PROPOSE AND DESIGN A TRICYCLE WITH CLEANING MECHANISM

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in fulfilment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled "Propose and Design a Ticycle with Cleaning Mechanism" is the result of my own work except as cited in the references.

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Design & Innovation).

Signature	:	....
Name of Supervisor	:	....
Date	:	....

DEDICATION

To my beloved mother and father.

ABSTRACT

Cleanliness is very important to human and every country. One of the goals of Melaka is to become a ‘zero waste’ state but there is still a lot of rubbish in public area such as park, sidewalk, and parking lot. Waste in public area can influence the health of people nearby and also the image of a country. This project was carried out to propose and design a human-powered tricycle with cleaning mechanism to clean the city. Searching online, studying internet article, and reviewing past research were employed to collect the information. This project is conducted by following the engineering design steps, which are conceptual design, design selection, parametric design, detail design, cost analysis and design analysis. In conceptual design stage, four conceptual designs were generated by using morphological chart. In design selection stage, the best design among four conceptual designs was selected by using Pugh selection method. In parametric design stage, the pulley and gear ratio were determined in order to get the desired output. In detail design stage, the materials used for each part of the design were determined which are aluminium, plastic, steel and synthetic material. The dimensions of each part of design were also determined and converted into 3-Dimension by using CATIA V5R21 software. The total cost to fabricate a tricycle with cleaning mechanism is RM 627.20 which included raw material, manufacturing and purchase cost. In design analysis stage, CATIA V5R21 FEA was employed to analyze the critical part of final design and result shows that the final design is safe to use. The design analysis result shows that the tricycle with cleaning mechanism has good sweeping effectiveness only when it is moving at the speed between 2km/h and 5km/h.

ABSTRAK

Kebersihan adalah sangat penting kepada manusia dan setiap negara. Salah satu matlamat Melaka adalah untuk menjadi sebuah negeri yang tiada sampah tetapi masih terdapat banyak sampah di kawasan awam seperti padang, laluan pejalan kaki, dan tempat letak kereta. Sampah di kawasan awam boleh mempengaruhi kesihatan orang yang berdekatan dan juga imej negara. Projek ini telah dijalankan untuk mencadangkan dan mereka bentuk basikal roda tiga yang menggunakan kuasa manusia dengan mekanisme pembersihan untuk membersihkan bandar. Mencari internet, membaca artikel internet, dan mengkaji laporan penyelidikan masa lalu telah digunakan untuk mengumpul maklumat. Projek ini dijalankan dengan mengikuti langkah-langkah reka bentuk kejuruteraan, iaitu reka bentuk konsep, pemilihan reka bentuk, reka bentuk berparameter, reka bentuk terperinci, analisis kos dan analisis terhadap produk. Dalam peringkat reka bentuk konsep, empat reka bentuk konsep telah dihasilkan dengan menggunakan carta morfologi. Dalam peringkat pemilihan reka bentuk, reka bentuk yang terbaik telah dipilih dengan menggunakan kaedah pemilihan Pugh. Dalam peringkat reka bentuk berparameter, nisbah takal dan gear ditentukan untuk mendapatkan output yang dikehendaki. Dalam peringkat reka bentuk terperinci, bahan yang digunakan untuk setiap bahagian reka bentuk telah ditentukan iaitu aluminium, plastik, keluli dan bahan sintetik. Dimensi bagi setiap bahagian reka bentuk juga ditentukan dan ditukar kepada 3-Dimensi dengan menggunakan perisian CATIA V5R21. Jumlah kos untuk membina satu basikal roda tiga dengan mekanisme pembersihan ialah RM 627.20 termasuk kos bahan, kos pembuatan dan kos pembelian. Dalam peringkat analisis terhadap produk, CATIA V5R21 FEA telah digunakan untuk menganalisis bahagian kritikal produk dan keputusan menunjukkan bahawa reka bentuk tersebut adalah selamat untuk digunakan. Hasil analisis reka bentuk menunjukkan bahawa basikal roda tiga dengan mekanisme pembersihan boleh menyapu berkesan hanya apabila ia bergerak dengan kelajuan yang antara 2km/h dan 5km/h.

ACKNOWLEDGEMENT

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Secondly, I would like to thank my final year project second examiner Dr. Mohd Basri bin Ali for giving me his suggestion and guidance. He gave me his opinion on my final year project report so that I can improve my report. Last but not least, I would like to thank my family and course mates for giving me their support and encouragement.

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CATIA	Computer Aided Three-Dimensional Interactive Application
HOQ	House of Quality
QFD	Quality Function Deployment
r.p.m.	Rotation per minute
3D	Three-Dimension

LIST OF SYMBOL

ζ	=	Bristle tip height
L	=	Bristle length
$\emptyset$	=	Bristle mount angle
R_b	=	Mount radius
β	=	Brush tilt angle
Δ	=	Brush penetration
N_1	=	Speed of driver in r.p.m.
N_2	=	Speed of driven in r.p.m.
d_1	=	Diameter of driver
d_2	=	Diameter of driven
t	=	Thickness of belt
N	=	Rotational speed in r.p.m.
w	=	Angular velocity
d	=	Diameter
t	=	Number of teeth
τ	=	Torque
D	=	Diameter of wheel
P	=	Perimeter of wheel
v	=	Velocity of tricycle
w_1	=	Angular velocity of gear (wheel) in r.p.m.
w_2	=	Angular velocity of gear (rear brush) in r.p.m.
w_3	=	Angular velocity of pulley (rear brush)
w_4	=	Angular velocity of pulley (front brush)

n	=	Gear ratio
$\emptyset$	=	Pressure angle
P_d	=	Diametral pitch
N_1	=	No. of teeth of gear (wheel)
N_2	=	No. of teeth of gear (rear brush)
d_1	=	Pitch diameter of gear (wheel)
d_2	=	Pitch diameter of gear (rear brush)
d_3	=	Diameter of pulley (rear brush)
d_4	=	Diameter of pulley (front brush)
C	=	Centre distance
a	=	Addendum
b	=	Dedendum
d_b	=	Base circle diameter
d_a	=	Addendum circle diameter
d_d	=	Dedendum circle diameter

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Cleanliness is one of the most important aspects for human. However, it is also one of the biggest issues in Malaysia. With speedy increasing of urban population, waste in streets escalated as usage levels of sidewalk and road increase. Statistics show the urban population in Malaysia increase more than 50% in the last few decades and number of cities in peninsular Malaysia increase 400% from year 1957 to 2000 (Tarmiji, 2011). Malaysians like to throw their rubbish in the rivers and on the streets while driving because they are more worried about the cleanliness of their vehicles rather than public areas. With low awareness level about littering among Malaysians, rubbish on the roads increase every year. Waste on the streets can influence the health of residents nearby and also the dignity or image of a country (Nur Imani, 2016).

With the increase of vehicular traffic and road usage levels, it is necessary to carry out street sweeping program. Based on the study of quantifies broom sweeper litter pick up ability, increasing the frequency of sweeping operations by using sweeper machine from monthly to weekly does not improve the cleanliness of drainage system. Problem discovered was that large waste stuck at the suction head of the sweeper fell into the drain when the sweeper went over a drain inlet. However, large amount of waste did removed by sweeping operation. This indicates that mechanism of cleaner is much more important than frequency of sweeping operation (Lippner & Moeller, 2000).

Melaka green technology council and Melaka green technology corporation have been established on 23 May 2011 and 1 October 2013. The blue print is to become a green technology city by year 2020. Therefore, it is necessary to develop a green technology device that can effectively collect the rubbish on the streets. Push sweeper is a cleaning device that manually-operated without using electricity. It uses the rotation of wheel to spin the hard brush and collect the rubbish by using the gear transmission concept. It is one of the simplest and modest mechanism devices that help people to collect debris in short time (Solis, 2013).

In the past, people collected rubbish on the street by using broom and dustpan which took very long time and waste manpower. With booming development of technology, cleaning tool has been evolved from broom and dustpan to vacuum cleaner, floor sweeping machine, electric road cleaner and dust cleaning robot. But all these high technology cleaning products require electricity to operate and some of them will emit unhealthy gas such as carbon dioxide. For electric road cleaner, it emit 12.6 gram of carbon dioxide per kilometre (Avinash, 2014).

However, these high technology cleaning products are not suitable to be used in some areas such as park, playground, sidewalk and street. This is because they are very expensive and also quite costly to be operated since they consume large amount of electrical energy. Manual push sweeper is the most suitable cleaning product to be used to collect rubbish in public area since it does not make noise and save energy. Nowadays, it is not just used for collecting debris in industry and public areas, most of the resident also use it for cleaning house and garden.

Manual push sweeper is very useful compare to other cleaning products. However, every product has its own disadvantages and will be modified again and again in the future. The weakness of manual push sweeper is its slow moving speed. Its moving speed is dependent on the user walking speed. Therefore, it takes very long time to clean a big city. Until now, people still use manual push sweeper to clean a large area this is because there is still no modification and improvement to be made regarding on this product. Hence, tricycle sweeper with high moving speed has high potential to be developed and very useful for future generation.

1.2 PROBLEM STATEMENT

One of the goals of Melaka green city action plan (GCAP) is to put Melaka on the path to become a 'zero waste' state. However, there is still a lot of rubbish in public area such as park, sidewalk and parking lot. The Figure 1.1(a) and 1.1(b) show the rubbish in playground and street at the location Jalan Delima 5, Taman Bukit Melaka.

(a) (b)

Figure 1.1: (a) Rubbish in playground

(b) Rubbish in street

Unfortunately, most of the cleaning devices are not suitable to clean the rubbish in city because the city area is very large. If high technology cleaning product such as electric road cleaner or street cleaning machine is used, large amount of electrical energy, petrol and fund will be wasted. Besides that, it also emits unhealthy gas (carbon dioxide) which is not friendly to environment. Nowadays, people use the environment friendly product such as manual push sweeper to clean the rubbish in city. It is the most suitable cleaning device to be used in public area since it only use human energy and does not make any noise. However, it takes very long time to clean the rubbish in city due to its slow movement speed. It is manually operated and moved by user, its movement speed is as slow as human walking speed. A lot of manpower has been wasted due to this problem.

1.3 OBJECTIVE

The objectives of this project are as follows:

1. To propose a suitable cleaning device to clean the city.
2. To design a human-powered tricycle with cleaning mechanism.

1.4 SCOPE OF PROJECT

This project focuses on designing a human-powered tricycle with cleaning mechanism that can clean the rubbish effectively in public area. The main considerations of this project are the product's materials, structure, cleaning mechanism, working principle, and how it will aid the user. Other aspects such as the marketing price and the production of the cleaning tricycle will not be covered in this project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In order to propose a new design of tricycle with cleaning mechanism, some research on the invention of the tricycle since early stage of the century has been made. The purpose of studying the type of tricycle transmission mechanism is to understand and generate some ideas on designing the tricycle mechanism. The characteristics of the bristle brush material were studied in order to choose the most suitable material for bristle brush to get the maximum sweeping effectiveness. Journal on brush parameter for different type of waste has been reviewed in order to design a tricycle with cleaning mechanism that can sweep different type of waste effectively. The purpose of studying gear and belt drive system is to design an effective and desired cleaning mechanism.

2.2 HISTORY OF TRICYCLE

In 17th century, a watch-maker named Stephan Farffler, was the first person who built a three-wheeled and hand-power vehicle in order to maintain his mobility as he was disabled. By 1820, there were many tricycles in Germany, France and England, but they were just prototypes and never been used as a transportation product. In 1860, riding a bicycle had become a trend, hobby and mainstream pastime. But people always pursue safety, therefore, tricycle was developed in 1877. In March 1877, a sewer-machine maker named James Starley developed a tricycle in Coventry England. It was the first rotary chain drive tricycle in the world. It had a big wheel on the left and two much smaller wheels on the right and rider sat between the wheels (Daniel, 2014).

2.3 TRICYCLE TRANSMISSION MECHANISM

Tricycle has a transmission mechanism that used to transmit the human power to the rotation of the wheels. There are several types of transmission mechanism used in tricycle which are chain transmission, gear transmission, and single slider mechanism.

2.3.1 Gear Transmission Mechanism

Figure 2.1 shows the gear transmission mechanism by using three spur gears. The human power input on the pedal is transmitted from the pedal gear to the wheel gear and cause the rotation of the wheel. Table 2.1 shows the advantages and disadvantages of gear transmission mechanism.

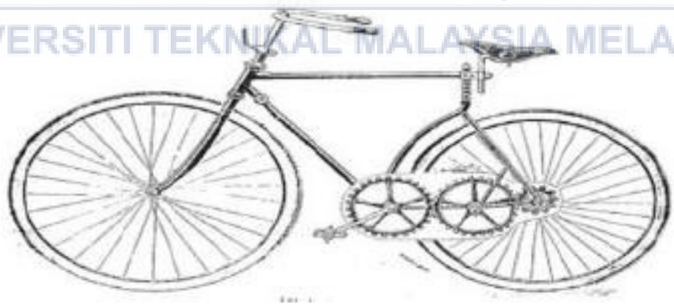


Figure 2.1: Gear transmission mechanism

(Source: Gicky, 2015)

Table 2.1: Advantages and disadvantages of gear transmission mechanism

Advantages	Disadvantages
Less noise produced	The system is not compact because the size of the intermittent gear is large
Easy maintenance and lubrication	More on slack and backlash

2.3.2 Chain Transmission Mechanism

Chain drive is used to transmit power from one location to another which mostly used in wheel applications. Chain drive mechanism consist two sprocket gears and one chain link which the teeth of the gear meshing with the holes of chain link. Human power is applied to rotate the sprocket gear and pull the chain link at the same time which result the rotation of another sprocket gear. Table 2.2 shows the advantages and disadvantages of chain transmission mechanism.

Table 2.2: Advantages and disadvantages of chain transmission mechanism

Advantages	Disadvantages
Compact transmission system	High maintenance frequency
Cheap	Chain link disengages from the sprocket gear sometimes occur
Can use in multi gear system	More on slack and backlash

2.3.3 Single Slider Mechanism

Single slider mechanism in tricycle consist three parts which are slider, connecting rod and rotating disc as shown in figure 2.2. The human power is transmitted from steering bar to rear wheel through connecting rod and rotating disc. This mechanism requires less effort compare to other mechanism (Vaidya, 2016).

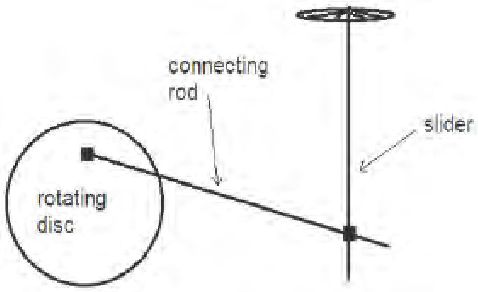


Figure 2.2: Single slider mechanism

The wheel is rotated by pulling and pushing the steering bar in backward and forward direction as shown in figure 2.3. This mechanism requires human hand power to cycle instead of leg power which is suitable for movement disable people.

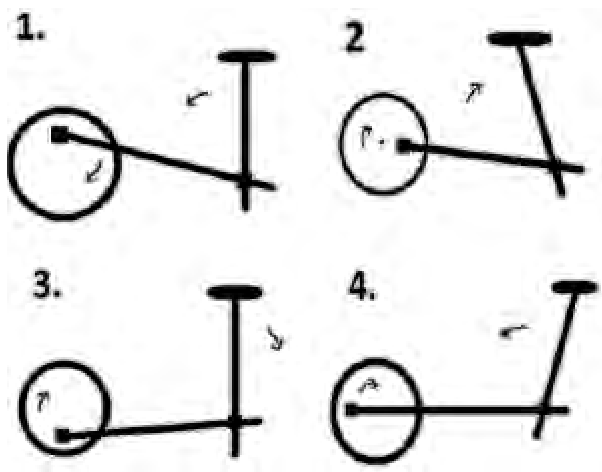


Figure 2.3: Steps to cycle for single slider mechanism

(Source: Vaidya, 2016)

2.4 BRUSH PARAMETER

Brush parameters are the main factor that will affects the sweeping effectiveness. Brush parameters include the bristle tip height, bristle length, bristle mount angle, brush tilt angle, brush penetration, and mount radius as shown in figure 2.4. All these parameters are related to each other. If one of the values of these parameters is altered, other value of parameters will be affected also. Other factors that will affect the sweeping effectiveness are material of bristle, material of the surface such as concrete floor and asphalt road, and surface roughness (Magd, 2011).

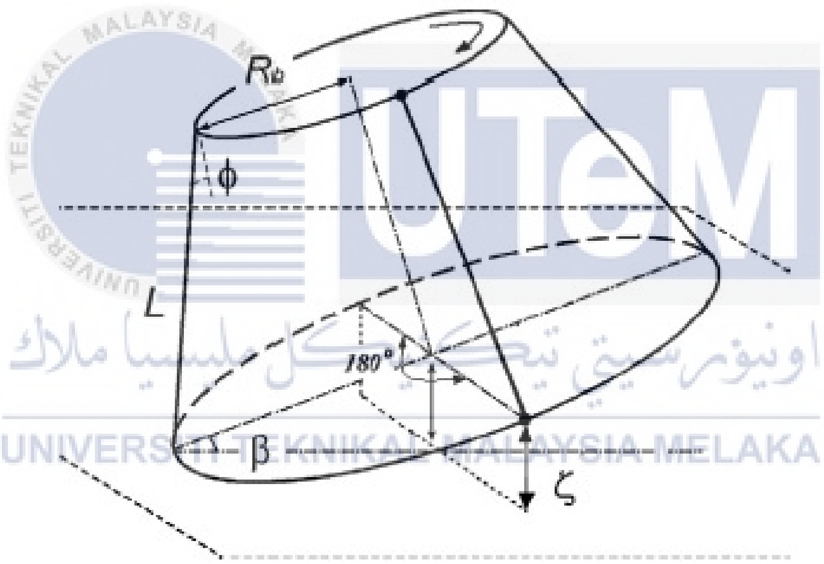


Figure 2.4: Parameters of Brush

(Source: Magd, 2011)

The bristle tip height can be calculated by

$$\zeta = (L \cdot sin\emptyset + R_b) \cdot sin\beta - \Delta \quad (2.1)$$

ζ = Bristle tip height

L= Bristle length

$\emptyset$ = Bristle mount angle

R_b= Mount radius

β = Brush tilt angle

Δ = Brush penetration

2.5 ROAD SWEEPING CRITERIA FOR DIFFERENT TYPE OF WASTE

According to Magd M. Abdel-Wahab research, different types of waste require different sweeping parameters in order to obtain the maximum sweeping effectiveness. In this study, concrete floor and asphalt road with a gutter of 0.25cm width and 10° slope as shown in figure 2.5 are used as the road's geometric parameters because this kind of road gutter is difficult to sweep.

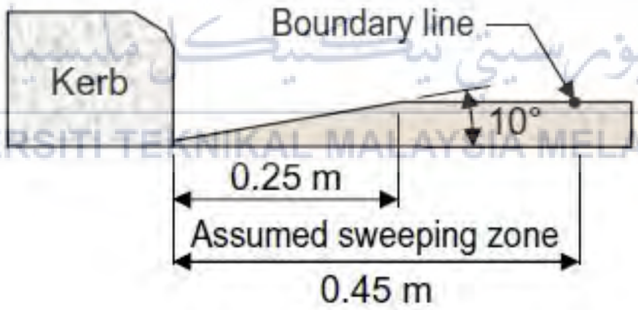


Figure 2.5: Geometry of the road gutter

(Source: Magd, 2011)

The geometric parameters of brush used are: bristle length, L=240mm; number of bristle per cluster, n_{bc}= 60; number of cluster per row, n_c= 24; two rows of cluster; bristle mount orientation angle, $\emptyset$ = 27°; outer mount radius, R_{b1}= 115mm; inner mount radius, R_{b2}= 90mm.

2.5.1 Large Object

Large object refer to the waste sizes between 3cm to 8cm. Backward-sweeping problem sometimes occur when sweeping the large waste, shown in figure 2.6. This is because the large waste can be trapped under the brush and the rotating brush sweeps it backward. This problem can be solved by increasing the brush tilt angle, β so that bristle tips in the rear part are far from the surface and the large object will not be trapped under the brush. Another factor that causes the backward sweeping is that the gap between the two clusters is big and the large object can be trapped between them easily. This problem can be solve by increasing the angular velocity of the brush to produce higher centrifugal force and large object has less chance to be trapped into the gap (Magd, 2011).

(a) (b) (c)

Figure 2.6: Sweeping test for large wastes; (a) before sweeping; (b) β= 5°, Δ=0mm, ω=60rpm; (c) β= 15°, Δ=0mm, ω=100rpm

(Source: Magd, 2011)

Zero brush penetration can be used because the brush can produce high enough force to remove the large waste. This can save the energy consumption. Increasing the stiffness of the bristle can improve the efficiency of sweeping operation for large object because it provides larger removal force. To obtain the maximum effectiveness and minimum energy consumption, brush tilt angle, $\beta = 10°$, brush penetration, Δ=0mm, and angular velocity, ω=100rpm should be used (Magd, 2011).

2.5.2 Medium Size Object

Medium size object refer to waste sizes around 15mm which is the most frequently seen on the road such as bottle cap and small piece of paper. The tilt angle, β and the penetration, Δ of brush are the main parameters that will affect the sweeping effectiveness for medium size object. The tilt angle, β should large enough so that the bristle tip can reach the edge of gutter and backward-sweeping problem will not occur. However, if the tilt angle, β is larger than 10°, it starts to have negative effect. The penetration, Δ of brush should large enough in order to keep the contact area between the brush and surface wide. If the penetration, Δ of brush is too large, it will consume more energy and increase the brush wear rate. Insufficient surface area contact if the penetration, Δ of brush is too small. Figure 2.7 shows the results after sweeping the medium size wastes by using different value of tilt angle, β and penetration, Δ of brush. To obtain the maximum effectiveness and minimum energy consumption, brush tilt angle, $\beta = 10°$ and brush penetration, Δ=30mm should be used (Magd, 2011).

(a) (b) (c)

Figure 2.7: Sweeping test for medium size wastes; (a) before sweeping; (b) β= 5°, Δ=10mm, ω=100rpm; (c) β= 15°, Δ=20mm, ω=100rpm

(Source: Magd, 2011)

2.5.3 Small Fine Particle

Small particle refer to waste sizes in millimetre (mm) and fine particle refer to waste sizes in micrometre (µm). Sweeping small and fine particle on a smooth surface require very small removal forces. On the other hand, sweeping small and fine particle on a rough surface is very difficult such as the asphalt road. This is because these small and fine wastes are filled in the concavities of the surface. The surface roughness depends on the surface material and the surface treatment method (Magd, 2011).

For 2mm coarse sand particles, it is found that the areas at the middle part of the road are very easy to sweep. However, the areas beside the kerb or at the boundary line are difficult to sweep. To sweep 2mm waste, the bristle tip height, ζ should be same with the size of the waste which is around 2mm and the sweeping edge should be 180°. The 180 ° sweeping edge can be generated by adjusting the brush tilt angle, β and penetration, Δ of brush properly. According to the figure 2.4 and equation 2.1, in order to obtain 2mm bristle tip height, ζ and 180° sweeping edge, brush tilt angle, β=10° and penetration, Δ=35mm should be used (Magd, 2011).

For 0.1mm average size of dry soil particles, it is more difficult to sweep compare to the coarse sand either at the edge or at the middle part of the road. Figure 2.8 shows the sweeping results for fine dry soil particles. There are large amount of dry soil still left in the concavities of the surface due to the insufficient of brush-surface contact requirement. The result shows that sweeping can be improved by reducing the brush tilt angle and penetration of the brush, and increase the brush rotational speed. This is because smaller bristle curvature allows the bristle tips to penetrate more deeply inside the surface concavities and higher rotational speed of brush allows the area can be swept more times in a certain time. However, the rotational speed of brush should not exceed 120 r.p.m. otherwise it will blow the fine particles and threaten the public health. In conclusion, brush with tilt angle, β=5° and penetration, Δ=55mm has the best sweeping performance for fine particles (Magd, 2011).

(a) (b) (c) (d)

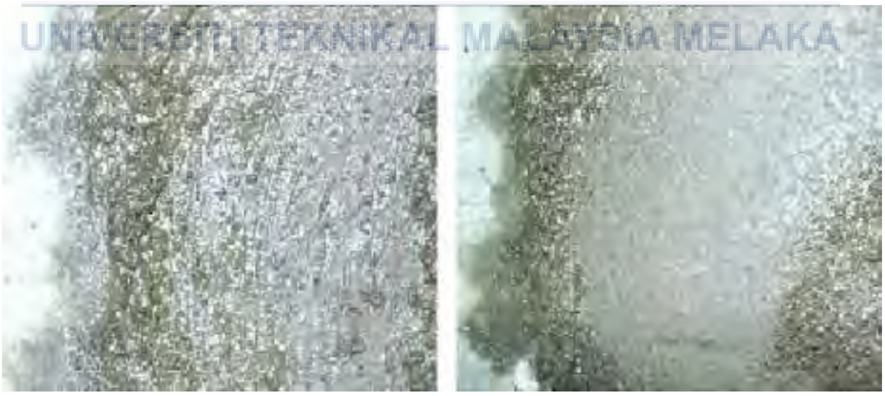
Figure 2.8: Sweeping results for fine particles; (a) before sweeping; (b) β= 15°, Δ=60mm, ω=100rpm; (c) β= 5°, Δ=20mm, ω=100rpm; (d) β= 5°, Δ=20mm, ω=150rpm

(Source: Magd, 2011)

2.5.4 Wet and Dry Mud

Wet and dry mud can be often seen on roadways. It belongs to adhesive material which requires high removal forces to remove them. The contact angle between the surface and brush should always maintain at 180 ° in order to get the best sweeping performance. However, this make a constraint for brush tilt angle, β and brush penetration, Δ because if brush tilt angle is small, brush penetration must also be small in order to achieve 180° of contact angle.

Figure 2.9 shows the sweeping results for wed mud. It shows that the sweeping effectiveness can be improved by increasing the brush tilt angle, β, brush penetration, Δ and brush rotational speed, ω. This is because higher removal forces are generated by increasing these three parameters. Since the wet mud is less likely to be blown into the air, high rotational speed of brush can be used to remove the wet mud. As a conclusion, to get the best sweeping performance for wet mud, brush tilt angle, β=15°, brush penetration, Δ=60mm and brush rotational speed, ω > 150 rpm should be used (Magd, 2011).



(a) (b)

Figure 2.9: Sweeping results for wet mud, ω= 100rpm; (a) β= 5°, Δ=20mm; (b) β= 15°, Δ=60mm

(Source: Magd, 2011)

Dry mud has stronger bonding force compare to wet mud. However, dry mud is much easier to be removed because it has larger cohesion force and smaller adhesion force compare to wet mud. Due to this property, dry mud tends to be broken into large parts when the removal forces are applied and they can be removed together at once. But this condition is for the dry mud on smooth surface only such as flat concrete floor. If the dry mud is adhered to the rough surface such as asphalt road, it is very difficult to remove from the surface because the dry mud on the surface and the dry mud inside the surface concavities form a whole body. In order to break the connection between the rough surface and dry mud, the shear stress produced must be larger than fracture shear stress of dry mud. Therefore, a brush that can produce large shear force is required. Figure 2.10 shows the results of sweeping dry mud on rough surface with different brush penetration.

(a) (b) (c) (d) (e)

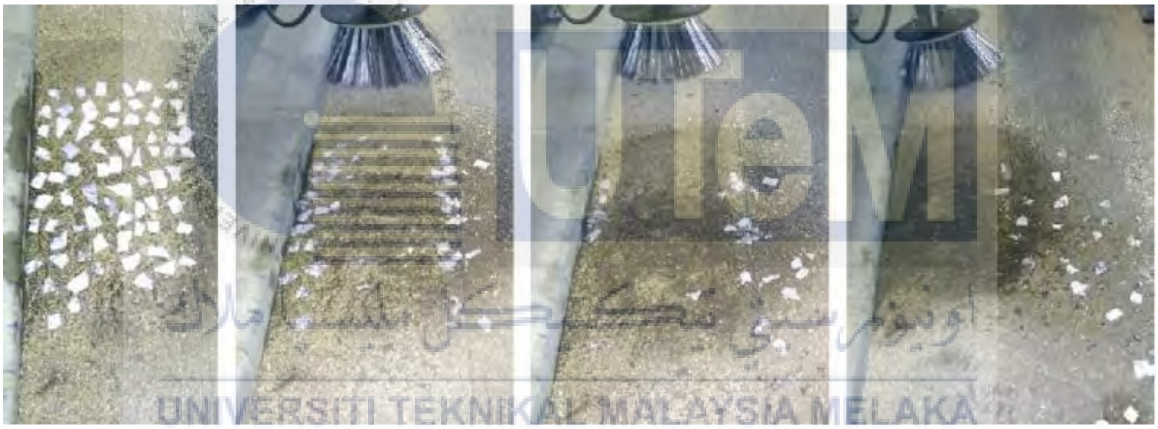
Figure 2.10: Results of sweeping dry mud on rough surface with ω =120 rpm, β=15°; (a) before sweeping; (b) Δ=50mm; (c) Δ=60mm; (d) Δ=70mm; (e) Δ=80mm

(Source: Magd, 2011)

As a conclusion, brush tilt angle, β=15°, brush penetration, Δ=80mm and brush rotational speed, ω =100 rpm should be used in order to remove the dry mud effectively. Although these brush parameters will cause backward-sweeping problem, but it is less serious compare to adhesion problem. The brush rotational speed must less than 120 rpm to prevent the dust blowing (Magd, 2011).

