Design and Analysis of a Multi-Purpose Small Personal Transport System with In-Wheel Drive System

by

Wan Ahmad Ridhwan b Wan Khairul Anuar

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

MAY 2011

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Design and Analysis of a Multi-Purpose Small Personal Transport System with In-Wheel Drive System

By

Wan Ahmad Ridhwan b Wan Khairul Anuar

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

(Mr Mohd Faizairi)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2011

CERTIFICATION OF ORIGINALITY

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

WAN AHMAD RIDHWAN B WAN KHAIRUL ANUAR

ABSTRACT

Multi-purpose small personal transport system is a simple design chassis which allow a personal to ride the vehicle while standing and use steering mechanism to steer the vehicle. The transport system includes a chassis having a front wheel as drive system and a pair of rear wheels attached to the chassis supporting the load and balancing the vehicle. The drive system include an in wheel motor system powered by battery and controlled by throttle that supporting by control system. The frame configuration that used for the design chassis is ladder frame chassis. Then the design and analysis of the chassis will be based on some criteria like load, bending and twisting of the frame. Rectangular mild steel tubing with 1" height and 2" wide was used for the platform of the chassis. Engineering software was used to assist in analyzing the chassis before proceed to the fabrication process.

ACKNOWLEDGEMENTS

First and foremost I would like to express my utmost gratitude to my supervisor Mr Mohd Faizairi Mohd Nor for his attention and guidance throughout my Final Year Project. He had provided me with vital recommendations and ideas that were crucial towards the completion of this project.

I would also like to thank the Examiners from the Mechanical Engineering department especially to Dr. T. Nagarajan, Dr. Hasan Fawad and Dr. Fakhruldin Mohd Hashim for taking their time off to evaluate my project and my presentation throughout the whole progress of Final Year Project. They have contributed to the completion of this project through their constructive comments and opinions during these sessions.

Special thanks to Mr. Mohd Syaifuddin as my co-supervisor for his support and ideas throughout this project.

Last but not least, I would like to express my greatest appreciation for my family for their continuous support, motivation and encouragement.

Thank You.

WAN AHMAD RIDHWAN B WAN KHAIRUL ANUAR
Universiti Teknologi PETRONAS
MAY 2011

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, many transportation companies have design electric or hybrid vehicles as alternative motorized transport to obtain zero emission. People gain awareness about the environment and come up with a solution that can potentially solve the pollution by developing a transport system with green concept. There are many types of green concept transport or called sustainable transport that use alternative power such as solar and electric. So, designing and develop a small multi-purpose transport system with-in wheel drive system is in line with the current technology and situation.

Chassis is the most important part of a small personal transport system, which hold all the components together and must be able to withstand all types of load under normal operating conditions. Good handling performance requires adequate chassis stiffness. This mean the vehicle's frame structure must be rigid enough to resist bending and twisting. Vehicle chassis must satisfy these two objectives, where it could hold the total weight of the components and the rider under all perceivable static and dynamic conditions. Chassis must be meet the requirement of the transport system such as available to attach the tyres and appropriate placed for drive system.

1.2 PROBLEM STATEMENT

A multipurpose small personal transport system can achieve greater range, lower operating cost, faster respond time and reduce fatigue on the operators. The transport system can serve multiple roles as petrol vehicle, logistic support, small delivery vehicle and personal vehicle.

1.2.1 Air pollution by fuel gas transportation

Fuel gas transportation has produces harmful chemical and it affect the environment and cause global warming. Using an alternative energy to drive the transportation system like electric, we could reduce the harmful gas that come out form the gas fuel exhaust.

1.2.2 Dependent on non-renewable sources

As we know, the prices for gas and oil have increase year after year because of limitation of the product nowadays. Transportation too depends on the gas and oil to produce combustion system. Using green energy can be the alternative ways to reduce the dependent on the sources.

1.3 OBJECTIVE AND SCOPE OF STUDY

The main objective of this project is to design and to analyze of the multipurpose small personal transport system. This process will be followed with fabrication of chassis, as a prototype for this project.

The scopes of study for this project are divided with three main processes which are design, analysis and fabrication. Firstly, the frame structure and chassis designed based on the requirements needed for a small personal transport system. The design of chassis able to operate by one personal and placed all the necessary components in balance. Engineering software, CATIA V5 was used to model the chassis design to generate an accurate dimension of the vehicle.

Analysis as the second main task will be conducted initially by using analytical design calculations and is followed by design refinement using finite element analysis to examine the design frame structure and chassis to determine whether it could handle all the stresses and loads. In this process, engineering software like CATIA V5 and ANSYS will be utilized to optimize the design. The design process itself is iterative in nature and will go through three design reviews before the design is finalized.

The last task is fabrication process where the chassis were fabricated as designed and using selected materials.

CHAPTER 2

LITERATURE REVIEW

2.1 Chassis and Frame

A chassis consists of an internal framework that supports various mechanical compartments like engine, steering, tires, braking system etc. The chassis is the most important element in any transport system where it gives strength and stability to the vehicle under different conditions. Any types of loads will receive by transport system and chassis as the backbone for the transport to withstand the loads. The chassis also keeps the transport rigid, stiff and unbending. There are different types of transports chassis and the following are:

Ladder Chassis: This kind of chassis is the earliest form of chassis. Almost all cars using this type of chassis back in 60s and it still employ by SUVs till today. The ladder chassis look like a ladder where two longitudinal rails interconnected by several lateral and cross braces. The longitude members deal with the longitudinal load caused by acceleration and breaking while lateral and cross braces provide resistance to lateral forces and increase torsional rigidity.

Tubular Space Frame: tubular space frame employs dozens of circular-section tubes where it connected to each other in different angle to provide strength on the chassis against all types of load that counter to the frame. Basically, tubular space frame used by sport car as it could enhance the rigidity over weight ratio. However, the construction of this kind of chassis is very complex and costly.

Monocoque frame: monocoque frame is an incorporated single piece structure which prescribes the overall shape of a vehicle. The basis of this frame is floorpan and welded together with other pieces of metal to create a single piece of body frame. Since the frame give more spaces for compartments and people to fill in, most of the vehicles produced by the steel monocuque chassis. It also has low cost production in high scale production and suitable for robotized production.

Backbone Chassis: backbone chassis is a simple rectangular tube which designed like a backbone where it used for jointing front and rear axle together. Usually, glass fibre used as the body on the backbone. The chassis is very strong for smaller sports cars and provide more space but does not provide protection against the side impact. Because of the design is simple and easy to produce, it has low production cost and being able to produce in low mass production [8].

2.2 Segway-P

In Segway PT, two different DC motors use to drive the transporter. Both motors are connected to two distinguish gearboxes before it is connected to tires. In figure 1, the picture shows the location where the motor is placed inside the Segway-PT.

Figure 2.1: Drive motor is placed at the side of Segway-PT main body

2.3 Honda U3-X personal transport device

Honda U3-X is said to be the newest revolutionary personal transport device. Weighing just less than 10kg, roughly one meter tall, 30cm long and 15cm wide – this self-righting unicycle is so small that it can fit into the car door of Honda's new concept electric car the EV-N.

Figure 2.2: Honda U3-X transporter and also how it fit into EV-N door

The U3-X boasts about an hour of battery life and it has top speed of just under 10kmp/h. The key concepts behind the design are simply to make a personal transport device that is easily stored, non-obtrusive if taken on larger public transportation like trains or buses, easy to operate and fun. Table below shows key specification of the model.

Table 1: Key specification of the U3-X personal transporter

Length × Width × Height(mm)	315 × 160 × 650
Weight	less than 10kg
Battery Type	Lithium ion battery
Operation time (with fully charged battery)	1 hour

Honda developed the world's first wheel structure which enables movement in all directions including forward, backward, side-to-side and diagonally. Multiple small-diameter motor-controlled wheels were connected in-line to form one large-diameter wheel. By moving the large-diameter wheel, the device moves forward and backward, and by moving small-diameter wheels, the device moves side-to-side. By combining these movements the device moves diagonally.

Winglet Personal Transporter

The Winglet, Toyota's personal transporter in the style of Segway, will start initial production next year, 2009. Aiming for corporate customers, Toyota will deliver the first batch of 10 Winglets to the Central Japan International Airport in Aichi Prefecture.

