapes is turning. Turning is defined as the part is being rotated while it is being machined. The starting material is generally a work piece that has been made by other process such as casting, forging, extrusion or drawing. Turning process is typically carried out on a lathe machine. A lathe machine can be manual handled or automatically operated. A lathe machine can be used to produce a wide variety of shapes [7].

Turning: produce straight, conical, curved, grooved work piece.

Facing: produce flat surface at the end of the part and perpendicular to its axis.

Drilling: produce a hole

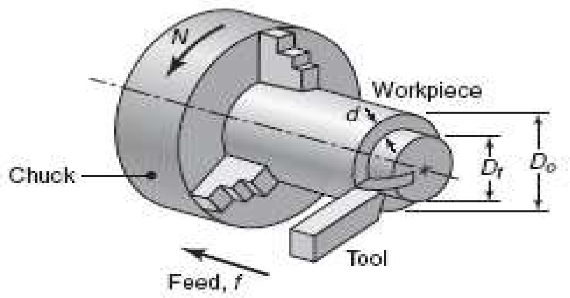

Figure 6 Schematic illustration of the basic turning operation

The material removal rate (MRR) in turning is the volume of material removed per unit time .For each revolution of the work piece, a ring-shaped layer of material is removed, which has a cross-sectional area that equals the product of the distance the tool travels in one revolution (feed,f) and the depth of cut,(d).The volume of this ring is the product of e cross sectional area (f)(d) and the average circumference of the ring ,given below as,

- $Davg = (do + df)/2$
- $MRR = dfV$ where V= cutting speed
- $V = \pi lN$ where l=distance travelled
- $t = l/(fN)$

TABLE 23.4

General Recommendations for Turning Operations

Workpiece material	Cutting tool	General-purpose starting conditions: Depth of cut, mm	Feed, mm/rev	Cutting speed, m/min	Range for roughing and finishing: Depth of cut, mm	Feed, mm/rev	Cutting speed, m/min
Low-C and free machining steels	Uncoated carbide	1.5–6.3	0.35	90	0.5–7.6	0.15–1.1	60–135
	Ceramic-coated carbide	"	"	245–275	"	"	120–425
	Triple-coated carbide	"	"	185–200	"	"	90–245
	TiN-coated carbide	"	"	105–150	"	"	60–230
	Al_2O_3 ceramic	"	0.25	395–440	"	"	365–550
	Cermet	"	0.30	215–290	"	"	105–455
Medium and high-C steels	Uncoated carbide	1.2–4.0	0.30	75	2.5–7.6	0.15–0.75	45–120
	Ceramic-coated carbide	"	"	185–230	"	"	120–410
	Triple-coated carbide	"	"	120–150	"	"	75–215
	TiN-coated carbide	"	"	90–200	"	"	45–215
	Al_2O_3 ceramic	"	0.25	335	"	"	245–455
	Cermet	"	0.25	170–245	"	"	105–305
Cast iron, gray	Uncoated carbide	1.25–6.3	0.32	90 (300)	0.4–12.7	0.1–0.75	75–185
	Ceramic-coated carbide	"	"	200	"	"	120–365
	TiN-coated carbide	"	"	90–135	"	"	60–215
	Al_2O_3 ceramic	"	0.25	455–490	"	"	365–855
	SiN ceramic	"	0.32	730	"	"	200–990

(*Continued*)

Figure 7 General recommendations for turning process [7]

Drilling is also an important process in making disc brakes. Drilling can be done on a lathe machine but the parameters and tools used are different. Drills typically have high length-to-diameter ratios. The material-removal-rate (MRR) is the volume of material removed by drill per unit time. For a drill with a diameter D, the cross sectional area of the drilled hole is $\frac{\pi D2}{4}$. The velocity of the drill perpendicular to the work piece is the product of the feed, f and the rotational speed is N, where

- $\mathbf{N = \frac{V}{\pi D}}$.
- $\mathbf{MRR = \left(\frac{\pi D2}{4}\right) fN}$

TABLE 23.11

General Recommendations for Speeds and Feeds in Drilling

		Drill diameter			
Workpiece material	Surface speed	Feed, mm/rev		rpm	
	m/min	1.5 mm	12.5 mm	1.5 mm	12.5 mm
Aluminum alloys	30–120	0.025	0.30	6400–25,000	800–3000
Magnesium alloys	45–120	0.025	0.30	9600–25,000	1100–3000
Copper alloys	15–60	0.025	0.25	3200–12,000	400–1500
Steels	20–30	0.025	0.30	4300–6400	500–800
Stainless steels	10–20	0.025	0.18	2100–4300	250–500
Titanium alloys	6–20	0.010	0.15	1300–4300	150–500
Cast irons	20–60	0.025	0.30	4300–12,000	500–1500
Thermoplastics	30–60	0.025	0.13	6400–12,000	800–1500
Thermosets	20–60	0.025	0.10	4300–12,000	500–1500

Note: As hole depth increases, speeds and feeds should be reduced. Selection of speeds and feeds also depends on the specific surface finish required.

Figure 8 General recommendations for drilling process [7]

Tapping is a process to make internal threads in a work piece. A tap is a chip-producing threading tool with multiple cutting tools with multiple cutting teeth. Taps generally are available with two, three or four flutes. The most common production tap is the two-flute spiral-point tap. Tappered taps are designed to reduce the torque required for the tapping of through holes. Tapping may be done by hand or a lathe machine.

Honing is an abrasive machining process that produces a precision surface on a metal work piece by scrubbing an abrasive stone against it along a controlled path. Honing is primarily used to improve the geometric form of a surface, but may also improve the surface texture [8].Typical applications are the finishing of cylinders for internal combustion engines, air bearing spindles and gears. Types of hone are many and various but all consist of one or more abrasive stones that are held under pressure against the surface they are working on. Since honing is a high precision process, it is also relatively expensive. Therefore it is only used in components that demand the highest level of precision. It is typically the last manufacturing operation before the part is shipped to a customer. The dimensional size of the object is established by preceding operations, the last of which is usually grinding. Then the part is honed to improve a form characteristic such as roundness and flatness. Since honing is a relatively expensive manufacturing process, it can only be economically justified for applications that require very good form accuracy. The improved shape after honing may result in a quieter running or higher precision component [9].

Quality control is a compulsory procedure in every manufacturing industry. Quality control is a process by which entities review the quality of all factors involved in production [10]. Quality control inspection is a compulsory procedure in manufacturing plants. Products produced by a plant must be inspected to ensure that the product fulfills the design specifications. Poor quality control system can cause great losses to the company. Consumers are liable to take legal actions against the company if the marketed products are proven to be not within the specifications.

In the case of ensuring the quality of the disc brake manufactured, many types of equipments can be used. Specific gadgets are used in measuring and quantifying the specifications of the disc brake. The parameters and the suitable measuring device are shown in the table below.

Parameters	**Devices**
Lengths	Vernier Caliper
Thickness	Micrometer
Inside/outside dimensions	Micrometer
Diameters	Vernier Caliper, Micrometer
Angle	Bevel Protractor, Sine Bar, Surface Plate
Straightness	Autocollimator
Flatness	Dial Indicator,Surface Plate, Optical Flat(Interferometry Method)
Roundness	V-Block

Figure 9 Measurement parameters and suitable measuring devices for quality control inspection [7].

CHAPTER 3

METHODOLOGY

This chapter discusses the project's procedure identification as well as the tools and equipments utilized throughout the course of completing this project

3.1 Procedure Identification

Procedures of a project are very important to guide us through the project. Below are the procedures in sequence in order to complete the project.

