Simon Fraser University [redacted]

MSE 320: Trike Project - Part 1

[redacted]

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Letter of Transmittal

School of Mechatronic Systems Engineering
[redacted]
250-13450 102 Avenue
Surrey, B.C.
Canada V3T 0A3

Dear [redacted]

It is indeed a great pleasure for us to be able to design a single-passenger trike vehicle.

This report is being submitted on behalf of Team 18, to fulfill the project 1 requirements as part of MSE 320. This report is due on November 4, 2019, and is being submitted by [redacted], Sepehr Rezvani and [redacted]

The purpose of this report is to present design analysis performed during part 1 of this assigned project, in which the team will design a three wheeled, single passenger, paddle driven vehicle. The scope of this phase of the project is limited to identifying general specification of the vehicle, user requirements.

Thank you for supporting this project and reviewing this submission. The team looks forward to working closely with you to address any comments you may have.

Sincerely,

[redacted]

Member of Team 18, MSE 320.

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Executive Summary

The purpose of this report is to present design analysis performed during part 1 of this assigned project, in which the team will design a three wheeled, single passenger, paddle driven vehicle. The scope of this phase of the project is limited to identifying general specification of the vehicle, user requirements. Additionally, a literature review of relevant patents,standards and codes that apply to a three wheeled vehicle is presented. Works outside the project scope included detailed design of the electrical and control systems, as well as the construction of a physical prototype.

Initially, the team established their ideal user. Identifying the customer's requirement was a key factor in successfully designing this vehicle. Additionally, context and technical constraints such as user environment, frequency of use, environmental impact of the product was determined, which dictated the design objectives of the trike. The team reports a diverse list of appropriate materials and frame configuration that are considered for the construction of the automotive body and chassis and discusses their impact on the design objectives.

Our team generated multiple design alternatives using the information gathered and stated above. Finally, with the aid of various engineering tools such as CES EduPack, structural and cost analysis and a design matrix we recommend the most suitable concept.

Introduction

With cities around the world increasing in density and population, there is a need for cities to come up with alternative transportation options and replace traditional methods. In addition to limited space, fossil fuels have major contribution to global warming. This report covers the design of an Electric, Tadpole, Space Frame trike (tricycle) that was chosen to be the best option due to several factors between three different designs.

According to the requirements of the assigned project, this part primarily covers the design and analysis of the structural frame with only basic implementations of steering, seating, braking and suspension. Potential client that was chosen for part 1 is an adult in his thirties or early forties, 30-45 years old. He lives in Vancouver, BC, Canada and has asked our engineering team to build a trike for him. According to our client, the main purpose of his investment is to ride the trike in his neighbourhood only, which is relatively flat and does not have steep hills. He is 6 feet tall, approximately 200 pounds, and does not intend to carry any additional objects (bags, persons, pets, etc) with him on the trike ride. Therefore, our engineering team came up with multiple designs that could have potentially been the right fit for our client. Designs were grouped based on three main categories: Paddle Driven versus Electric Based Model, Tadpole versus Delta, and Space Frame versus Monocoque. Difference between them will be discussed in the following paragraphs.

First, the main disadvantage of Paddle Driven over Electric Based Model is lack of efficiency. Electric Based Models have been more efficient than Paddle Driven trikes according to our research, and the difference is significant enough to eliminate Paddle Driven immediately. Second, Tadpole versus Delta design. It is clear that the advantages of Tadpole design are endless over Delta for a three-wheel vehicle. By definition, the difference between these two are wheel configuration: Tadpole design has two wheels in the front, one wheel in the back, Delta is the exact opposite. Our team chose Tadpole over delta for three main reasons: Dynamic Stability, Braking and Aerodynamics. Tadpole is dynamically more stable than Delta, because its reaction to unexpected events (turning too fast during high speed) is safer and more predictable. Weight transfers to the front of the vehicle when it decelerates and the front wheels on any vehicle provide the majority of your stopping power. Therefore, Tadpole has an advantage over Delta because of the extra wheel in the front when it comes to braking. Lastly, The Tadpole design has aerodynamic advantage over Delta with a more suitable length/width ratio and you have to enclose more empty space with the Delta.

Finally, Space Frame versus Monocoque. The main advantage of Space Frame over Monocoque is how stress is concentrated on the structure. Unlike Monocoque, Space Frame would have almost no bending stress on the structure.

Design objectives

1. **Light Weight**

   A top priority in the design requirements is being able to reduce greenhouse gas, reduction of emission and optimizing fuel efficiency. The most optimal method of improving fuel efficiency is to add lightweight materials for the automotive product.

2. **Eco-Friendly / Recyclability**

   Stated earlier, a primary objective is reduction of CO2 emission and being able to protect resources by recycling parts used in the vehicle. The global warming has been on the rise from the past couple of decades. The transportation sector is the driving force behind modern economy. But, the transportation sector is also the largest contributor to the

   greenhouse emission as listed by the US Environmental Protection Agency.