Figure 2.3: Winglet PT by Toyota

The two machines (Segway PT and Winglet PT) look similar and employ similar technologies- self-balancing technology. One noticeable difference is the size: the 10kg Winglet is just one-third the weight of the Segway PT, which looks more robust. The Winglet's top speed is 6km/h compared to 12.5km/h for the Segway PT. With Toyota's focus on portability, the small size and light weight is a step in the right direction. However, expect to see more rugged versions of the Winglet in the future. The Winglet range consists of the L, M and S versions, the latter two of which don't have handlebars and instead are gripped by the calves. L version has maximum range of 5 km/single charge while M and S versions can go to 10 km/single charge.

2.4 Yikebike

The 'yikebike' by inventor Grant Ryan and engineer Peter Higgins of New Zealand, is a mini-farthing bike designed to battle the increasing urban congestion of today. It uses carbon fiber frame and weighs less than 10kg. Yikebike's electronic can travel at speeds up to 20 km/h and having range of 10 km.

Figure 2.4: Folded and non-folded Yikebike

The transporter cost around 5,500 USD. It uses Electric brushless DC motor which generates 1 kW of power.

Built from carbon fiber and weighing in at 22 pounds, the Yike Bike is powered by a custom 1kW motor, a better power to weight ratio than many sports cars, and can be fully recharged in under 30 minutes. Weight limit for the usage is about 100 kg. In terms of form factor, the Yike Bike operates using an electric chainless drive on its front 20′ hubless wheel.

CHAPTER 3

METHODOLOGY

3.1 OVERVIEW

Development of the project will be based on three main processes which will be visited sequentially, and then revisited as required to suit the changes and requirements of the project. Each revisit will be done according to the needs of the project. Once satisfying all the conditions, the development is halted. This methodology is chosen as a means to adapt to changes found during the development of the project, such as a new requirement or a time constraint.

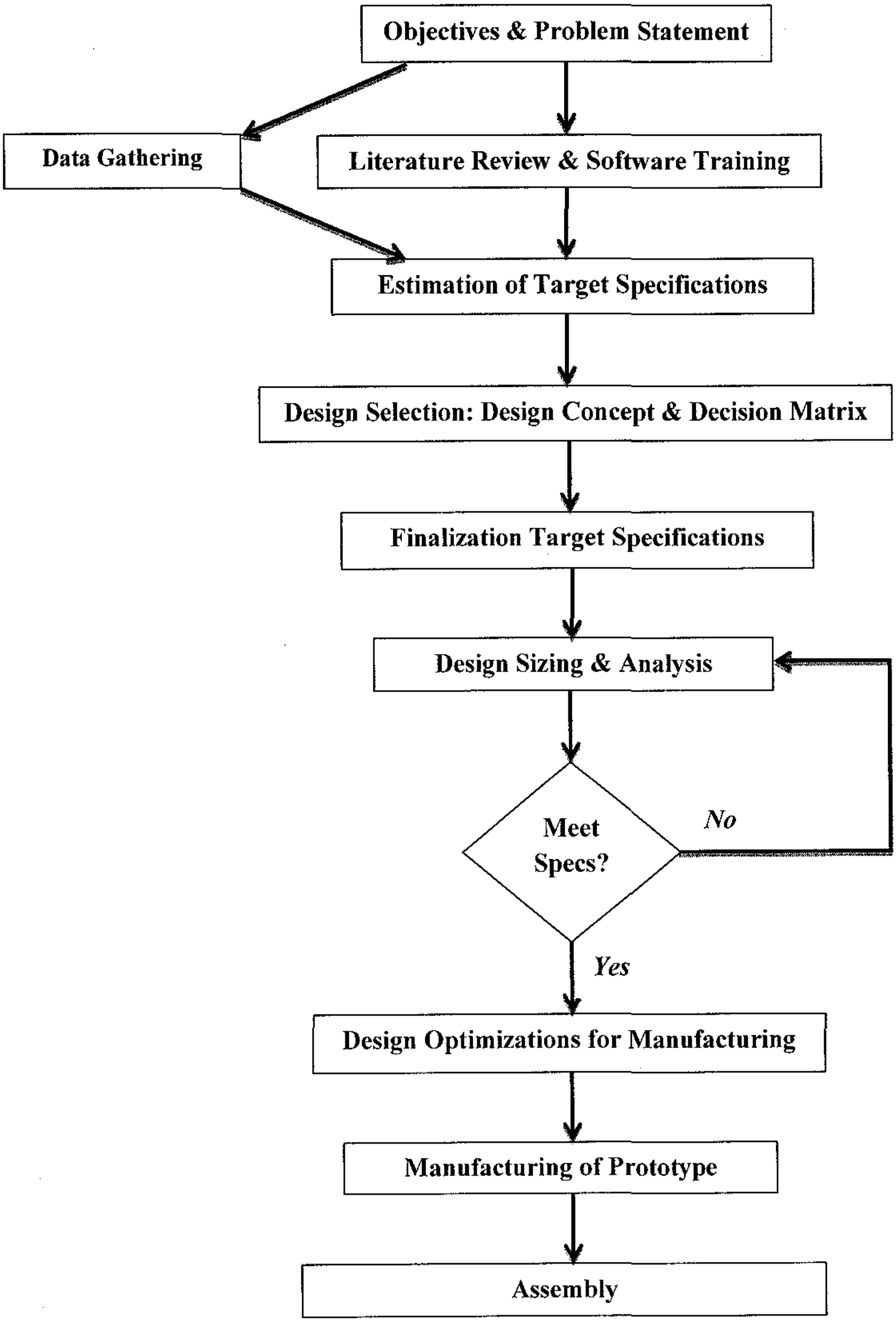


Figure 3.1: Flowchart of the design process

3.1.1 Objective and Problem Statement

Problem statement regarding to the project is discussed with supervisor through the data gathering. Objective is discussed with supervisor to get better vision and filtered to focus on the main subject of doing the project.

3.1.2 Literature Review and Software Training

Information that related to the project which finding through relevant data from the books, journals, texts and internet is gathered. Engineering software which CATIA V5 is used to assist in this project. Some tutorials have been done to familiar with the software.

3.1.3 Estimation of Target Specifications

Some design specifications of personal transport system are discussed with the supervisor.

3.1.4 Design Selection: Design Concept and Decision Matrix

Several raft designs of personal transport system are made based on the target specification and data gathered.

3.1.5 Finalization Target Specification

Together with the design concept and target specification of the personal transport system, the finalization of the design is made. Design concept with the highest marks in the decision matrix is selected.

3.1.6 Design Sizing and Analysis

The design of the chassis is based on the finalization of the target specification and the selected design concept. Sizing of the chassis is related with the analysis of the chassis using CATIA V5. Accurate graphic visualization of the chassis can be display using this software and it also can proceed with the analysis of the chassis.

Static load

Static load is calculated when the vehicle in stationary position and not force against the vehicle. Only the load from the driver and compartments is calculated. Design of the chassis must be aware of these loads to withstand from deflection and deformation.

Stresses Criteria

Designing the chassis need to consider the stresses applied on the chassis.

Tension Member

This type of stress is defined as member having two pulling forces applied at either end. When the load within the member coincides with the longitudinal centripetal axis of the member, the dress distributed through the member can be assumed to be uniform and defined by

$$\text{Stress, } \sigma = {}^{F}/_{A}$$

Where, F = Force or load applied

A = Cross sectional area

Failure of the chassis will happened if the tensions members are exceed yield strength of the material where there frame experienced plastic deformation. To avoid this failure, the design of chassis must acknowledge the yield strength of the material and include the safety factor.

Deflection

Deflection is being taken into consideration during designing the chassis. Deflection is defined by

$$\text{Deflection, } \delta = \frac{PL}{AE}$$

Where, P = load

L = Length

A = Cross sectional area

E = Modulus of elasticity

Bending

Bending stresses occur when a member is subject to a rotational moment load. It defined by one side of the member is tension and the other sides will compression. The bending stresses is defined by

$$\text{Bending stress, } \sigma = \frac{My}{I}$$

Where, M = moment

Y = distance from the neutral axis

I = moment of inertia of the cross section

3.1.7 Design Optimization for Manufacturing

Some modification is done for a better manufacturing process. With limitation of materials and technical skills, design of the chassis is modified.

3.1.8 Manufacturing of Prototype

Manufacturing of the chassis is based on the final design of the chassis. Steel is used to fabricate the chassis. With constraint of budget and technical skills, high quality material such as aluminium is not been selected.