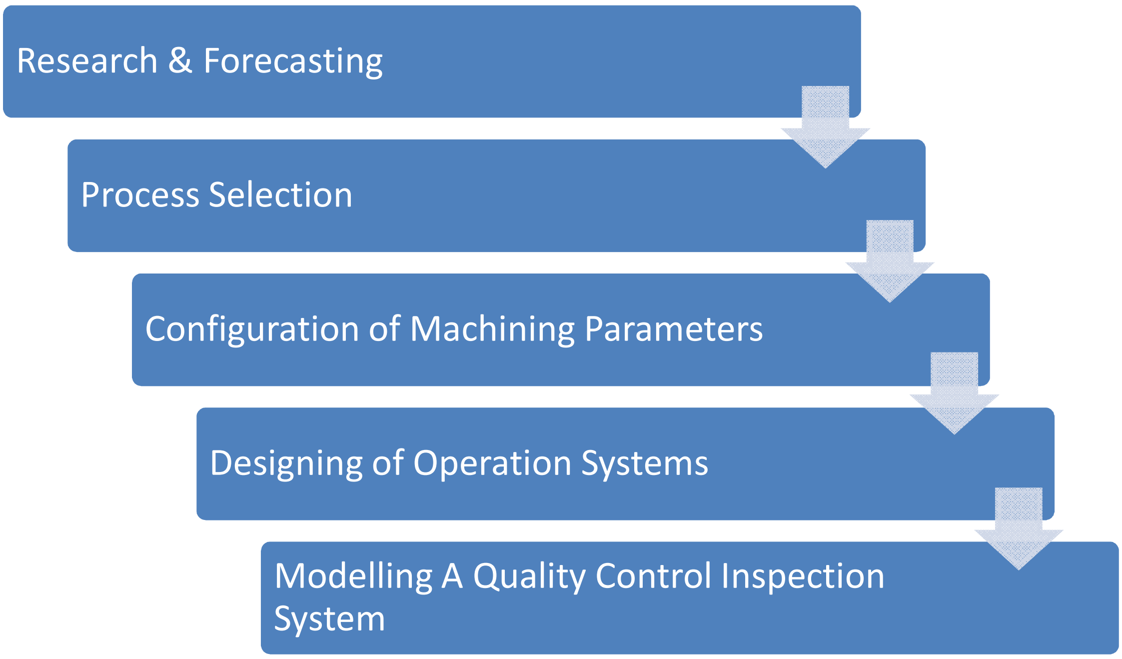

Figure 10 Flow chart of project methodology

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3.2 Tools and Equipments

The equipments and tools which are expected to be used in the project are bulleted below.

1. AUTOCAD/SOLID WORKS
2. WITNESS Software

CHAPTER 4

RESULTS AND DISCUSSION

This chapter discusses the outcomes of every stage and phase of the project.

4.1 Forecasting

Trend projection method is used to calculate the disc brake demand forecast for the year 2009 to 2022.This method is used because the future demand of the disc brakes can be determined based on the historical data gathered. The maximum capacity of the plant will be ±20% of the maximum forecasted values. Research shows that 70% of total cars assembled in Malaysia are local Malaysian cars. The assumption that we make during forecasting is as below.

Assumption:

- 50% of total Malaysian cars assembled in a year use the solid type disc brake.

Year	Total assembled cars ,A	No. of Malaysian cars, B(70% of A)	No. of cars using Solid type disc brakes (50% of B)
2005	372 225	260 558	130 279
2006	377 952	264 566	132 283
2007	403 245	282 272	141 136
2008	484 512	339 158	169 579

Figure 11 Historical data to be used in forecasting.

Year	Time period ,X	Disc Brake Demand, Y	X^2	XY
2005	1	130 279	1	130 279
2006	2	132 283	4	264 566
2007	3	141 136	9	423 408
2008	4	169 579	16	678 316
	$\sum X = 10$	$\sum Y = 573\ 277$	$\sum X^2 = 30$	$\sum XY = 1\ 496\ 569$

Figure 12 Analysis of the historical data into trend projection forecasting

$x = \sum X / n$

= 10/4

x = 2.5

$\breve{y} = \sum Y / n$

= 573 277 / 4

$\breve{Y}$ = 143 319

b = $(\sum XY - n\, x\, \breve{y}) / (\sum X^2 - n\, x^2)$

= [1 496 569– (4) (2.5) (143 319)] / [30 – (4) $(2.5)^2$]

= (1 496 569– 1 433 190) / 5

b = 12 676

a = $\breve{Y}$ - b x

= 143 319 – 12 676 (2.5)

a = 111 629

Therefore, the least square trend equation is **Y = 111 629 + 12 676x .**To project demand for the following years, we replace the denoted years into the equation thus generating the future forecasted values.

Forecast for year 2009

Y = 111 629 + 12 676x

= 111 629 + 12 676 (5)

= 175 009 units

Forecast year	**Time Period (X)**	**Forecasted Value**
2009	5	175 009
2010	6	187 685
2011	7	200 361
2012	8	213 037
2013	9	225 713
2014	10	238 389
2015	11	251065
2016	12	263741
2017	13	276417
2018	14	289093
2019	15	301769
2020	16	315998
2021	17	315998
2022	18	315998

Figure 13 Forecasted values for the year 2009-2022

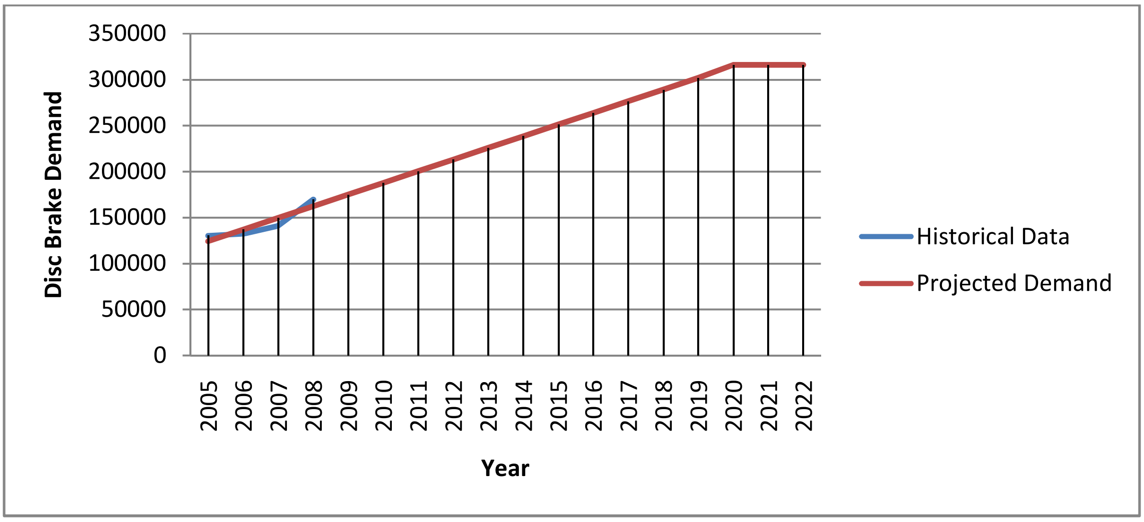

Figure 14 Demand projection graph

4.2 Process Selection

The processes identified to machine the disc brake are turning and facing processes. Drilling and tapping will be done at the end of the machining process. CNC lathe machine will be used to carry out the turning, facing, drilling and tapping process. The drilling and tapping process will be incorporated in a single process called Draping. During this process, the drilling process and tapping process will be done simultaneously. The Draping tool has a drilling bit at the tip and followed by a tapping section. Therefore, when the drill moves downwards, a hole will be drilled followed by a tapping process. These can increase the production rate of the system. After the machining process, a finishing process will be carried out. Superfinishing method has been identified to be used in this system. Superfinishing, also known as micromachining and short-stroke honing, is a metalworking process that improves surface finish and work piece geometry. This is achieved by removing just the thin amorphous surface layer left by the last process with an abrasive stone; this layer is usually about 1 μm in magnitude and it creates a cross-hatch pattern on the work piece [11].