2.5.5 Wet Thin Debris

Thin debris is also often seen in public areas such as leaves, paper and grass. Wet thin debris is investigated rather than dry thin debris because the wet thin debris is always sticks at the surface firmly. In order to tear off the wet thin debris from the surface, the bristle tips have to produce large enough abrasive forces. Figure 2.11 shows the sweeping results for wet paper chips.



(a) (b) (c) (d)

Figure 2.11: Sweeping results for wet paper chips, ω= 100rpm; (a) before sweeping; (b) β= 5°, Δ=10mm; (c) β= 5°, Δ=20mm; (d) β= 15°, Δ=40mm

(Source: Magd, 2011)

Figure 2.11 (b) and (c) show that the wet paper chips are difficult to be removed from the area near the kerb and easily broken into small ones and attached on the surface firmly. This is because the brush cannot reach to the edge due to the small brush tilt angle and insufficient abrasive forces are provided due to the small brush penetration. In order to remove the wet thin debris effectively, the brush setting must meet three requirements, which are 180° contact edge, proper tilt angle to sweep the edge of the kerb, and proper penetration to produce sufficient abrasive forces. However, the brush tilt angle and penetration cannot be too larger or else the bristles will tear the wet thin debris apart. The rotational speed of brush much low enough to prevent the bristles cut the wet thin debris into smaller pieces. By considering all the factor, brush with tilt angle, β= 15°, penetration, Δ=40mm and rotational speed, ω= 80 rpm has the best sweeping performance for wet thin debris (Magd, 2011).

2.6 BRISTLE BRUSH MATERIAL WITH PROPERTIES AND APPLICATION

Bristle brush material can be divided into four categories, which are animal hair, vegetable fibre, synthetic material and wire. Every types of material have their own unique characteristic. Choosing material for bristle brush is very critical since it can greatly affect the sweeping effectiveness. Surface condition, chemical reactivity, stiffness, durability, liquid retention and cost are important aspects that need to take into consideration. Basically, animal hair and vegetable fibre brushes cannot be used for wet and oily surface but polypropylene will do the job (Marko, Inc., 2016).

2.6.1 Animal Hair

There are many types of animal hair that used for making bristles brush such as goat hair, hog bristle, horse hair, camel hair, ox hair and squirrel hair. However, goat hair, camel hair, ox hair and squirrel hair are not suitable to be used for sweeping because they belong to soft hair. Normally, they are used for cosmetic, dental and artist brush.

Hog bristle brush as shown in figure 2.12 is also known as China brush which is normally used for heavy dust. Hog bristle is very expensive because it is very rare and insufficient for demand. It has unique elasticity that cannot be found in other hairs because the tip end of each hog bristle is split into two or more branches. Stiffness of hog bristle ranged from medium to high which depend on the texture. It has good durability and water resistance.

Figure 2.12: Hog bristle brush

(Source: Gordon Brush Manufacturing Cp., Inc., 2016)

Figure 2.13 shows the horse hair brush. Horse hair is a medium to high cost material and its stiffness ranged from soft to slightly stiff which depend on which part of horse hair used. Tail hair is stiffer than mane hair. Its slightly stiff property gives a scratch-free sweeping which is suitable to be used for cleaning indoor mosaic and window. It has excellent durability.

Figure 2.13: Horse hair brush

(Source: Gordon Brush Manufacturing Co., Inc., 2016)

2.6.2 Vegetable Fibre

There are many vegetable fibre brush bristle materials such as Piassava, rice root and Tampico. Piassava brush as shown in figure 2.14 is made of leaves of palm trees. This fibre has two types which are Calabar Fibre and Sherebro Fibre. Calabar Fibre is very coarse and brittle and Sherebro Fibre is very stiff and pliable. This fibre is used mainly in street brooms due to its coarse and stiff properties.

Figure 2.14: Piassava

(Source: Nessentials, 2016)

Tampico brush as shown in figure 2.15 is made from the stalk of Agave plant. Its porous fibre allows it to absorb water and can be used for sweeping wet and dry surface. It has medium stiffness texture and resistant to heat, acid and alkali. Normally, it is used for removing surface particle and dusting.

Figure 2.15: Tampico brush

(Source: Gordon Brush Manufacturing Co., Inc., 2016)

2.6.3 Synthetic Material

Synthetic material such as proex, nylon and polyester is made by chemical synthesis to imitate the natural product such as animal hair brush. Proex material as shown in figure 2.16 has high efficiency which can be used for indoor and outdoor sweeping. It is not suitable for high temperature sweeping application but it can be used in humid environment.

Figure 2.16: Proex brush

(Source: Cardinal Brush Co., 2016)

Polyester and nylon have similar characteristics. They have an excellent abrasion resistance and high bend recovery. They perform well on rough surface and can be used in high temperature environment because of their high durability and melting point. However, they have low performance when sweeping in humid environment. Figure 2.17 shows the polyester brush.

Figure 2.17: Polyester brush

(Source: Cardinal Brush Co., 2016)

2.7 POWER TRANSMISSION

Power transmission is a process of transmitting energy that generated at a location to another location for working purpose. There are three main power transmission which are mechanical power transmission, electrical power transmission and hydraulic power transmission. Mechanical power transmission has been studied in order to propose a human-power tricycle with cleaning mechanism. Mechanical power transmission system includes gear drive system, belt drive system and chain drive system.

2.7.1 Belt Drive System

Belt drives are used to transmit power from driver shaft to driven shaft. Belt drive system consists of two or more pulleys that connected with belts. The pulleys are installed on shafts that are supported by bearings. There are 4 types of belt drive arrangement which are open, crossed, turned and serpentine belt drive as shown in figure 2.18.

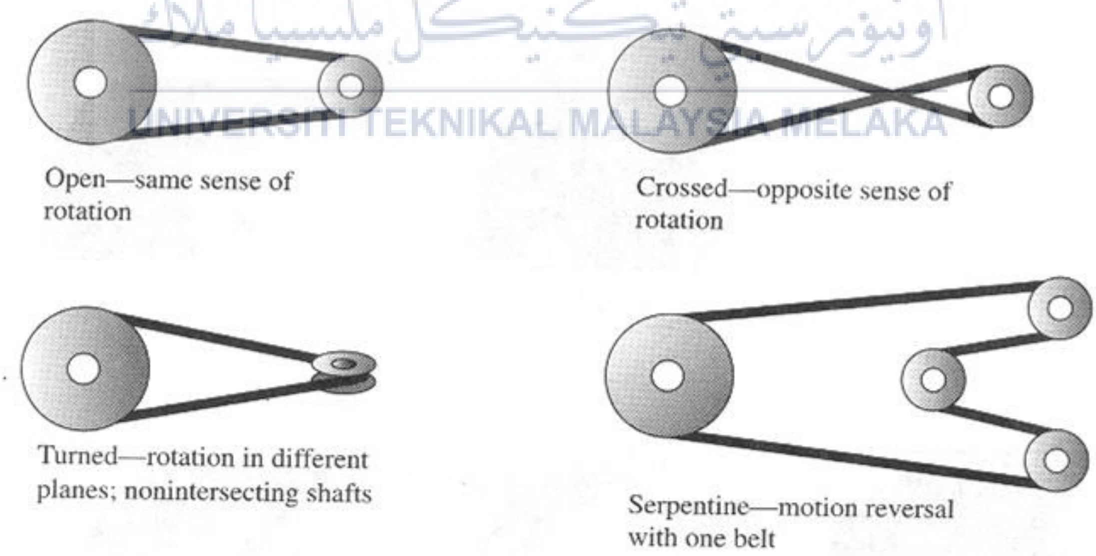


Figure 2.18: Type of belt drive arrangement

(Source: Cleghorn, 2005)

The velocity ratio can be calculated by

$$n = \frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t} \quad (2.2)$$

N_1= Speed of driver in r.p.m.

N_2= Speed of driven in r.p.m.

d_1= Diameter of driver

d_2= Diameter of driven

t = Thickness of belt

2.7.1.1 Belt

There are 3 main types of belt which are flat belt, V-belt and timing belt. Different type of belt has different characteristic and performance. The flat belt as shown in figure 2.19 is mostly used in workshops and factories. It has moderate power transmission from driver pulley to driven pulley. This kind of belt can be twisted and connected between two non-parallel pulleys and shafts. It must keep under tension and requires higher friction to prevent slippage occur (Khurmi, 2005).

Figure 2.19: Flat belt

(Source: Bando Chemical Industries, LTD., 2016)

V-belt as shown in figure 2.20 transmits great amount of power from driver pulley to driven pulley when the pulleys are near to each other. It can absorb the shock between driver and driven shaft. It requires friction and proper tension to function without slipping. Improper tension and high temperature can shorten the belt life significantly (Khurmi, 2005).

Figure 2.20: V-belt

(Source: Bando Chemical Industries, LTD., 2016)

Timing belt as shown in figure 2.21 is useful in operations requiring high efficiency, timing or constant velocity because this kind of belt will not slip and stretch. It requires very low belt tension to function. However, it requires shorter distance between driver and driven pulley compare to flat belt. It has higher cost and can only be used on parallel shaft only because it cannot be twisted.

Figure 2.21: Timing belt

(Source: SKF, 2016)

2.7.1.2 Pulley

Pulleys are used to transmit the power from driver shaft to driven shaft by using belts. The stage of choosing pulleys is very important, there are many aspects that need to take into consideration such as the type of belt used, required friction force and desired velocity ratio. The diameter of pulleys is selected based on the desired velocity ratio. Pulleys can be made of cast iron, pressed steel, wood and plastic. The materials used to make pulley should have good friction and wear characteristic (Khurmi, 2005).

2.7.2 Gear Drive System

Gear drive is a system that used to transmit the power from driver gear to driven gear and alter the speed, torque or direction of rotating shaft. Gear drive system consists of two or more gears and shafts. Figure 2.22 shows the gear terminology.

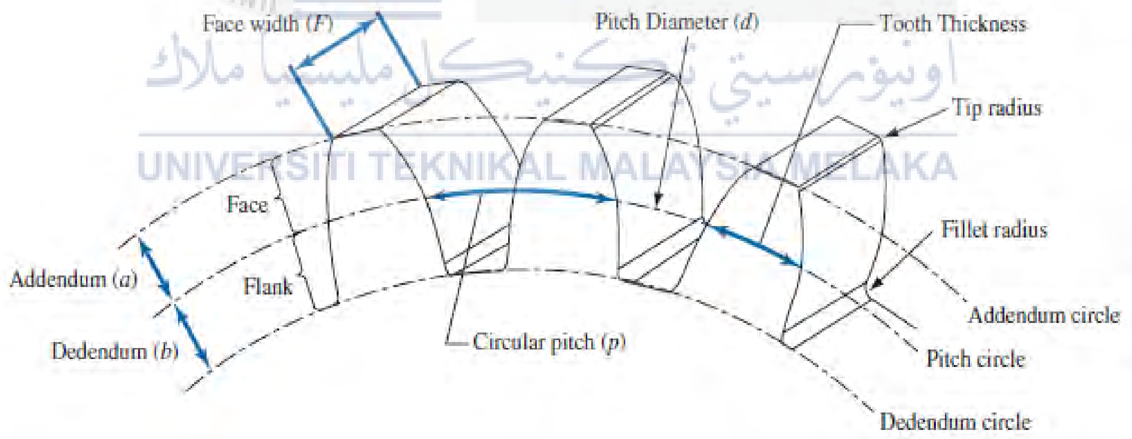


Figure 2.22: Gear terminology

(Source: David, 2012)

Pitch circle - noticeable circle that the gear is treated like a smooth cylinder

Addendum circle - outer most profile circle of gear

Dedendum circle - inner most profile circle of gear

Diametral pitch - number of teeth per diameter of pitch circle

Circular pitch - space in pitch circle used by each teeth of gear

Diametral pitch is the first selection parameter when design mating gears. This is because it represents the size of gear tooth at which the transmitted force and gear material will influence this decision. Second parameter that should be selected is pressure angle. The standard gear pressure angles are 14.5°, 20°, and 25°. Mating gears must have the same diametral pitch and pressure angle. If the mating gear tooth is contact inside the base circle or gear, noise, vibration and wear will be produced (David, 2012).

Gear ratio and gear efficiency can be calculated by

$$n = \frac{N_2}{N_1} = \frac{w_2}{w_1} = \frac{d_1}{d_2} = \frac{t_1}{t_2} \tag{2.3}$$

$$\eta = \frac{P_2}{P_1} = \frac{\tau_2 w_2}{\tau_1 w_1} \tag{2.4}$$

1 stand for driver and 2 stand for driven,

N = Rotational speed in r.p.m.

w = Angular velocity

d = Diameter

t = Number of teeth

P = Power

τ = Torque

2.7.2.1 Type of Gear

Spur gear, internal ring gear, helical gear, bevel gear and worm gear are the main types of gear. Each type of gear has different characteristic and shaft direction. Figure 2.23 shows the spur gears which are the most common type used. Spur gears have straight teeth and they are used to transmit the power between parallel shafts. Spur gear can be used at any speed but it produces a lot of noise when in high speed (David, 2012).

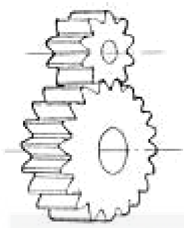


Figure 2.23: Spur gear

(Source: Engineer Edge, 2016)

Helical gears is same as spur gears, the only different is the teeth geometry. Helical gears have helicoid shape of teeth as shown in figure 2.24. They operate with less noise and vibration than spur gears due to their helicoid shape teeth. Therefore, helical gears are usually used at high speed application (David, 2012).

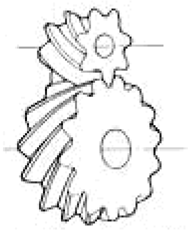


Figure 2.24: Helical gear

(Source: Engineer Edge, 2016)

Internal ring gear consist one or more external gear (spur gear) which the teeth formed on the outer surface and an internal gear which the teeth formed on the inner surface as shown in figure 2.25.

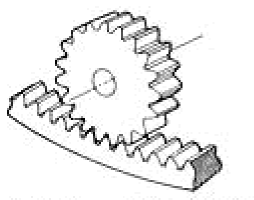


Figure 2.25: Internal ring gear

(Source: Engineer Edge, 2016)

Bevel gears as shown in figure 2.26 are used to transmit the power between non-parallel shafts. The shaft angles can be larger or smaller than 90°. Normally, these two shafts are perpendicular to each other (David, 2012).

Figure 2.26: Bevel gear

(Source: Engineer Edge, 2016)

2.7.2.2 Pressure Angle of Gear

Pressure Angle is the angle between pressure line and pitch line as shown in figure 2.27.

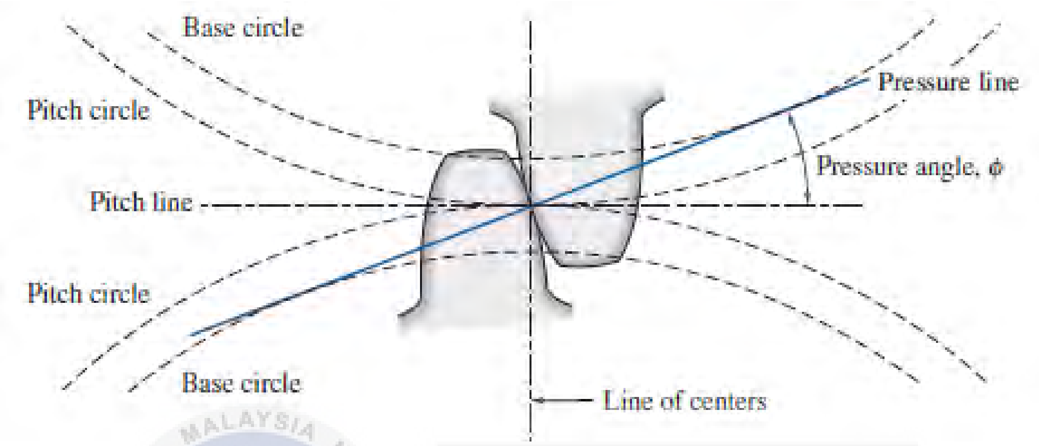


Figure 2.27: Pressure angle of gear

(Source: David, 2012)

The standard gear pressure angles are 14.5°, 20°, and 25°. Gear with 14.5° pressure angle is outdated and used mostly for gear replacement. Gear with 20° pressure angle are suitable for general application and gear with 25° pressure angle are suitable for high speed and low force application. Mating gears must have the same pressure angle so that they can transmit smooth motion and constant velocity (David, 2012). The pressure angle influences the shape of gear tooth as shown in figure 2.28.

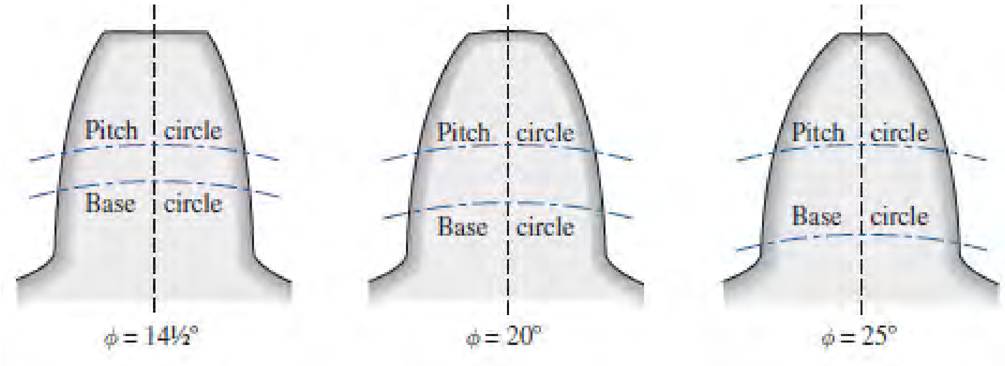


Figure 2.28: Tooth shape with different pressure angle

(Source: David, 2012)

2.8 CATIA SOFTWARE

CATIA stands for Computer Aided Three-dimensional Interactive Application which is the widely used CAD (computer aided design) software. Nowadays, almost all the products are designed by using CAD software and CATIA plays an important role in the design process. There are many companies over the world are using CATIA which include aerospace, architecture, automotive, construction and electronic industries (Childress, 1986).

CATIA include sketches, part design, assembly design, and drafting stage. Sketcher is the stage to sketch and constraint very simple to very complex 2D profiles. Part design is the stage to create 3D parts by using pad, pocket, fillet and shell and the part shapes are based on the 2D profile sketched. Assembly design is the stage to assemble all the parts together. Drafting is the stage to transfer the assembly design to engineering drawing with top view, side view, front view, isometric view, and exploded view (Plantenberg, 2009).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter elaborates the methodology used to design a tricycle with cleaning mechanism. Figure 3.1 shows the flowchart of the processes in carrying out the development of tricycle with cleaning mechanism in order to achieve the project objectives. This flow chart is the guideline of this project from beginning stage until final stage.

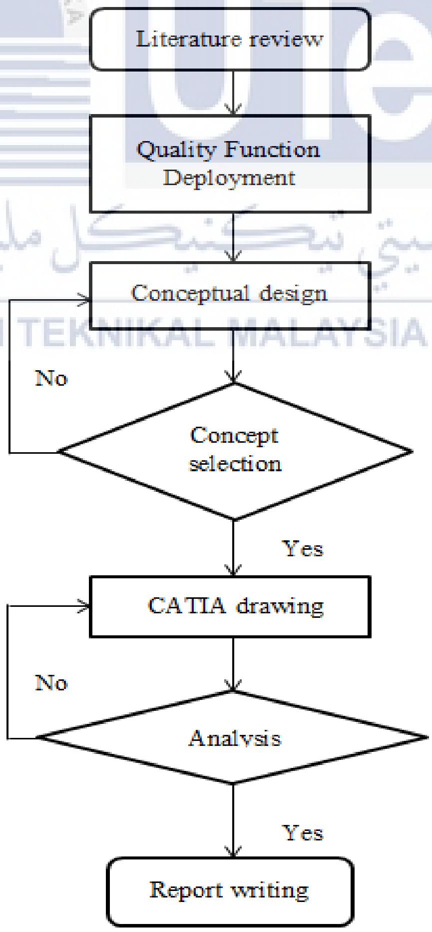


Figure 3.1: Flowchart of project

3.2 QUALITY FUNCTION DEPLOYMENT (QFD)

Quality Function Deployment (QFD) was conceived in Japan in 1960s as a quality system focused on delivering products and services that satisfy customers (Glenn, 1996). It is known as a method to integrate customer requirement and engineering characteristic into every phase of design (Patil, 2016). QFD can ensure the quality of design while the product is still in the design stage (Akao, 1990). House of quality (HOQ) is one of the methods of QFD system which are used in this project to plan the customer requirements and engineering characteristics.

3.2.1 Questionnaire

This method is used to collect the customer requirement information and opinion on the tricycle with cleaning mechanism from the society. 30 respondents are chosen to answer the question paper where the respondents are among UTeM Faculty Mechanical Engineering staffs and students. The questionnaire is divided into two sections which are section A and section B. Section A is about the respondent background where the gender, age and occupation are asked. Section B is about developing tricycle with cleaning mechanism where all the questions focus on the customer opinion, expectation and requirement.

3.2.2 Customer Requirements

Customers have basic needs and requirements for every product. Human needs divided into three levels, which are basic needs, psychological needs and self-fulfilment needs (Maslow, 1943). Basic need such as safety is a must for every product and it becomes design constraints. Psychological needs such as product appearance and cost belong to "desirable" requirements and they are weighted by importance.

Customer requirement information is collected by using questionnaire method. Customer requirement information included customer opinion, expectation and ranking requirement. The design criteria are always related to the customer needs in order to deliver a customer satisfied product.

3.2.3 Engineering Characteristics

Engineering characteristic is established to interpret the customer requirements based on the engineering knowledge. Engineering characteristics include design parameters, design variables and constraints. Design parameters are a set of properties or values which determined the behaviour of a design. Design variable is a parameter that the designer can choose from. Constraints are the limitation of design where the parameters have been fixed during the design process. Several engineering characteristics are discussed in order to meet the customer requirements.

i. Material
ii. Number of parts
iii. Size
iv. Shape
v. Colour
vi. Lifespan
vii. Efficiency
viii. Weight

3.2.4 House of Quality (HOQ)

House of quality is a house structure diagram which used to plan the relationship between the customer requirements and engineering characteristics. It translates the voice of customer to target value of engineering characteristics. This method is used to rank the engineering characteristic of tricycle with cleaning mechanism so that the important engineering characteristics can be focused in order to meet the customer requirements. Figure 3.2 shows the streamline configuration of HOQ.

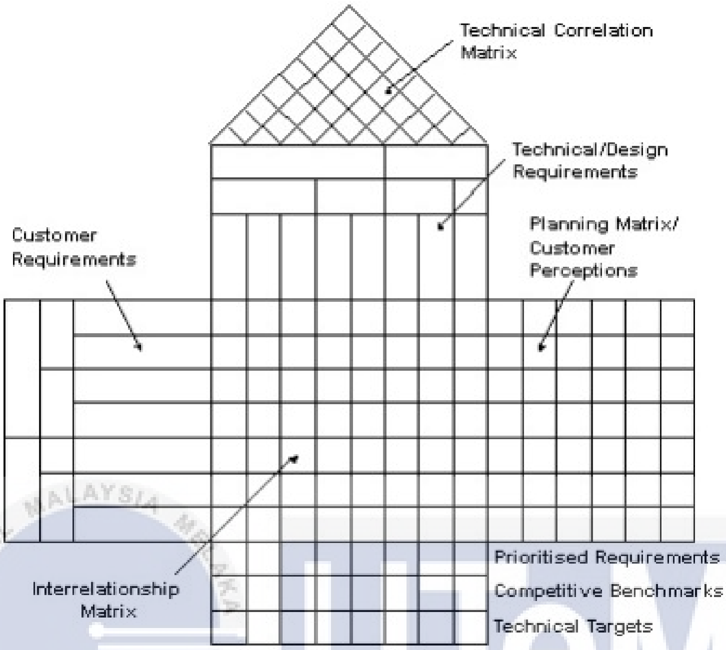


Figure 3.2: Streamline configuration of HOQ

3.3 CONCEPTUAL DESIGN

Conceptual design is the early stage of design of any new product development project. It is a phase in the evolution of product when different design concepts are generated, assessed, and selected for further development (Eggert, 2005). Each concept design has different physical, material and geometric term. This method is used to generate four different design of tricycle with cleaning mechanism and each concept design is analyzed. The concept designs are generated by using morphological chart.

3.3.1 Morphological Chart

Morphological chart is a method that used to generate ideas for concept designs in systematic and analytical way. First of all, list the functions and sub-functions of product tricycle with cleaning mechanism on the left side of chart. After that, different mechanisms that can perform the functions are drawn in right side of the chart. The concept designs are generated by combining the functions with different mechanisms. Finally, analyze the concept designs based on human factor, industrial and environment design.

3.4 CONCEPT EVALUATION

This method is used to compare and evaluate the concept designs that generated by using morphological chart and then select the best and highest potential concept design for further development. Pugh concept selection method is used to evaluate the concept design.

3.4.1 Pugh Concept Selection Method

This method was invented by Stuart Pugh that used to compute and evaluate the concept designs by comparing the criteria. Figure 3.3 shows the example of Pugh matrix. First of all, choose the criteria for comparison. These criteria are weighted based on their importance. After that, choose one concept design as a datum and other concept designs are compared with this datum. The concept designs are evaluated as being better (+), same (s), and worse (-). Finally, compute the total score and concept design with highest score is selected for further development.

		Baseline	Weight	A	B	C	D
Criteria							
1		0	2	+2	-2	0	+2
2		0	4	0	-4	0	+4
3		0	3	+3	+3	+3	0
4		0	5	-5	0	0	+5

Figure 3.3: Example of Pugh matrix

Several criteria are chosen for comparison between the concept designs of tricycle with cleaning mechanism.

i. Energy consumption
ii. Moving speed
iii. Efficiency
iv. Waste storage capacity
v. Brush lifespan
vi. Reliability

3.5 PARAMETRIC DESIGN

Parametric design is the process to determine the input information by using the given and output information in order to get the desired output. Input variable such as diameter and length that have to determine before the detail design stage because they will affect directly the product output such as angular velocity. Gear and belt drive system are used to develop the cleaning mechanism of tricycle. The input variables such as diameter of pulley and gear have to determine in order to get the desired output.

3.5.1 Parametric Design of Belt Drive System

Velocity ratio, center distance and driven pulley diameter have to be determined before the detail design stage so that the final design of tricycle with cleaning mechanism has desired outputs.

The given information is the fixed parameters which have been fixed due to the design behavior.

Table 3.1: Given parameter of belt drive system

Parameter	Symbol	Units	Value
Driver velocity	v_1	m/s	
Driver pulley diameter	d_1	m	
Angular velocity of driver	w_1	$r.p.m$	

The input information is the variable parameters which should be determined in order to get the desired output.

Table 3.2: Input variable of belt drive system

Variable	Symbol	Units	Value
Velocity ratio	n	-	
Driven pulley diameter	d_2	m	
Center distance	x	m	

The output information is the desired output of engineering characteristic also known as responding parameters.

Table 3.3: Output engineering characteristic of belt drive system

Engineering Characteristic	Symbol	Units	Value
Driven velocity	v_2	m/s	
Angular velocity of driven	w_2	$r.p.m$	

3.5.2 Parametric Design of Gear Drive System

Diametral pitch and pressure angle are the most important parameters when design mating gears. This is because mating gears must have the same diametral pitch and pressure angle. Therefore, gear teeth are standardized based on the diametral pitch and pressure angle. The standard gear pressure angles are 14.5°, 20°, and 25° as shown in figure 3.4. The gear with 14.5° pressure angle is outdated and used mainly for gear replacement. Gears with 20° pressure angle are chosen to be used in the gear drive system of tricycle with cleaning mechanism. Gears with 20° pressure angle are chosen because they are suitable for general application (David, 2012).

Table 3.4: Given parameter of gear drive system

Parameter	**Symbol**	**Units**	**Value**
Driver gear velocity	v_1	m/s	
Angular velocity of gear driver	w_1	$r.p.m$	
Pressure angle	$\emptyset$	°	
Diametral pitch	P_d	m^{-1}	
Pitch diameter of gear driver	d_1	m	
No. of teeth of gear driver	N_1	$-$	
Circular pitch of gear driver	p_1	m	
Module	m	m	
Base circle diameter of gear driver	d_{b_1}	m	

Table 3.5: Input variable of gear drive system

Variable	Symbol	Units	Value
Gear ratio	n	$-$	
Pitch diameter of gear driven	d_2	m	
No. of teeth of gear driven	N_2	$-$	
Circular pitch of gear driven	p_2	m	
Base circle diameter of gear driven	d_{b_2}	m	
Center distance	C	m	

Table 3.6: Output engineering characteristic of gear drive system

Engineering Characteristic	Symbol	Units	Value
Driven gear velocity	v_2	m/s	
Angular velocity of driven gear	w_2	$r.p.m$	

The other gear tooth specifications are calculated by using the standardized formula as shown in figure 3.4.