3.1.9 Assembly and Testing Using Drive System

Chassis and handling are assembled as final product. Testing using real drive system will be as recommendation for this project.

3.2 Gantt Chart

Please refer to the appendix for the proposed project Gantt chart.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 DESIGN REQUIREMENT

Before start designing the chassis, the requirements of a small transport system has been discussed. Below are the requirements for a small transport system that has been discussed.

Vehicle Data:

Target weight = 250 kg (include weight of personal driver)

Estimate C_d = 0.5 (blunt body, not aerodynamic)

Frontal area estimate = 1.1 m^2

Wheel size estimate = 40 cm diameter

Motor Design Envelope (max dimensions allowed*) = diameter 20 cm x 15 cm

**based on measured small scooter wheel*

Target performance (similar vehicles**):

Maximum Speed = 30 km/h

Acceleration = 0-30 km/h in 8 seconds

Climbing ability = 20 percent grade at 10 km/h

Maximum load (weight) = 250 kg

***based on T3 Motion ESV and Segway*

Based on the data and requirements of a small transport system, some analysis had done to achieve the performance. All the results would be as references in the manufacturing and modification stages.

4.2 DESIGN SELECTION

Before design the chassis, any consideration of the concept of transport system must be analyze. To outcome the best design concept of chassis, four criterions had narrowed down for the personal transport systems which are;

- **a)** Either two motor been used or only one motor been used.
- **b)** Either the new transporter is two wheels or three wheels
- **c)** either the transporter is rear wheel drive (RWD) or Front wheel Drive (FWD) – for three wheel only
- **d)** Either two tyres in front or one at the back or vice versa – for three wheel only

Each criteria need to be evaluated in order to decide the best option for a small transport system. To come with the best design concept, the writer uses Weighted Decision Matrix. Weighted decision matrix is a method of evaluating completing concepts by ranking the design criteria with weighting factors and scoring the degree to which each design concept meets the criterion. To determine the score, a 5-point scale is used as the criteria for evaluation is not very detailed. Higher points will be given to the parts that meet the criteria the most.

The weight factor value is obtained by multiplying the weight of each values and the weight of parts itself. Figure below shows the hierarchical objective tree

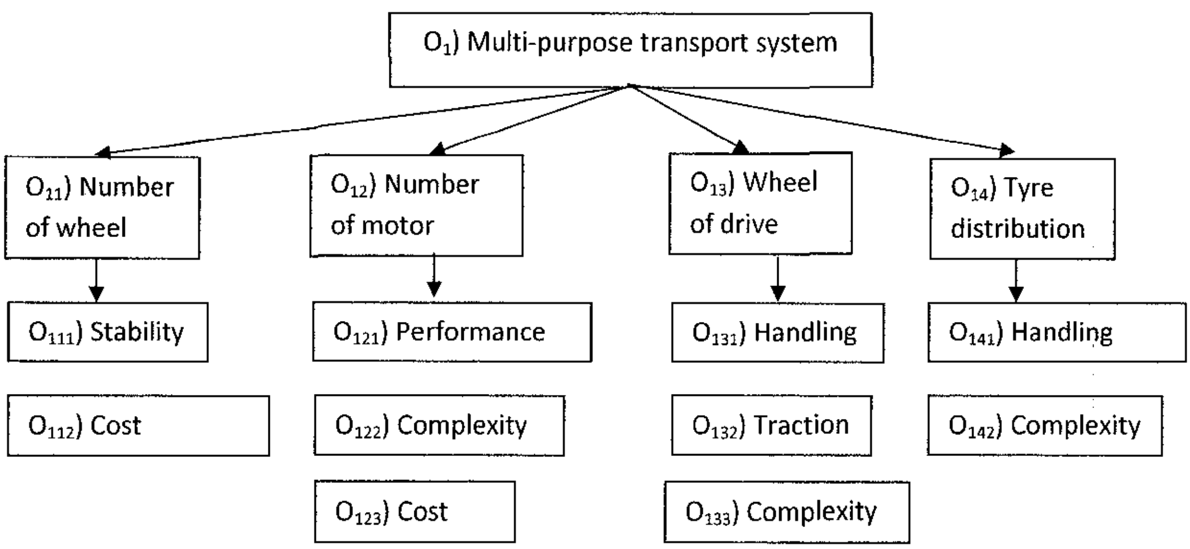


Figure 4.1: Criteria for a Personal transport system

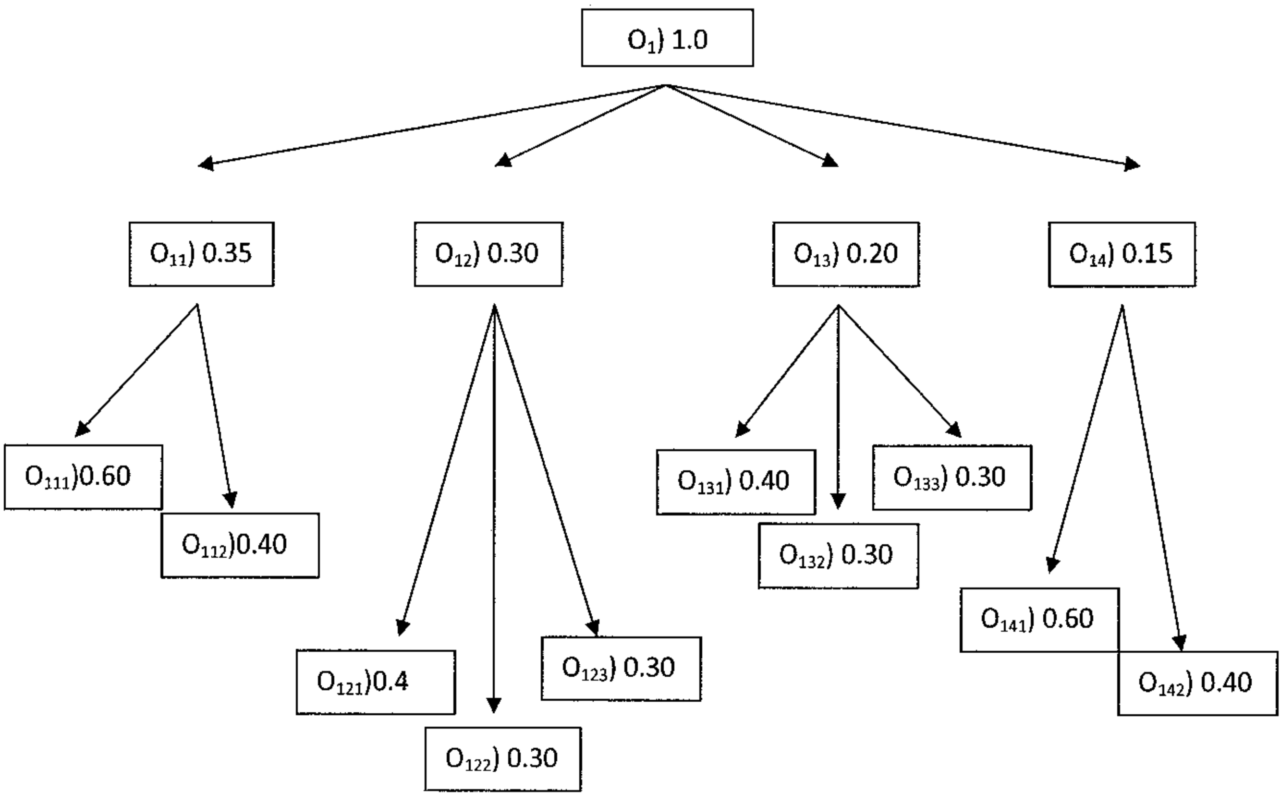


Figure: 4.2: Weight factor for personal transport system

4.2.1 Number of wheels (two or three)

As the diagram above, stability, complexity, and cost weighted as 0.4, 0.3, and 0.3 respectively. Stability weighted the most due to safety reason where high stability could prevent the rider from falling. Beside, complexity and cost score weighted the lowest as it is not a critical issue as compared to stability.

•High stability

Three wheels transport system has higher stability compared to 2 wheels vehicle. With number of wheels used is three, the transport system will be balance as the tire align in triangle shape. While by using two wheels only, the transport system cannot stand by it alone and the rider must has the ability to control the transport system while driving.