The disc brake must be machined in few different processes. The machining process distribution of the top layer and bottom layer of the disc brake is shown below.

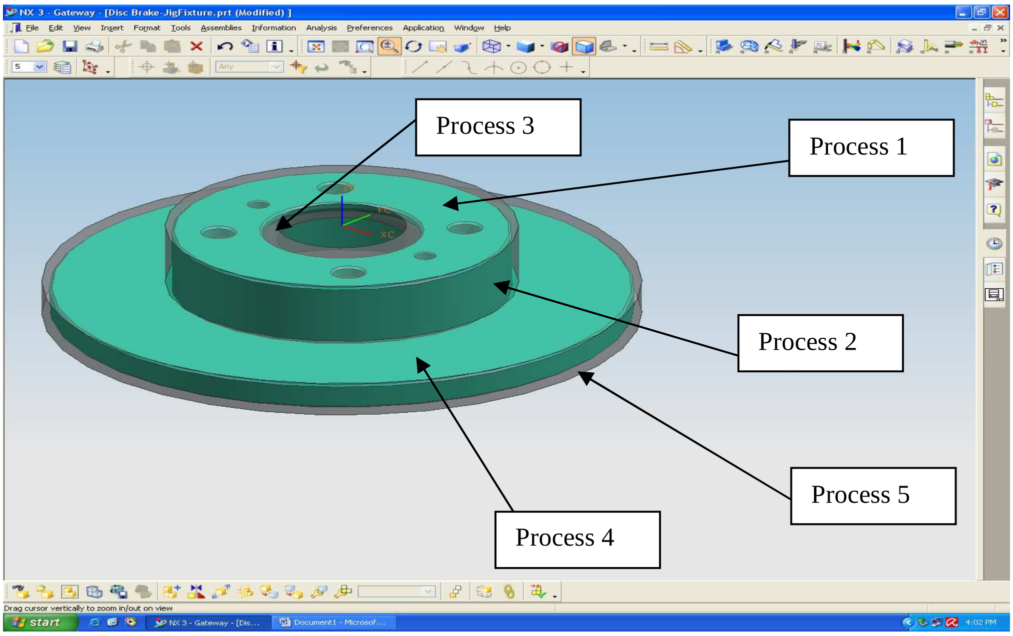

Figure 15 Process distribution for the top layer machining for disc brake

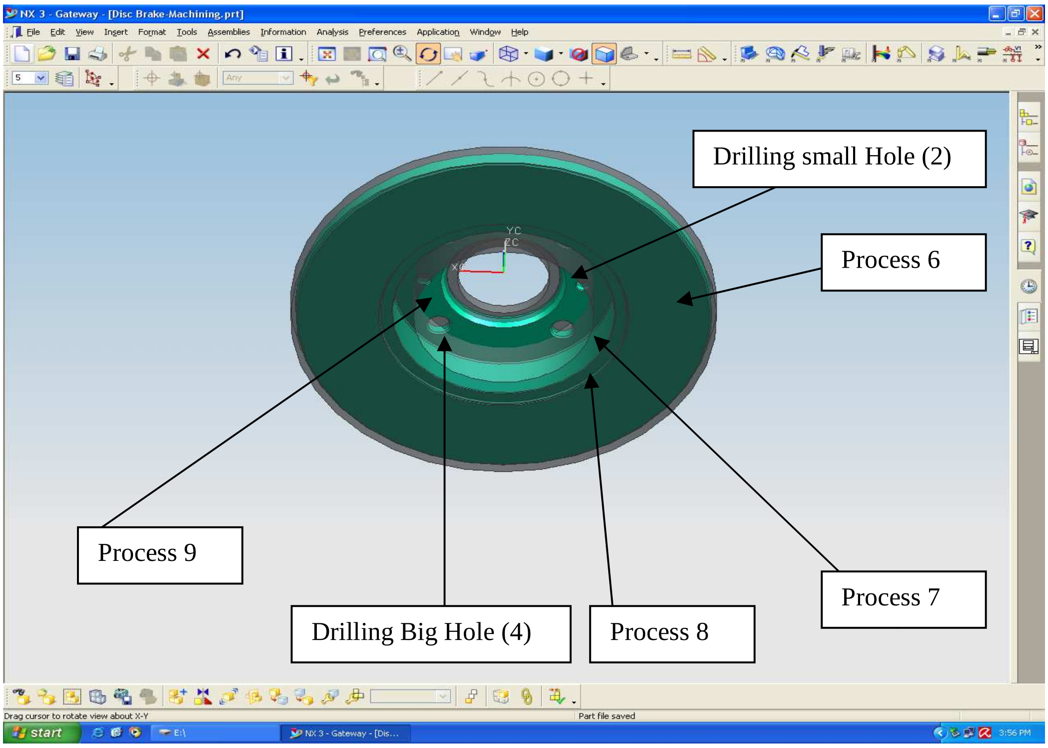

Figure 16 Process distribution for the bottom layer of the disc brake

The disc brake must go through a set of process before it achieves its final desired shape and dimensions. The process flow for the disc brake machining and the equipments involved are shown below.

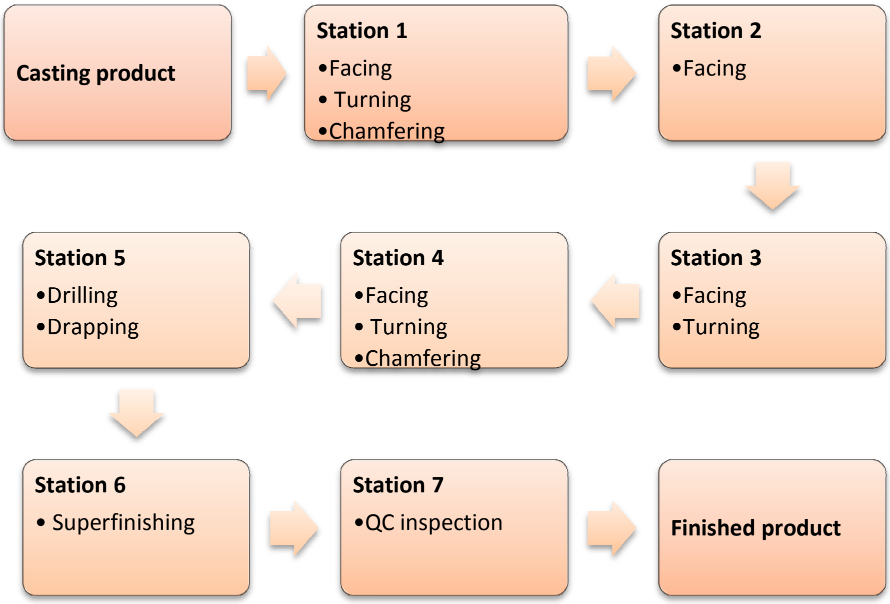

Figure 17 Process involved in disc brake machining operations

4.3 Configurations of Machining Parameters

In this section, the machining parameters for the turning, facing and drilling process are calculated. Machining parameters such as, cutting speed, feed and drilling spindle speed are chosen from the general recommendation given in the book. The parameters are chosen while considering the work piece material and the design requirements. Design requirement includes the surface quality and dimensional accuracy. While, other parameters such as, lathe spindle speed and cutting time are calculated with the selected parameters. The formulas that are used in the calculations have been elaborated in the chapter 2.

Below are the calculations involved in the process of calculating the cutting time for each facing and turning process and followed by a summarised table which contains all the parameters.