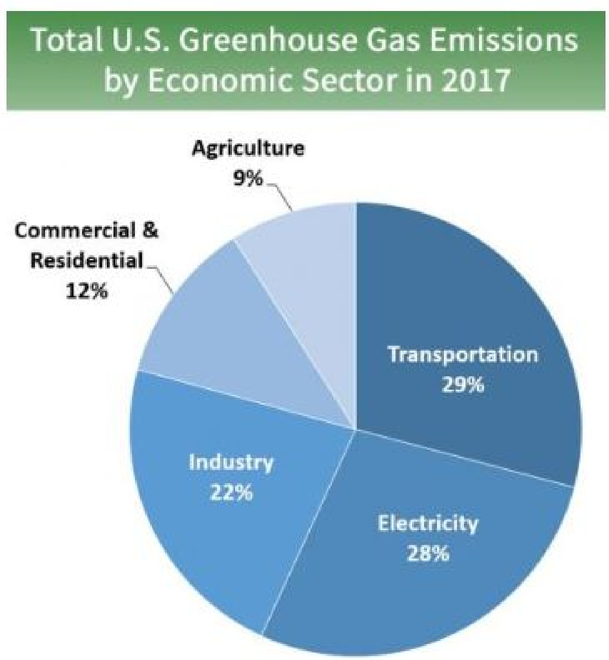


Figure:(https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions)

3. **Dynamically stable, when turning or when braking/ Safety:**

   "Crashworthiness" is a term used in the automotive industry to define the capability of a vehicle to absorb impact energy and protect the passenger with minimal injuries.

4. **Should be functional at wet roads, like in vancouver.**

   Corrosiveness of materials used. Additionally, Delta design is not favoured because of the disadvantages of this design when it comes to the vehicle balance. The traction of the vehicle must be considered, for better functionality on the wet roads and snow.

5. **Cost efficient**

   Even Though our client did not set a price range for this project, it is important for our team to come up with the cheapest design possible that meets all other design objectives, specifically safety.

6. **Good durability(strength and stiffness)**

   The vehicle should have high strength and high stiffness to withstand different loading conditions and the vehicle should not be very heavy as well.

7. **Should be of compact design.**

   Vancouver city is growing city, but with that the city also lacks parking space, therefore the vehicle should have compact design, so that it can be used in the city's congested places.

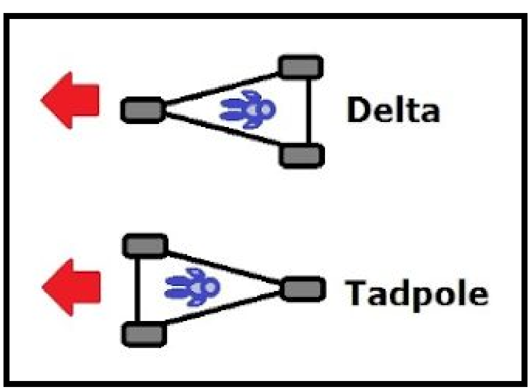


Figure 1

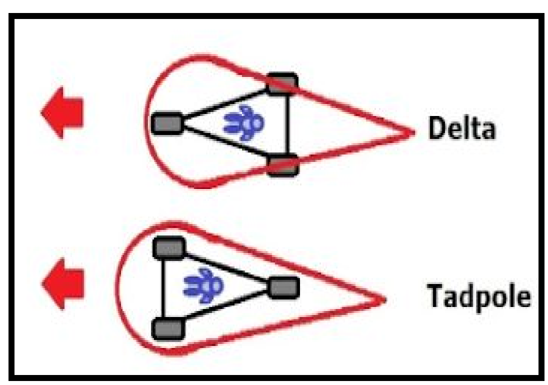


Figure 2

Therefore, our team decided to choose a Tadpole, Space Frame and an Electric trike over all other design possibilities. However, detailed analysis of rejected designs are also included in this report.

Description

Standards and Codes

All vehicles made for sale in Canada and all vehicles imported into Canada must meet the Canada Motor Vehicle Safety Standards. Manufacturers and importers must follow the Motor Vehicle Safety Regulation and related safety standards, technical standards documents and test methods. The Canadian Justice and Law Website provides detailed description of various standards and codes that apply to several vehicle types. The vehicle type of interest for this project is a three-wheeled vehicle. The codes that apply to three-wheeled vehicle are provided in the table below. [1]

Code (CMVSS)	Brief Description of codes
101	Location and Identification of Controls and Displays
102	Transmission Control Functions
103	Windshield Defrosting and Defogging
104	Windshield Wiping and Washing System
106	Brake Hoses
108	Lighting System and Retroreflective Devices
110	Tire Selection and Rims for Motor Vehicles With a GVWR of 4 536 KG or Less

111	Mirrors and Rear Visibility Systems
113	Hood Latch System
114	Theft Protection and Rollaway Prevention
115	Vehicle Identification Number
117	Motor Vehicle Brake Fluids
118	Power-Operated Window, Partition and Roof Panel Systems
120	Tire Selection and Rims for Motor Vehicles With a GVWR of More Than 4536 kg
124	Accelerator Control Systems
135	Light Vehicle Brake Systems
201	Occupant Protection
202	Head Restraints
203	Driver Impact Protection and Steering Control System
204	Steering Column Rearward Displacement
205	Glazing Materials
206	Door Locks and Door Retention Components
207	Anchorage of Seats
208	Occupant Protection In Frontal Impacts
209	Seat Belt Assemblies

210	Seat Belt Anchorages
214	Side Impact Protection
301.1	LPG Fuel System Integrity
301.2	CNG Fuel System Integrity
302	Flammability of Interior Materials
305	Electrolyte Spillage and Electrical Shock Protection
401	Interior Trunk Release
505	Vehicle Stability
1106	Noise Emissions

Table 1. Canada Motor Vehicle Safety Standards

Patents and Literature search results

Patent 1:

Title :Three Wheeled Vehicle

Inventors: James A. J. Holroyd

- Gustavo A. Aramayo
- Brian T. Utter
- Jason J. Hohenstein
- Vittorio Tomolillo
- Mark Alan Ziliak

Patent No : US 8,544,587 B2

Date of Patent: Oct. 1, 2013 [2]

Patent 2:

Title: Stabilized Three Wheeled Vehicle

Inventor: Wolfgang Trautwein

Patent No. : 4,020,914

Date of Patent: Feb. 23, 1976 [3]

Patent 3:

Title: Reverse Trike

Inventors:

- Adam J. Canni
- Clyde T. Sliger
- Merrill C. Hall

Patent No.: US D678,124 S

Date of Patent: Mar. 19, 2013 [3]

Competitors products and their specification

Vanderhall Venice [17]:

Figure 3

ENGINE	1.4 L turbocharged DOHC 16 valve I-4/200 hp, 200 lb-ft
TRANSMISSION	6-speed automatic
LAYOUT	0-door, 2-passenger, front-engine, FWD autocycle
L x W x H	145.2 x 68.9 x 48.8 in
WHEELBASE	100.4 in
WEIGHT	1,475 lb
TOP SPEED	130 mph

Table 2 : Specifications for Vanderhall Venice [17]

Solo- Electra Meccanica [18] :

Figure 4

TOP SPEED	80 mph
Engine	AC Synchronous Electric Motor
Toque	128 ft-lbs
Curb weight	1488 lbs
L x W x H	122 x 52 x 53 in

Table 3: Specifications for Electra Meccanica [18]

Description of concept alternatives

The group thought about various concept alternatives during our meetings, but based on our design objectives, we finalised 4 concepts tabulated below:

Concepts	Design Factors	Impact on Design Factors
1. Paddle Driven Delta Tricycle Space Frame  	**1. Delta Type Configuration.** **2. Rear Wheel Drive(RW).** **3. Paddle Driven** **4. Space Frame** **5. Carbon Fiber Built**	**Pros:** **1. Easy to design.** **2. Low cost of maintenance.** **3. Eco-Friendly** **4. Light Weight** **5. High Speed steering control and precision**[9] **Cons:** **1. Not very dynamically stable,** **Could oversteer** [1]**at curves.** **2. Not very good braking system,due to the center of mass is at the back.** **3. Delta configuration is not very suitable for climbing, as it**

[1] Vehicle turns more sharply than intended and could get into a spin

		pulls toward one side[9] 4. **Needs differential at the rear wheels to compensate for the distance between the rear wheels.** 5. **Not Suitable for long distance travel.** 6. **High material cost** 7. **Not very suitable Aerodynamically**
2. Foldable Trike  [5]	**1. Delta Type Configuration.** **2. Pedal Driven** **3. Rear Wheel drive(RW)** **4. Carbon Fiber Built.**	**Pros:** 1. **Less Space requirement, good for congested cities.** 2. **Eco- Friendly** 3. **Light Weight.** 4. **Highly saleable in the market.** **Cons:** 1. **Very difficult to design.** 2. **Having hinges in chassy create weak joints in the**

		structure. 3. Having hinges, creates vibration issue. 4. Cannot travel long distances.
3. Tadpole Type Electrically Driven with monocoque Frame  **[6]**	**1. Tadpole Type Configuration** **2. Electric Motor Driven** **3. Monocoque Frame** **4. Rear Wheel Drive** **5. Carbon Fiber Built**	**Pros:** **1. Dynamically stable on curves.** **2. Eco- Friendly** **3. Monocoque Frames are good for distributed loads.** **4. Suitable for mass production manufacturing.** **5. Aerodynamically very suitable.** **Cons:** **1. Not good for small scale manufacturing.** **2. Compared to space frame, the monocoque fame vehicles are heavy.** **3. When designing, the rider size must be kept in mind.**

		4. **Not suitable for point forces loading.**
4. Tadpole Type Electrically Driven with space Frame	1. **Tadpole Type Configuration** 2. **Electrical motor Driven** 3. **Space Frame** 4. **Rear Wheel Drive** 5. **Aluminium Alloy Built**	**Pros:** 1. **Dynamically Stable at curves and at greater speed.** 2. **Good Braking System.** 3. **Eco-Friendly** 4. **Light Weight** 5. **Aerodynamically stable, can achieve good speed.** 6. **Needs no differential, which means less cost.** 7. **Eco-friendly** **Cons:** 1. **Difficult to design.** 2. **Steering control not very smooth.** 3. **Due to less mass at the back the traction at the back is not very optimal**

Table 3.

Concept Analysis and Selection:

Technical Analysis:

Design Factors, considered in the concepts are listed below:

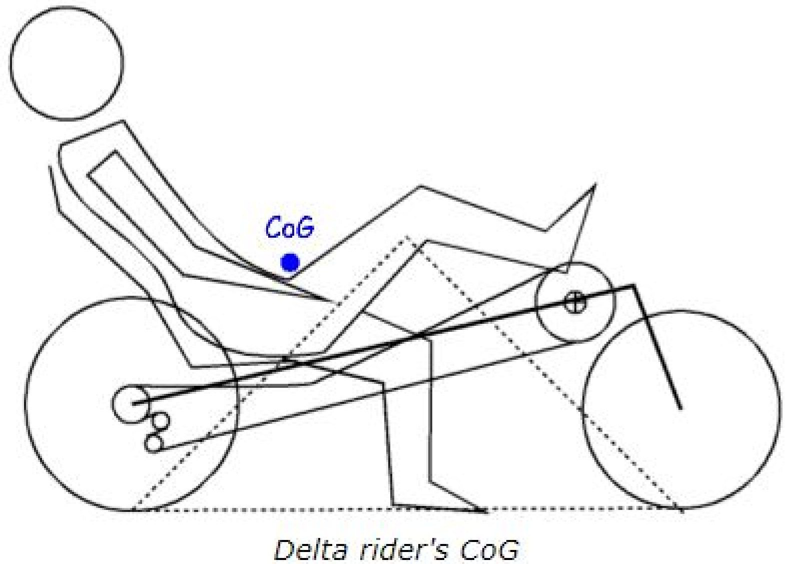
Drive Wheel Configuration : The wheels which receive power from the engine to perform the traction. Depending on the configuration we can have three outcomes:

a. Front-wheel Drive(FWD): In this configuration, power is transferred to the front wheels from the engine. The vehicle with this configuration is cheaper to design and has good traction in snow and rain.But on the contrary, handling of the vehicle is not very good at curves and higher speed.
b. Rear Wheel Drive(RWD): Here, the power is transferred to the rear wheel. This type of configuration is good for handling of the car. In this configuration, the vehicle will be
c. All Wheel Drive(AWD): Power from engine is transferred to all the wheels.[5]