•Low cost

Three wheels transport system will need extra cost than two wheels as bigger chassis design is needed and more compartments need to apply to the system.

Consideration	Weight	Weight Factor	3 wheels		2 wheels	
			Score	Rating	Score	Rating
High stability	0.60	0.21	7	1.47	3	0.63
Low cost	0.40	0.14	5	0.7	7	0.98
Total	**1**	**0.35**		**2.17**		**1.61**

Table 4.1: Score and rating of number of wheels

From the analysis above, three wheels transport system score more than two wheels transport system. So, three wheels are better than two wheels in terms of number of wheels used. So, the chassis will be design base on three wheel transport system.

4.2.2 Number or motor used (one or two)

Based on figure 7, performance, complexity and cost weighted 0.40, 0.30 and 0.30 respectively. Performance weighted the most as it is the main evaluation of a transport system. Complexity has same weighted number with cost as complexity of the transport system will proportional with the cost to manufacturing the system. More cost will need when more complexity the system is.

•Better performance

Using two motors will give more torque to the wheels and the performance of the transport system will be higher than using only one motor. To evaluate the performance of the motor, same motor specification will be compared. With two motors has twist power generated than one motor, the speed of transport system will increase and better it will give better performance.

•Low complexity

Design a transport system with two motor will be more complex than design the system with single motor. Two motor will need extra transition to the wheels. With using single motor, there is many ways to transfer the rotation energy to the tire while using two motors, the transition must be align and parallel to obtain stability of the transport system. So, the driver systems with two motors will more complexity than single motor.

•Low cost

Two motors will need bigger chassis design to locate the motors and more compartments needed to complete the driver system to the transport system. So, the cost to build a transport system with two motors will be costly.

Consideration	Weight	Weight Factor	Single motor		Two motor	
			Score	Rating	Score	Rating
Better performance	0.40	0.12	3	0.36	6	0.72
Low complexity	0.30	0.09	7	0.63	5	0.45
Low cost	0.30	0.09	8	0.72	4	0.36
Total	**1**	**0.30**		**1.71**		**1.53**

Table 4.2: Score and rating of number of motor used

As the result above, single motor score more than two motor. Although two motor give high performances, with complexity and cost also considered in designing the transport system, using single motor is more suitable.

4.2.3 Wheel of drive (FWD or RWD)

As the project is to design a small transport system, it does not need all wheels drive. With front wheel drive or rear wheel drive is considered sufficient. To evaluate whether front or rear wheel drive is more suitable for the transport system, handling, traction and complexity weighted 0.4, 0.3 and 0.3 respectively. Handling and traction score the highest as it is the most important thing to be considered when choosing the drive system.

•Better handling

Front wheel drive has better handling than a Rear Wheel Drive. The front wheels pull the transport system instead of the rear wheels pushing it. With handling the transport system also at the front wheel, it will give to stability and handle the direction easily compared with the rear wheel drive.

•Better traction

The location of load from the weight of driver and batteries will be the main issues in traction. To obtain better traction, the batteries will locate either front or rear wheel drive. Therefore, the traction for front and rear wheel drive is considered same.

•Low complexity

With steering mechanism is placed at the front of the transport system, complexity will be higher if front wheel drive chosen compared to rear wheel drive. It is because the front wheel will have multiple responsibilities to move the transport system which are as a direction device and driver system agent.

Consideration	Weight	Weight Factor	FWD		RWD	
			Score	Rating	Score	Rating
Better handling	0.40	0.08	8	0.64	4	0.32
Better traction	0.30	0.06	5	0.30	5	0.30
Low complexity	0.30	0.06	5	0.30	7	0.42
Total	**1**	**0.2**		**1.24**		**1.04**

Table 4.3: Score and Rating of wheel of drive (FWD or RWD)

Front wheel drive (FWD) scores higher than Rear wheel drive (RWD) and therefore FWD will be used in designing the transport system.

4.2.4 Tyres distribution (One tyres in front or two tyres in front)

As the design is using three tyres for the transporter, it is crucial to decide on the location of the tyres. To decide on this matter, the evaluation looks into handling and also complexity. The weights for both criteria are 0.6 for traction and 0.4 for complexity.

•Better handling

As steering mechanism locate in front of the transport system and single wheels placed at the front also, it will give better handling with it can turn more radius than two wheels placed at the front. If two wheels placed in front of the system as a steering mechanism, it will has limit rotation and low radius to turn out.

•Low complexity

To build steering mechanism with two wheels is more complex than single wheel. With single wheel placed at the front of the transport system, simple steering mechanism can be design as it only has to control single wheel.

Consideration	Weight	Weight Factor	single tyre in front		2 tyre in front	
			Score	Rating	Score	Rating
Better handling	0.6	0.09	7	0.63	5	0.45
Low complexity	0.4	0.06	7	0.42	5	0.30
Total	**1**	**0.15**		**1.05**		**0.75**

Table 4.4: Score and rating of tyres distribution

Base on the evaluation above, single tyre placed in front of the transport system give more score than two tyre placed in front.

After all the criteria had evaluated, the small multi-purpose transport system will be design with three wheels which are single tyre placed at front and two wheels placed at behind. One motor will be used to drive the transport system where it will attach to the single tyre as front wheel drive (FWD).

Design Concept

Several types of chassis configuration are mentioned on chapter 2; literature review. To select the best type of chassis, many variables are taking into consideration to meet the target specification. Ladder chassis type is chosen because it easy to design and very suitable for a 3 wheel vehicle system. The chassis also has less weight because it has low number of members and joint.

Two design configurations of ladder chassis are made. The sketch designs are based on design selection in the decision matrix.