Process 1

Cut 1 (DOC =2.5mm)

$V = \pi l N$

$300*10^{\wedge 3}$ mm/min= (Π) (36mm)(N)

N =2653 RPM

T=L/FN

= [36mm/ (0.32mm/rev) (2653RPM)] *60sec

= 2.4sec

Cut2 (DOC =1.0mm)

$V = \pi l N$

$185*10^{\wedge 3}$ mm/min = (Π) (36mm)(N)

N =1636 RPM

T=L/FN

= [36mm/ (0.25mm/rev) (1636RPM)] *60sec

= 5.28sec

Cut 3 (DOC =0.6mm)

$V = \pi l N$

$75*10^{\wedge 3}$ mm/min = (Π) (36 mm)(N)

N =663.15 RPM

T=L/FN

= [36mm/ (0.10mm/rev) (663.15RPM)] *60sec

= 32.57sec

Total time for process 1 = 40.25sec

Process	Cut No.	Length of Cut(L)/ mm	Depth of Cut(DOC)/ mm	Variables: Feed,F=mm/rev, Cutting Speed,CS=mm/min	Spindle Speed(N)/ RPM	Cutting Time(T)/ sec	Total Cutting Time(T)/ sec
1	1	36	2.5	F=0.32,CS=300*E3	2653	2.4	
	2		1	F=0.25, CS=185*E3	1636	5.28	
	3		0.6	F=0.25 ,CS=75*E3	663.15	32.57	40.25
2	1	26.64	3	F=0.25, CS=285*E3	3405.3	1.87	
	2		2	F=0.25 ,CS=185*E3	2210.5	2.89	
	3		1.21	F=0.10 ,CS=75*E3	896.1	17.84	22.13
3	1	5.46	2.5	F=0.10, CS=75*E3	4372.4	0.7492	
	2		2	F=0.10, CS=75*E3	4372.4	0.7492	1.5
4	1	47	3	F=0.10, CS=185*E3	1252.9	22.51	
	2		2	F=0.10, CS=75*E3	1252.9	22.51	
	3		0.36	F=0.10, CS=75*E3	507.9	55.5	100.52
5	1	13	2.5	F=0.10 ,CS=75*E3	4897.1	1.593	
	2		2	F=0.10, CS=75*E3	4529.8	1.722	
	3		1.08	F=0.10 CS=75*E3	1836.4	4.247	7.562
6	1	47	1.5	F=0.25 ,CS=185*E3	1252.9	9	
	2		5	F=0.10 ,CS=75*E3	507.9	55.5	40.25
7	1	32	2	F=0.25 ,CS=185*E3	1840.9	4.17	
	2		2	F=0.25 ,CS=185*E3	1840.9	4.17	
	3		1	F=0.25 ,CS=185*E3	746.04	25.7	34.04
8	1	7.02	1.5	F=0.1 ,CS=75*E3	3400.7	1.24	
	2		0.5	F=0.1 ,CS=75*E3	3400.7	1.24	2.48
9	1	36	1	F=0.1 ,CS=75*E3	663.15	32.57	
	2		1	F=0.1 ,CS=75*E3	663.15	32.57	65.14

Figure 18 Summary of calculation on the facing and turning operations

Below are the calculations involved in the process of calculating the cutting time for each drilling process and followed by a summarised table which contains all the parameters.

Drilling (∅12.5mm)

MRR $_{drilling}$ = $(\pi D^2/4)$f N

= $\pi(12.5)^2/4(0.3)(800)$

= 29452.4mm^^{3} /min

Volume of the hole

= πj^2t

= $\pi(6.25^2)7.74$

=9.49 mm^^{3}

Time required to remove the amount of material for 1 hole is:

= (9.49 mm) / (29452.4 mm^^{3}/min) *60sec

= 1.93sec

For 4 holes, 1.93 * 4 = 7.72sec

Process	Diameter(D) /mm	Feed(f)=mm/rev	Rotational Speed(N)/rpm	Drilling Time(T)/sec	T*4/sec	T*2/sec
1	12.5	0.30	800	1.93	7.72	
2	6.64	0.0225	700	29.5		59.0

Figure 19 Summary of calculation on drilling

4.4 Designing of Operation Systems

4.4.1 Theoretical Model

In the previous section, the machining time for facing, turning and drilling was configured. The cutting time is now used to design the processing line in the plant. A set of machines must be arranged in a sequence to machine every part of the disc brake. The arrangement must be done in the best possible way to achieve the optimum production output. Analysis of the assembly line must be made before the modelling is done. There are a few formulas used in this analysis.

The assembly line must be designed to achieve a production rate Rp, sufficient to satisfy demand for the product. Product demand is often expressed as an annual quantity which can be reduced to an hourly rate. Management must decide on the number of shifts per week that the line will operate, and the number of hours per shift. Required hourly production rate is given by:

$Rp = D/WSH$ Where: Rp= Hourly production rate

D= Annual demand for the product

S=Number of shifts/week

H=Number of hours/shift

Production rate must be converted to a cycle time Tc, which is the time interval at which the line will be operated. The cycle time must take into consideration the reality that some production time will be lost due to occasional equipment failures, power outages and labour problems. As a consequences of these losses, the line will be up and operating only a certain portion of time out of the total shift time available. This uptime proportion is referred as line efficiency. The cycle time is determined as:

$Tc = (60E)/Rp$ Where: E=line efficiency

A machined product requires a certain total amount of time to complete its process. It is called Work Content Time, Twc. This is the total time of all the work elements that must be performed on the line to make one unit of the product. The formula is:

$$Twc = process1 + process2 + process3 +,,,,,,,,,,+ process9$$

Repositioning losses, Tr is the amount of time lost at each station for repositioning of the work unit. The repositioning time must be subtracted from the cycle time, Tc to obtain the available time remaining to perform the actual machining task at each station.

Owing to the difference in minimum rational work element and the precedence constraints among the elements, it is virtually impossible to obtain a perfect line balance. Measures must be defined to indicate how good a given line balancing solution is. One possible measure is balance efficiency which is the work content time divided by the total available service time in the line. Balance efficiency is given by:

$$Eb = Twc/wTs$$

Where: Eb=balance efficiency
Twc= Work content time
Ts=Maximum available service time
W=number of workers

4.4.2 Analytical Model

No.	Work Element Description	Tek (sec)
1	Process 1	40.25
2	Process 2	22.13
3	Process 3	1.5
4	Process 4	100.52
5	Process 5	7.562
6	Process 6	40.25
7	Process 7	34.04
8	Process 8	2.48
9	Process 9	65.14
10	Drilling (12.5mm)	7.72
11	Draping(Drilling+Tapping) (6.64mm)	59
12	Superfinishing	100
13	Quality Control	100

Figure 20 Time distribution for each work element in seconds

4.4.2.1 Case 1 (Assuming 50 weeks/year, 21 shifts/week, 7.5 hours/shift)

Assumptions

1. Production running for 50 weeks, 21 shifts per week, with 7.5 hours per shift.
2. Applying semi-automated processing system.1 machine has 1 operator
3. Assuming annual demand 178 692 units
4. Uptime efficiency is 95%
5. Repositioning time lost per cycle is 0.5 min
6. Defect rate is 5%

Total Work Content time

T_{wc} =

(40.25 +22.13+1.5+100.52+7.56+40.25+34.04+2.48+65.14+7.72+59.0+100+100) sec

= 580.6sec

= 9.68 min

Required hourly production rate

R_p = 178692/ [(50) (21) (7.5)]

= 22.69 units /hour

Corresponding cycle time

T_c = 60(.95) / 22.69

= 2.51 min

Available service time with which the line must be balanced

T_s = 2.51-0.5

= 2.01 min

Line balance Efficiency

E_b = 9.68/ 7(2.01)

= 0.6880 ≈ 68.8 %

Annual demand	Twc(sec)	Twc(min)	Rp (units/hr)	Tc(min)	Ts(min)	Line Balancing Efficiency,Eb
178692	580.6	9.68	22.69	2.51	2.01	68.80%
187056	580.6	9.68	23.75	2.4	1.9	72.78%
195421	580.6	9.68	24.82	2.29	1.79	77.25%
203785	580.6	9.68	25.87	2.203	1.703	81.20%
212150	580.6	9.68	26.94	2.11	1.62	85.00%
238770	580.6	9.68	30.32	1.88	1.38	100.00%
250000	580.6	9.68	31.75	1.79	1.29	107%