Type of Configuration for Three-wheeler:

Depending upon the design objectives, we could have two configurations of three-wheeler:

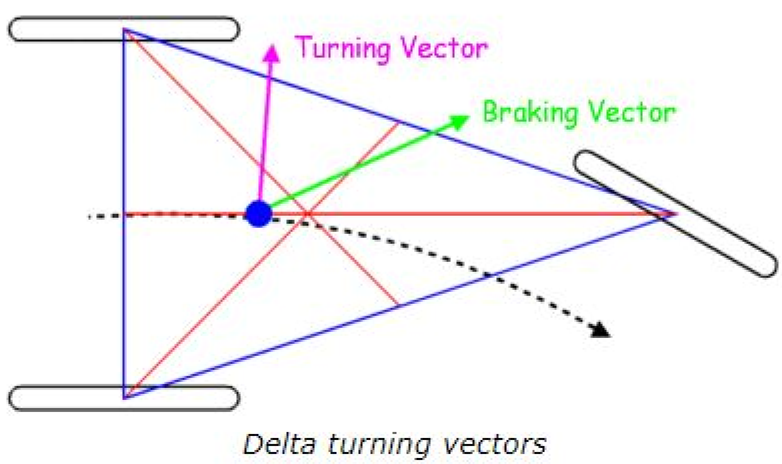
1. **Delta Configuration**: In this configuration the front of the vehicle has one wheel and back of the vehicle has 2 wheels. This configuration is easy to manufacture, requires less capital.
    a. **Braking System:**
    As the center of gravity is on rear drive, therefore the braking system suffers. And as the COG is on the back, while it can also lead to lift of the front wheel, when climbing steep slope.[6].



Fig(2)

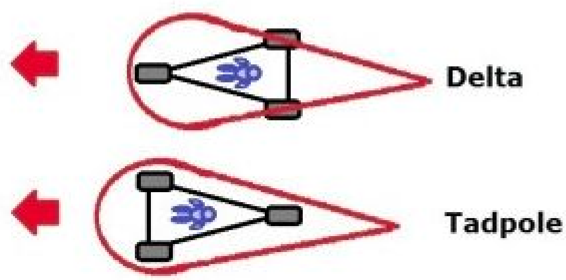
b. Turning/Stability:

For this configuration, the vehicle has high speed steering control and precision. As the center of gravity is towards the back, therefore the chances of oversteering are more[8][6].



c. Aerodynamics Stability:

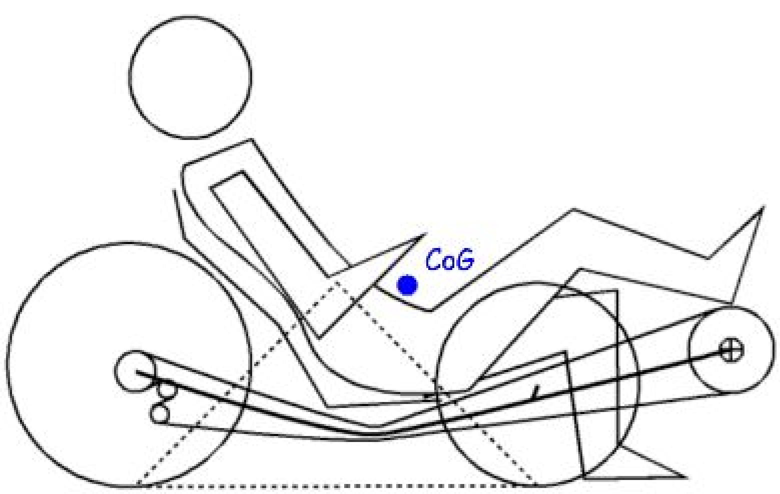
This configuration is not very aerodynamically stable[6][8].



2. **Tadpole Configuration**: In this configuration, two wheels are in the front and one wheel is in the back.It is difficult to design as compared to the delta configuration.

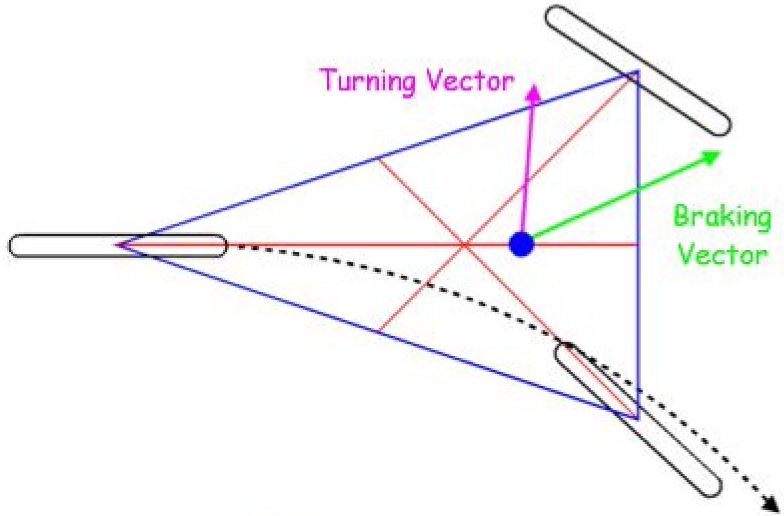
a. Braking:

The weight of the vehicle is in the front, therefore this helps when vehicle is decelerating. But as the weight is in the back, if very hard braking is applied the vehicle can get tipped from the back.[6][8].



b. **Turning/Stability:**

This configuration is suitable for achieving maximum stability as the center of gravity is in front, therefore this condition favours understeering. But, with two wheels in the front, steering system becomes hard to design and due to less mass in the back, the vehicle also lack traction.[6][8]



Tadpole turning vectors

c. Aerodynamically Stability:

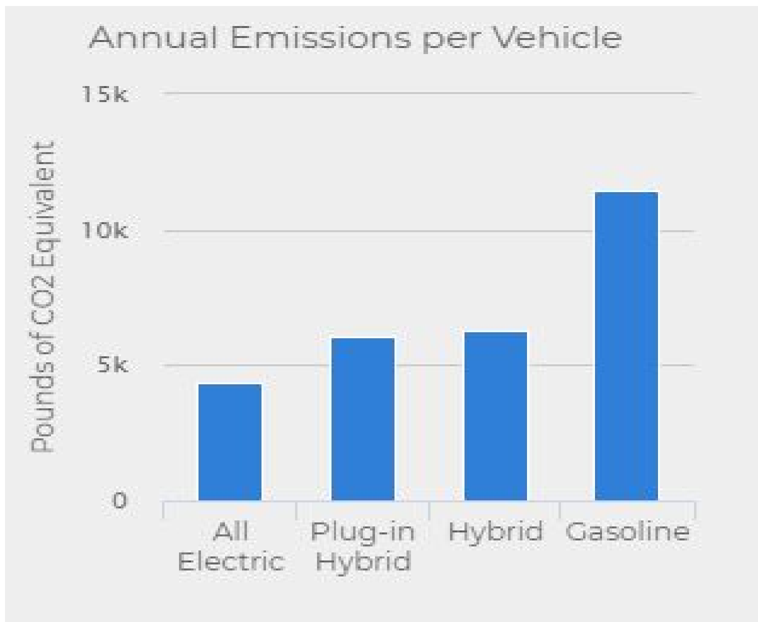
This shape is very aerodynamically stable.[8]

<u>Type of Vehicle (Power Source):</u>

1. **Pedal Driven Vehicle:** This type of vehicle is very suitable for the crowded cities and is healthier form of transportation.

Figure 5:A Pedal Driven Car Veemo(a Vancouver based company)[9]

2. **Electric Vehicles**: In this type of vehicles, power train is powered using an AC motor. These types of vehicles are very eco-friendly and with advancement in battery technology, these vehicles are becoming very popular. As the world moves towards cleaner source of generating electricity, the electric vehicles will become more eco-friendly. The data for carbon footprint for various types of vehicle as listed by US Department of Energy is shown below:



Figure[10]

3. **Standard Engine Driven Cars:** These types of vehicles are easy to manufacture and have huge infrastructure to back them. But has a high carbon footprint on the environment and has contributed heavily to the global warming.

Type of Vehicle Frame/Chassis:

1. **Space Frame:**

   It uses several small tubes to create a 3-D chassis. The tubes are usually placed in trusses like structure to avoid any bending stress. These frames only have tensile or compressive stresses. The circular cross section is used due to its bending moment and torsional advantages over other sections shown below in the table[11]

Section		Mass (kg/m)	Torsion constant I_t (10^4 mm^4)
C section	UPN 200	25.3	11.9
I section	INP 200	26.2	13.5
Box section	140*140*6	24.9	14.75
Tubular section	168.3*6	24.0	20.17

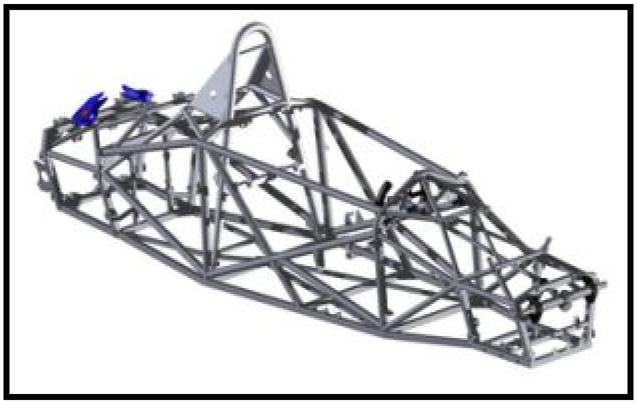


Figure 6:Monocoque Frame[11]

It is a one piece structure. These types of frames are widely used in industry. But these frames are comparatively heavier than the space frames.

Material Selection/ Cost Analysis

The first and most important factor for automotive design is the choice of materials. A variety of materials are available in the market that can be used in the automotive body and chassis. Certain criterias should be met when choosing the material, these criterias are highly dependant on legislation and regulations as well as requirement of the customer.

Material Selection:

a. **Common materials that are used in automotive body and chassis and their impact on the design objectives are discussed below.**

   The most significant criteria, as per our design objective, that a material should meet are lightweight, economic efficiency, safety, non-corrosive, durability and recyclability.