Tooth Feature Pressure angle, ϕ	Coarse Pitch ($P_d < 20$) 14½° or 20° or 25°	Fine Pitch ($P_d \geq 20$) 20°
Addendum, a	$\frac{1.000}{P_d}$	$\frac{1.000}{P_d}$
Dedendum, b	$\frac{1.250}{P_d}$	$0.002 + \frac{1.2}{P_d}$
Working depth, h_k	$\frac{2.000}{P_d}$	$\frac{2.000}{P_d}$
Whole depth, h_t	$\frac{2.250}{P_d}$	$0.002 + \frac{2.200}{P_d}$
Circular tooth thickness, t	$\frac{1.571}{P_d}$	$\frac{1.571}{P_d}$
Fillet radius, r_f	$\frac{0.300}{P_d}$	not standardized
Min. clearance, c	$\frac{0.250}{P_d}$	$0.002 + \frac{0.200}{P_d}$
Clearance (ground tooth), c	$\frac{0.350}{P_d}$	$0.002 + \frac{0.350}{P_d}$
Min top land width	$\frac{0.250}{P_d}$	not standardized
AGMA standard	201.02	207.04
Face width	$\frac{12}{P_d}$	$\frac{12}{P_d}$

Figure 3.4: Gear tooth specification standardized by AGMA organization

(Source: David, 2012)

3.6 DETAIL DESIGN

Detail design is the stage that uses the final information of the product to make the remaining decision on specific details. The activities in detail phase are as follow:

i. Determine all of the dimensions of components with standard engineering value so that all the components of product can be assembled and fixed together well.
ii. Select the suitable material for every component.
iii. Draw the components of design with front, side, top and isometric view by using computer aided three-dimensional interactive application (CATIA).

iv. Create the engineering drawing with assembly and exploded view of design.

v. Complete bill of materials list on each components of product.

vi. Final design review.

3.6.1 Material Selection

Material selection is a critical stage because it will affect the product cost, shape, appearance and manufacturing process. Material is selected for each components based on their required properties such as chemical resistance and light weight. If there are some materials fulfill the properties requirement, material with lowest cost will be selected in order to cut down the cost. There are five categories of materials properties that need to be taken into consideration when choosing the material, which are mechanical, thermal, physical, chemical, electrical properties. There are four main types of materials which are metals, ceramics and glass, woods and organics, and polymer and plastic. These four types of materials are very different in properties and the designer can choose the most suitable material based on the required properties of product.

3.6.2 Detail Drawing

Computer Aided Three-Dimensional Interactive Application (CATIA V5R21) is used to create engineering drawing in this stage. It assists in creation, modification, analysis and optimization of the design. Steps to complete the detail drawing are as follow:

1. Draw every parts of design in 3D form with specific dimensions.
2. Transfer these parts drawing to engineering drawing with side, front and top view.
3. Show the part number, name and specific dimensions for every part of design in engineering drawing with title block.

4. Select the materials for each part.
5. Assemble all the parts together can transfer to engineering drawing with side, top and front view.
6. Create the exploded view of design and apply the bill of material.

3.7 COST ESTIMATION

Detailed cost can be estimated after the detail design stage because appropriate materials are identified and accurate dimensions are specified. There are three types of costs when fabricate a design which are material cost, manufacturing cost and purchase cost. Material cost is the amount of expenses that used to purchase the raw material such as aluminum rod and plastic block or powder. Manufacturing cost is the amount of expenses that used to manufacture the raw material into desired shape. Purchase cost is the amount of expenses that used to buy the components from vendor such as gear.

3.8 DESIGN ANALYSIS

Design analysis is the final stage in designing a new product. The powers, forces, stresses, movement of each component of design are analyzed to ensure the design quality and reliability. Two methods are used to analyze the design, which are calculation by using theoretical formula and CATIA software analysis.

3.8.1 Theoretical Formula Calculation

Theoretical formulas are used to calculate the final design outputs as following:

1. Angular velocity of brushes
2. Gear and belt system transmission
3. Relative angular velocity between the brushes and wheel

4. Stresses in each component

5. Safety factor

3.8.2 CATIA Analysis

Computer Aided Three-Dimentional Interactive Application (CATIA) provides multi-platform facilities which include conceptualization, design (CAD), manufacturing (CAM), and engineering (CAE). The components that have critical part such as small cross-sectional areas or high forces applied are analyzed. The components that have large cross sectional area and withstand very small force will not be analyzed. The result outcomes are as follow:

1. Deformation of parts
2. Displacement of parts
3. Von Mises Stress

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter discusses about the process of development on tricycle with cleaning mechanism design. The development of tricycle with cleaning mechanism includes the customer requirements analysis, conceptual designs generation, concept evaluation, parametric design, detail design and design analysis.

4.2 QUESTIONNAIRE

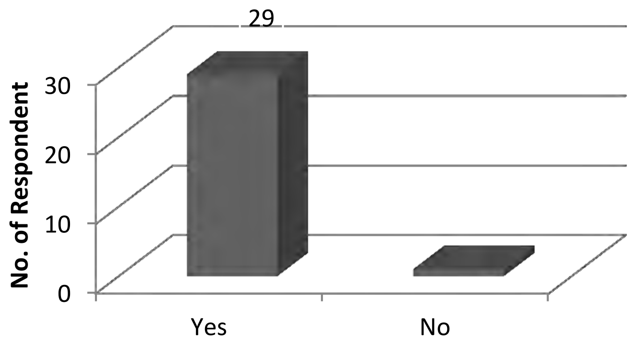
Respondent background and the results of question on developing of tricycle with cleaning mechanism are discussed in this part.

4.2.1 Respondent Background

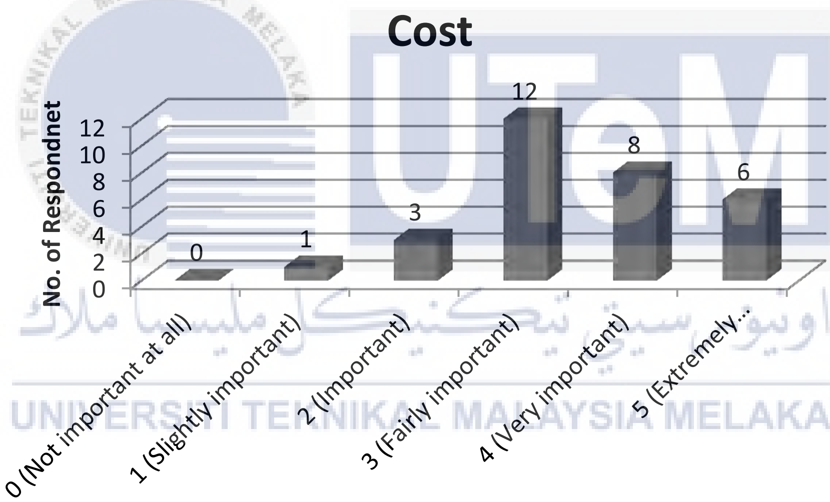
Total respondent is 30, 16 respondent are male and 14 respondent are female. Number of student is 22 which have range age 20 to 30 year old and total number of staff and lecturer is 8 which age is above 30.

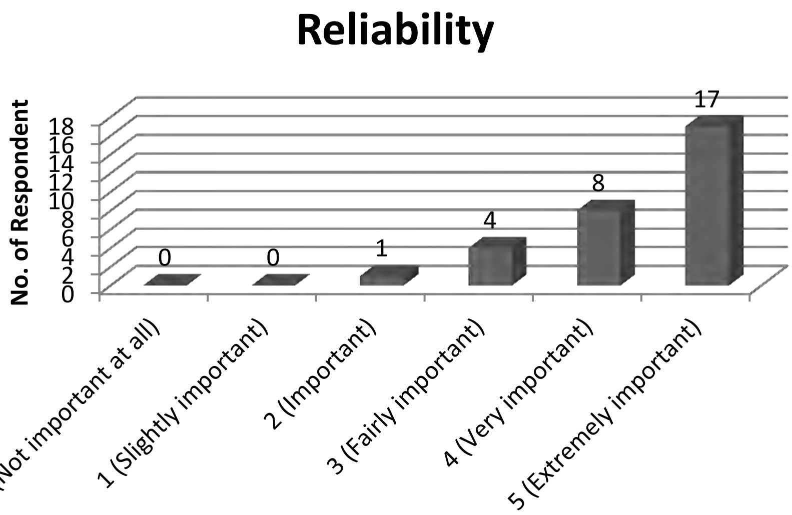
4.2.2 Developing Question

1. Is human-powered tricycle with cleaning mechanism a useful product?

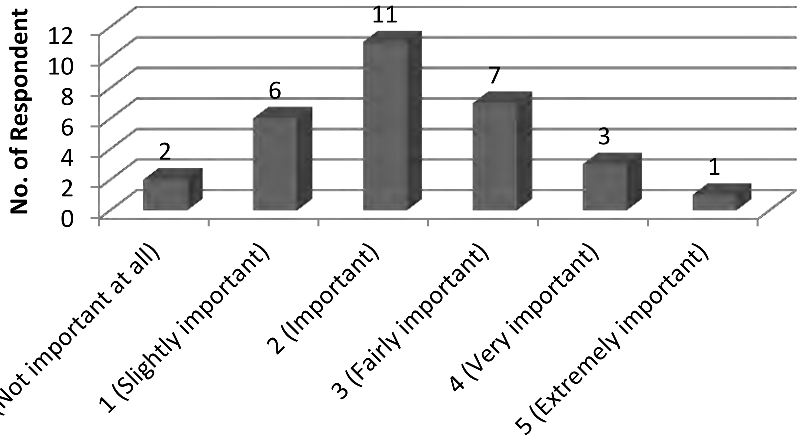


2. Rate the following by using a scale of 0=Not important to 5=Very important.

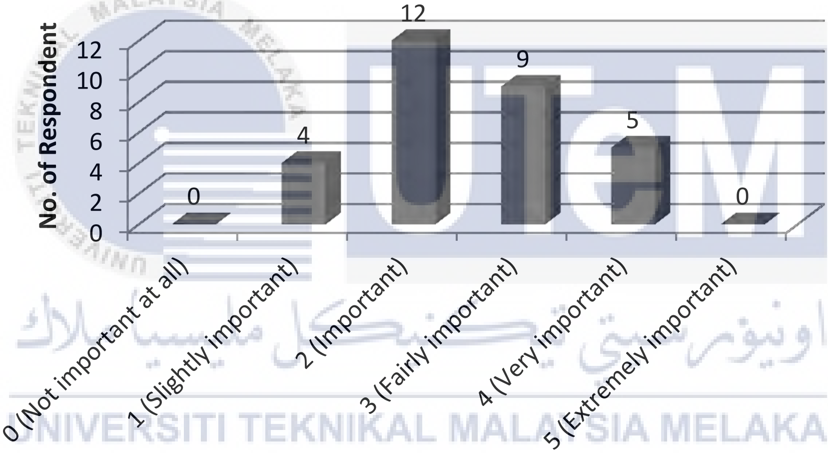




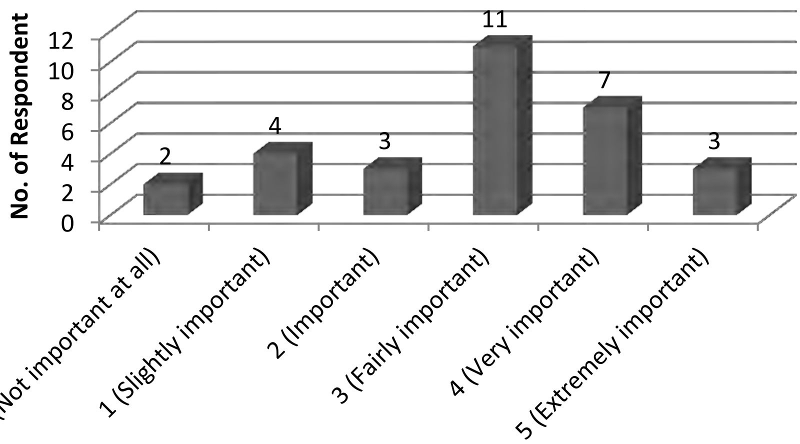
Appearance

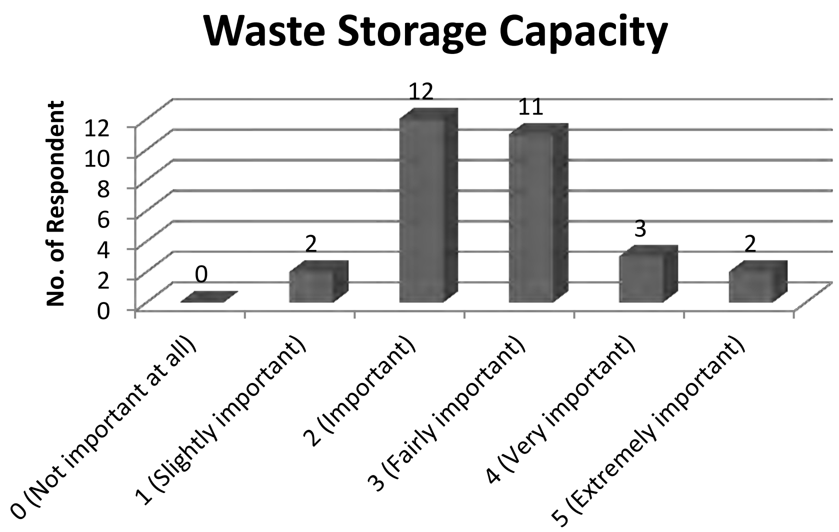


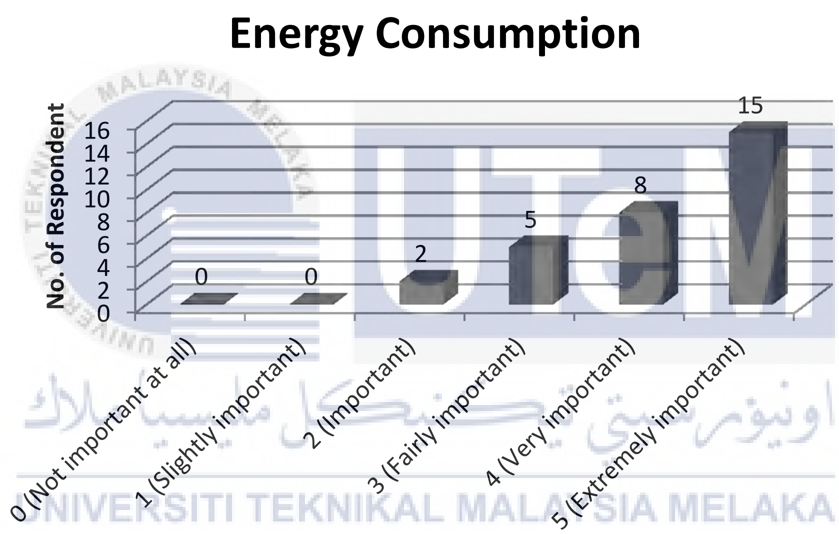
Moving Speed

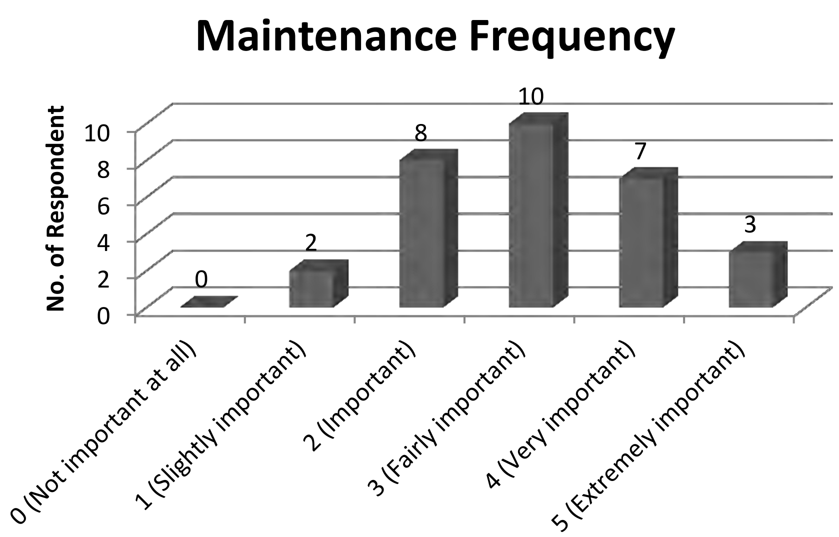


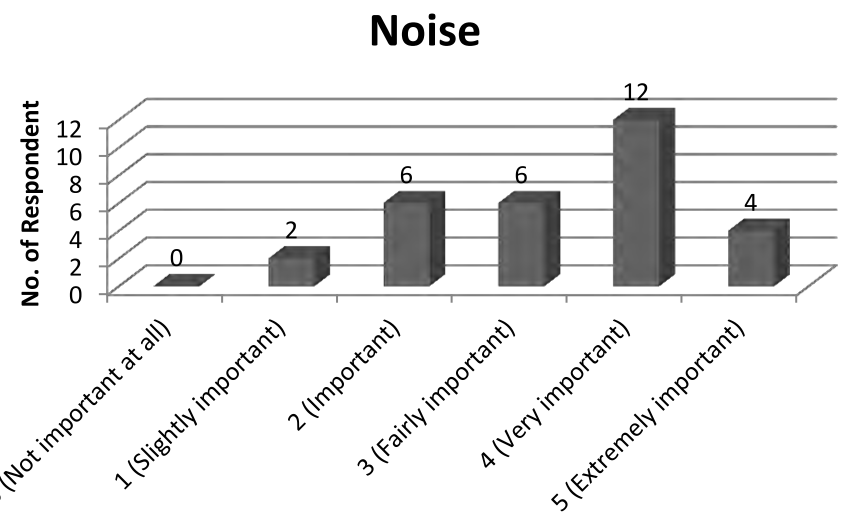
Ease of Use




Waste Storage Capacity
No. of Respondent
0
2
12
11
3
2
0 (Not important at all)
1 (Slightly important)
2 (Important)
3 (Fairly important)
4 (Very important)
5 (Extremely important)


Energy Consumption
No. of Respondent
0
0
2
5
8
15
0 (Not important at all)
1 (Slightly important)
2 (Important)
3 (Fairly important)
4 (Very important)
5 (Extremely important)

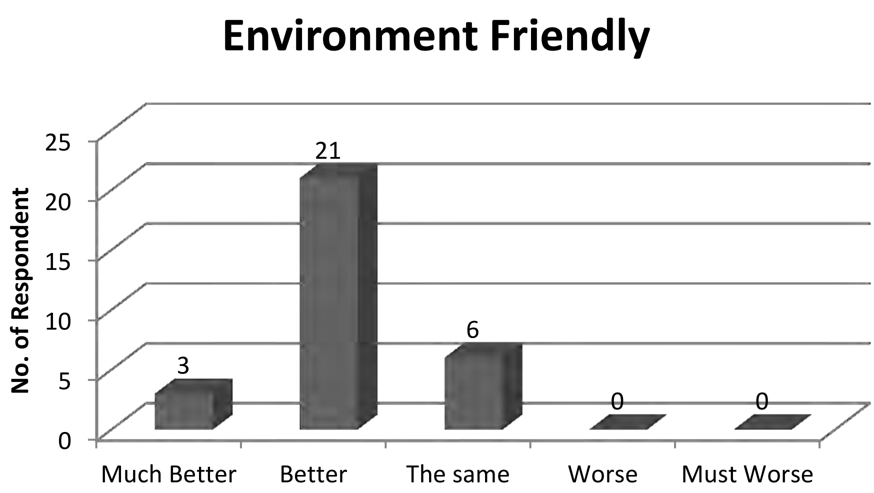

Maintenance Frequency
No. of Respondent
0
2
8
10
7
3
0 (Not important at all)
1 (Slightly important)
2 (Important)
3 (Fairly important)
4 (Very important)
5 (Extremely important)



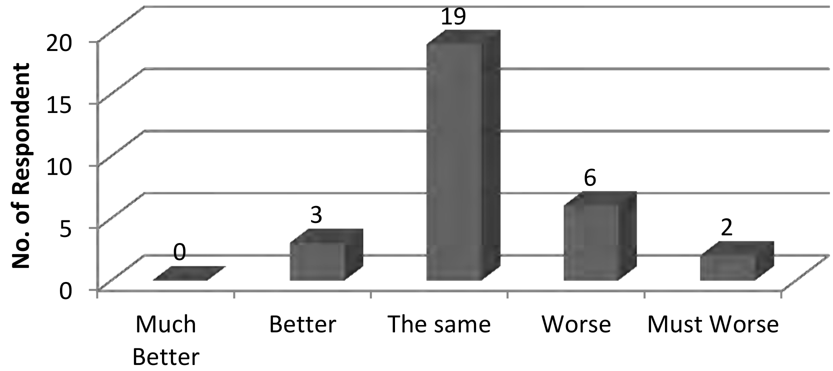
3. Other expectation for this product.

   Their expectations for this product are high durability, kid and user friendly, able to sweep the rubbish at corners, and also high efficient which can sweep the rubbish effectively.

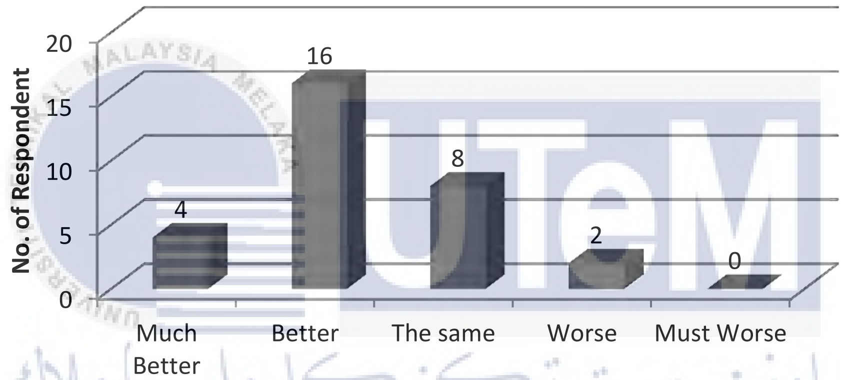
4. Comparison between human-powered tricycle with cleaning mechanism and other existing sweeping product.



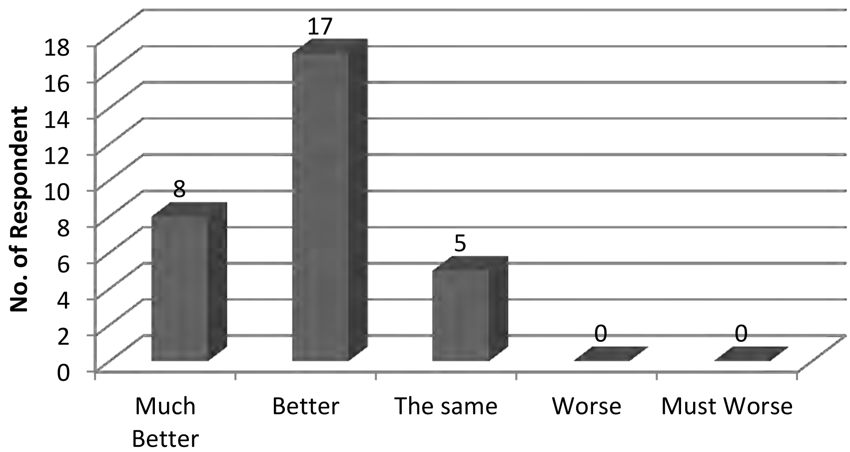
Efficiency



Time Saving



Overall



4.3 QUALITY FUNCTION DEPLOYMENT (QFD)

4.3.1 Customer Requirements

Based on the results of questionnaire, the importance of each customer requirement are analysed and weighted as following:

Table 4.1: Customer requirements and its weight of Tricycle with Cleaning Mechanism

Customer Requirement	Weight
Cost	3
Reliability	5
Appearance	2
Moving speed	2
Ease of use	3
Waste storage capacity	2
Energy consumption	5
Maintenance frequency	3
Noise pollution	4

4.3.2 House of Quality (HoQ)

Table 4.2 shows the House of Quality of Tricycle with Cleaning Mechanism. It shows that the efficiency of performance is the most important aspect when design it in order to meet customer requirements. Lifespan and material resistance are the second important aspect that need take into consideration when design it.

Table 4.2: HOQ of Tricycle with Cleaning Mechanism

Improvement Direction		↓	↓	n/a	↑	n/a	↓	↑	↑	↑
Engineering Characteristic / Customer Requirements	Customer Importance	Number of parts	Weight	Color	Lifespan	Shape	Size	Material strength	Material resistance	Efficiency
Cost	3	5	1	-	9	5	9	9	9	9
Reliability	5	1	1	-	9	-	-	9	9	5
Appearance	2	1	-	9	-	5	-	-	-	-
Moving speed	2	-	5	-	-	-	1	-	-	9
Ease of use	3	9	-	-	-	-	1	-	-	-
Waste storage capacity	2	-	-	-	-	5	9	-	-	5
Energy consumption	5	-	9	-	-	-	1	-	-	9
Maintenance frequency	3	5	-	-	9	-	-	5	9	5
Noise (Vibration)	4	1	-	-	5	-	-	-	1	-
Raw score		68	63	18	119	35	55	87	103	140
Relative weight (%)		9.9	9.2	2.6	17.3	5.1	8.0	12.6	15.0	20.3
Rank order		5	6	9	2	8	7	4	3	1

4.3.3 Product Design Specification (PDS)

Table 4.3 shows the design specification of Tricycle with Cleaning Mechanism. The criteria include the performance, size, weight, material, ergonomic, safety and maintenance as a guide to generate the conceptual designs.