Figure 21 Summary of the analysis for case 1

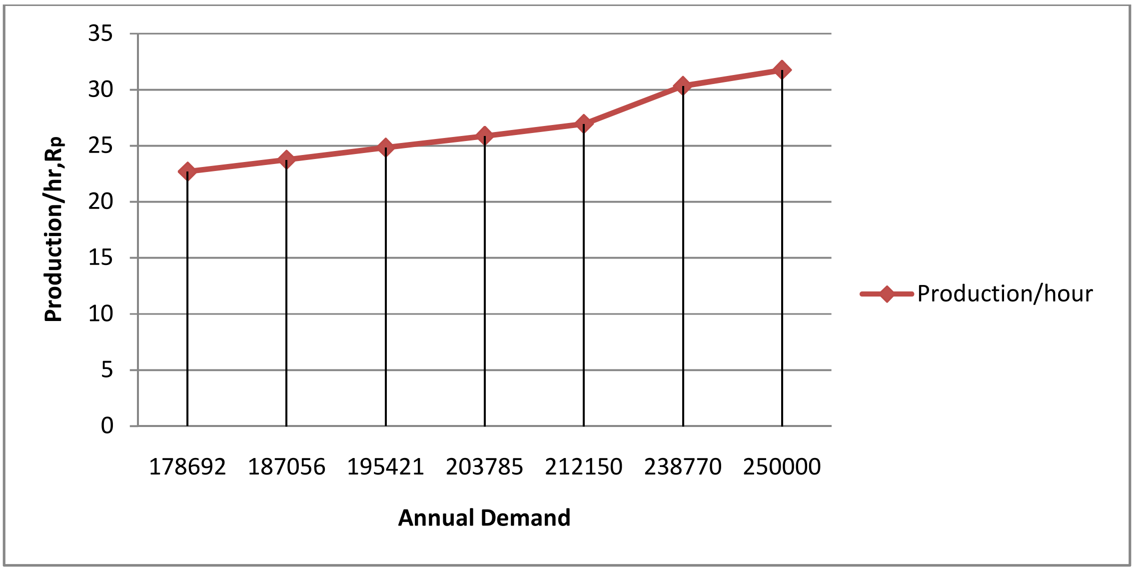

Figure 22 Production Rate versus Annual Demand graph

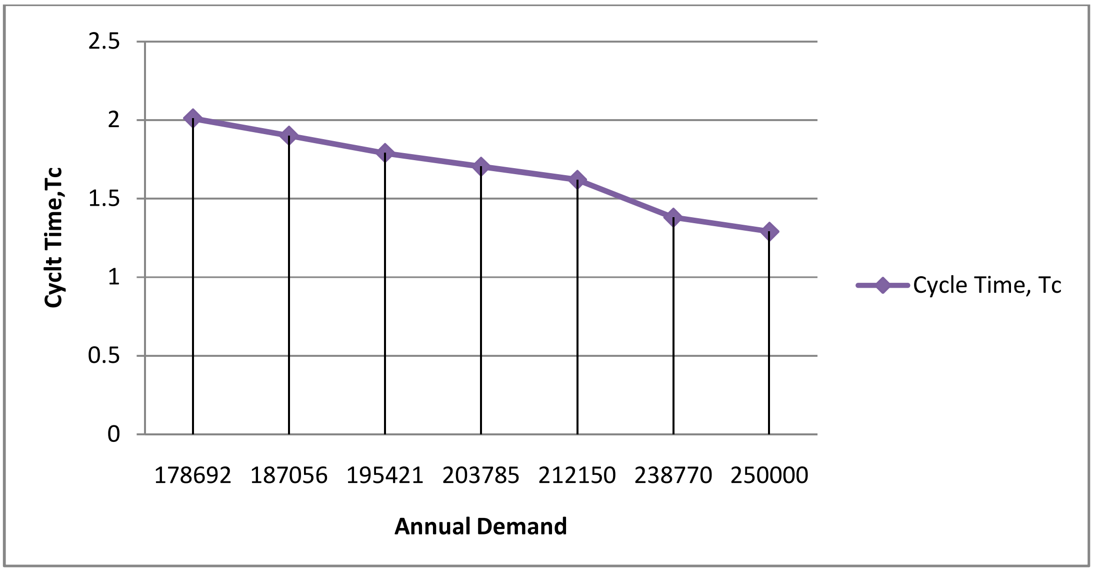

Figure 23 Cycle Time versus Annual Demand graph

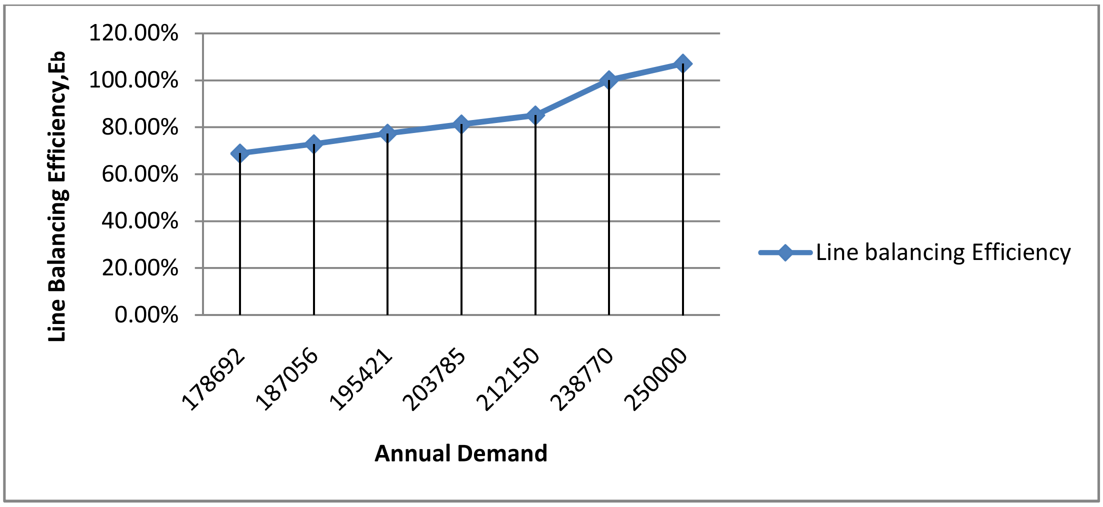

Figure 24 Line Balancing Efficiency versus Annual Demand graph

4.4.2.2 Case 2 (Assuming 50 weeks/year, 15 shifts/week, 7.5 hours/shift)

Assumptions

1. Production running for 50 weeks, 15 shifts per week, with 7.5 hours per shift.
2. Applying semi-automated processing system.1 machine has 1 operator
3. Assuming annual demand 120 000 units
4. Uptime efficiency is 95%
5. Repositioning time lost per cycle is 0.5 min
6. Defect rate is 5%
7. Using two similar processing lines

Total Work Content time

Twc =

(40.25 +22.13+1.5+100.52+7.56+40.25+34.04+2.48+65.14+7.72+59.0+100+100) sec

= 580.6sec

= 9.68 min

Required hourly production rate

Rp = 120000/ [(50) (15) (7.5)]

= 21.33 units /hour

Corresponding cycle time

Tc = 60(.95) / 21.33

= 2.67 min

Available service time with which the line must be balanced

Ts = 2.67-0.5

= 2.17 min

Line balance Efficiency

Eb = 9.68/ 7(2.17)