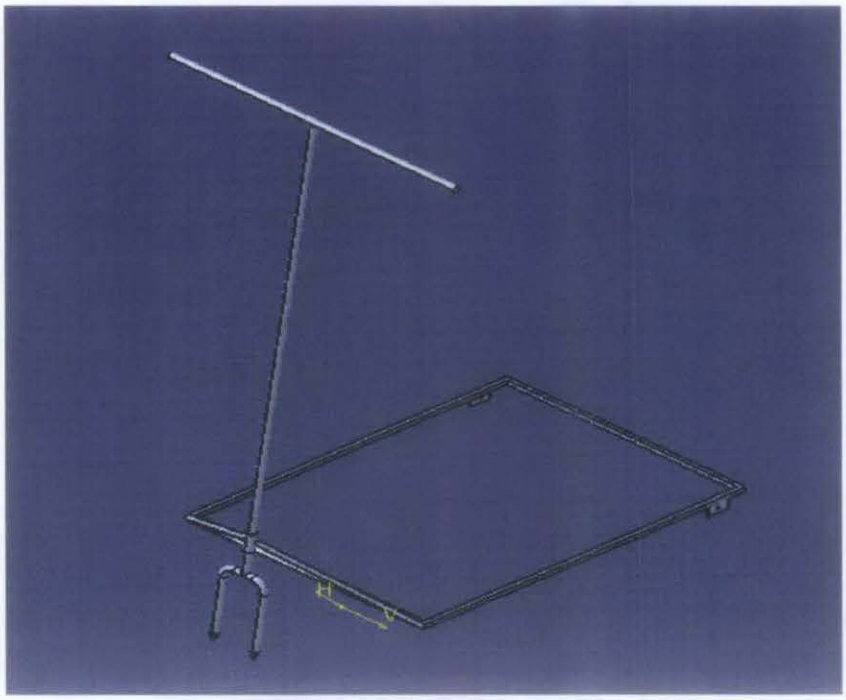


Figure 4.3: Ladder chassis concept design A

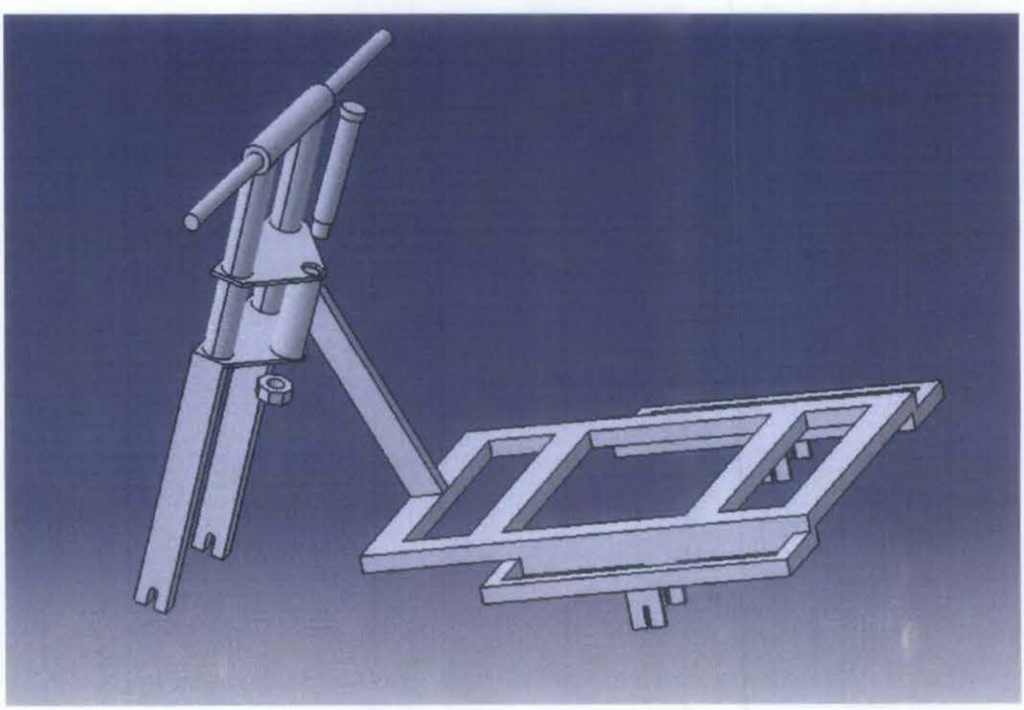


Figure 4.4: Ladder chassis concept design B

4.3 FINALIZATION TARGET SPECIFICATION (DESIGN CONCEPT)

Each frame will be evaluated based on chassis configuration. Ladder chassis concept design B is more reliable because from the configuration of the ladder chassis, it can withstand more loads than Ladder chassis concept A. Besides, the handling system of Ladder chassis concept B is more suitable than the other concept design. Ladder chassis concept design A has more complicated joint between chassis and front fork while Ladder chassis concept design B is simpler and way easier to fabricate. Hence, Ladder chassis concept design B is selected as final chassis design.

4.4 DESIGN SIZING

A design sizing is made base on target specifications. The design sizing took into consideration of compartments and one person driver. If the dimensions is too large and having wide range of unused space, it will be costly. Hence, deflection and stresses on the chassis will be affected.

	Dimension
Length	45" = 1143mm
Width	30" = 762mm
Height	35" = 889mm
Weight	100kg

Table 4.5: Estimated basic dimensions of ladder chassis design

4.5 DESIGN ANALYSIS

4.5.1 Deflection Analysis

The chassis deflection is analyzed using CATIA V5 finite element analysis. The deflection analysis is done using the final design dimensions that made using CATIA V5. Weight from compartments and driver is estimated around 250kg. So, with the loads of 2500N is applied on the chassis from upward. Loads applied is to simulate the real load conditions when the chassis in stationary condition. CATIA V5 finite element analysis is analyzed the deflection of the chassis and the result can be visualized and determined by the software.

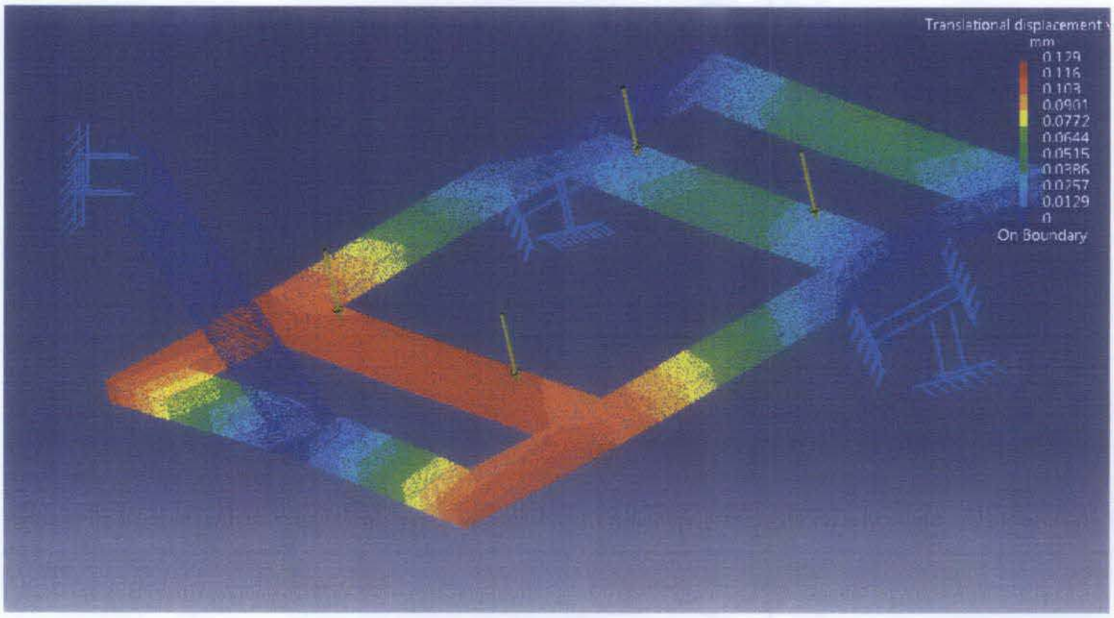


Figure 4.5: Deflection analysis of the chassis

From the analysis, the maximum displacement of the chassis is about 0.129mm. It shows that the deflection is about 0.5% of the thickness of chassis which is 25.4mm.

4.5.2 Stresses Analysis

CATIA V5 also is used to analyze the stresses on the chassis. Von Mises Stress FEA model in CATIA V5 will determine the stresses spots experienced by the chassis. The Von Mises Stress on the chassis is based on the static loads that being applied to the chassis which is 2500N. The spots stresses on the chassis are visualized on the figure below.

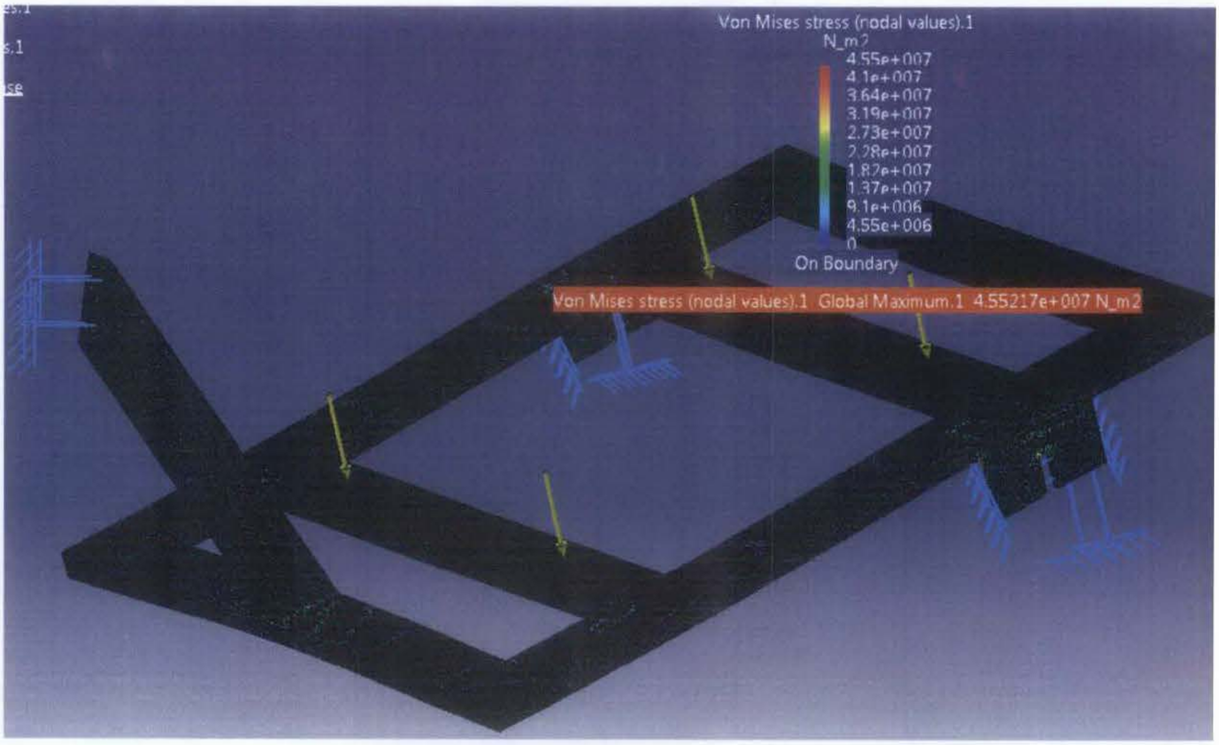


Figure 4.6: Von Mises Stress of chassis

Safety factor is added to the design calculation.

$$\sigma_{vm} < \frac{\sigma_y}{N}$$

Where, N = factor of safety`

σ_{vm} = Von Mises Stress

σ_y = yield strength

From the FEA analysis, the maximum stress is 45.5MPa.with adding the safety factor of 1.5, the maximum stress is equal to 68.25MPa. The yield strength of steel is 248MPa.