1. Steel

The primary characteristics that make steel, a highly desirable material to be used for automotive body is it's high thermal, chemical or mechanical resistance, durability and ease of manufacture. Over the past several years, there has been a steady increase of the usage of high strength, low-alloy steels. These materials form the basis of Ultralight Steel Autobody (ULSAB), which indicated a 19% mass reduction in a body structure, in addition to that, had superior strength and structural performance. [4]

The prime reason for using steel in the body structure is its inherent capability to absorb impact energy in a crash situation. [4]

2. Aluminium

Aluminium plays a significant role in automotive design , their usage includes but are not limited to powertrain, chassis and body structure. It's low density and high specific energy absorption makes it a perfect candidate for the required design objective, the potential to significantly reduce the weight of the vehicle body. Aluminium has high resistance to corrosion. Aluminium castings can be used for pistons, cylinder heads, intake manifolds and transmission.[4]

Recent studies and developments indicate upto 50% weight saving for the body in white (BIW) can be achieved by substituting steel by aluminium, which may result in almost 25-30% of total vehicle weight reduction.The cost of aluminium and price stability is its biggest obstacle for its application [4]

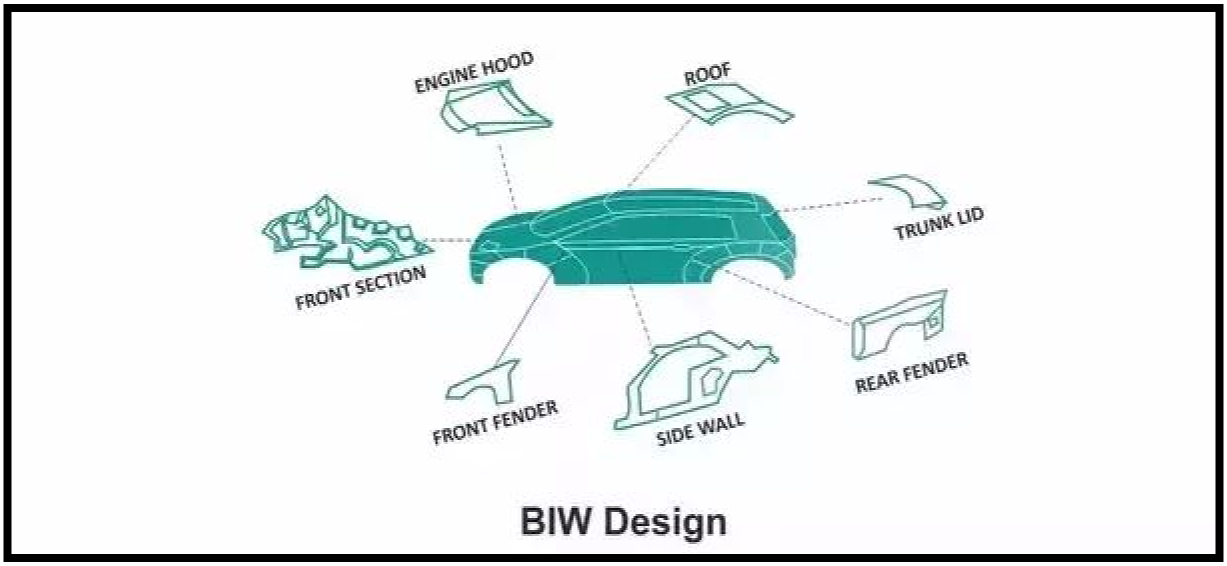


Figure 7: BIW Design

3. **Magnesium:**

Magnesium is another light material that is being frequently utilized in the automotive industry. It is 22% lighter than aluminium and 75% lighter than steel/cast iron components. Even Though Magnesium is a lighter material, their components have many mechanical/physical property disadvantages that require unique design applications to automotive products. Although it's tensile yield strength is about the same, magnesium has lower tensile fatigue strength, and creep strength compared to Aluminium. [4]

b. <u>CES Analysis for Material Selection:</u>

The requirement for our vehicle is to have high **tensile strength(σ)** as the chassi is made up of trusses.The another requirement for our design is to have high **stiffness(E),** so that it can withstand different loading conditions. The last characteristic of our vehicle is it, to have it very light weight, which means low **density(ρ).**