= 0.6372 ≈ 63.72 %

Annual demand	Twc(sec)	Twc(min)	Rp (units/hr)	Tc(min)	Ts(min)	Line Balancing Efficiency,Eb
120000	580.6	9.68	21.33	2.67	2.17	63.72%
140000	580.6	9.68	24.89	2.318	1.818	76.06%
160000	580.6	9.68	28.44	2	1.5	92.00%
170550	580.6	9.68	30.32	1.88	1.38	100.00%
180000	580.6	9.68	32	1.78	1.28	108.00%

Figure 25 Summary of the analysis for case 2

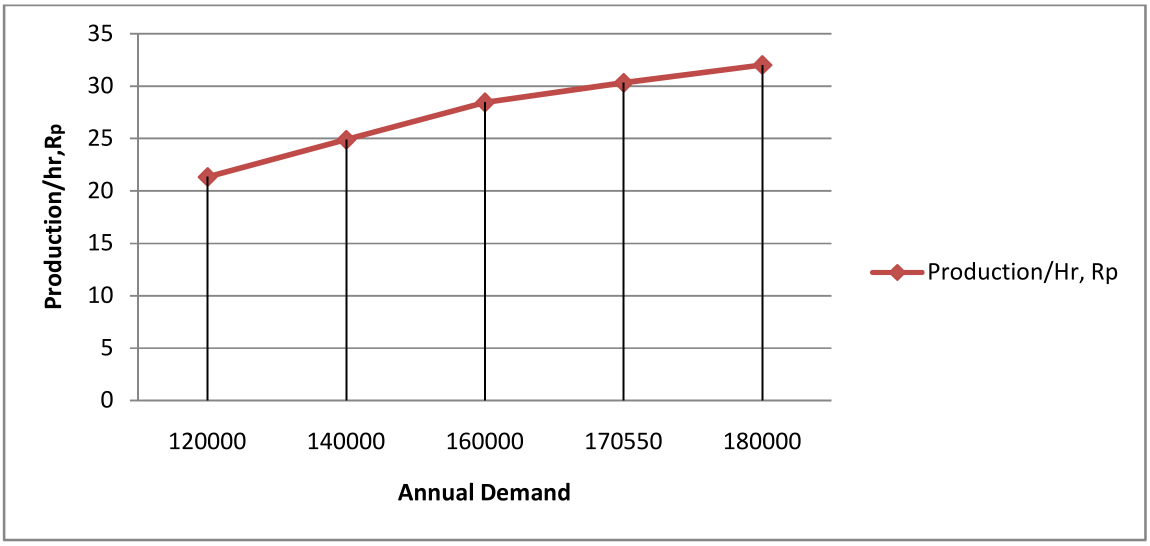

Figure 26 Production Rate versus Annual Demand graph

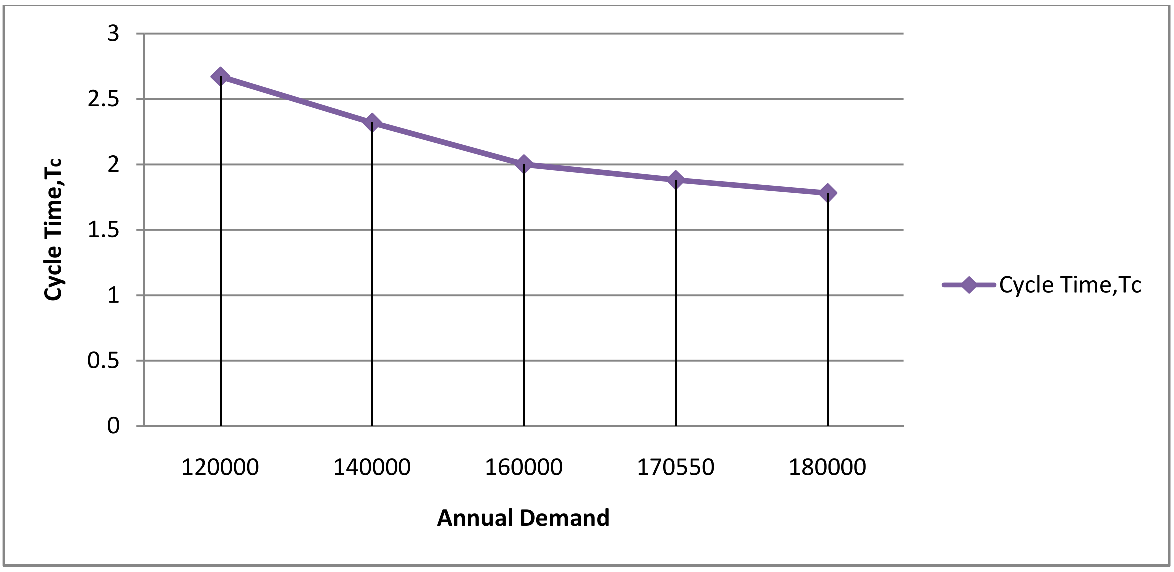

Figure 27 Cycle Time versus Annual Demand graph

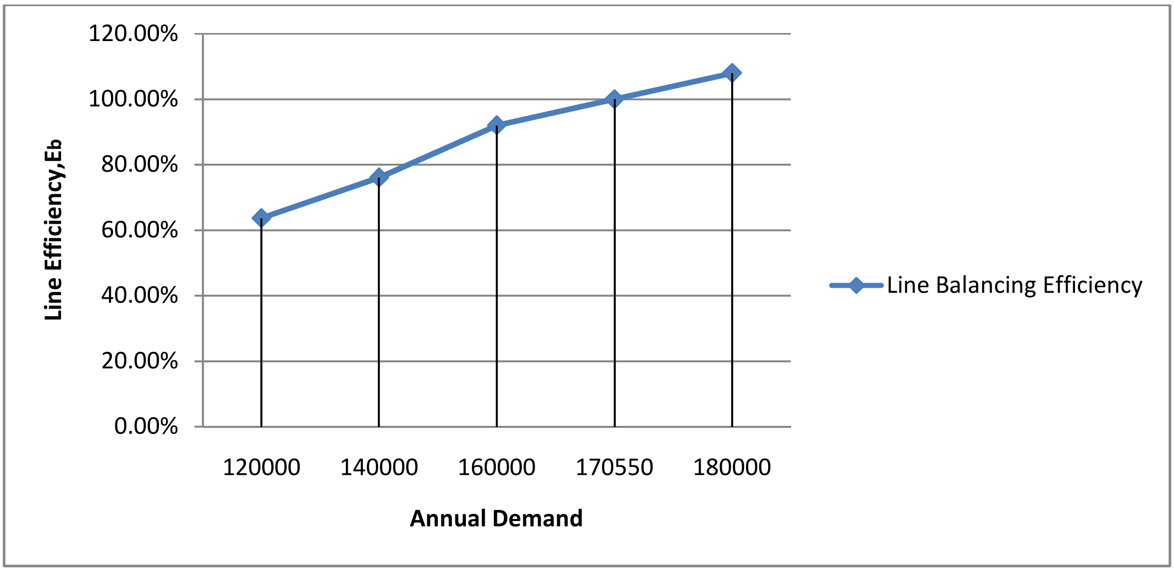

Figure 28 Line Balancing Efficiency versus Annual Demand graph

Analysing Figure 21 to Figure 24, it can be seen that the Production Rate, Cycle Time and Service Time and Line Balancing Efficiency varies depending on the Annual Demand. In Case 1, it is assumed that the plant runs 50 weeks/year, 21 shifts/week and 7.5 hours/shift. As the Annual Demand increases, the Production Rate and the Line Balancing Efficiency increases. However, the Cycle Time and Service Time decrease. The Line Balancing Efficiency's value is the critical parameter that decides the design of the processing line. Analyzing Figure 21, shows that a processing plant that operates as the parameter of Case 1 can produce up to 238 770 units/year. This is the maximum annual output that can be gained with the given cutting parameters and available time.