From the data comparison above, it shows that the stress experienced by the chassis is below than the steel's yield strength.

So, the chassis is safe from yielding and experienced small deflection in theoretical analysis. The chassis design also meets the target specification and it's ready for a prototype.

4.6 MANUFACTURING OF PROTOTYPE

The material that used for manufacture is mild steel. For the chassis base, 1" X 2" rectangular mild steel tubing is used while for the front fork is several types of circle mild steel tubing with rectangular mild steel.

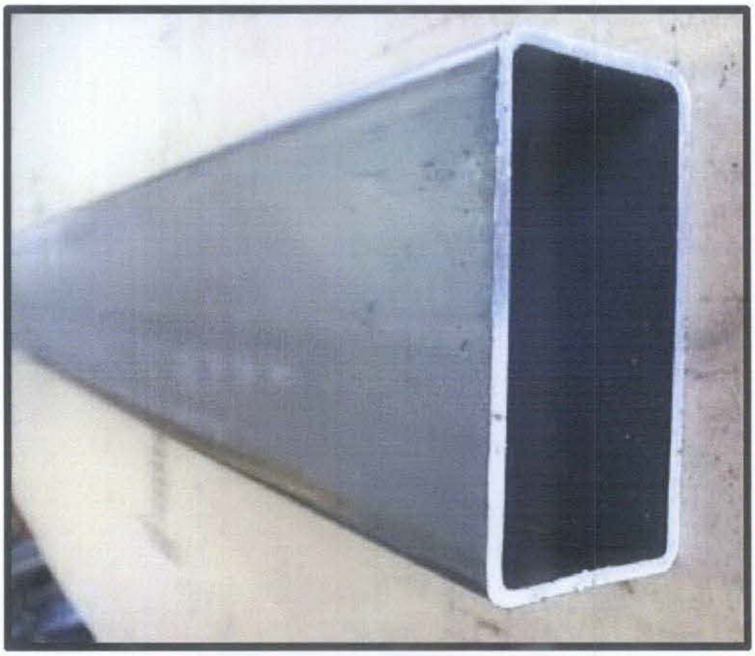


Figure 4.7: 1" X 2" rectangular mild steel tubing

Additional configuration had attached to the chassis base. The design for the rear tires holder is only having one holder each tire. If more loads are applied greater than the estimated loads, the shaft of the rear tire will be bending and the vehicle cannot move in good condition. So, a better configuration is added where the rear tires will have two holders on each tire instead of one holder.

Figure 4.8: Rear tire holder

Table below shows the quantity of the materials for chassis base

Type	Dimension
1" X 2" Rectangular tubing	142" (3606.8mm) long
1" X 1" square tubing	96" (2438.4mm) long
2" Circle tubing	5" (127mm) long
¼" width plate	6" (152.4mm)Width X 5 1/2" (139.7mm) long

Table 4.6: Chassis base: Total materials dimension

Front Fork

Type	Dimension
1" X 2" Rectangular tubing	32" (812.8mm) long
1 3/4" Circle	36 ½" (927.1mm) long
1" circle tubing	19" (482.6mm) long
¼" width plate	9" (228.6mm) width X 6" (152.4mm) long

Table 4.7: Front Fork: Total materials dimension

Bolt and nut are used as jointing mechanism between chassis base and front fork.

Figure 4.9: Bolt and nut

4.7 ASSEMBLY PROCESS

First, the rear tires are installed. The nuts are tightening to secure the tires from slip from the rear tires holder. Second, the front tire is installed at the front fork and the nuts are is tighten. Last process is jointing between chassis base and front fork using bolt and nut.

4.8 FINAL PRODUCT

Figure 4.10: Prototype of Final Design

4.9 CALCULATION

4.9.1 Torque-required Estimation

The drive system should be able to provide sufficient amount of traction force to counter these opposition forces in order to make the transporter move. The force requires is formulated as:

$$F_{Total} = F_{Traction} = D = F_{Air} + F_{Roll} + F_{Slope} + F_{Accel}$$

Where;

Component	Unit	Equation
Air resistance	N	$F_{Air} = ½ \rho v^2 A C_D$ Where: ρ = Air density (kg/m^3) v = Velocity of the transporter (m/s) A= Frontal Area of Transporter + Rider(m^2) C_D = Drag Coefficient
Body surface area	m^2	**BSA = √(h * m / 3600)** Where: h = Rider height (cm) m = Rider mass (kg)
Frontal surface area	m^2	**FSA = A = 2/5 BSA** Where: BSA = Body surface area ($m^{2)}$
Rolling Force	N	$F_{Roll} = C_R N_f$, $C_{rr} = 0.0136 + 0.04 * 10^{-6} * (v * 3.6)^2$ Where: N_f = Normal force C_{rr} = Rolling Coefficient V = Velocity of the transporter (m/s)
Slope Force	N	$F_{Slope} = m\ g\ \sin\theta$ Where: s = Slope inclination measured from surface (°) m = Mass of transporter + Rider (Kg) g = Gravity ($m/s^{2)}$
Acceleration Force	N	$F_{Accel} = m\ a$ Where: m = Mass of transporter + Rider (kg) a = Transporter acceleration (m/s^2)
Angular Velocity	Rad/se c	$\omega = v/r$ Where: v = Velocity of the transporter (m/s) r = Wheel radius (m)
Torque	Nm	□ = F×r Where : F = Force exerted (N) r = wheel radius (m)
Power	W	**P = (2Π ×□ × RPM)/60** Where: □= Torque (N.m)

Table 4.8: Formulas of forces, torque and power

4.9.1.1 Area of air resistance

The frontal area of the transport system is assumed same as T3 Motion ESV which is $1.1m^2$. the air resistance force for the transport system is calculated below;

With Air density: $\rho = 1.225\ kg/m^3$

Velocity, $v = 8.33m/s$

Frontal Area, $A = 1.1\ m^2$

Drag Coefficient, $C_D = 0.5$

Air Resistance Force, $F_{air} = ½(1.225kg/m^3)(8.33m/s)^2(1.1m^2)(0.5)$

$= \mathbf{23.375N}$

4.9.1.2 Roll resistance

The roll resistance occurs when the tyre rolls on a flat surface in linear velocity. Type of tyre effect the equation as tyre contact with the surface to move ahead. For calculation purpose, the transport system will use radial ply tyre. The roll resistance for the transport system is as below;

$$\mathbf{F_{Roll} = C_R\ N_f}$$

As maximum load for the transport system is 250kg.

So, normal force N_f = 250kg x 9.81 N/kg

= 2452.5 N

Where: C_{rr} = 0.02

F_{roll} = 0.02x2452.5N

= **49.305N**

4.9.1.3 Slope force

The slope force is the force required to lift a vehicle uphill is a function of the angle of the hill and the force of gravity. The transport system will be design to be capable of carrying the rider at terrain up to 20° of slope.

Where

Slope, s = 20°

mass, m = 250kg (maximum load)

Garavity, g = 9.81 m/s^2

Slope force, F_{slope} = (250kg) (9.81m/s^2) sin (20°)

= **838.804N**

4.9.1.4 Acceleration force

As transport system want to achieve maximum speed which is 30km/h within 5 seconds, the acceleration of the system become 1.67m/s^2. The maximum acceleration will be at the starting point where the transport system just started to move and it will reach zero acceleration at its top speed at 8.33m/s.