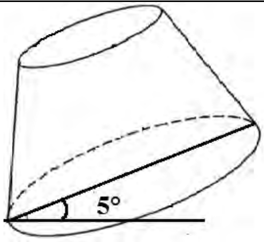
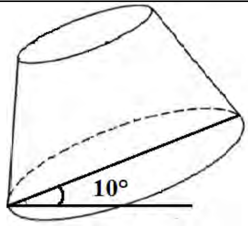
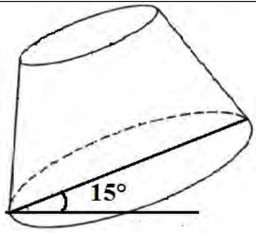
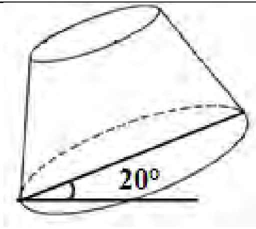
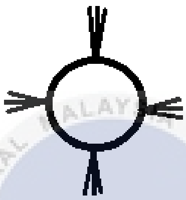
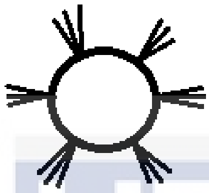
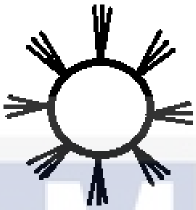
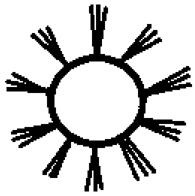
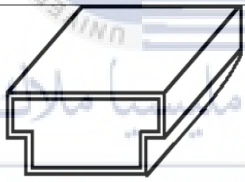
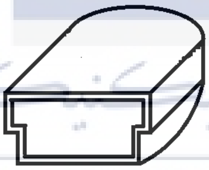
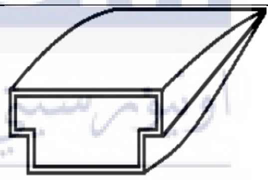
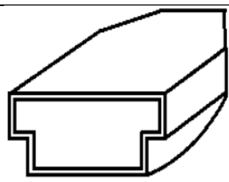
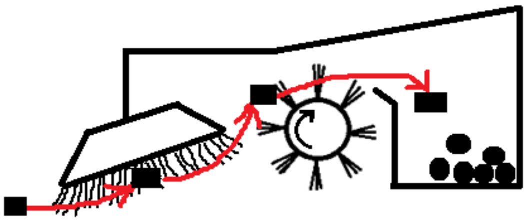
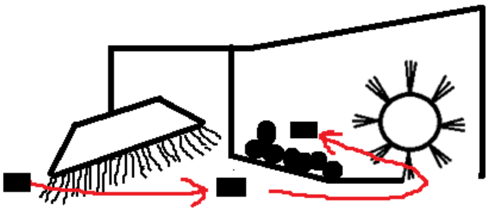
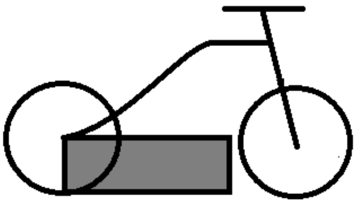
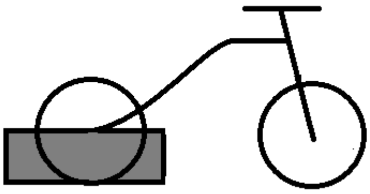
Table 4.3: Design Specification of Tricycle with Cleaning Mechanism

Criteria	Characteristic
Performance	• Sweeping and collecting rubbish by using rotating brushes • Brushes rotate at a speed around 100 r.p.m. • Tricycle moving speed can up to 8 km/h
Size	• Small size to attract customer and easy keep • Maximum allowable size of tricycle 200x80x110cm • Maximum allowable size of cleaning device 80x56x35cm
Weight	• Light in weight to minimize energy consumption • Maximum allowable weight is 20kg
Material	• Frame of tricycle : Aluminium • Frame of cleaning device : Aluminium • Body of cleaning device : Plastic
Ergonomic	• Easy to operate and handle • Less energy consumption • Human body in comfortable position when operating
Safety	• Safe to be used by adult and senior citizen • Not safe to be used by kid due to large size of tricycle
Maintenance	• Brushes need to be replaced every half year on average • Parts that need to maintain or replace must be easily accessible

4.4 CONCEPTUAL DESIGN

4.4.1 Morphological Chart

Table 4.4: Morphological chart of Tricycle with Cleaning Mechanism

Feature	Option 1	Option 2	Option 3	Option 4
Angle of front brushes				
Number of row of cluster for rear brush				
Bristle material	Hog bristle (Animal Hair)	Proex (Synthetic Material)	Tampico (Vegetable Fibre)	Polyester (Synthetic Material)
Shape of waste container				
Angular velocity of brushes	80 r.p.m.	100 r.p.m.	120 r.p.m.	150 r.p.m.
Position of back brush (Cleaning mechanism)				
Position of cleaning device				

4.4.2 Concept 1

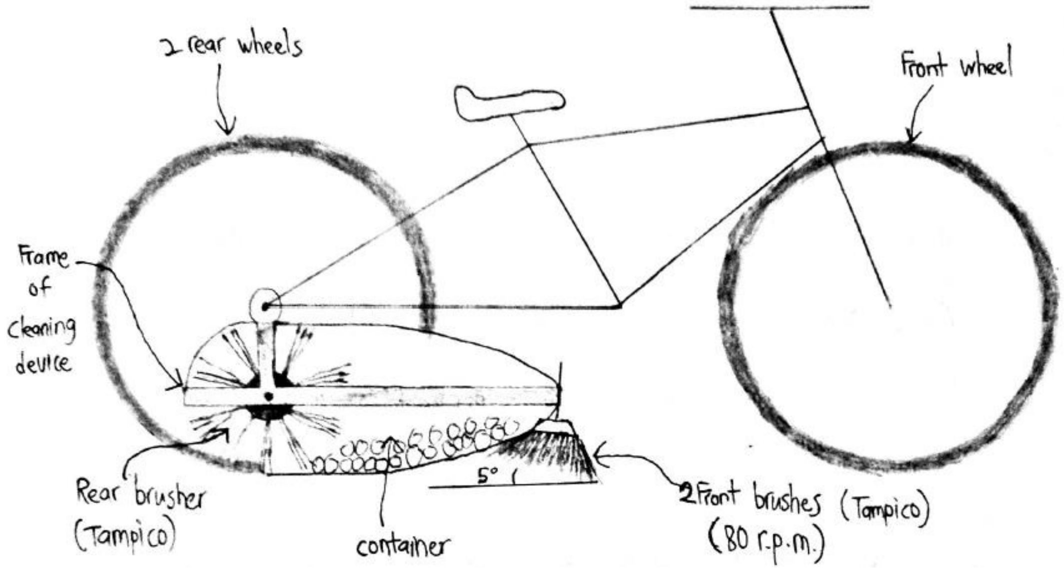


Figure 4.1: Side view of concept 1

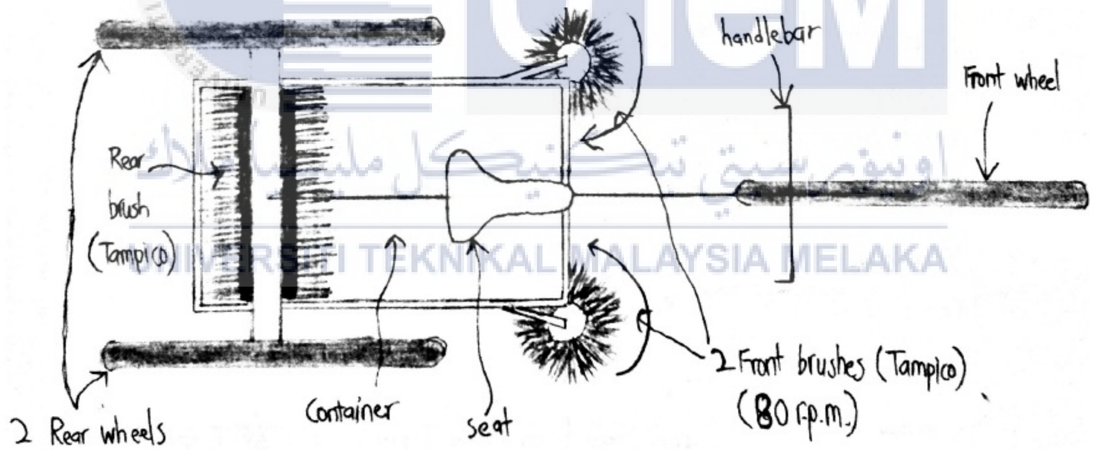


Figure 4.2: Top view of concept 1

The angle of front brushes for this concept is 5° which is very efficient in sweeping sand particle with around 0.1mm. However, it performs badly in sweeping wet rubbish and average in small to big rubbish (2mm to 8cm). The angular velocity of brushes for this concept is 80 r.p.m. which is slow enough to prevent dust blowing. The material of brushes used for this concept is Tampico (vegetable fibre) which is very suitable for sweeping small particle and resistance to heat, alkali and acid. The appearance of waste container is good but it can only store small amount of rubbish.

4.4.3 Concept 2

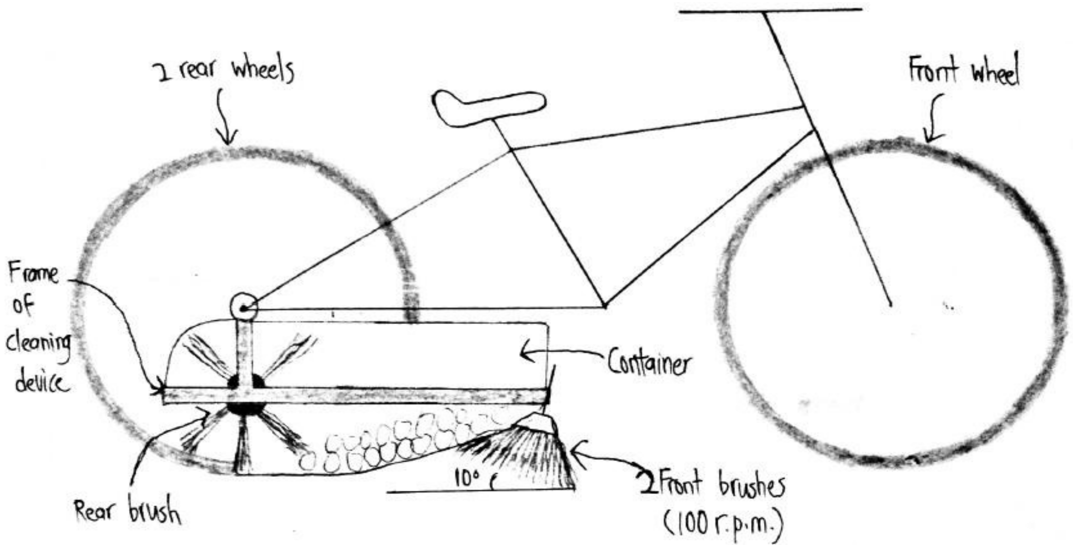


Figure 4.3: Side view of concept 2

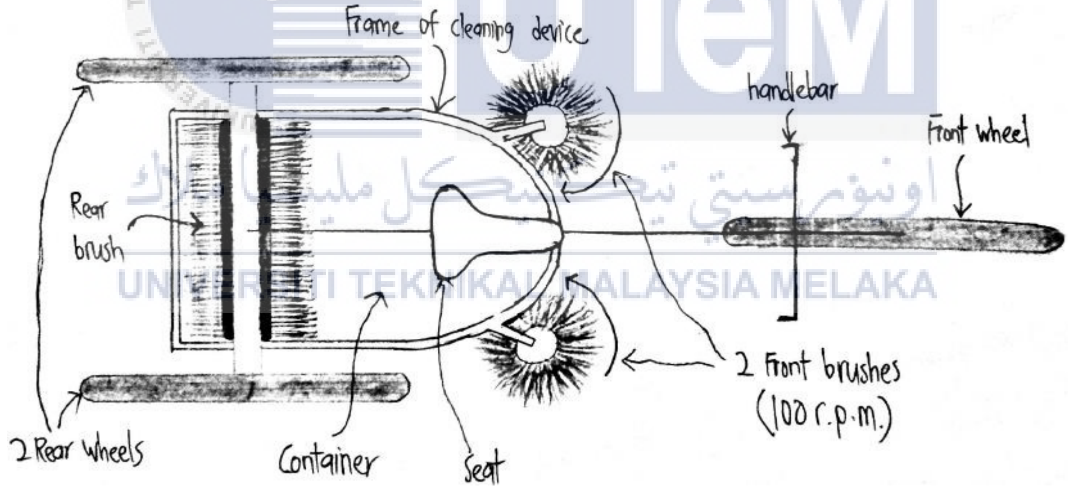


Figure 4.4: Top view of concept 2

The angle of front brushes for this concept is 10° which is very efficient in sweeping small to big rubbish (2mm to 8cm). However, it performs average in sweeping wet rubbish and sand particle. The angular velocity of brushes for this concept is 100 r.p.m. which is slow enough to prevent dust blowing. The material of brushes used for this concept is Proex (synthetic material) which have high efficiency in sweeping and can be used in humid environment. The appearance of waste container is good and it can store quite large amount of rubbish.

4.4.4 Concept 3

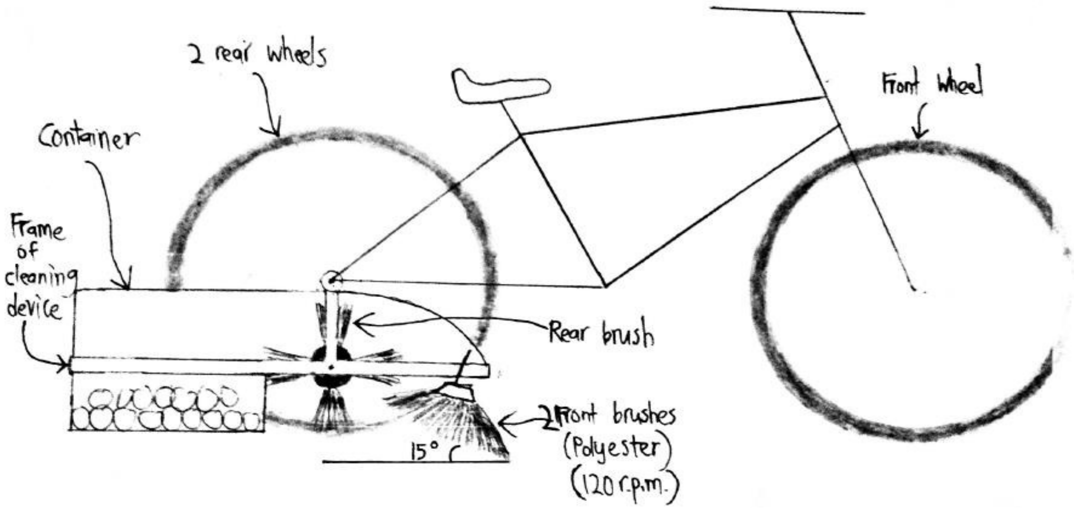


Figure 4.5: Side view of concept 3

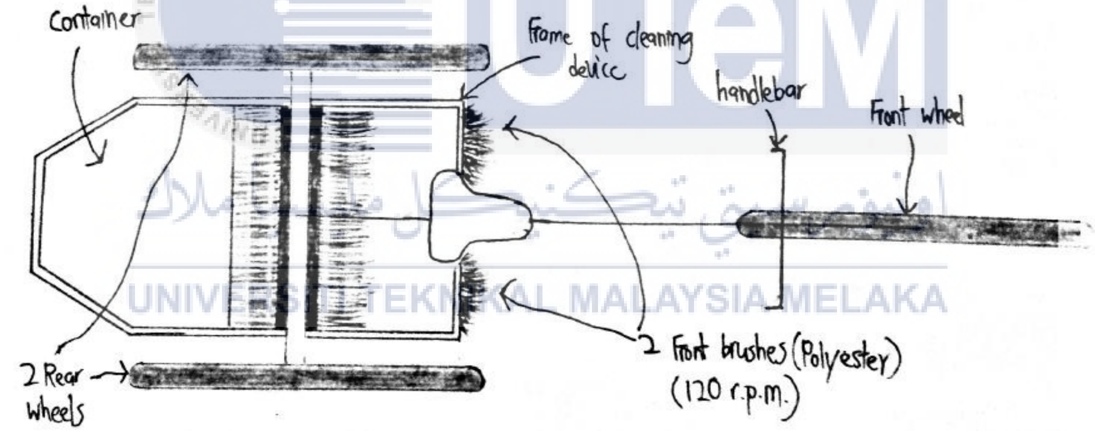


Figure 4.6: Top view of concept 3

The angle of front brushes for this concept is 15° which is very efficient in sweeping wet rubbish. However, it performs badly in sweeping sand particle and average in small to big rubbish (2mm to 8cm). The angular velocity of brushes for this concept is 120 r.p.m. which is fast and efficient but it will blow the dust slightly. The material of brushes used for this concept is Polyester (synthetic material) which has high bend recovery and durability. This material performs good on rough surface. The appearance of waste container is good and it can store quite large amount of rubbish. The disadvantage of this concept is it occupies more space due to the cleaning device mechanism and position.

4.4.5 Concept 4

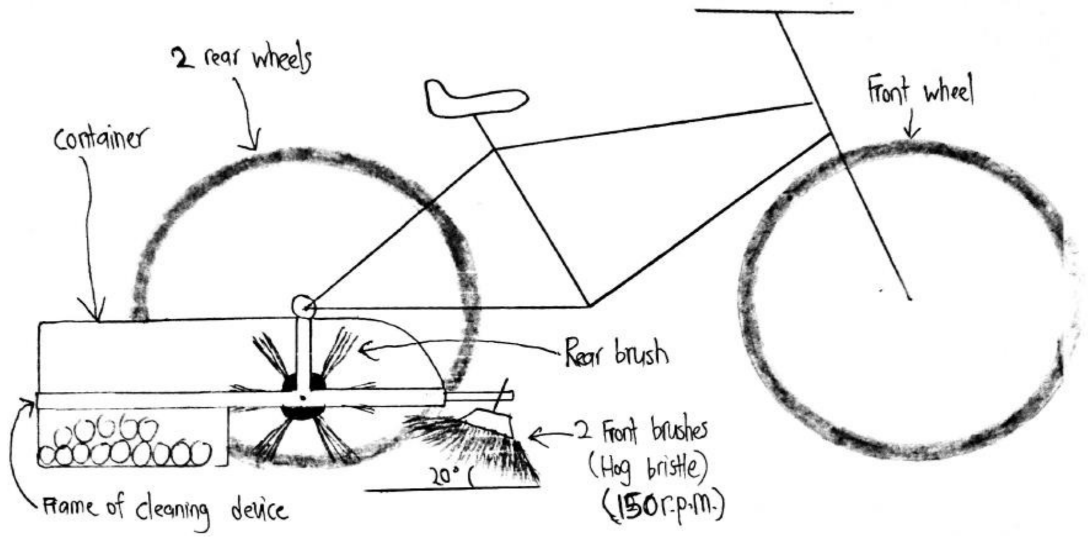


Figure 4.7: Side view of concept 4

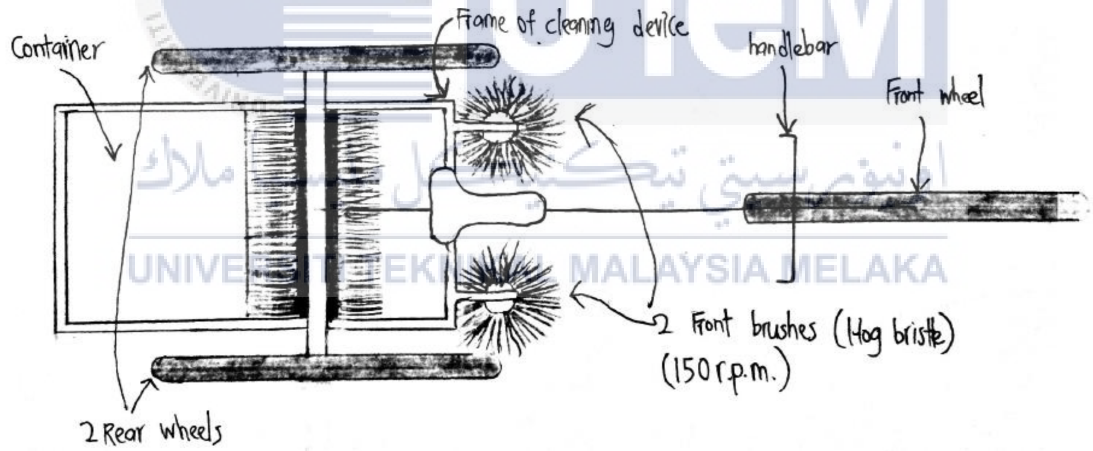


Figure 4.8: Top view of concept 4

The angle of front brushes for this concept is 20° which perform very badly in sweeping small to big rubbish (2mm to 8cm) and sand particle (0.1mm). The angular velocity of brushes for this concept is 150 r.p.m. which is very fast and blow the sand particles greatly. The material of brushes used for this concept is hog bristle (animal hair) which has water resistance and good durability but very expensive. The appearance of waste container is poor but it can store very large amount of rubbish. The disadvantage of this concept is it occupies more space due to the cleaning device mechanism and position.

4.5 CONCEPT EVALUATION

Conceptual designs were evaluated by using Pugh method selection method as shown in table 4.5 below.

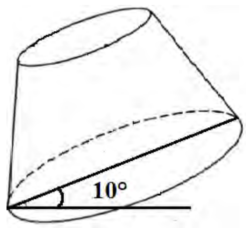
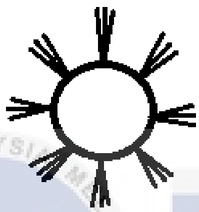
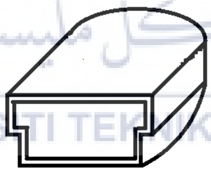
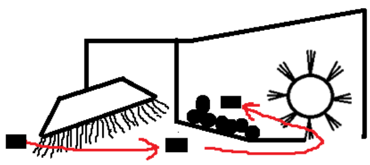
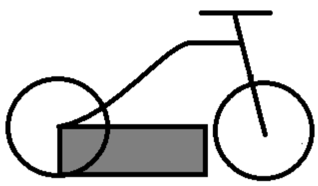
Table 4.5: Pugh matrix

Criteria	Weight	Concept			
		1	**2**	**3**	**4**
Cost	3	S	S	DATUM	-
Reliability	5	-	+		+
Appearance	1	+	+		-
Efficiency	5	S	+		-
Ease of manufacturing	3	-	S		+
Waste storage capacity	2	-	+		+
Size	4	+	+		S
Maintenance frequency	3	-	-		S
	∑+	5	17	N/A	10
	∑ -	13	3	N/A	9
	∑S	2	2	N/A	2
	Net score	-8	14	N/A	1
	Rank	4	1	3	2

Concept 2 is the best concept among four conceptual designs since it has the highest net score and it consequence with the consideration of engineering characteristics and customer requirements.

4.5.1 Best Concept

Table 4.6: The feature of best concept for Tricycle with Cleaning Mechanism

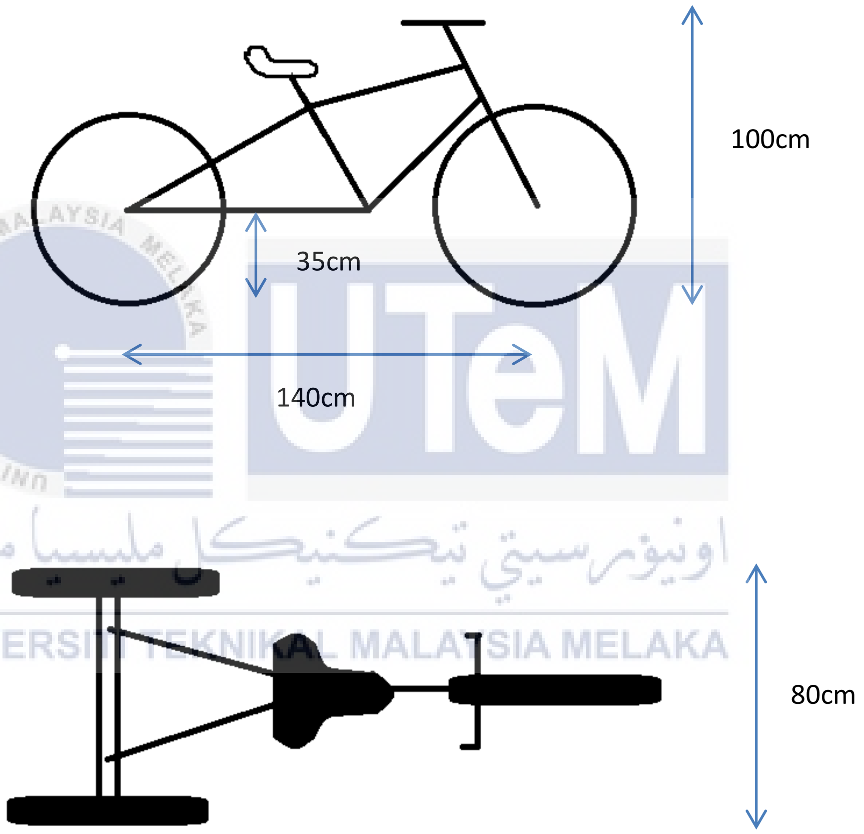
Feature	Option	Reason
Angle of front brushes		Front brushes with angle 10° is very efficient in sweeping small to big rubbish (2mm to 8cm) and average in sweeping wet rubbish and sand particle.
Number of row of cluster for rear brush		Eight row of cluster for rear brush can sweep small particle and big rubbish into container.
Bristle material	Proex (Synthetic material)	Proex material has high efficiency in sweeping and can be used in humid environment.
Shape of waste container		This shape of container has good appearance and large waste storage capacity.
Angular velocity of front brushes	100 r.p.m.	This speed is slow enough to prevent dust blowing and fast enough to sweep rubbish.
Cleaning mechanism		This cleaning mechanism is efficient in sweeping because it prevent rubbish left behind.
Position of cleaning device		The position of cleaning device is under the tricycle and does not occupy extra space causes the product size bigger.

4.6 PARAMETRIC DESIGN

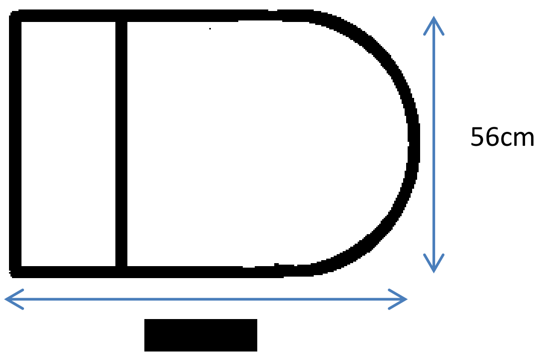
Some parameter like velocity ratio, center distance and driven pulley diameter have been determined before the detail design stage so that the final design of tricycle with cleaning mechanism has desired outputs.

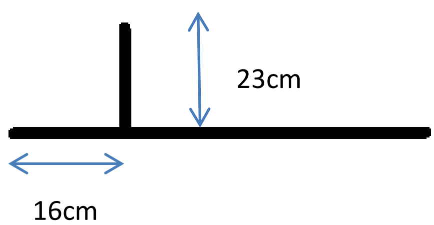
4.6.1 Components

Tricycle

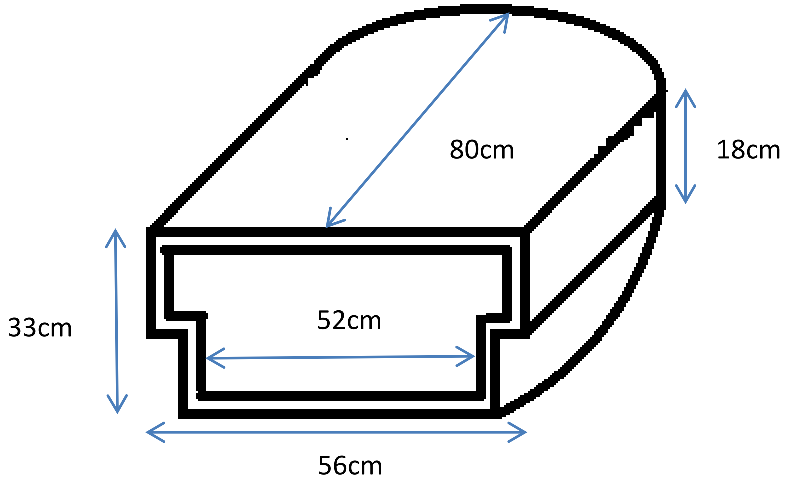


Frame of cleaning device

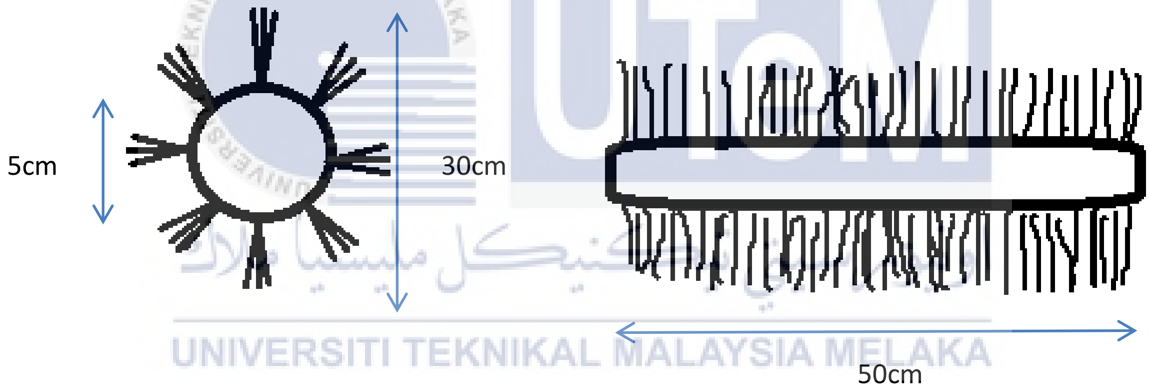




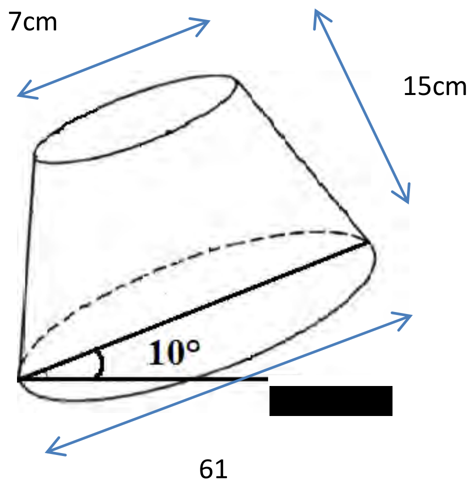
Container



Rear brush



Front brushes



4.6.2 Gear Transmission

<u>Gear (wheel) to gear (rear brush)</u>

Diameter of wheel, D = 70cm = 0.7m

Perimeter of wheel, P = πD = π(0.7)

= 2.2m

Average velocity of tricycle, v = 5.5 km/h = 1.528 m/s

Rotation of wheel per second, $\omega_1 = \frac{\text{Average velocity of tricycle,v}}{\text{perimeter of wheel,P}} = \frac{1.528}{2.2}$

= 0.7 r.p.s.

Rotation of wheel per minute, ω_1 = 42 r.p.m.

Rotation of rear brush per minute, ω_2 = 200 r.p.m.

Gear ratio between wheel and rear brush, $n = \frac{N_2}{N_1} = \frac{200}{42}$

≈ 5

For two mating gears, both must have the same diametral pitch and pressure angle.