Referring to Figure25 to Figure 28, it can be interpreted that the Production Rate, Cycle Time, Service Time and Line Balancing Efficiency varies against the Annual Demand. In the analysis of Case 2, it is assumed that the plant runs 50 weeks/year, 15 shifts/week and 7.5 hours/shift. The Production Rate and the Line Balancing Efficiency increases while Cycle Time and Service Time decreases as the Annual Demand increases. The Line Balancing Efficiency reaches 100% at a lower Annual Demand compared to Case 1. This is because of the limitations on the available time. The operating time available for Case 2 is lesser than in Case1 as there are only 15 operating shifts in Case 2 but 21 shifts in Case 1. Implementing Case 2 as the operations system can only produce a maximum of 170 550 units/year.

Based on the analysis above, there are two types of potential operating systems that can be adapted to the processing line of the disc brake manufacturing systems. Taking into account the forecasted values in the previous sections, both the operating systems can be adopted at a different time line. Referring to Figure 13, the forecast on the annual demand up to year 2014 is only 238 389 units which is lesser than the maximum output capability of Case 1.While the forecast till year 2022 which is also the ultimate maximum value of the disc brake annual demand is 315 998 units.

Therefore, it is proposed that a single processing line is used up to year 2014 while adapting the parameters of Case 1 and for the consequence years, another processing line is added and both the processing lines adopt the parameters of Case 2 up to year 2022.This is because up to year 2014, one processing line could cater all the annual demands and after year 2014, each of the lines can produce 170 550 units amounting to 341 100 units of disc brakes. This can certainly cater the ultimate maximum value preset by this project which is 315 998 units. Applying Case 1 will require the plant to operate 7 days a week. But however, when another processing line is added and parameters of Case 2 are implemented, the operating hours can be reduced from seven to five days. Even though the initial investments are high, but it can be justified as the maximum market demand can be satisfied as well as the savings on utilities and salary.

4.4.2.3 Process Flow of the Disc Brake Processing Line

The parameters of the processing line have been determined in the previous section. Applying the parameters into the real case scenario is another task. The processes are arranged in groups in which the machining will be done. The process chart below shows the processes that are allocated in their respective stations.

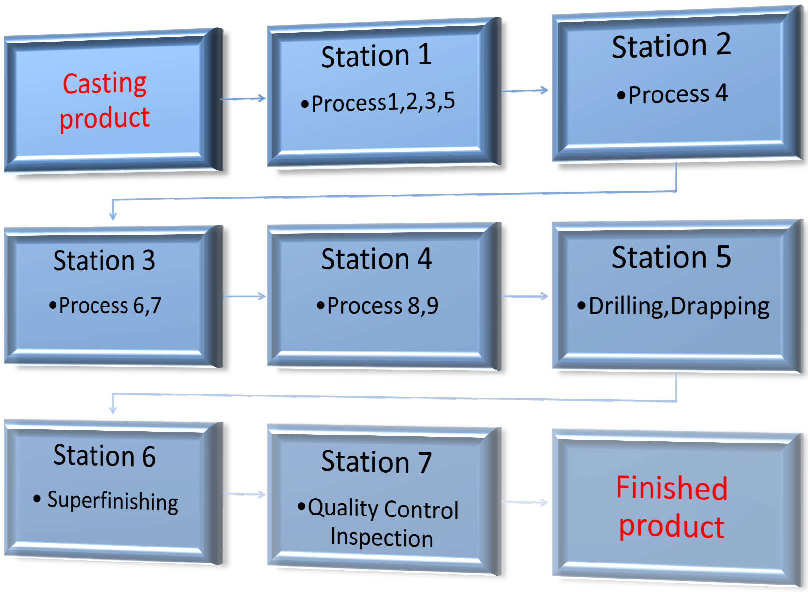

Figure 29 Specific Process Flow Chart for processing disc brake

4.4.2.4 WITNESS Simulation for Case 1

WITNESS Simulation is used to check the feasibility of the processing parameters in real time scenario. Below is the simulation for the processing line per shift when Case 1 parameters are used.

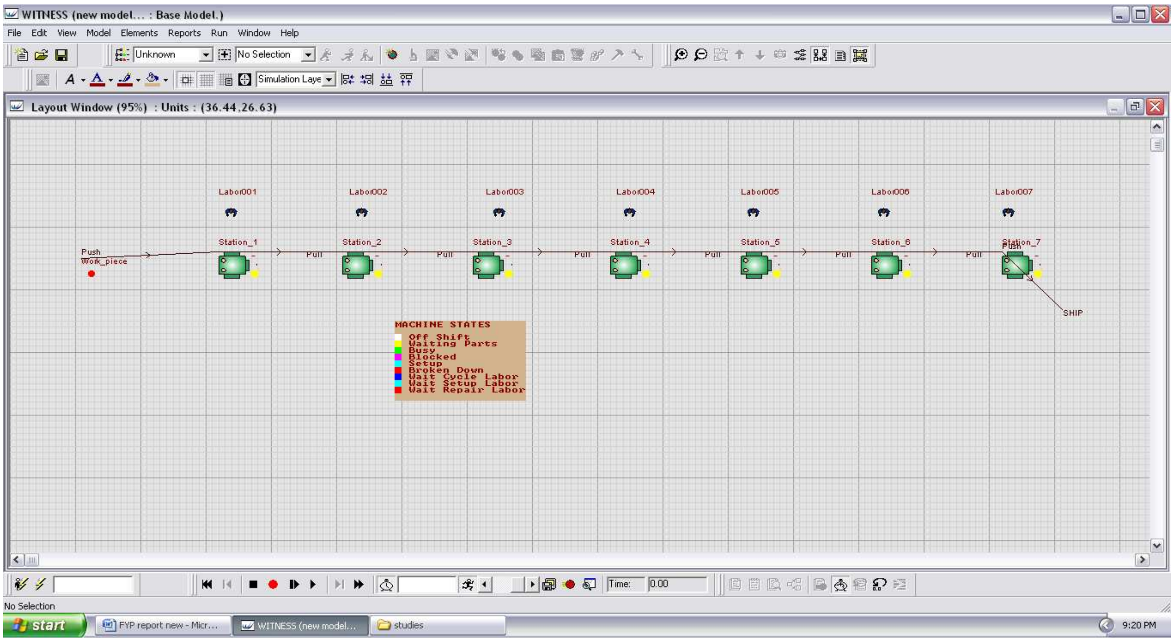

Figure 30 WITNESS Simulation using Case 1 parameters

Name	Station_1	Station_2	Station_3	Station_4	Station_5	Station_6	Station_7
% Idle	7.59	8.06	8.53	9.00	9.47	9.97	18.55
% Busy	80.44	80.04	79.64	79.23	78.83	78.40	77.57
% Setup	11.97	11.90	11.83	11.77	11.70	11.63	3.88

Name	No. Entered	No. Shipped	No. Scrapped	W.I.P.
Units	181	170	8	3

Figure 31 WITNESS Analysis for Case 1 parameters

4.4.2.5 WITNESS Simulation for Case 2

Below is the simulation of the processing line when parameters of Case 2 are used. The processing line must have 2 similar lines. Since the WITNESS simulation is unable to cater more elements, the simulation is done on one processing line and multiplied into two.