Where

Mass, m = 250kg

Acceleration, a = 1.67m/s^2

Acceleration force, F_{acc} = (250kg)(1.67m/s^2)

= **417.5N**

Total force, F_{total} = 23.375N + 49.054N + 838.804N + 417.5N

= **1328.729N**

4.9.2 Power at Flat Surface

There are two force considered for total power of transport system in flat surface. First is Aerodynamic Power (P_{aero}) and second is Rolling Power (P_{roll}).

Aerodynamic Power (P_{aero})

Aerodynamic power need to be calculated as it will used to find electrical power to supply to the motor.

Aerodynamic Power, $P_{aero} = ½ \rho v^3 A C_D$

Where

Air density: $\rho = 1.225$ kg/m^3

Velocity, v = 8.33m/s

Frontal Area, A= 1.1 m^2

Drag Coefficient, $C_D = 0.5$

$P_{aero} = ½(1.225kg/m^3)(8.33m/s)^3(1.1m^2)(0.5)$

= 194.7 Watt

Rolling Power (P_{roll})

Rolling Power also will calculate to find the total power for the transport system

Rolling Power (P_{roll}) = $m*g*C_{rr}*v$

Where

mass, m = 250kg (maximum load)

Gravity, g = 9.81 m/s^2

$C_{rr} = 0.02$

Velocity, $v = 8.33m/s$

$(P_{roll}) = (250kg)(9.81m/s^2)(0.02)(8.33m/s)$

$= 408.59Watt$

Total Power, $P_{total} = P_{aero} + P_{roll}$

$= 194.7$ Watt + 408.59Watt

= 603.29 Watt

To find the Electrical Power (P_{elect}), the writer assumes that motor efficiency is 60%.

So, $P_{elect} = P_{total}/\text{motor efficiency}$

$= 603.29/(60/100)$

= 1005.48 Watt

4.9.3 Electrical Parts

The major electrical parts for electric drive system of small multi-purpose transport system are motor and batteries. Motor need electric energy to rotate and generate mechanical energy to the transport system. Below are overview of motor and battery that will use to drive the transport system.

4.9.3.1 Brushless DC Motor

The small multi-purpose transport system will use brushless DC motor as the compartment for drive system. Brushless motor powered by direct current (DC) electricity and having electronic communication system, rather than mechanical commutators and brushes. Nowadays, brushless DC motor has been used in electric vehicles and hybrid vehicles widely. There are some advantages of using this type of motor such as long lifespan, low maintenance and high efficiency.

Figure 4.11: Example of brushless DC motor

4.9.3.2 Battery

To supply electric energy to the motor, lead-acid battery is used. As per discussion, the transport system will use three unit of lead-acid battery to supply sufficient electric energy to the motor. Each lead-acid battery has 12V voltage, 40Amp maximum current, and provide 1000W of power.

Battery performance

The maximum battery performance calculates based on the assumption that the transport system operates on flat surface which inclination is 0^{o}.

As calculated above, P_{elect} = 1005.48 Watt. Three unit of battery will be used to supply the electric energy to the motor.

So, the current supply by each battery is calculated below

= $P_{elect}/(12V*3)$

= 1005.48Watt/36V

= **27.93Amps**

Assume that the transport system will drive at average speed of 10km/h and the targeted duration for the transport system to travel is 4 hours. So the energy required is calculated below

Energy required = $P_{total\ at\ 10km/h}$ *time duration

= 143.5Watt*4h

= 574Watt hour

Depth of Discharge Utilized has assume as 0.7

So the actual energy required is,

= 574Watt hour/0.7

= 820 Watt hour

So the Ampere-hour required is

= 820Watt hour /36V

= 22.78 Ampere-hour

= 22.78 Ampere hour/3

= 7.59 Ampere hour

So, for a single battery will required 7.59 Ampere hour

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In conclusion, Ladder chassis concept type was used as the final configuration for a multi-purpose personal transport system with in-wheel drive system. From the stress and deflection analysis of the ladder chassis, it shows that it could withstand all the static loads with the maximum displacement is 0.129mm which is about 0.5% of the chassis thickness while the maximum stress is 45.5MPa which is much lesser than mild steel yield strength, 248MPa. It shows that the chassis can withstands the estimated loads and forces.

5.2 RECOMMENDATION

For the future works process, the prototype of the chassis can be test with the real drive system which is in-wheel drive system. With better analysis and testing, the vehicle could serve multiple roles as personal petrol vehicle or small delivery vehicle. Greater ranges, low operating cost, fast respond time and reduce fatigue on the operators are the keys of the system multiple a multi-purpose personal transport system can be achieved.

REFERANCES

[1] Herb Adams, 1993, Chassis Engineering: Chassis Design Building and Tuning for High Performance Handling

[2] Joseph E. Shigley and Charles R. Mischke, 2001, Mechanical Engineering Design, 6^{th} Edition

[3] Julian Happian-Smith, 2001, An Introduction to Modern Vehicle Design, pp. 125.

[4] Keith J. Wakeham, 2009, Introduction to Chassis Design Rev. 1.0

[5] D. C William, 2007, Material Science And Engineering: An Introduction, John Wiley & Sons, Inc.

[6] Leitman S. and Brant B., 2009, Electric Vehicle, 2^{nd} Edition

[7] George E. Dieter. Linda C. Schmidt, 2009, Engineering Design 4th Edition.

[8] AutoZine Technical School, 1998, Retrieve from, <http://www.autozine.org/technical_school/tech_index.html#Chassis-and-Body>

[9] Geoff D. September 24, 2009. Honda Unveils U3-X Personal Mobility Device. Retrieve from, < http://www.digitaltrends.com/lifestyle/honda-unveils-u3-x-personal-mobility-device/>

[10] Jose F. August 1, 2008. Toyota Announces Segway Killer: The Winglet Personal Transporter. Retrieve from < http://www.wired.com/gadgetlab/2008/08/toyota-announce/>

[11] Brb. 27 Dec, 2008. Toyota's Winglet Is Coming In 2009. Retrieve from <http://www.bouncingredball.com/2008/12/27/toyotas-winglet-is-coming-in-2009/ >

APPENDIX

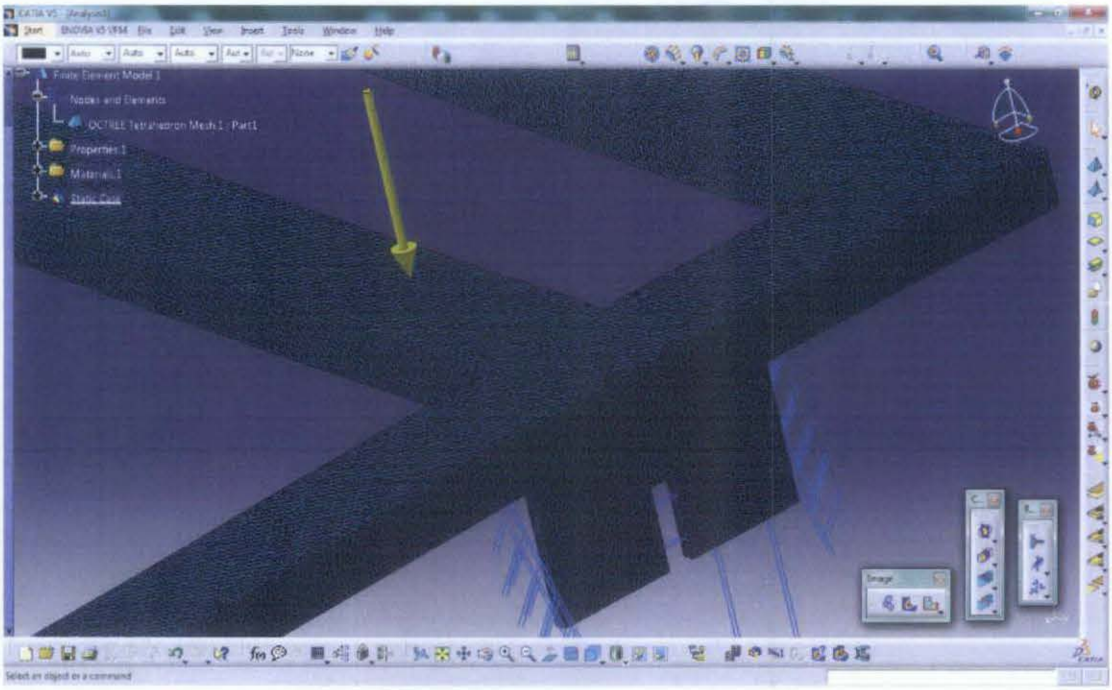
Gantt Chart for FYP I

No.	Activities /Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Data Gathering														
3	Proposal Submission														
4	Preliminary Report Submission														
5	Familiarization with CATIA Software														
6	Design chassis with CATIA														
7	Analysis														
8	Submission of Progress Report														
9	Result Gathering														
10	Submission of Interim Report														
11	Oral Presentation														