Chart 1: Strength VS Density

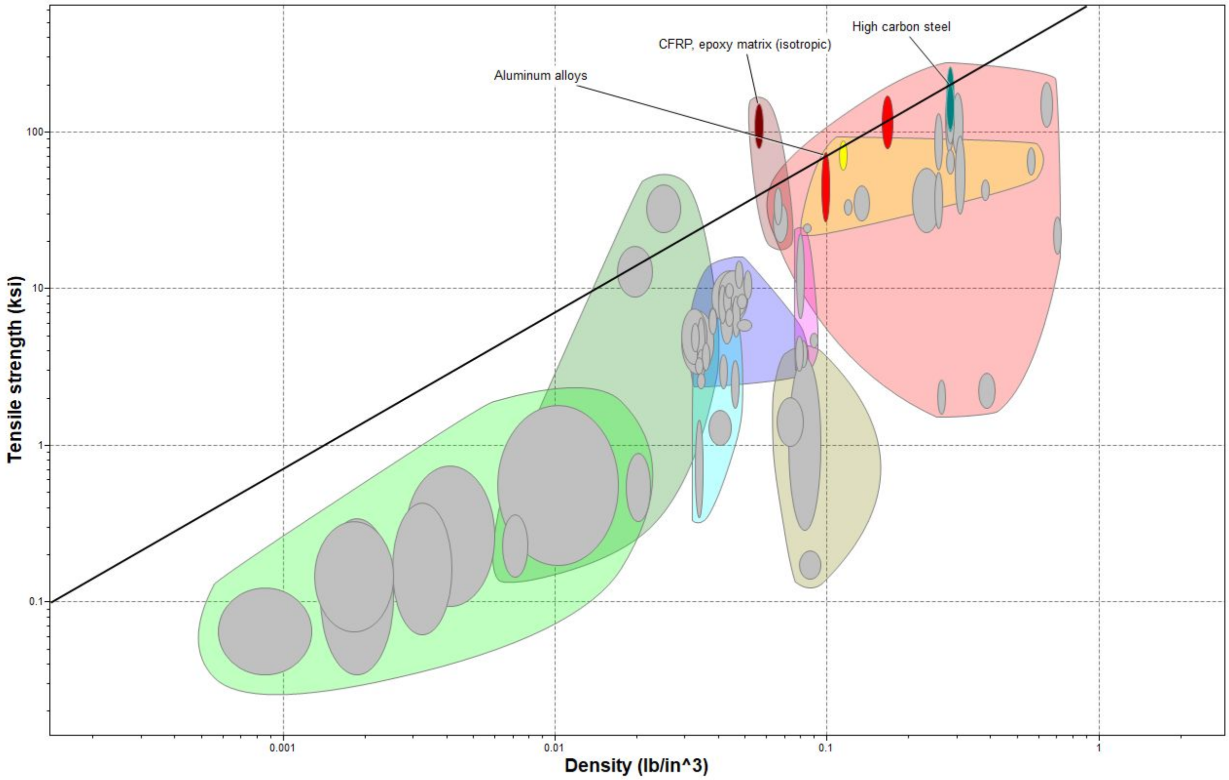


Fig: Strength Vs Density

It can be seen from the above graph, that carbon fibre, aluminium alloys and carbon steel are the best performing materials in this section.

Chart 2: Young Modulus(E) Vs Density:

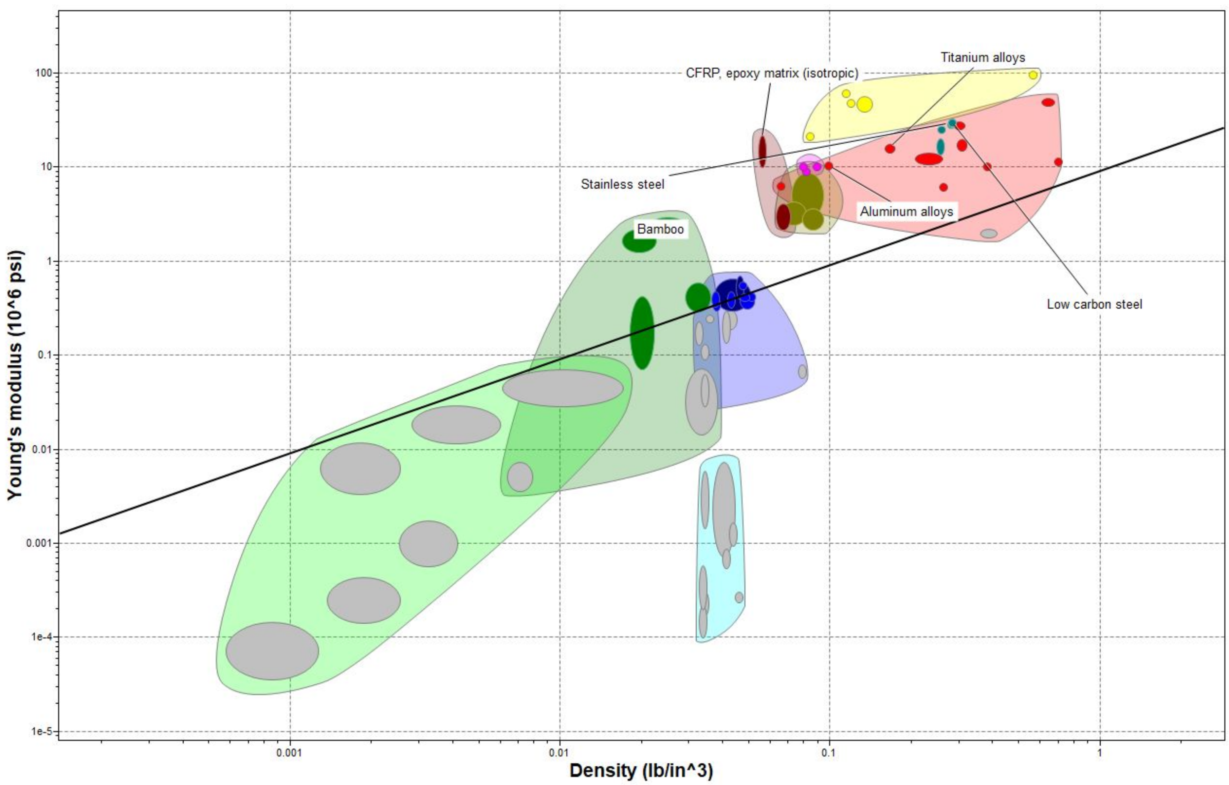
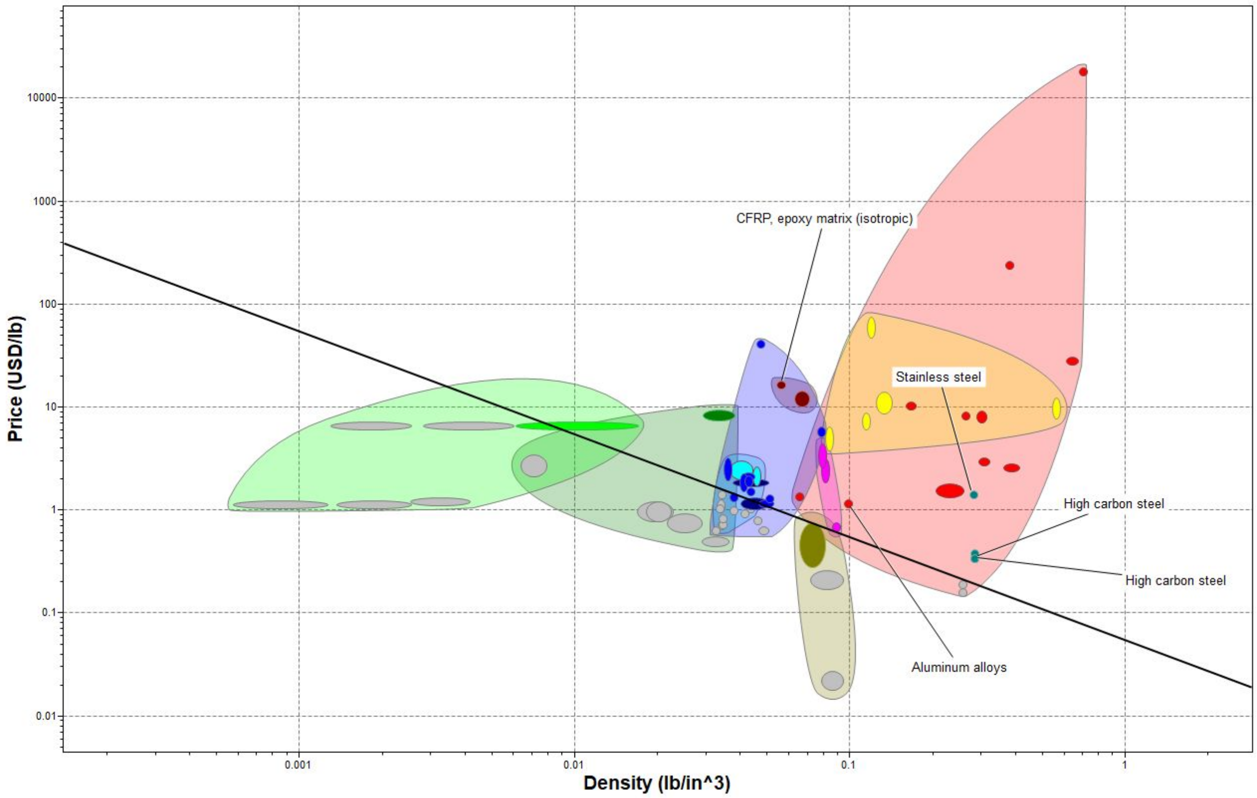