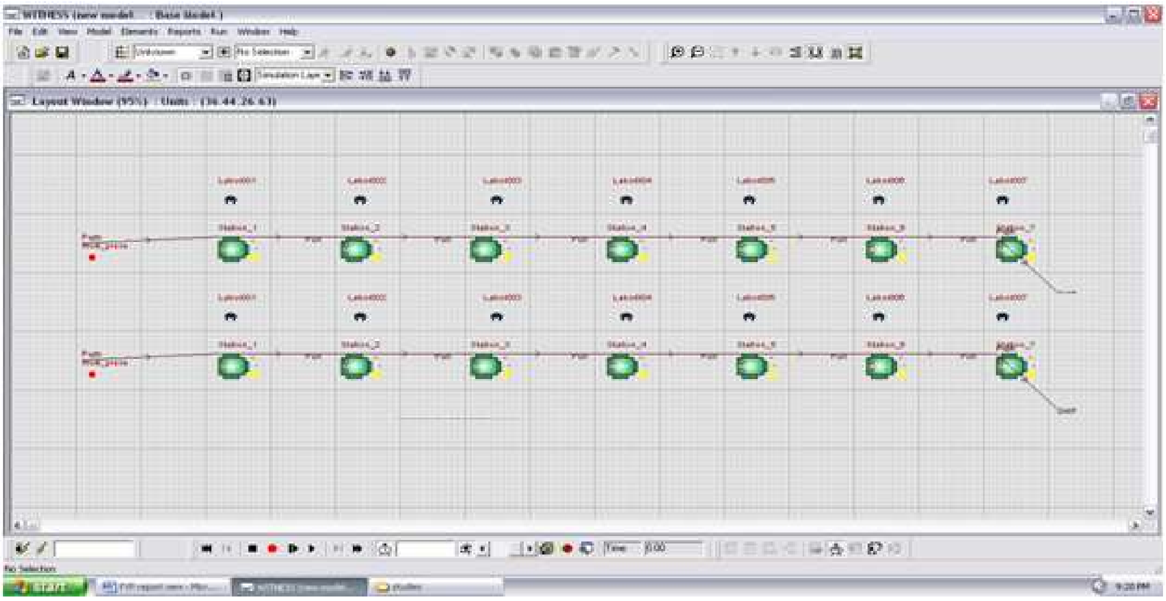

Figure 32 WITNESS Simulation using Case 2 parameters

Name	Station_1	Station_2	Station_3	Station_4	Station_5	Station_6
% Idle	2.90	3.44	3.98	4.52	5.08	5.63
% Busy	78.99	78.56	78.12	77.68	77.23	76.77
% Setup	18.11	18.00	17.90	17.79	17.69	17.60

Name	No. Entered	No. Shipped	No. Scrapped	W.I.P.
Units	174	160	11	3

Name	No. Entered*2	No. Shipped*2	No. Scrapped*2	W.I.P.*2
Units	348	320	22	6

Figure 33 WITNESS Analysis for Case 2 parameters

Figure 30 shows the WITNESS Simulation model for the processing line if Case 1 parameters are used. Inputting the Cycle Time and Service Time calculated earlier in to the model shows that the line is capable of producing the required output volume. Figure 31 shows the analysis of the processing line .The stations are well balanced as the idle time and busy time does not vary much between them even though the line balancing efficiency is only 68.80%.

According to the calculations in the previous section, the line should be able to produce 22.69units/hour for the given parameters. Therefore for a shift of 7.5 hours, the line should be able to produce 170.75units/shift. Taking in to account the 5% defect rate, the line must produce a total of 178units/shift. This is proven feasible by the analysis done on the WITNESS model. Based on the analysis, applying the model can produce 170 good units, 8 defect units while 3 more in the ‘Work In Progress” mode.

When the production rate need to be increased, The service time and cycle time need to be reduced according to Figure 21.This can be done by doing continuous improvement on the machining process. By doing this the Line Balancing Efficiency can also be increased which results in a more efficient processing line. Therefore, Case 1 parameters are proven to be able to cater the total demand of the disc brake plant until year 2014.

Figure 32 shows the WITNESS Simulation Model for the processing line when Case 2 parameters are used .The model has been build using the cycle Time and Service Time from the previous calculations .The processing line uses Case 2 parameters and therefore it should have 2 sets of processing line .Due to some limitations on the WITNESS Software, the second line could not be modelled. However, since both the lines are similar and the parameters are identical, the volume could be multiplied into 2 to gain the final volume.

According to the calculations in previous section, the lines should be able to produce 21.33units/hour for the given parameters. Since the plant operates for 7.5hours /shift and there are 2 processing lines, it can produce a total of 320units/shift.

Considering the 5% defect rate, the line should be able to produce at least 336units/shift. By observing Figure 33, it can be proven that Case 2 parameters are capable of meeting the annual demand as 320 units are shipped, 22 are scrapped and 6 still in progress. When the annual demand increases later, the Cycle time and Service Time must be reduced according to Figure 25 to cater the annual demand. As the annual demand increases, the line balancing Efficiency will increase thus making both the lines more efficient. Therefore, Case 2 parameters are proven to be able to cater the annual demand of the disc brake plant from year 2014 until 2022.

4.5 Modeling a Quality Control Inspection Plan

Operations	**Machine**	**Production Control Methods**	**Measurement Equipment**
Cast discs	Inspection by third person	Properties –hardness, strength, surface defect	Tensile testing, hardness testing, visual magnetic particle inspection
Turning, Facing, Chamfering	Lathe (CNC)	Dimensions- length, diameter, roundness, flatness	Digital Vernier calliper, Dial Indicator, V-Block
Drilling	Drilling machine (CNC)	Dimensions – hole size, hole depth	Depth calliper, Digital Vernier calliper
Tapping	Drilling Machine (CNC)	Dimensions- tap size	Digital Vernier calliper
Superfinishing	Aluminium Oxide, Silicon Carbide Abrasives	Surface Quality- flatness, straightness, surface hatching	Dial indicator, Surface Plate

Figure 34 Quality Control Plan for disc brake manufacturing.

Quality Control Inspection is crucial in every manufacturing plant. The manufactured products must be regularly inspected to ensure the products are meeting the specifications. Above is the table on the measurement equipments that are used to inspect the specific dimensions.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

This chapter concludes the entire project and proposes several recommendations which could improve the outcomes of the project.

5.1 Recommendations

Despite achieving the objectives, there are several recommendations, which would be considered in order to improve the outcomes.

- **Use lower cutting speed and feed for configuration of machining system.** This can improve the surface quality of the machined disc brakes .However the time required to machine the surface will increase.

- **Reduce the number of machine used.** Reducing the number of machine and trying to incorporate all the processes into the machines available can reduce the capital cost. The number of machines has been predetermined in this project.

- **Use a complete version of WITNESS Software to simulate the model.** The WITNESS Software used to simulate the model is an educational version. Therefore it is has some limitations and some elements could not be modeled.

- **Use better technology for Quality Control Inspection Plan.** The equipments used in quality control inspection must be upgraded to a better technology to enhance the quality of the products produced. High technology equipments can produce higher tolerance in measuring the specifications.

5.2 Conclusion

A disc brake manufacturing system was successfully modelled. The historical data on car manufacturing has been used to predict the spare part market. The disc brake machining configuration was modelled thus used to design the operational system. Finally before completing the manufacturing process, the completed disc brakes will go through a simple quality control inspection to ensure that it meets the design specifications. Simulation of the model using WITNESS proves that the design can be successfully used to produce disc brakes at the specified rates.

In conclusion, with the proposed model, it can be said that this project is a success.

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[10] http://en.wikipedia.org/wiki/Quality_control

[11] http://en.wikipedia.org/wiki/Superfinishing

APPENDIX A

	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MEI	JUN
Selection of topic and supervisor												
Preliminary Study												
Preliminary Report												
Literature Review on disc brake												
Mathematical Modal of disc brake												
MID-SEMESTER BREAK												
Progress Report												
Demand Forecasting												
Configuration of cutting parameters												
Draft Report												
Interim Report & Oral Presentation FYP 1												
SEMESTER BREAK												
Process Selection												
Design of Operation Systems												
Progress Report 1												
Design of Quality Control Inspection Methods												
Progress Report 2												
Documentation												
Final Report(softcopy)												
Technical Report												
Oral Presentation FYP 2												
Final Report(hardcopy)												