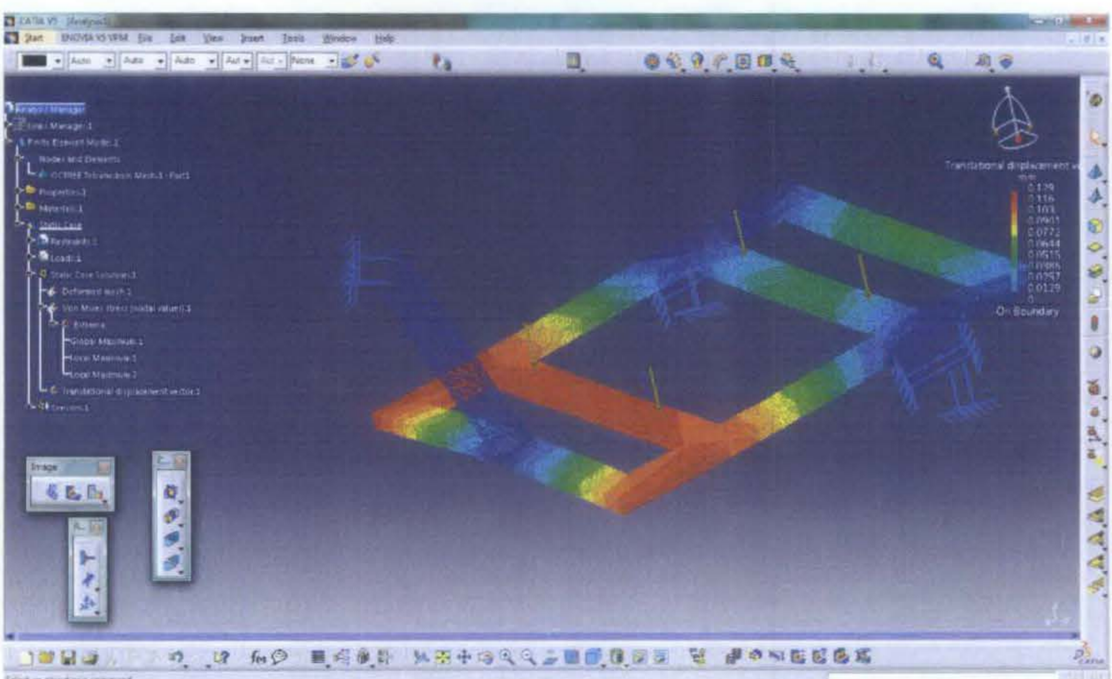
Gantt chart for FYP II

No.	Activities /Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	EW
1	Final Design Review															
2	Submission of Progress Report															
3	Fabrication process															
4	Assembly proces															
5	Pre-Edx Poster															
6	Project testing															
7	Result Compilation & Report															
8	Submission of Project Dissertation Final Draft															
9	Oral Presentation															
10	Submission of Project Dissertation(Hardbound)															

Analysis

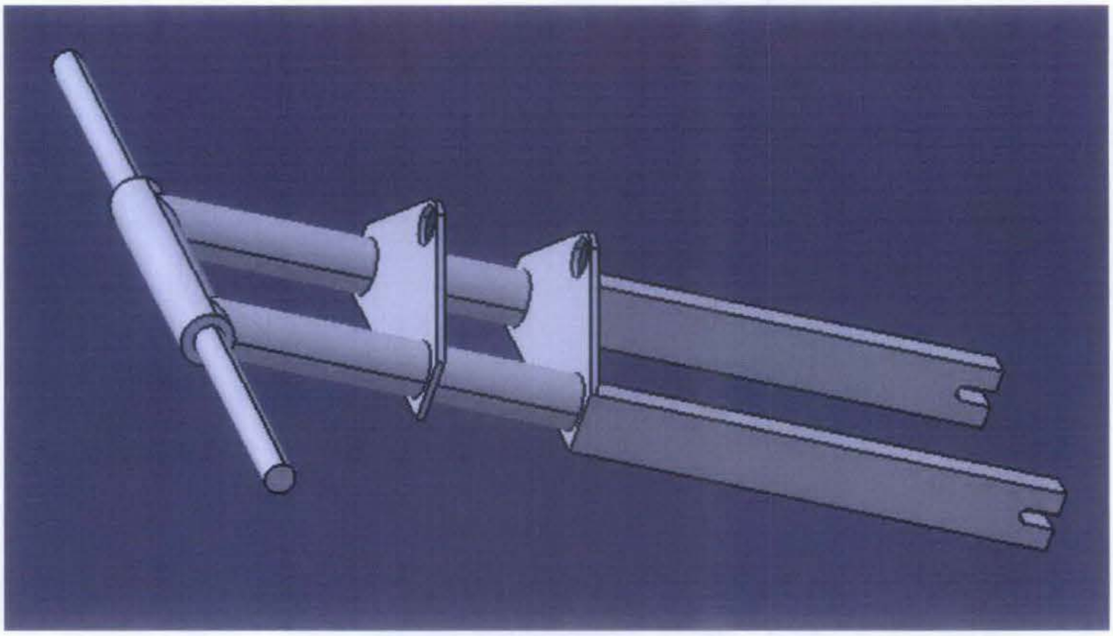


Chassis Deformation

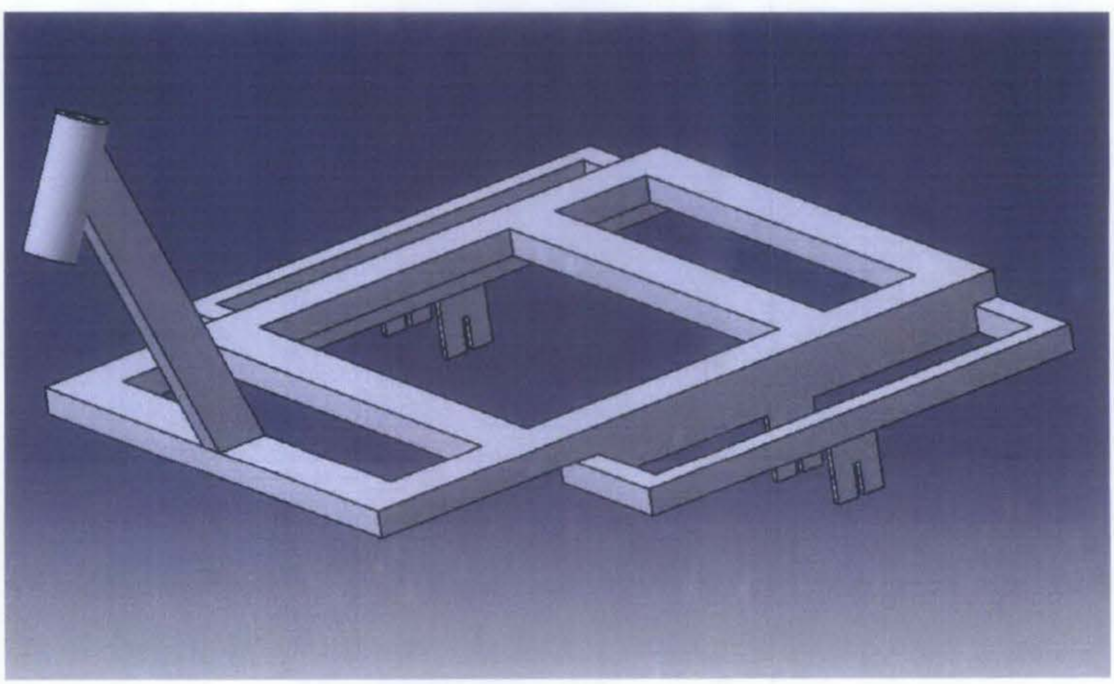


Chassis Displacement Analysis

Technical Drawing



Front Fork



Chassis Base

Prototype Construction

Front View

Back View

Side View

Perspective View

Joint between Chassis and Front Fork

Raw Idea