Pressure angle, $\emptyset = 20°$

Diametral pitch, $P_d = 6\ \text{inch}^{-1} = 236.2205\ \text{m}^{-1}$

$$P_d = \frac{N_1}{d_1} = \frac{N_2}{d_2}$$

$$n = \frac{N_1}{N_2} = \frac{d_1}{d_2}$$

$$5 = \frac{d_1}{d_2}$$

$$d_1 = 5d_2 \text{ ---------------(1)}$$

N_1 = No. of teeth of gear (wheel)

N_2 = No. of teeth of gear (rear brush)

d_1 = Pitch diameter of gear (wheel)

d_2 = Pitch diameter of gear (rear brush)

Centre distance between gear (wheel) and gear (rear brush), C = 19cm = 0.19m

$$C = \frac{d_1 + d_2}{2}$$

$$0.19 = \frac{d_1 + d_2}{2}$$

$$0.38 = d_1 + d_2 \quad \text{-----------(2)}$$

Substitute equation (1) into (2),

$$0.38 = 5d_2 + d_2$$

$$d_2 = 0.0633\text{m}$$

$$d_2 \approx 2.5 \text{ inch}$$

Substitute $d_2 = 0.06333\text{m}$ into equation (1),

$$d_1 = 5(0.06333)$$

$$d_1 = 0.3167\text{m}$$

$$d_1 \approx 12.5 \text{ inch}$$

Addendum, $a = \frac{1}{P_d}$

$$a = \frac{1}{6}$$

$$a = 0.1667\text{inch} = 0.004234\text{m}$$

Dedendum, $b = \frac{1.25}{P_d}$

$$b = \frac{1.25}{6}$$

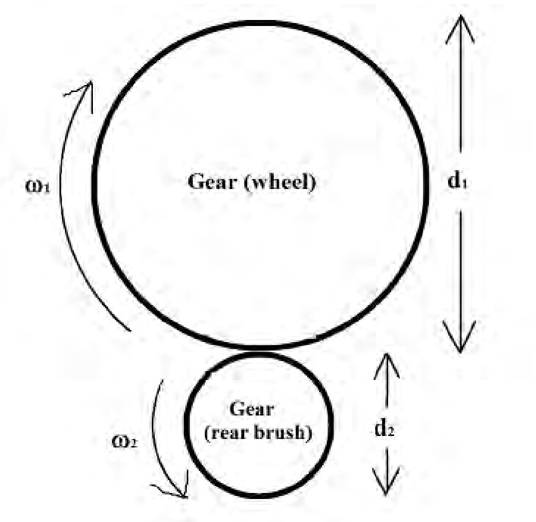
$$b = 0.2083\text{inch} = 0.00529\text{m}$$

Base circle diameter, $d_b = d\cos\emptyset$

Addendum circle diameter, $d_a = d + 2a$

Dedendum circle diameter, $d_d = d - 2b$

No. of teeth, $N = P_d \times d$



Gear (wheel):

Pitch diameter, $d_1 = 0.3167\text{m}$

No. of teeth, $N = 6 \times 12.5$

$= 75$

Base circle diameter, $d_b = 0.3167\cos 20$

$= 0.2976\text{m}$

Addendum circle diameter, $d_a = 0.3167 + 2(0.004234)$

$= 0.3252\text{m}$

Dedendum circle diameter, $d_d = 0.3167 - 2(0.00529)$

$= 0.30612\text{m}$

Gear (rear brush):

Pitch diameter, $d_2 = 0.0633\text{m}$

No. of teeth, $N = 6 \times 2.5$

$= 15$

Base circle diameter, $d_b = 0.0633\cos 20$

$= 0.05948\text{m}$

Addendum circle diameter, $d_a = 0.0633 + 2(0.004234)$

$= 0.071768\text{m}$

Dedendum circle diameter, $d_d = 0.0633 - 2(0.00529)$

$= 0.05272\text{m}$

Table 4.7: Parameters of gear (wheel) and gear (rear brush)

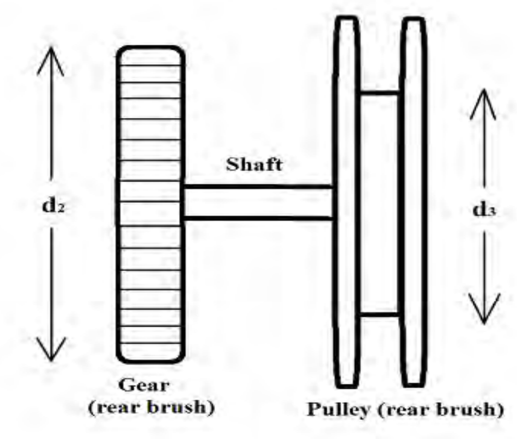
Parameter	Gear (wheel)	Gear (rear brush)
Angular velocity, $\boldsymbol{\omega}$	42 r.p.m	200 r.p.m.
Pitch diameter, d	0.3167m	0.0633m
No. of teeth, N	75	15
Base circle diameter, $\mathbf{d_b}$	0.2976m	0.05948m
Addendum circle diameter, $\mathbf{d_a}$	0.3252m	0.071768m
Dedendum circle diameter, $\mathbf{d_d}$	0.30612m	0.05272m
Gear ratio, n	5	
Centre distance, C	19cm	
Pressure angle, Ø	20°	
Diametral pitch, P_d	6	

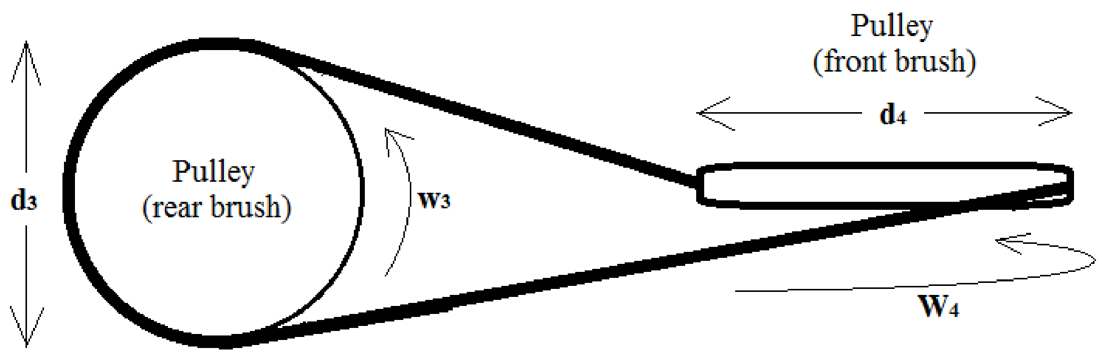
4.6.3 Belt Transmission

<u>Pulley (rear brush) to pulley (front brush)</u>

Angular velocity of gear (rear brush) and pulley (rear brush) is the same because they share the same shaft.

$$\omega_2 = \omega_3 = 200 \text{ r.p.m.}$$





Angular velocity of pulley (rear brush), $\omega_3 = 200 \text{ r.p.m.}$

$$= 20.944 \text{ rad/s}$$

Angular velocity of pulley (front brush), $\omega_4 = 100 \text{ r.p.m.}$

$$= 10.472 \text{ rad/s}$$

Diameter of pulley (front brush), $d_4 = 4\text{cm} = 0.04\text{m}$

Pulley (rear brush) and pulley (front brush) have the same linear velocity because they are in the same belt system and connected by belt.

$$v_3 = v_4$$

$$r_3\omega_3 = r_4\omega_4$$

$$\frac{d_3}{2}\omega_3 = \frac{d_4}{2}\omega_4$$

$$\frac{d_3}{2}(20.944) = \frac{0.04}{2}(10.472)$$

$$10.472d_3 = 0.20944$$

$$d_3 = 0.02\text{m}$$

The diameter of pulley (rear brush), $d_3 = 0.02\text{m} = 2\text{cm}$

4.7 DETAIL DESIGN

4.7.1 Material Selection

There are five properties that need to consider when choosing the material for each part of the design. These five properties are physical, electrical, thermal, mechanical, and chemical properties.

4.7.1.1 Waste Container

Table 4.8: Required material properties for waste container

Properties	Requirement	Suitable Material
Physical	- Low weight - Rigid	Plastic: PAI (polyamide-imide)
Electrical	- No required	
Thermal	- No required	
Mechanical	- High flexural strength	
Chemical	- No required	

The function of waste container is to store the waste. It requires high flexural strength to support the weight of rubbish which up to 10kg. The weight of waste container should as low as possible to reduce the product's weight. The most suitable for waste container is PAI (polyamide-imide) because it has high flexural strength which can support 10kg rubbish and it also has low weight.

4.7.1.2 Frame of Cleaning Device

Table 4.9: Required material properties for frame of cleaning device

Properties	Requirement	Suitable Material
Physical	- Low weight - Rigid	
Electrical	- No required	
Thermal	- No required	Metal: Aluminium
Mechanical	- High strength	
Chemical	- No required	

The function of frame of cleaning device is to support all the other cleaning device components like waste container and brushes. Therefore, it required very high strength. The weight of frame of cleaning device should as low as possible to minimize the weight of product in order to reduce the human power required. The most suitable material for frame of cleaning device is aluminium because aluminium has low density and therefore low weight, high strength, and good corrosion resistance.

4.7.1.3 Cover

Table 4.10: Required material properties for cover

Properties	Requirement	Suitable Material
Physical	- Low weight - Rigid	

Electrical	- No required	LDPE (Low density polyethylene)
Thermal	- No required	
Mechanical	- No required	
Chemical	- No required	

The function of cover is to cover the components inside the cleaning device for good appearance. Therefore, no material properties are required but light in weight only. LDPE (Low density polyethylene) is the most suitable material for cover because it is light and also very cheap.

4.7.1.4 Bristles

Table 4.11: Required material properties for bristles

Properties	Requirement	Suitable Material
Physical	- Flexible - Water proof	Thermoplastic polymer: Proex (blend of 3 different diameter polypropylenes to improve sweeping effectiveness)
Electrical	- No required	
Thermal	- No required	
Mechanical	- Elastic - High bend recovery	
Chemical	- No required	

The function of bristle is to sweep and collect the rubbish into the waste container. It required elastic and high bend recovery characteristic for penetration so that it can sweep the rubbish effectively. Besides that, it required water proof so that it can sweep the wet rubbish under humid environment. Proex (synthetic material) is the most suitable material for bristle because Proex is elastic and having good sweeping effectiveness. Proex also can perform well in humid environment.

4.7.1.5 Gear

Table 4.12: Required material properties for gear

Properties	Requirement	Suitable Material
Physical	- Rigid - Low weight - Low friction	Plastic: MC901 Nylon (Alro Industrial Supply, 2017)
Electrical	- No required	
Thermal	- No required	
Mechanical	- Vibration resistance - Wear resistance - High strength	
Chemical	- No required	

The function of gear is to transmit the rotational motion from the wheel to the rear brush. MC901 nylon is the most suitable material for gear because it has light weight, vibration resistance, wear resistance and high strength properties which are the required properties for gear.

4.7.1.6 Pulley

Table 4.13: Required material properties for pulley

Properties	Requirement	Suitable Material
Physical	- Rigid - Low weight	Plastic: MC901 Nylon (Alro Industrial Supply, 2017)
Electrical	- No required	
Thermal	- No required	
Mechanical	- Vibration resistance - Wear resistance - High strength	
Chemical	- No required	

The function of pulley is to transmit the rotation motion of rear brush to the front brushes. MC901 nylon is the most suitable material for pulley because it has light weight, vibration resistance, wear resistance and high strength properties which are the required properties for pulley.

4.7.2 Working Mechanism

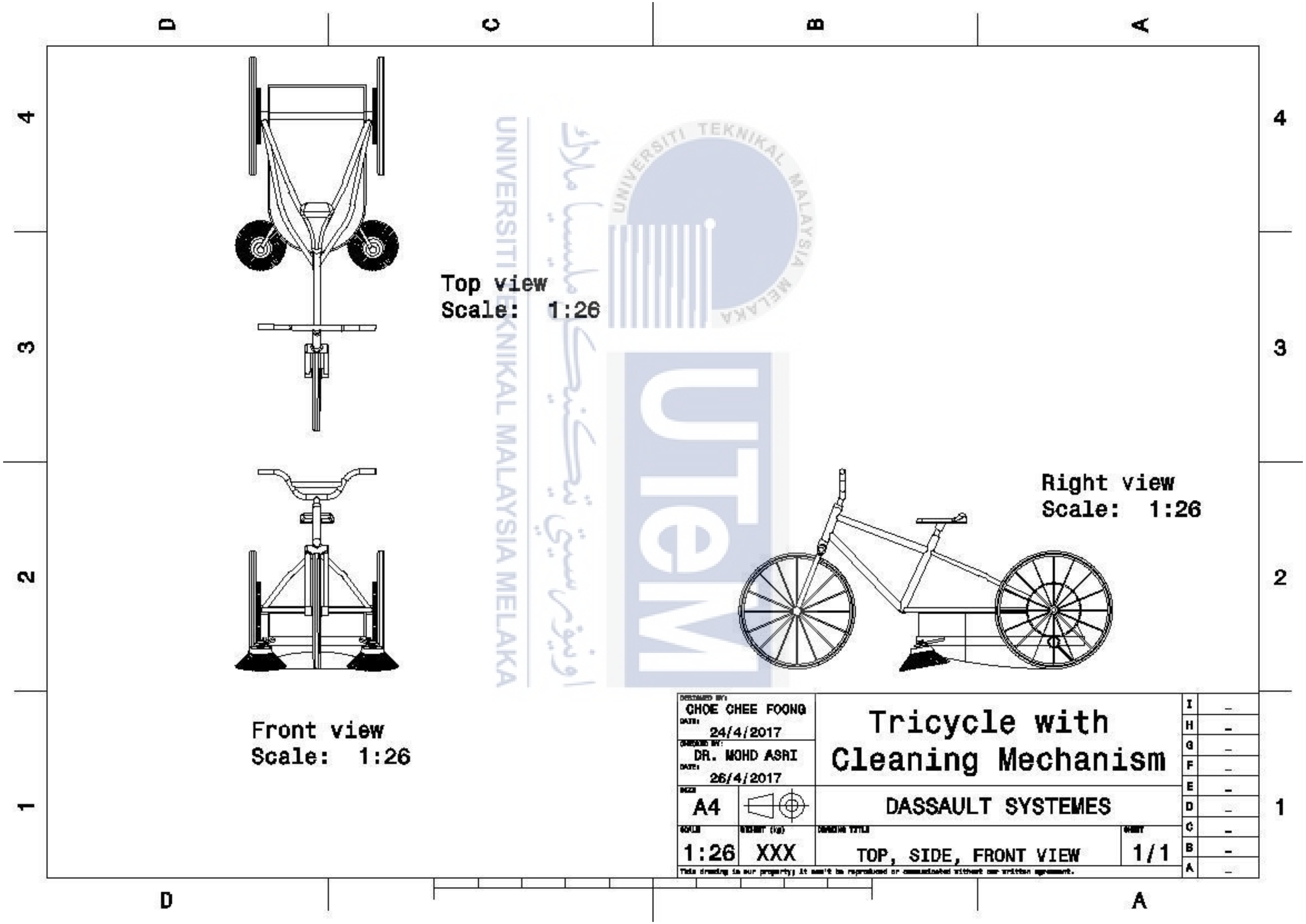
The design of tricycle with cleaning mechanism is inspired by the regular tricycle and manual push sweeper. The working principal of tricycle and manual push sweeper is applied to this design and combine them by using gear and belt transmission system.

The main working mechanism consists of tricycle, gear and belt system. The working mechanism used for the tricycle is chain mechanism which normally used for regular bicycle or tricycle. For the gear system, there are four spur gears are used for this design. One spur gear is attached to the right rear wheel of tricycle, one spur gear is attached to the left rear wheel of tricycle and another two spur gears are attached to the rear brush at the right and left side. For the belt system, there are four pulleys and two belts are used in this design. One pulley is attached to the front brush at the left side, one pulley is attached to the front brush at the right side, and another two pulleys are attached to the rear brush at the right and left side.

When user cycles the tricycle, the wheels of tricycle are rotated by chain. The rotational motion of wheels is transmitted to the rear brush of cleaning device by using gear system and cause the rear brush rotates. The gear ratio used is 1:5 which mean when the wheels rotate at speed 40 r.p.m., rear brush will rotates at speed 200 r.p.m.. The rotating rear brush sweeps the rubbish into the waste container where the tricycle passes by. The rotational motion of rear brush is transmitted to the front brushes by using belt system. The pulley ratio used is 2:1, so when the rear brush rotates at speed 200 r.p.m., front brushes will rotate at speed 100 r.p.m.. The rotating front brushes sweep the rubbish at the edge or rubbish from left and right side to the middle so that the rear brush can sweep them into the waste container. When user stops cycling the tricycle, the wheels of tricycle, rear brush and front brushes will stop rotating.

4.7.3 Detail Drawing

The concept of tricycle with cleaning mechanism is applied by using 3 Dimension (3D) CAD software in its actual size. For this project, Computer Aided Three-Dimensional Interactive Application (CATIA V5R21) is used. The design is divided into two parts, which are tricycle and cleaning device. Tricycle part consists of front wheel, rear wheels with gears, tricycle frame, handlebar and seat. Cleaning device part consists of front brushes with pulley, rear brush with gears, frame of cleaning device, waste container, cover and belt.



Top view
Scale: 1:26
Front view
Scale: 1:26
Right view
Scale: 1:26
DESIGNED BY:
CHOE CHEE FOONG
DATE:
24/4/2017
CHECKED BY:
DR. MOHD ASRI
DATE:
26/4/2017
SIZE
A4
SCALE
1:26
WEIGHT (kg)
XXX
Tricycle with
Cleaning Mechanism
DASSAULT SYSTEMES
DRAWING TITLE
TOP, SIDE, FRONT VIEW
SHEET
1/1
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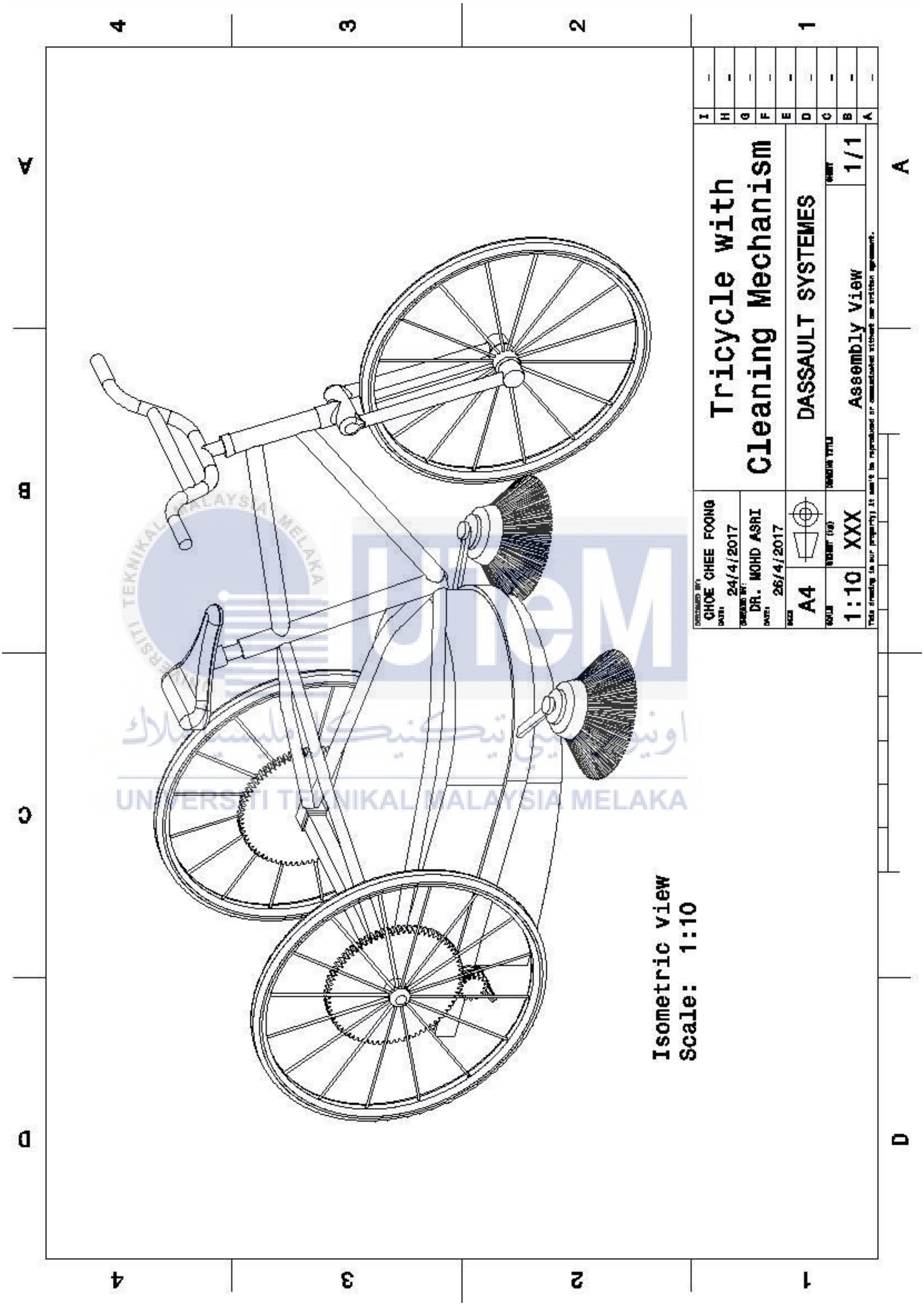
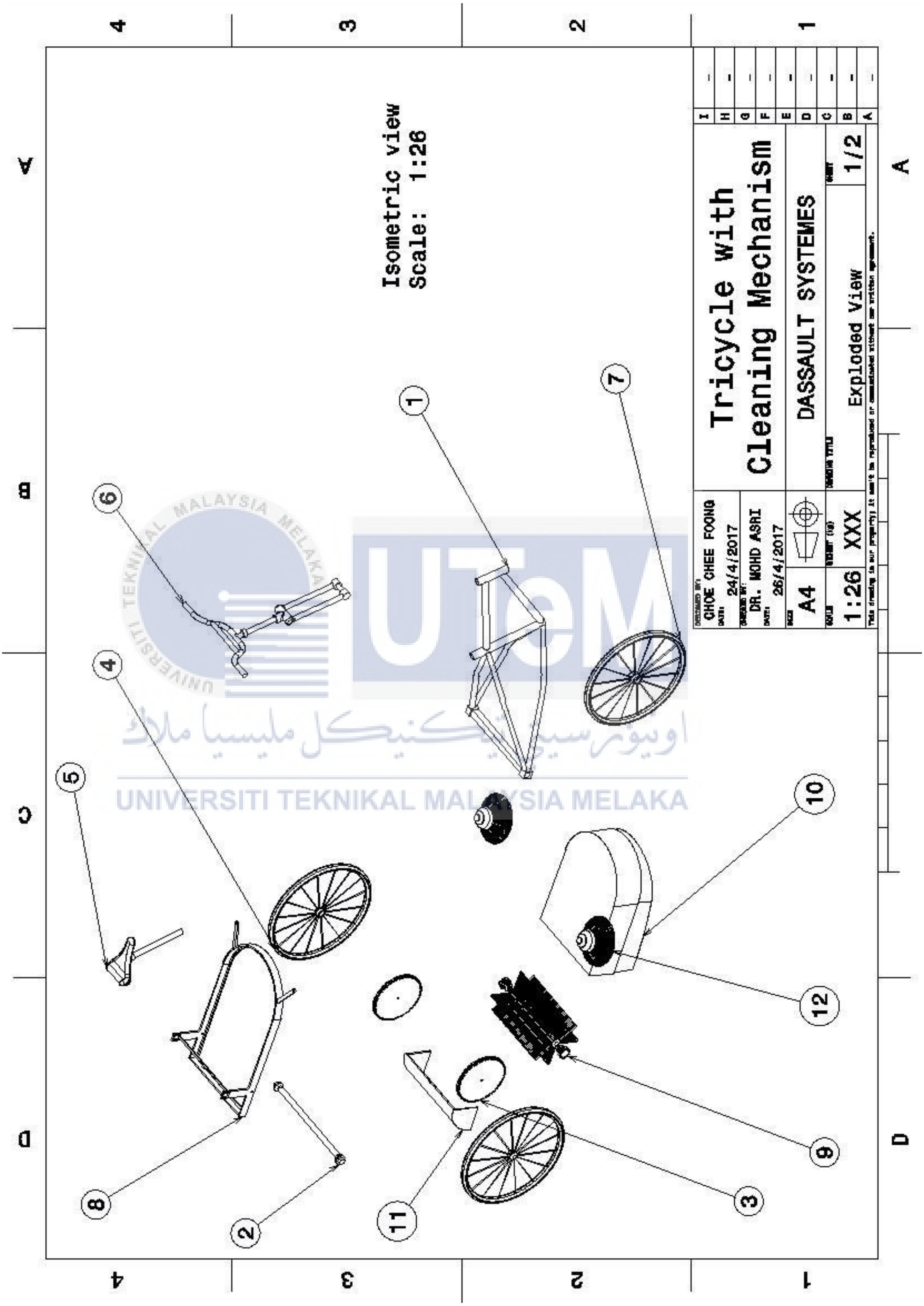


Isometric view
Scale: 1:10
CHOE CHEE FOONG
24/4/2017
DR. MOHD ASRI
26/4/2017
A4
1:10
XXX
Tricycle with
Cleaning Mechanism
DASSAULT SYSTEMES
Assembly View
1/1


Isometric view
Scale: 1:26
Tricycle with Cleaning Mechanism
DASSAULT SYSTEMES
Exploded View
CHOE CHEE FOONG
24/4/2017
DR. MOHD ASRI
26/4/2017
A4
1:26
XXX
1/2

Bill of Material: Tricycle with Cleaning Mechanism
Different parts: 12
Total parts: 15

Number	Name	Quantity	Material
1	Tricycle frame	1	Aluminium
2	Rod	1	Aluminium
3	Large gear	2	MC901Nylon
4	Rear wheel	2	Steel & Rubber
5	Seat	1	Leather and Steel
6	Handlebar	1	Steel
7	Front wheel	1	Steel & Rubber
8	Frame of cleaning device	1	Aluminium
9	Rear brush with gears and pulleys	1	MC901Nylon-(Gear&Pulley) Proex-Rear brush
10	Container	1	PAI
11	Cover	1	LDPE
12	Front brush with pulley	2	Proex-Front brush MC901Nylon-Pulley

DESIGNED BY: CHOE CHEE FOONG
DATE: 24/4/2017
CHECKED BY: DR. MOHD ADRI
DATE: 26/4/2017

Tricycle with Cleaning Mechanism

SIZE: A4
DASSAULT SYSTEMES
SCALE
WEIGHT (kg): XXX
DRAWING NUMBER: Bill of Material
SHEET: 2/2

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4.7.4 Product Structure Tree

Product structure tree shows the overall compilation of the product design. Product structure tree for tricycle with cleaning mechanism is divided into two main sub-assembly, which are tricycle and cleaning device.

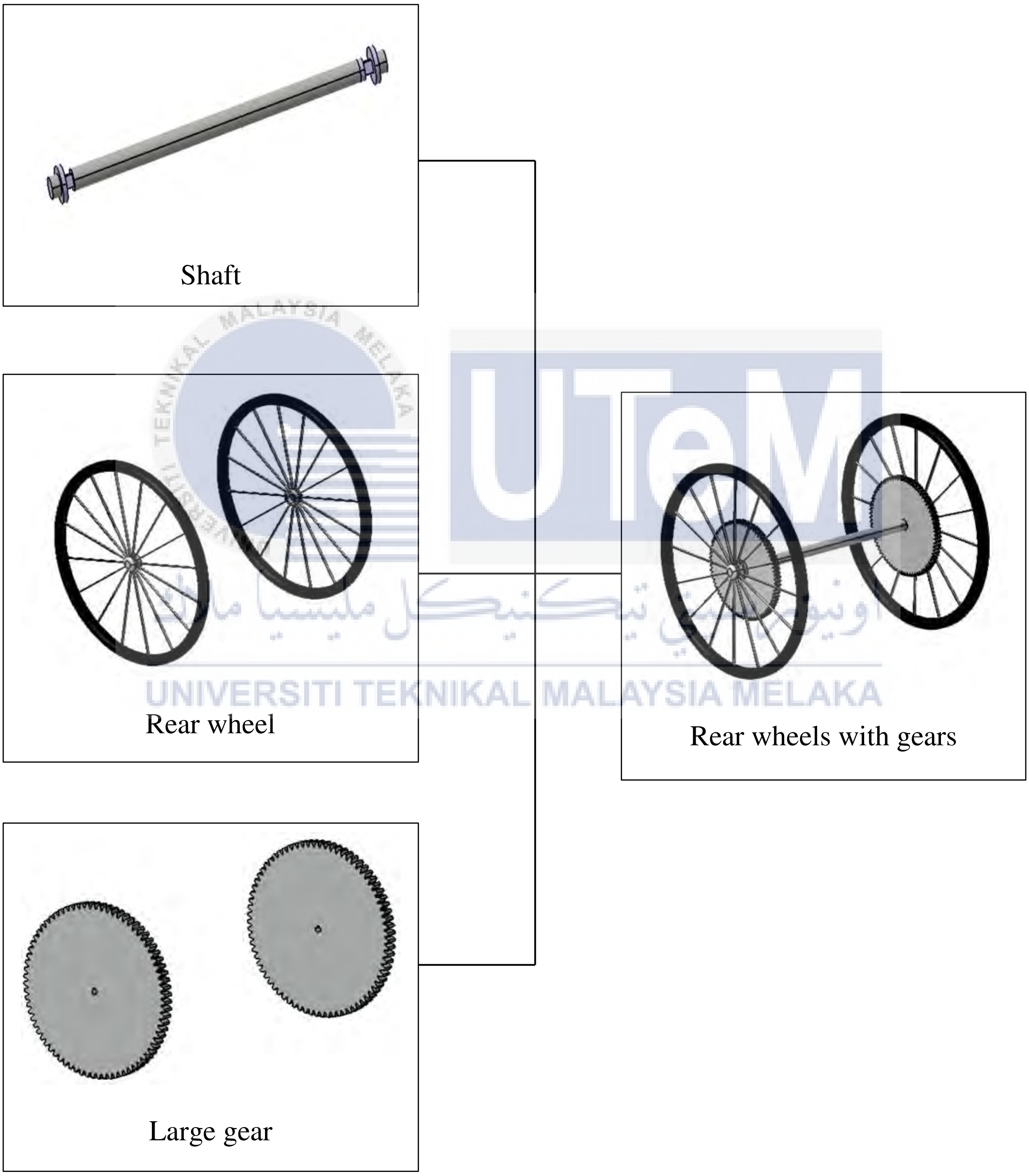

Figure 4.9: Product structure of rear wheels with gears

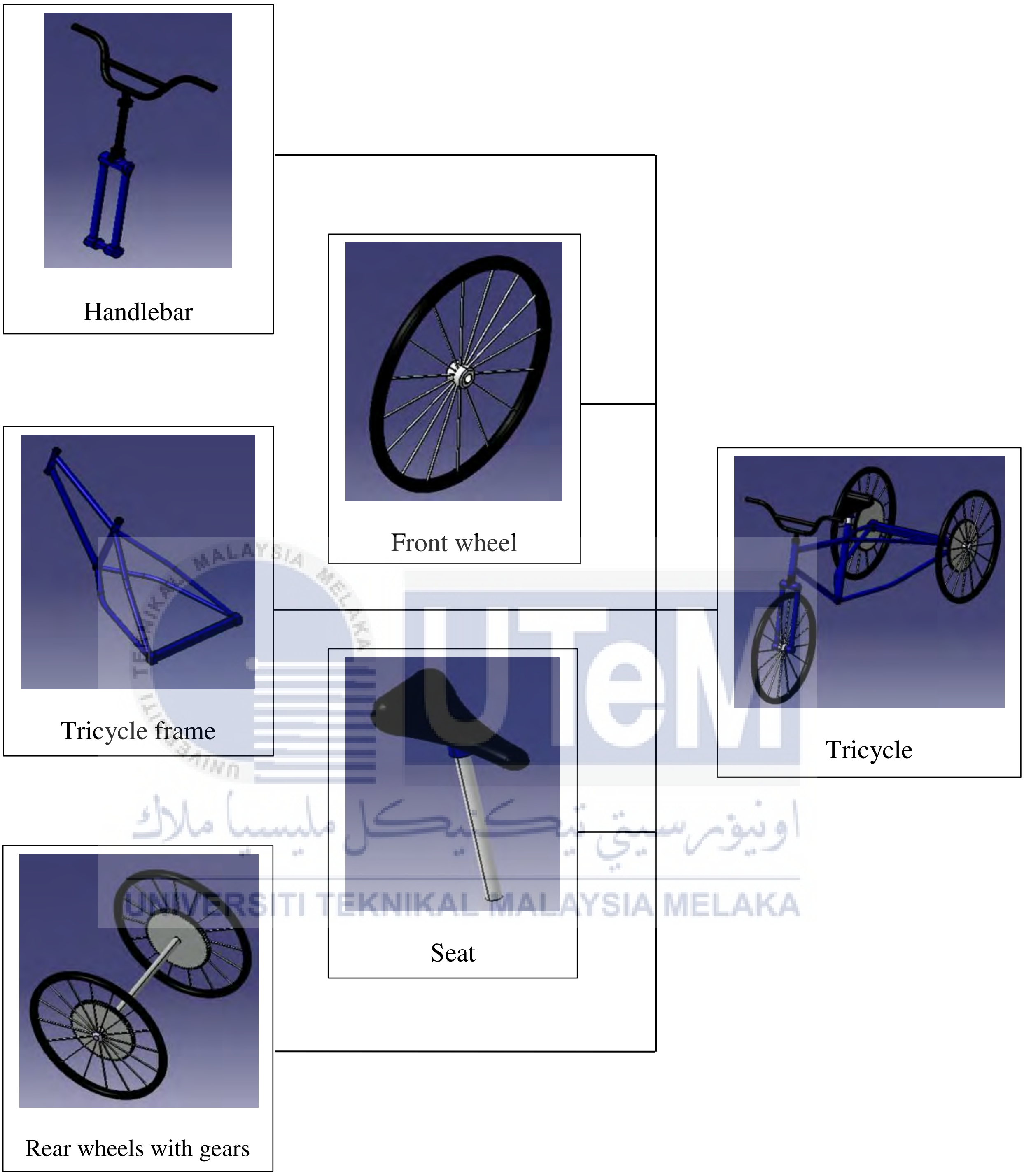

Figure 4.10: Product structure of tricycle

Figure 4.11: Product structure of cleaning device

4.8 COST ANALYSIS

Total cost of product design is one of the important factors to evaluate and produce high functioning and low cost product design. There are three types of costs when manufacture a design, which are material cost, manufacturing cost and purchase cost.

4.8.1 Material Cost

Material cost is the amount of expenses that used to purchase the raw material like sheet metal, aluminium rod, plastic pellets.

Table 4.14: Cost of raw material for each part of tricycle with cleaning mechanism

Part	Raw Material	Price/unit (RM)	Unit	Quantity	Total Price (RM)
Container	PAI (polyamide-imide) (Pellets)	10/kg	2kg	1	20.00
Cover	LDPE (Low density polyethylene) (Pellets)	7/kg	0.5kg	1	3.50
Frame of cleaning device	Aluminium (Aluminium sheet)	11/kg	1kg	1	11.00
Large Pulley	MC901Nylon (Block)	1/80cm^3	1280cm^3	2	32.00
Small pulley			72cm^3	2	1.80

Large gear	MC901Nylon (Pellets)	10/kg	1kg	2	20.00
Small gear	MC901Nylon (Pellets)	10/kg	0.2kg	2	4.00
Tricycle frame	Aluminium (Aluminium tube)	12/kg	4kg	1	48.00
Shaft	Aluminium (Rod)	9/kg	3kg	1	27.00
				Total	167.30

4.8.2 Manufacturing Cost

Manufacturing cost is the amount of expenses that used to manufacture the raw material into desired shape. Manufacturing costs included labor cost and operation cost.

Table 4.15: Manufacturing cost for each part of tricycle with cleaning mechanism

Part	Manufacturing Process	Raw Material Cost (RM)	Percentage of Manufacturing Cost (%)	Manufacturing Cost (RM)
Container	Injection molding	20.00	20	4.00
Cover	Injection molding	3.50	20	0.70
Frame of cleaning device	Rolling, cutting, welding, drilling	11.00	150	16.50

Large pulley	Milling	32.00	30	9.60
Small pulley	Milling	1.80	30	0.50
Large gear	Injection molding	20.00	20	4.00
Small gear	Injection molding	4.00	20	0.80
Tricycle frame	Cutting, welding	48.00	80	38.40
Shaft	Milling	27.00	20	5.40
			Total	79.90

*The manufacturing cost above is roughly analysed and estimated because it is influenced by the material selection, part geometry, machine condition, machinist's skill, and run quantities and frequencies.

4.8.3 Purchase Cost

Purchase cost is the amount of expenses that used to buy the standard parts from vendor or supplier.

Table 4.16: Purchase cost for each part of tricycle with cleaning mechanism

Part	Price/unit (RM)	Unit	Total Price (RM)
V-Belt	5/meter	2.4 meter	12.00
Front brush	20/unit	2 units	40.00
Rear brush	30/unit	1 unit	30.00
Tricycle wheel	60/unit	3 units	180.00
Handlebar	70/unit	1 unit	70.00
Seat	30/unit	1 unit	30.00
Chain	9/meter	2 meter	18.00
		Total	380.00

4.8.4 Total Cost

Total cost is total amount of expenses which included raw material cost, manufacturing cost and purchase cost. Total cost to fabricate a tricycle with cleaning mechanism is RM 627.20.

Table 4.17: Total cost of tricycle with cleaning mechanism

Type of Cost	Total (RM)
Raw material	167.30
Manufacturing	79.90
Purchase	380.00
Total	627.20

4.9 DESIGN ANALYSIS

Product tricycle with cleaning mechanism is analyzed by using theoretical calculation and CATIA software to ensure its safety and functioning.

4.9.1 Theoretical Calculation Analysis

Perimeter of tricycle wheel, $P = 2\pi r = 2\pi(0.35) = 2.2\text{m}$

Gear ratio (wheel to rear brush) $= 1:5$

Pulley ratio (rear brush to front brush) $= 2:1$

$$\frac{\text{Rotation of rear brush per minute, } N_2}{\text{Rotation of wheel per minute, } N_1} = \frac{5}{1}$$

$$\frac{\text{Rotation of front brush per minute, } N_3}{\text{Rotation of rear brush per minute, } N_2} = \frac{1}{2}$$

$$\text{No. of rotation of wheel per minute} = \frac{\text{Velocity of tricycle, v (m/s)}}{\text{Perimeter of wheel, P (m)}} \times 60$$

$1\text{km/h} = 0.2778\text{m/s}$

Table 4.18: Angular velocity of wheel, rear brush and front brush with different velocity of tricycle

Velocity of Tricycle, v (km/h)	**No. of rotation per minute (r.p.m.)**		
	Wheel ,N_1 (r.p.m.)	**Rear Brush, N_2 (r.p.m.)**	**Front Brushes, N_3 (r.p.m.)**
0	0	0	0
1	7.6	38.0	19
2	15.2	76.0	38
3	22.7	113.5	56.8
4	30.3	151.5	75.8

5	37.9	189.5	94.8
6	45.4	227	113.5
7	53.0	265	132.5

From the table 4.17, this design of tricycle with cleaning mechanism can sweep and collect the rubbish effectively only when it is moving at velocity 2 km/h until 5 km/h. When the tricycle is moving at velocity lower than 2 km/h, the rear brush and front brushes rotate at very slow speed and may cause some rubbish not collected and left behind. If the tricycle moves at velocity higher than 7 km/h, the front brushes will rotate at angular velocity which is higher than 120 r.p.m.. 120 r.p.m. is the rotational speed that will blow the dust slightly and harm the health of people nearby.

4.9.2 CATIA Analysis

The parts that withstand high force or having critical part are analysed to ensure the product is safe to use and having long lifespan.

4.9.2.1 Frame of Cleaning Device

Frame of cleaning device is analysed because it has small cross sectional area and withstand high force. The frame of cleaning device is made up of aluminium. Figure 4.11 shows the structural properties of aluminium. 120N force (weight of rubbish and cleaning device) is applied to the frame of cleaning device in downward direction (z-axis).

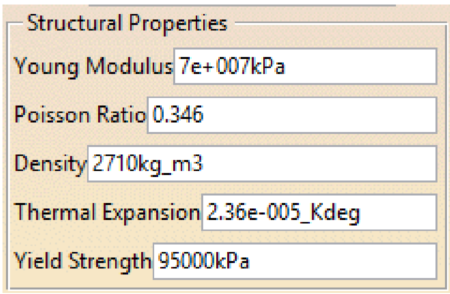

Figure 4.12: Structural properties of aluminium

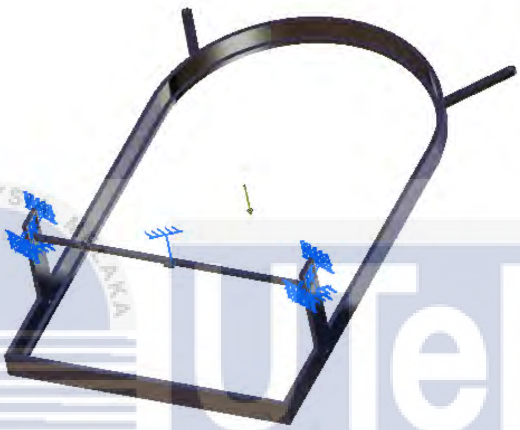

Figure 4.13: Frame of cleaning device with clamp and applied 120N downward force

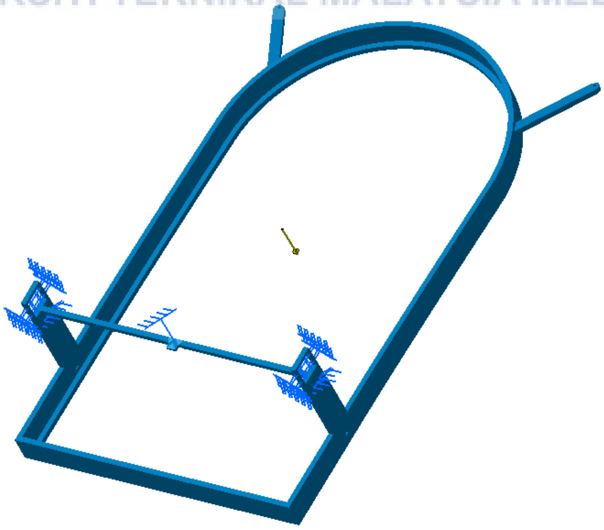

Figure 4.14: Deformation of frame of cleaning device

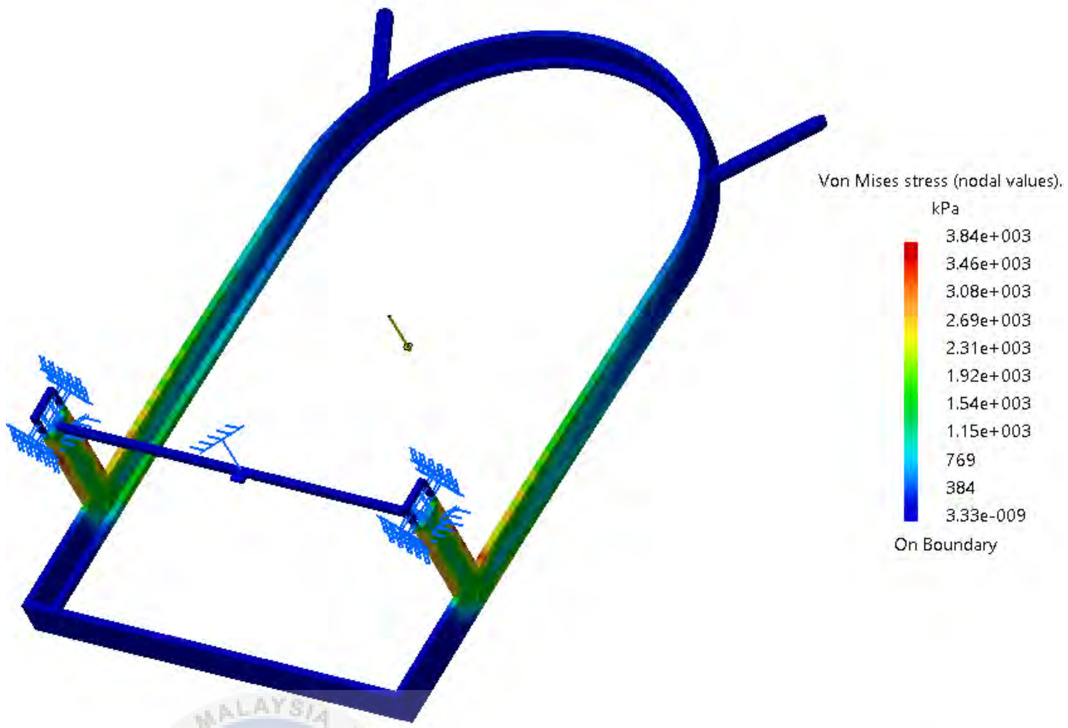

Figure 4.15: Von Mises stress of frame of cleaning device

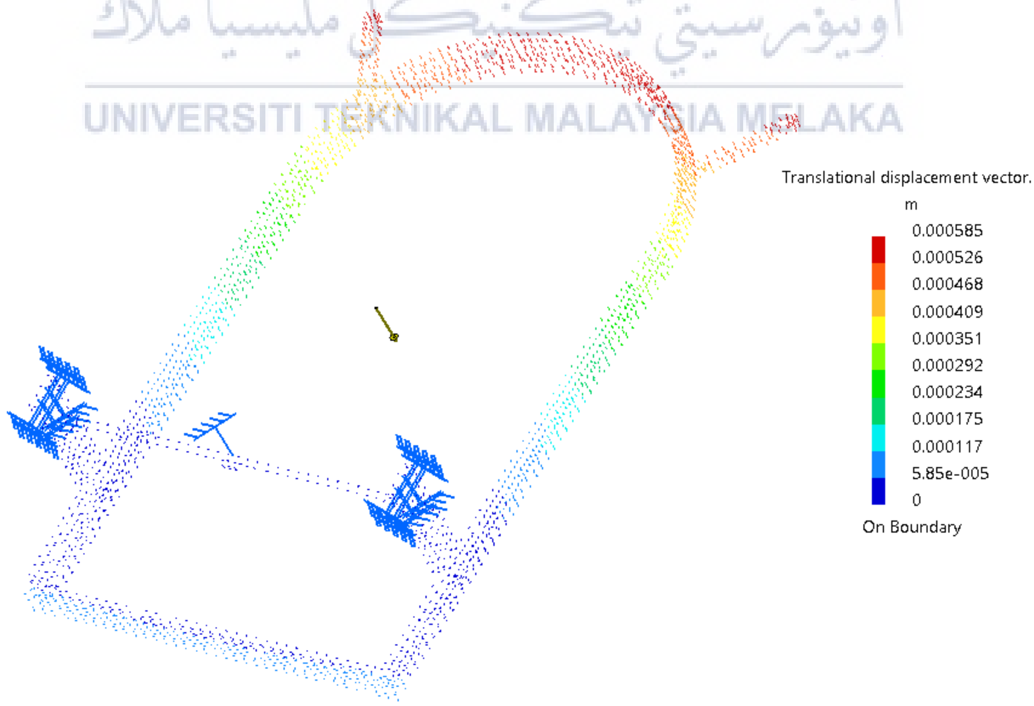

Figure 4.16: Translational displacement of frame of cleaning device

Figure 4.15 shows the Von Mises stress of frame of cleaning device. The blue colour region has very low Von Mises stress which is from 0 to 769kPa. Green and yellow regions are the regions that withstand medium Von Mises stress which is around 2000kPa. Orange and red regions are the regions that withstand very high Von Mises stress which is from 3000kPa to 3840kPa.

$$\text{Maximum Von Mises stress} = 3840\text{kPa}$$

$$\text{Minimum Von Mises stress} = 3.33 \times 10^{-9}\text{kPa}$$

$$\text{Yield strength of aluminium} = 95000\text{kPa}$$

$$\text{Safety factor} = \frac{\text{Yield strength}}{\text{Maximum Von Mises stress}}$$

$$\text{Safety factor} = \frac{95000\text{kPa}}{3840\text{kPa}}$$

$$\text{Safety factor} = 24.7$$

The safety factor for frame of cleaning device is around 25 which is very high. The standard safety factor should be from 3 to 5. This indicates that the exceed material is used. To solve this problem, the cross-sectional area of the frame of cleaning device should be minimized by using design optimization method.

Figure 4.16 shows the translational displacement of frame of cleaning device. The blue colour region is the region that has lowest displacement which is from 0mm to 0.117mm. Green and yellow regions are the regions that have medium displacement which is around 0.3mm. Orange and red regions are the regions that have highest displacement which is from 0.45mm to 0.585mm.

4.9.2.2 Shaft

Shaft is also one of the critical parts that need to be analysed because it withstand very high force which include weight of human, rubbish, tricycle frame, and cleaning device. The shaft is made up of aluminium. Figure 4.17 shows the structural properties of aluminium. 800N force (total half of the weight of human, cleaning device, rubbish and tricycle, because another half of the weight is applied at the front shaft) is applied to the shaft in downward direction (z-axis).

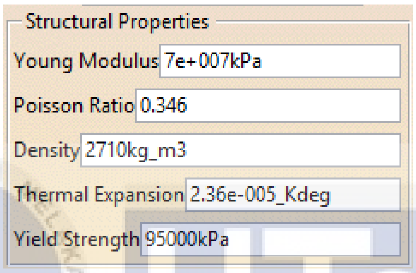

Figure 4.17: Structural properties of aluminium

Figure 4.18: Shaft with clamp and applied 800N downward force

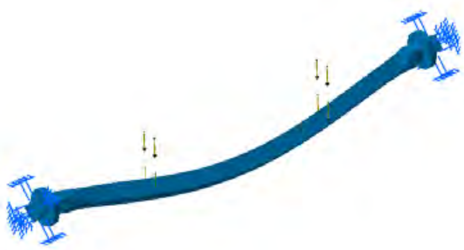

Figure 4.19: Deformation of shaft

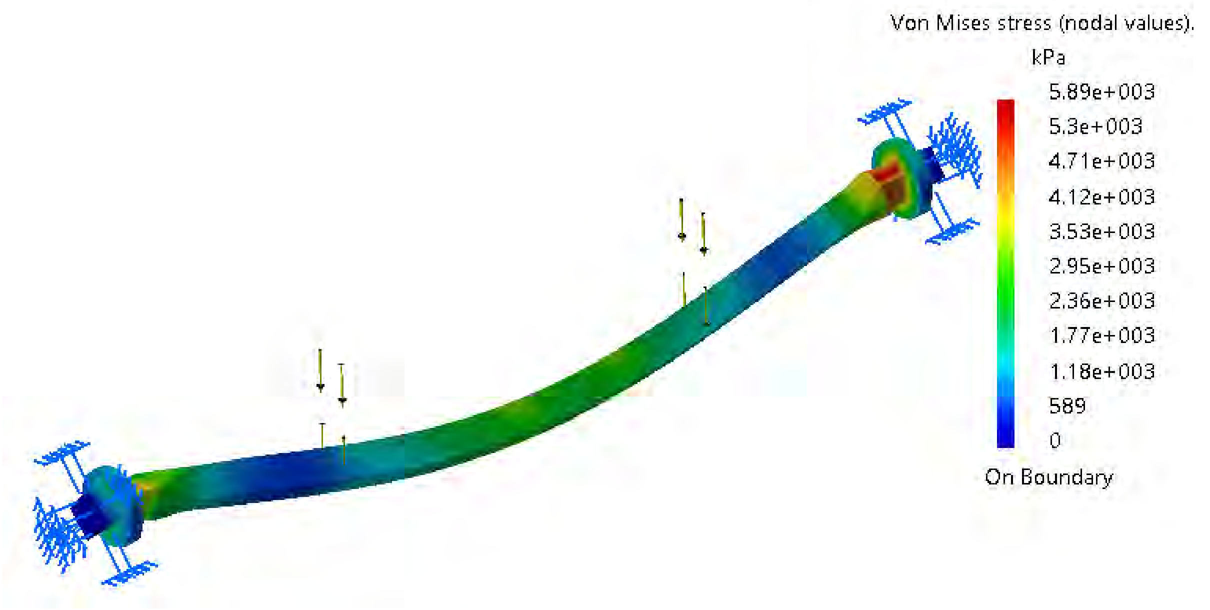

Figure 4.20: Von Mises stress of shaft

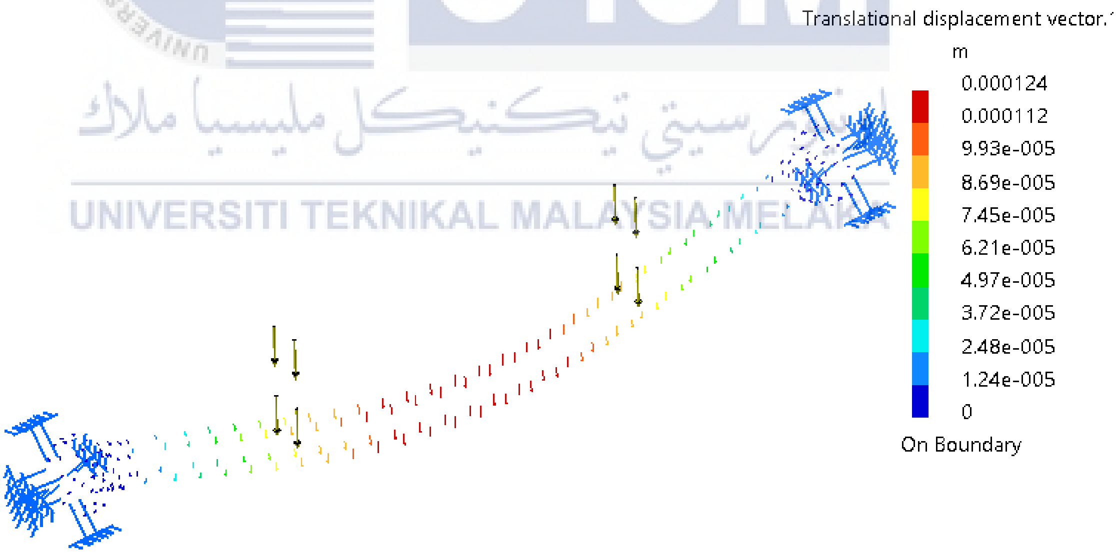

Figure 4.21: Translational displacement of shaft

Figure 4.20 shows the Von Mises stress of shaft. The blue colour region has very low Von Mises stress which is from 0 to 1180kPa. Green and yellow regions are the regions that withstand medium Von Mises stress which is around 3000kPa. Orange and red regions are the regions that withstand very high Von Mises stress which is from 4500kPa to 5890kPa.

$$\text{Maximum Von Mises stress} = 5890\text{kPa}$$

$$\text{Minimum Von Mises stress} = 0\text{kPa}$$

$$\text{Yield strength of aluminium} = 95000\text{kPa}$$

$$\text{Safety factor} = \frac{\text{Yield strength}}{\text{Maximum Von Mises stress}}$$

$$\text{Safety factor} = \frac{95000\text{kPa}}{5890\text{kPa}}$$

$$\text{Safety factor} \approx 16$$

The safety factor for shaft is around 16 which is very high. The standard safety factor should be from 3 to 5. This indicates that the exceed material is used. To solve this problem, the cross-sectional area of the shaft should be minimized or make the shaft with hollow by using design optimization method.

Figure 4.21 shows the translational displacement of shaft. The blue colour region is the region that has lowest displacement which is from 0mm to 0.0248mm. Green and yellow regions are the regions that have medium displacement which is around 0.05mm. Orange and red regions are the regions that have highest displacement which is from 0.09mm to 0.124mm.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

As a conclusion, the first objective which is to propose a suitable cleaning device to clean the city is achieved. Human-powered tricycle with cleaning mechanism has been designed and evaluated which is very suitable to be used to clean the city. This is because it has high moving speed, high cleaning effectiveness, and it is a green technology device since it operates without using electricity or petrol.

The second objective which is to design a human-powered tricycle with cleaning mechanism is also successfully achieved. The human-powered tricycle with cleaning mechanism is successfully designed by following the engineering design step by step. First stage is to generate four conceptual designs by using morphological chart. Second stage is to choose the best conceptual design among four conceptual designs by using Pugh selection method. Third stage is to determine and calculate the parameter of design so that the final design has the desired output. Forth stage is to select the most suitable material for each part of the design. Plastic, aluminium, steel and synthetic material will be used to fabricate this product. Fifth stage is to convert the design idea and draft into 3-Dimension by using CATIA V5R21 software. Sixth stage is to estimate the total cost of the final design which included raw material, manufacturing, and purchase cost. The total cost to fabricate a tricycle with cleaning mechanism with good quality material is RM 627.20 which is considered low cost in market price. Seventh stage is the last stage which is to analyze the final design to ensure its safety and functioning by using theoretical calculation and CATIA V5R21 software. Based on the design analysis, the final design product is very safe to use and having good sweeping effectiveness only when the tricycle is moving at the speed between 2km/h and 5km/h. As a conclusion, human-powered tricycle with cleaning mechanism is successfully proposed and designed.

5.2 RECOMMENDATION

This cleaning device product – tricycle with cleaning mechanism should continue to be developed and improved because this product has many limitations and flaws so far. It only can sweep the rubbish effectively at speed 2 km/h to 5 km/h. Besides that, it consumes a lot of human energy when cycling up the hill because it can store the rubbish up to 10kg. This product's front brushes angle cannot be adjusted because the design of front brushes angle is fixed. The front brushes mechanism should be modified so that the angle of front brushes is adjustable in order to clean the rubbish more effectively. This is because different type of rubbish required different brush angle.

Moreover, this product should always be modified because it has high potential to be one of the important green technology devices over the world due to its high moving speed and cleaning effectiveness. Melaka blue print is to become a green technology city by year 2020. Therefore, it is a good chance to start up this product in Melaka. This product can be used in industry sector, private area like shopping mall and government area like playground, roadside, street and school or university.

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Magd M., Chong, Libardo, V., & Parker, G. (2011). Experimental Determination of Optimum Gutter Brush Parameters and Road Sweeping Criteria for Different Type of Waste. Waste Management, 31, 1109-1120.

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APPENDIX A

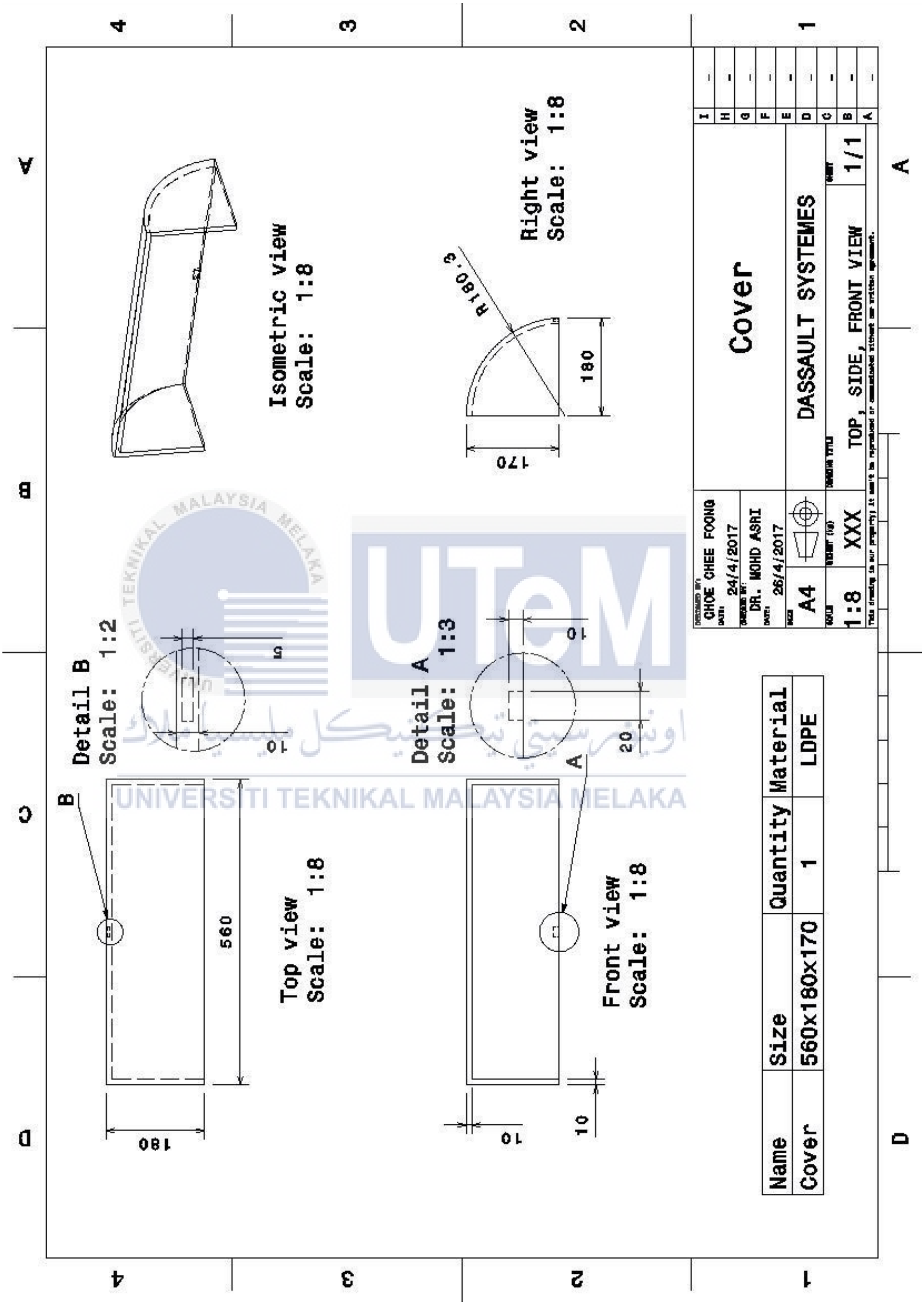
Table A1: Gantt chart for PSM I

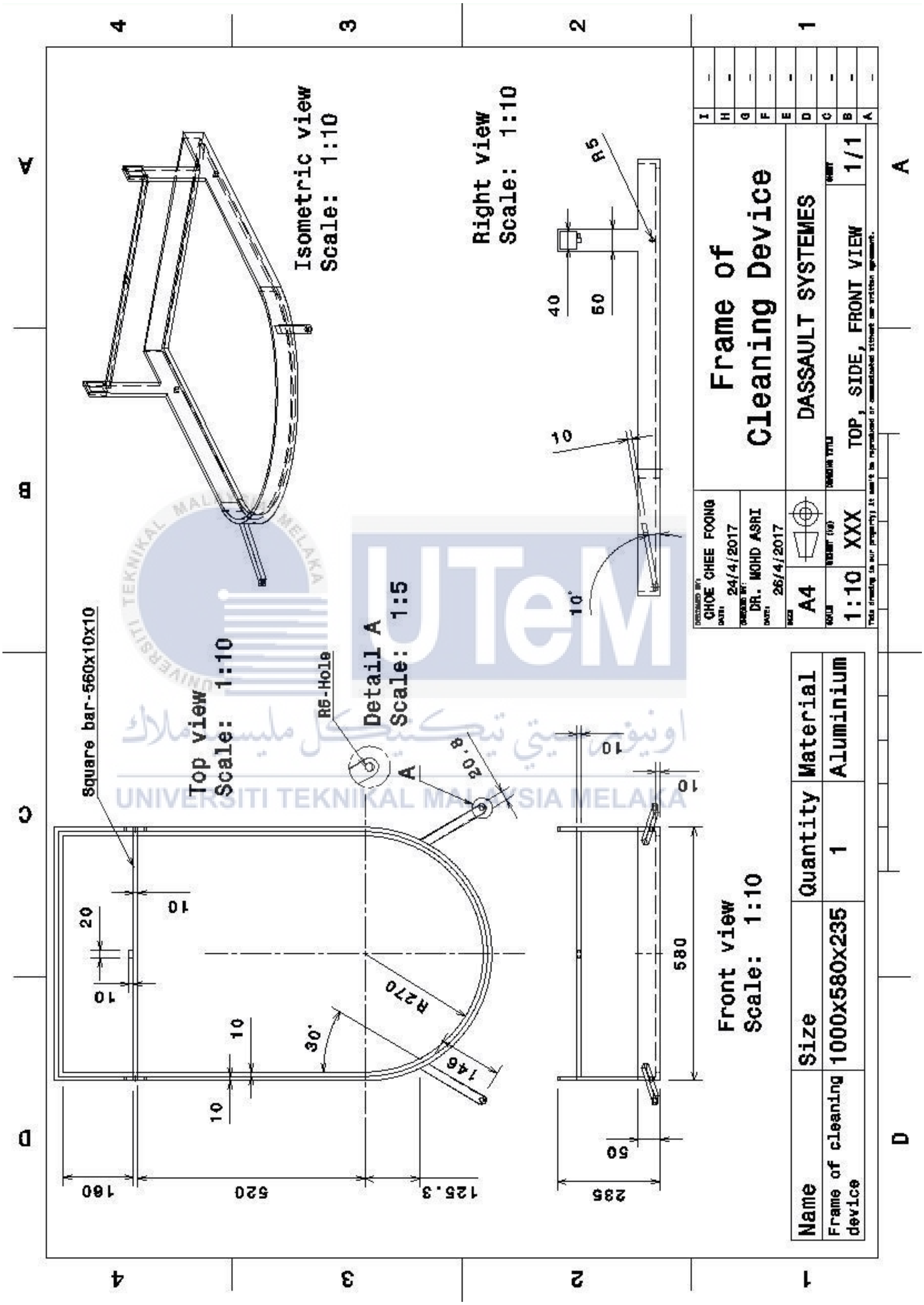
Activity	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tittle Selection	■														
Project Review		■	■												
Literature Review				■	■	■	■	■	■	■	■	■	■	■	
Idea Generation				■	■	■									
Progress Report Submission							■								
Parts Design								■	■						
Detail Design									■	■	■				
Final Design											■	■			
Report Writing								■	■	■	■	■	■	■	
Presentation															■
Report Submission															■

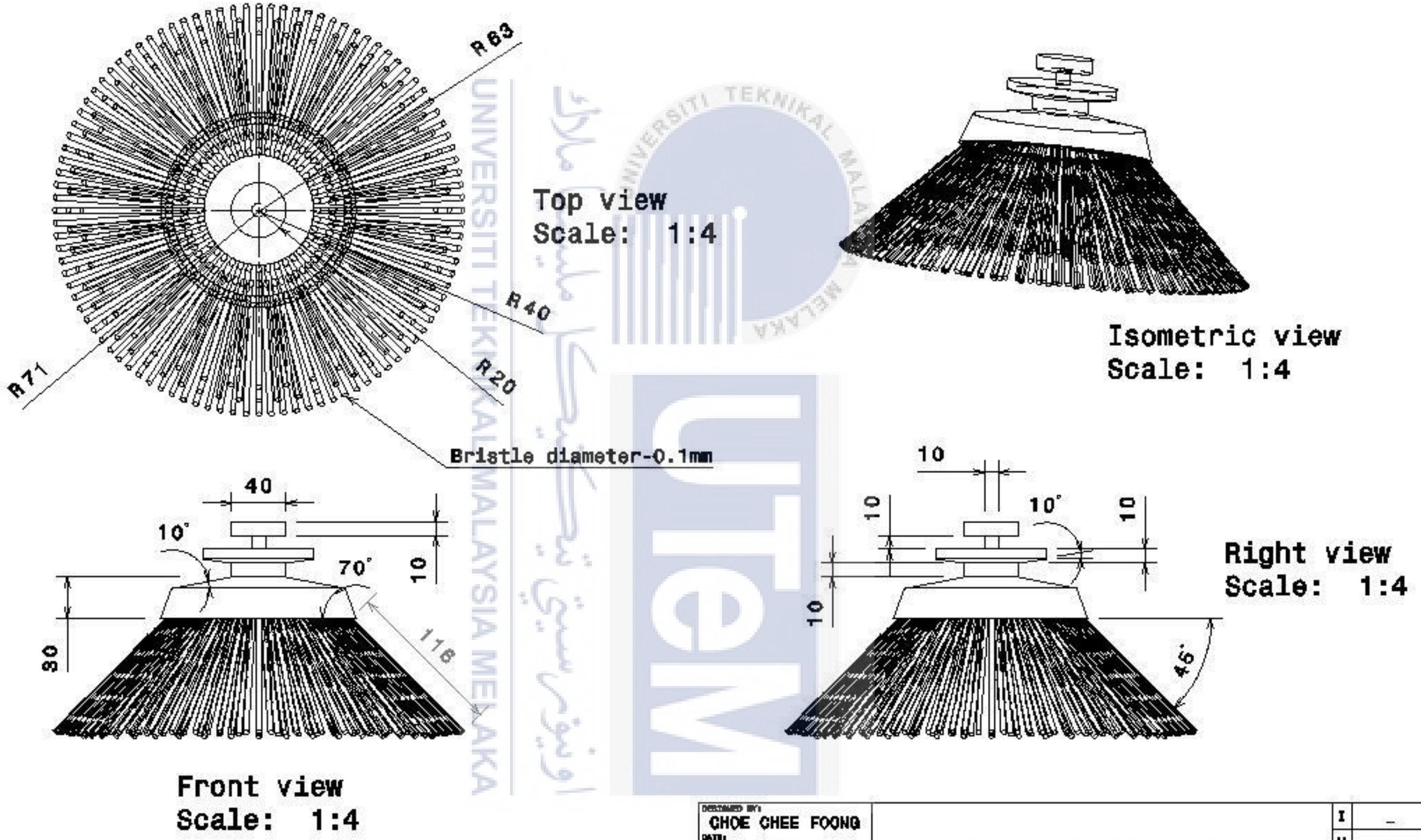
Table A2: Gantt chart for PSM II

Activity	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Design Improvement	■	■													
Overall Design Drafting		■	■												
Part Detail Drawing			■	■	■										
Sub-Assembly Drawing					■	■	■								
Final Assembly Drawing							■	■	■						
Bill of Material										■					
Final Design Analysis										■	■	■			
FEA Analysis												■	■		
Report Writing			■	■	■	■	■	■	■	■	■	■	■	■	
Presentation															■
Report Submission															■

APPENDIX B


Isometric view
Scale: 1:8
Right view
Scale: 1:8
R180.3
180
170
Detail B
Scale: 1:2
Detail A
Scale: 1:3
Top view
Scale: 1:8
Front view
Scale: 1:8
560
180
10
20
Name
Cover
Size
560x180x170
Quantity
1
Material
LDPE
Cover
DASSAULT SYSTEMES
TOP, SIDE, FRONT VIEW
CHOE CHEE FOONG
24/4/2017
DR. MOHD ASRI
26/4/2017
A4
1:8
XXX
1/1


Frame of Cleaning Device
DASSAULT SYSTEMES
TOP, SIDE, FRONT VIEW
CHOE CHEE FOONG
24/4/2017
DR. MOHD ASRI
26/4/2017
A4
1:10
XXX
1/1
Isometric view Scale: 1:10
Right view Scale: 1:10
Top view Scale: 1:10
Detail A Scale: 1:5
Front view Scale: 1:10
Square bar-560x10x10
R5-Hole
Name | Size | Quantity | Material
Frame of cleaning device | 1000x580x235 | 1 | Aluminium



Name	Size	Qauntity	Material
Pulley	Φ142x70	2	MC901Nylon
Bristle	Φ300x86	2	Proex

DESIGNED BY: CHOE CHEE FOONG
DATE: 24/4/2017
CHECKED BY: DR. MOHD ASRI
DATE: 26/4/2017
SIZE: A4
SCALE: 1:4
WEIGHT (kg): XXX

Front Brush

DASSAULT SYSTEMES

DRAWING TITLE: TOP, SIDE, FRONT VIEW

SHEET: 1/1

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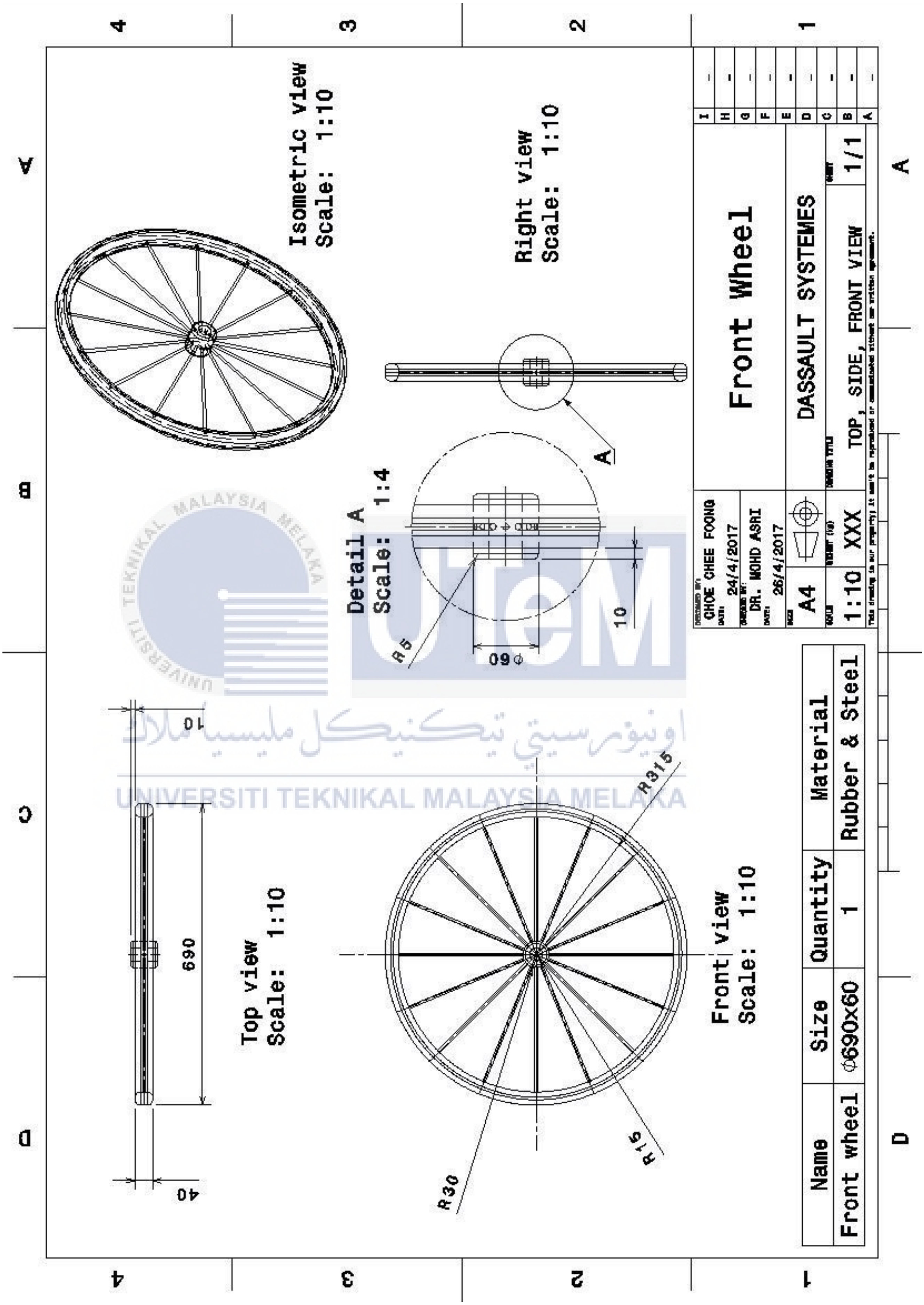
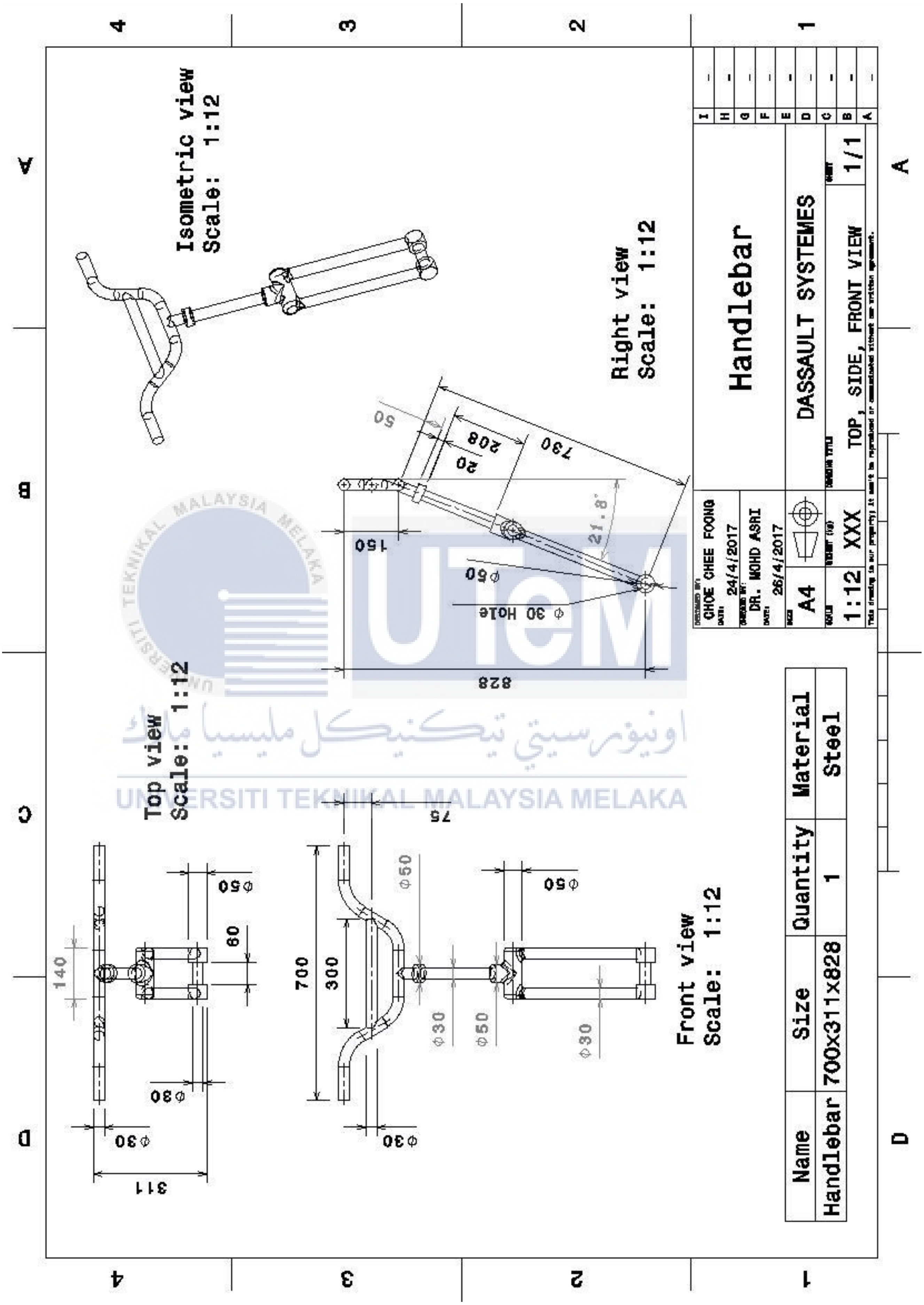
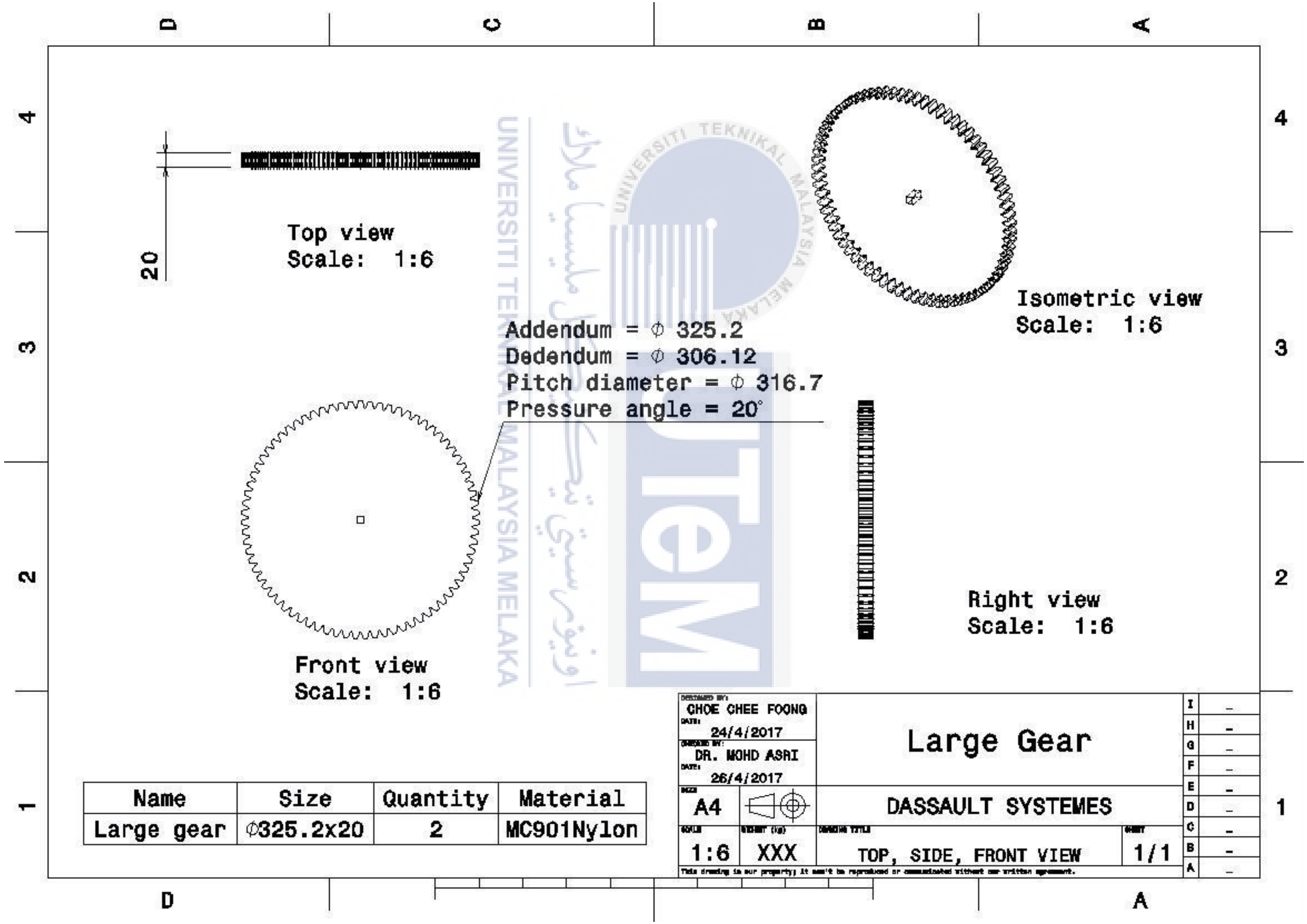
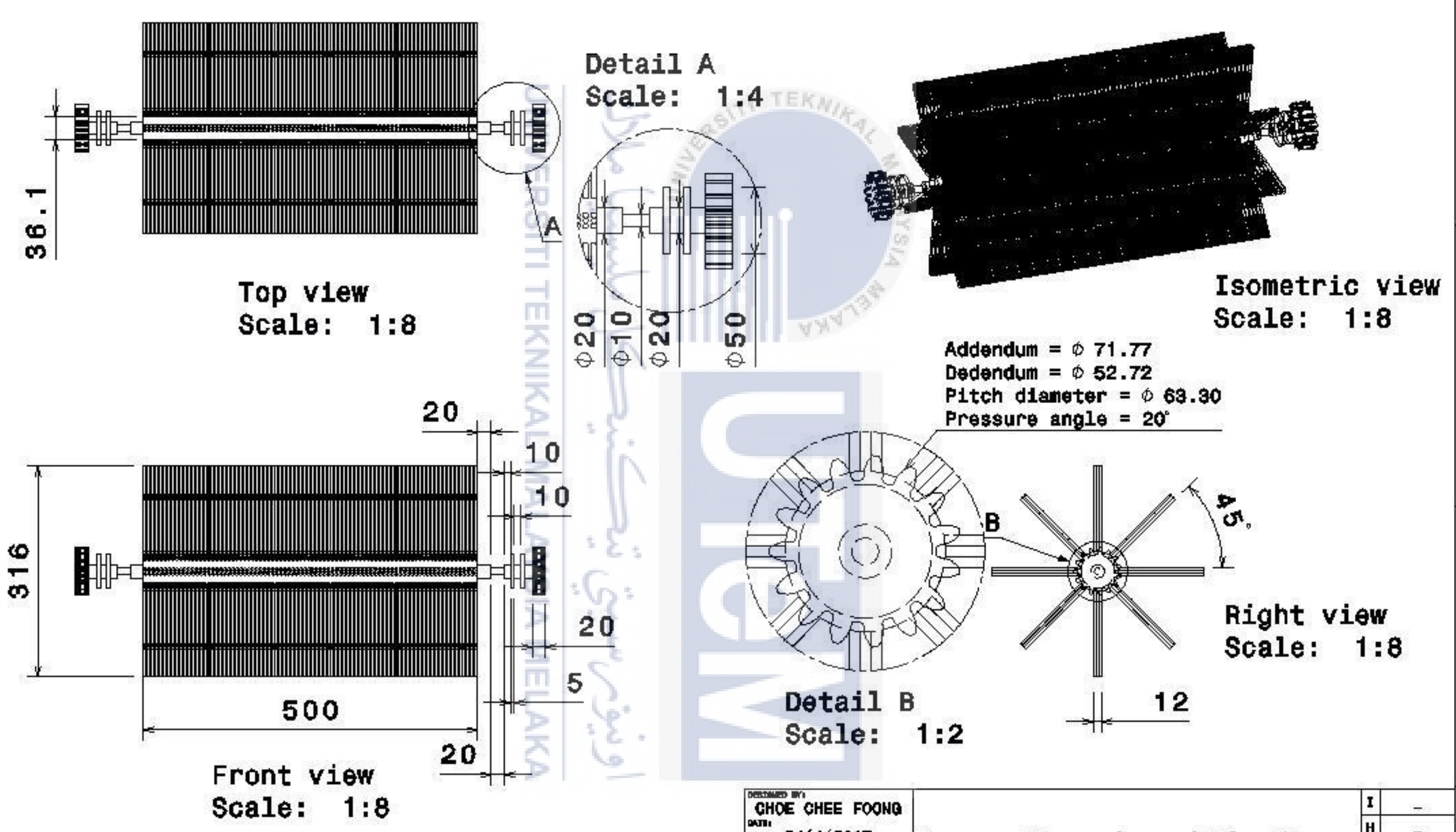

Isometric view
Scale: 1:10
Right view
Scale: 1:10
A
Detail A
Scale: 1:4
R5
ϕ60
10
Top view
Scale: 1:10
10
690
40
R315
R30
R15
Front view
Scale: 1:10
Front Wheel
DASSAULT SYSTEMES
TOP, SIDE, FRONT VIEW
CHOE CHEE FOONG
24/4/2017
DR. MOHD ASRI
26/4/2017
A4
1:10
XXX
1/1
Name
Front wheel
Size
ϕ690x60
Quantity
1
Material
Rubber & Steel



Name	Size	Quantity	Material
Handlebar	700x311x828	1	Steel



Name	Size	Quantity	Material
Large gear	ϕ325.2x20	2	MC901Nylon



Name	Size	Quantity	Material
Bristle	500x140x12	8	Proex
Gear	ϕ71.77x20	2	MC901Nylon

DESIGNED BY: CHOE CHEE FOONG DATE: 24/4/2017 CHECKED BY: DR. MOHD ASRI DATE: 26/4/2017	Rear Brush with Gear		
SIZE: A4		DASSAULT SYSTEMES	
SCALE: 1:8	WEIGHT (kg): XXX	DRAWING TITLE: TOP, SIDE, FRONT VIEW	SHEET: 1/1

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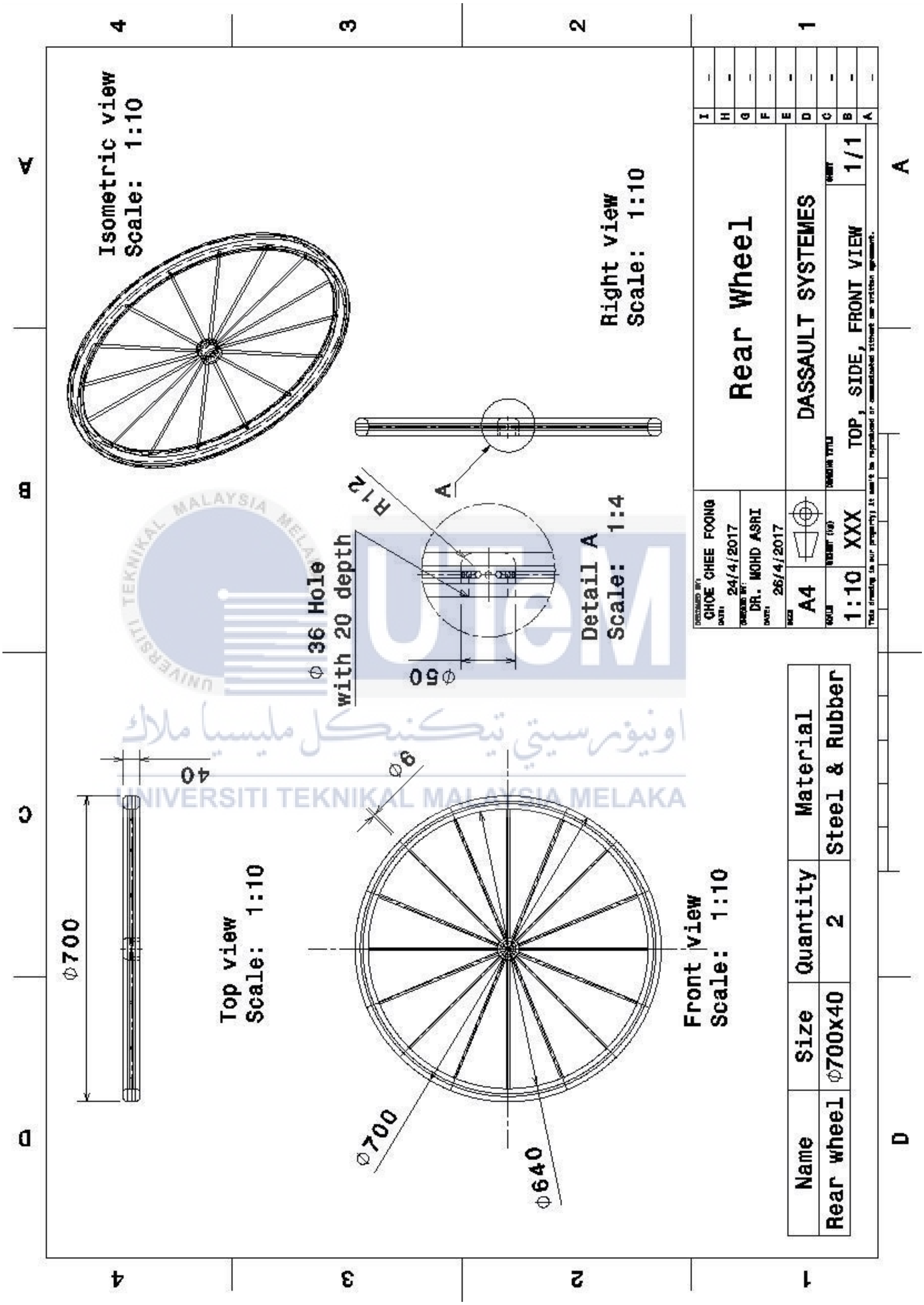
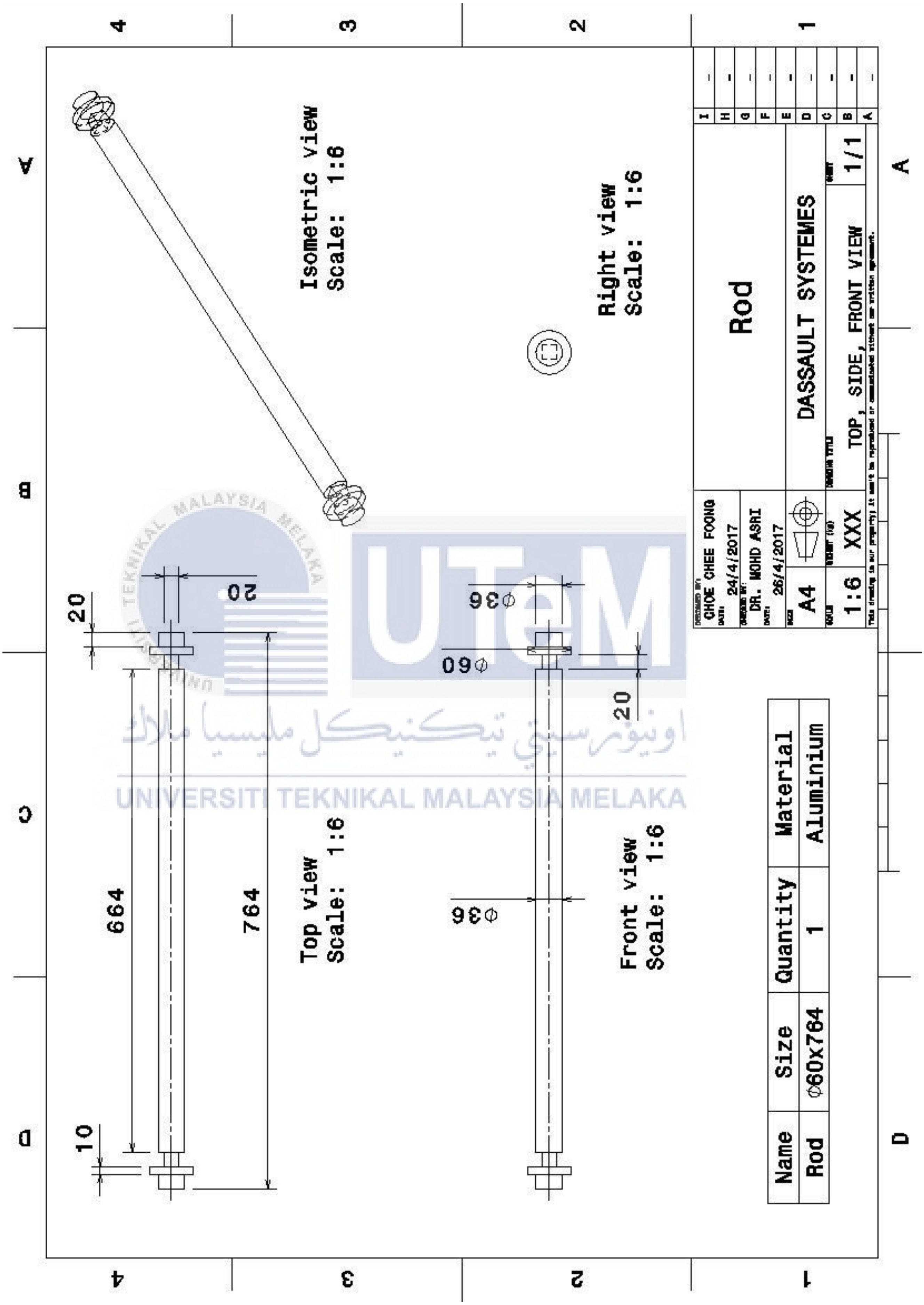
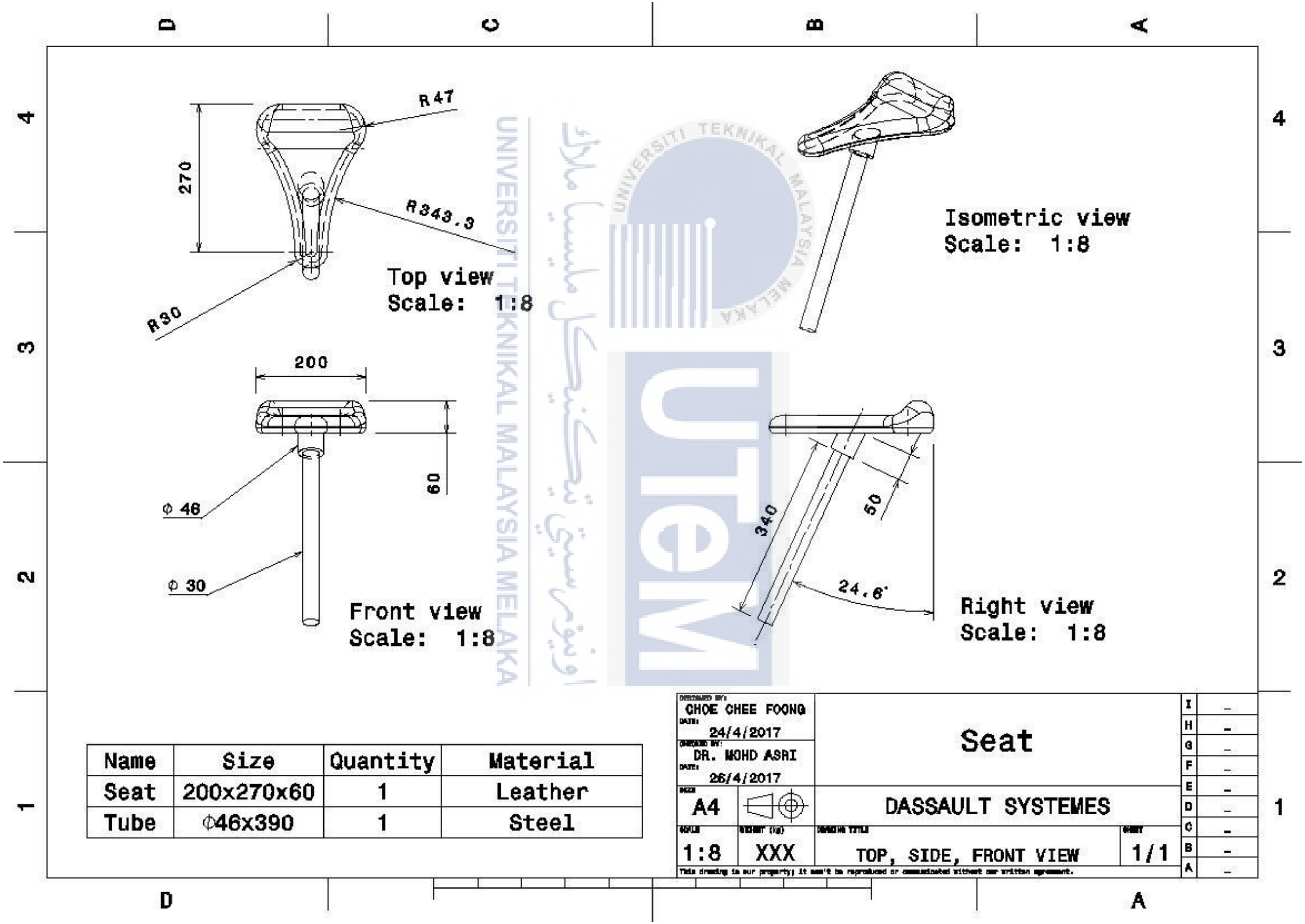
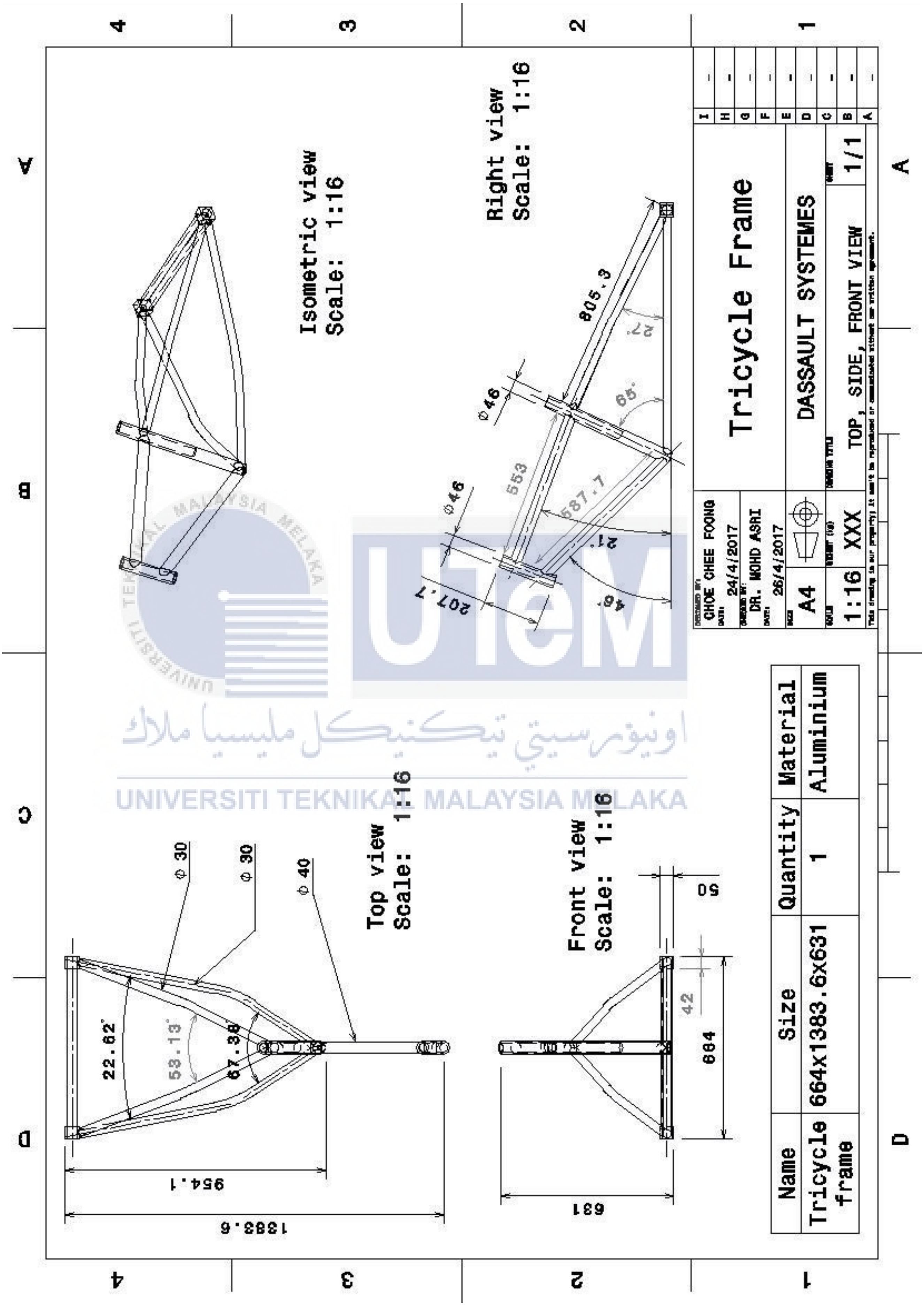
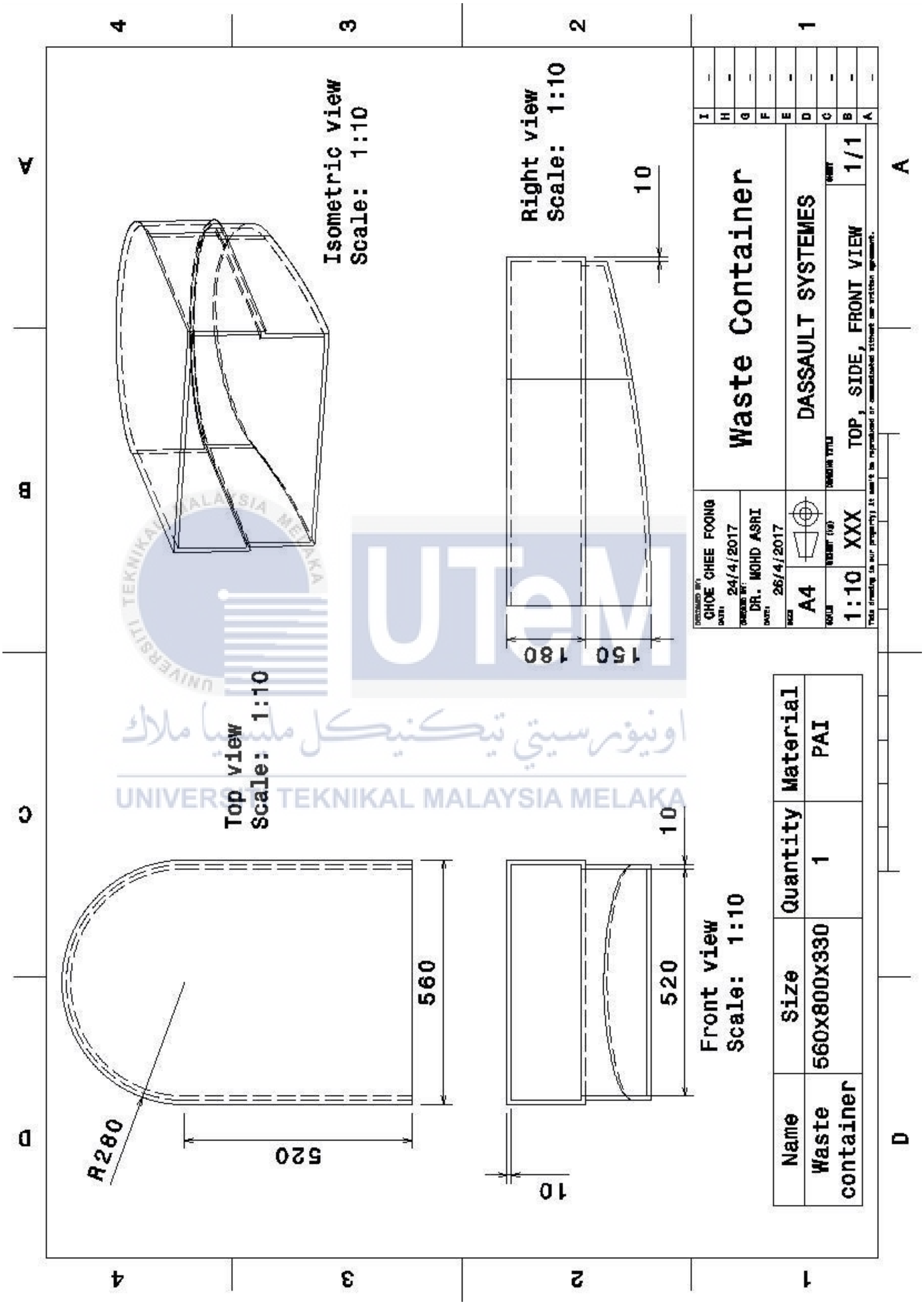

Isometric view
Scale: 1:10
Right view
Scale: 1:10
R12
A
ϕ 36 Hole
with 20 depth
ϕ50
Detail A
Scale: 1:4
40
ϕ8
ϕ700
Top view
Scale: 1:10
Front view
Scale: 1:10
ϕ700
ϕ640
Name
Rear wheel
Size
ϕ700x40
Quantity
2
Material
Steel & Rubber
CHOE CHEE FOONG
24/4/2017
DR. MOHD ASRI
26/4/2017
A4
1:10
XXX
Rear Wheel
DASSAULT SYSTEMES
TOP, SIDE, FRONT VIEW
1/1

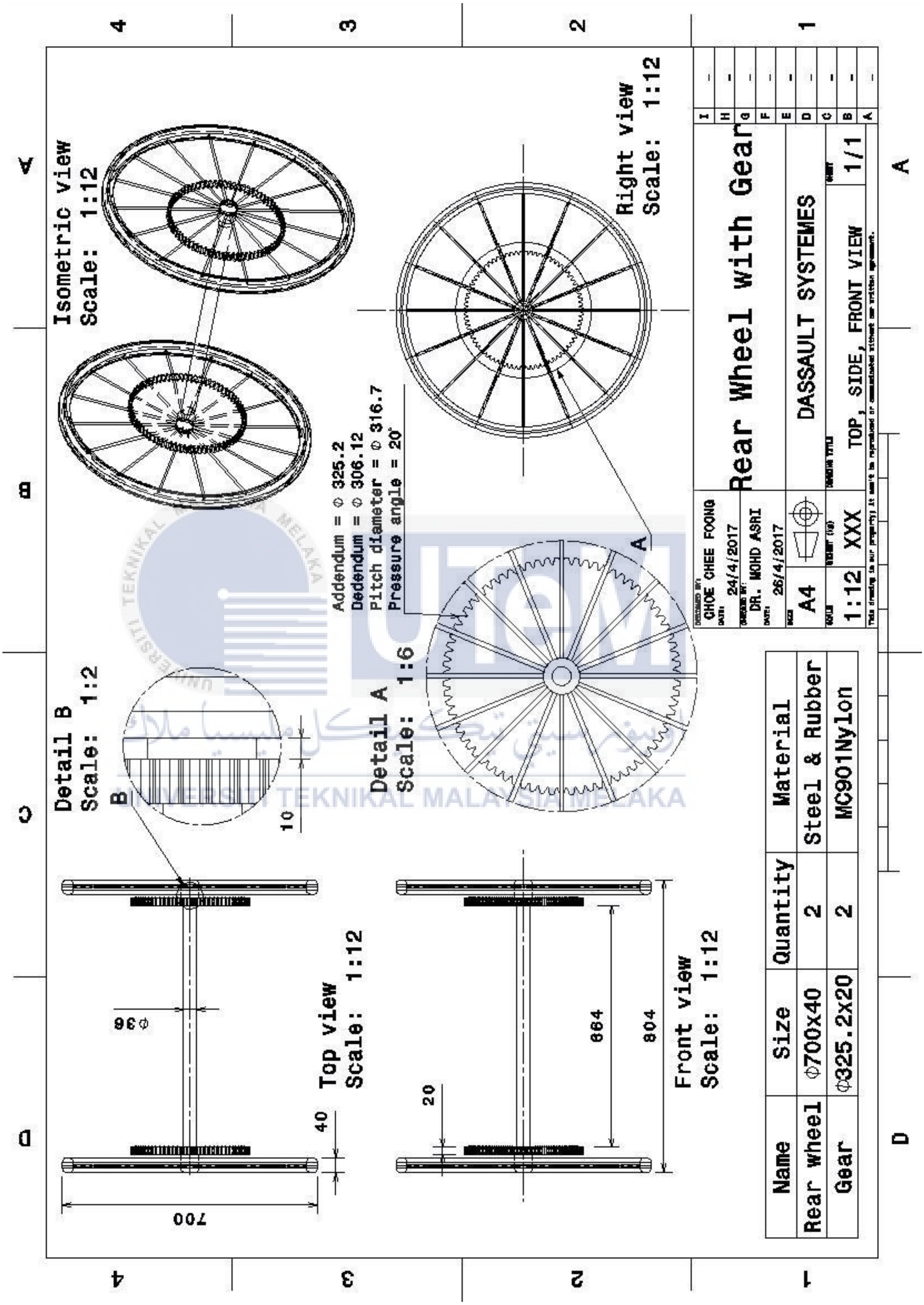

Isometric view
Scale: 1:6
Right view
Scale: 1:6
Top view
Scale: 1:6
Front view
Scale: 1:6
20
20
664
764
10
Φ36
Φ60
Φ36
20
Name | Size | Quantity | Material
Rod | Φ60x764 | 1 | Aluminium
Rod
DASSAULT SYSTEMES
CHOE CHEE FOONG
24/4/2017
DR. MOHD ASRI
26/4/2017
A4
1:6
XXX
TOP, SIDE, FRONT VIEW
1/1



Name	Size	Quantity	Material
Seat	200x270x60	1	Leather
Tube	Φ46x390	1	Steel


Tricycle Frame
DASSAULT SYSTEMES
TOP, SIDE, FRONT VIEW
Isometric view
Scale: 1:16
Right view
Scale: 1:16
Top view
Scale: 1:16
Front view
Scale: 1:16
805.3
27°
65°
Ø46
Ø46
553
587.7
21°
207.7
46°
Ø 30
Ø 30
Ø 40
22.62°
53.13°
67.38°
954.1
1383.6
631
50
42
664
GHOE GHEE FOONG
24/4/2017
DR. MOHD ASRI
26/4/2017
A4
1:16
XXX
1/1
Name
Tricycle frame
Size
664x1383.6x631
Quantity
1
Material
Aluminium


Isometric view
Scale: 1:10
Right view
Scale: 1:10
Top view
Scale: 1:10
Front view
Scale: 1:10
R280
520
560
10
520
10
180
150
10
Name
Waste container
Size
560x800x330
Quantity
1
Material
PAI
Waste Container
DASSAULT SYSTEMES
TOP, SIDE, FRONT VIEW
DESIGNED BY: CHOE CHEE FOONG
DATE: 24/4/2017
CHECKED BY: DR. MOHD ASRI
DATE: 26/4/2017
SIZE A4
SCALE 1:10
WEIGHT (kg) XXX
SHEET 1/1
A
B
C
D
1
2
3
4


Isometric view
Scale: 1:12
Right view
Scale: 1:12
Detail B
Scale: 1:2
Detail A
Scale: 1:6
Addendum = Φ 325.2
Dedendum = Φ 306.12
Pitch diameter = Φ 316.7
Pressure angle = 20°
A
B
10
Top view
Scale: 1:12
Front view
Scale: 1:12
700
Φ36
40
20
664
804
Name | Size | Quantity | Material
Rear wheel | Φ700x40 | 2 | Steel & Rubber
Gear | Φ325.2x20 | 2 | MC901Nylon
Rear Wheel with Gear
CHOE CHEE FOONG
24/4/2017
DR. MOHD ASRI
26/4/2017
A4
1:12
XXX
DASSAULT SYSTEMES
TOP, SIDE, FRONT VIEW
1/1

APPENDIX C

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Questionnaire

I am a final year student of Universiti Teknikal Malaysia Melaka (UTeM) which is assigned to gather information on the design of a tricycle with cleaning mechanism that is to be commercialized in order to fulfill my Final Year Project. Your responses are much appreciated. Thank you.

Product: Human-powered tricycle with cleaning mechanism

Usage: Sweeping and collecting rubbish by cycling the tricycle

Section A – Respondent profile

1. Gender
   - Male
   - Female

2. Age
   - Below 20 years old
   - 20-30 years old
   - Above 30 years old

3. Occupation

Section B

I would like to find out the customer requirements toward the new product of human-powered tricycle with cleaning mechanism. Please select the best answer as a guide for my Final Year Project.

1. Do you think human-powered tricycle with cleaning mechanism is a useful product?
   o Yes
   o No

2. Using a scale of 0=Not important to 5=Very important, please rate the following.

	Not Important 0	1	2	3	4	Very Important 5
Cost	o	o	o	o	o	o
Reliability	o	o	o	o	o	o
Appearance	o	o	o	o	o	o
Tricycle moving speed	o	o	o	o	o	o
Ease of use	o	o	o	o	o	o
Waste storage capacity	o	o	o	o	o	o
Human energy consumption	o	o	o	o	o	o
Maintenance frequency (1 to 6 months once)	o	o	o	o	o	o
Noise pollution	o	o	o	o	o	o

3. State the other expectations for this product. (Example: Small size)

4. Based on your awareness of [Product], do you think this product is better, the same, or worse than the other existing sweeping product in term of:

Environment friendly:

- Much better
- Better
- About the same
- Worse
- Must worse

Efficiency:

- Much better
- Better
- About the same
- Worse
- Must worse

Time saving:

- Much better
- Better
- About the same
- Worse
- Must worse

Overall:

- Much better
- Better
- About the same
- Worse
- Must worse