Fig: Young Modulus(E) Vs Density

We see that this graph also follows the same trend as the previous one. Here, also Aluminium Alloys, carbon fibre and high carbon steel outperform other materials.

Chart 3: Cost Vs Density (Cost Analysis)



Here, we can see that the price of the high carbon steel is the lowest followed by the aluminium alloys. We also observe that, carbon fibre material is very expensive.

Concept Selection

Decision Matrix:

Objective	Weight	Paddle Driven Delta	Foldable Trike	Tadpole Type Electrically Driven with monocoque Frame	Tadpole Type Electrically with space Frame
Light Weight	5	5/5	5/5	4/5	4/5
Eco-Friendly	10	9/10	9/10	7/10	8/10
Dynamically Stable	20	15/20	13/20	19/20	18/20
Functionality at wet roads	20	18/20	16/20	15/20	15/20
Cost Efficient	15	8/15	7/15	6/15	13/15
Good Durability/ Strength	15	15/15	15/15	15/15	13/15
Compact Design	15	12/15	15/15	10/15	13/15
Total	100	82/100	80/100	76/100	85/100

Table - Design Matrix

After examining all the alternative concepts and looking at decision matrix, our team chose Concept 4 (Tadpole Type Electrically Driven with Space Frame). The Tadpole configuration is very dynamically stable. Based on the requirement of our design, the vehicle should be lightweight, so we need to go with space frame. The circular sections are the most efficient, when making chassy. As, the carbon fiber is quite expensive, we will go with aluminium alloys for our vehicle. Based on the factors, our vehicle is shown below:

Final Recommendations and Conclusions

This project helped our team to understand the basics of designing a three wheeler vehicle. It helped us to understand the design cycle. The team went through all the steps of a design cycle, from studying the client belief to sketch the first draft of the vehicle. We studied the market for similar product and came up with the product, which would satisfy our design objectives and help us to deliver our product and make a profit out of it. While working on this project, we struggled to understand some of the requirements of the project, as some of the terminologies were very vague. We would recommend to make the project description more clear.

There were multiple methods for choosing the right design, but the most time efficient way was the process of elimination. Decision Matrix played an important role in choosing the right design between the final four candidates: “Paddle Driven Delta”, “Foldable Trike”, “Tadpole Type Electrically Driven with monocoque Frame” and “Tadpole Type Electrically with Space Frame”. In the Decision Matrix, seven main design objectives were scaled based on their importance. Design objectives were Light Weight, Eco-Friendly, Dynamic Stability, Functional on Wet Roads, Cost Efficient, Durability/Strength and Compact Design. In order to pick the right design, our team researched and analyzed each of the seven design objectives and concluded that the best option for our client would be “Tadpole Type Electrically with Space Frame”. This design was the most dynamically stable out of all four candidates.

Vancouver is known to be one of the most environmentally friendly cities on the plant. So, choosing an Electric Vehicle over an Engine Driven was not a difficult choice. Paddle Driven trike was rejected because of its inefficacy compared to an Electric trike.

Last but not least, our team used two softwares, EduPack and SolidWorks. The former was used to assist our team with trike’s material selection, and the latter to have a better visualization of trike’s structure. The ultimate goal we had for material selection was to have high tensile strength and stiffness, but low density. Therefore, Steel, Aluminum and Magnesium were compared on three different charts: Strength versus Density, Young’s Modulus versus Density, Cost versus Density.

References

[1] Laws-lois.justice.gc.ca. (2019). *Motor Vehicle Safety Regulations*. [online] Available at: https://laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._1038/ [Accessed 19 Oct. 2019].

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Appendices

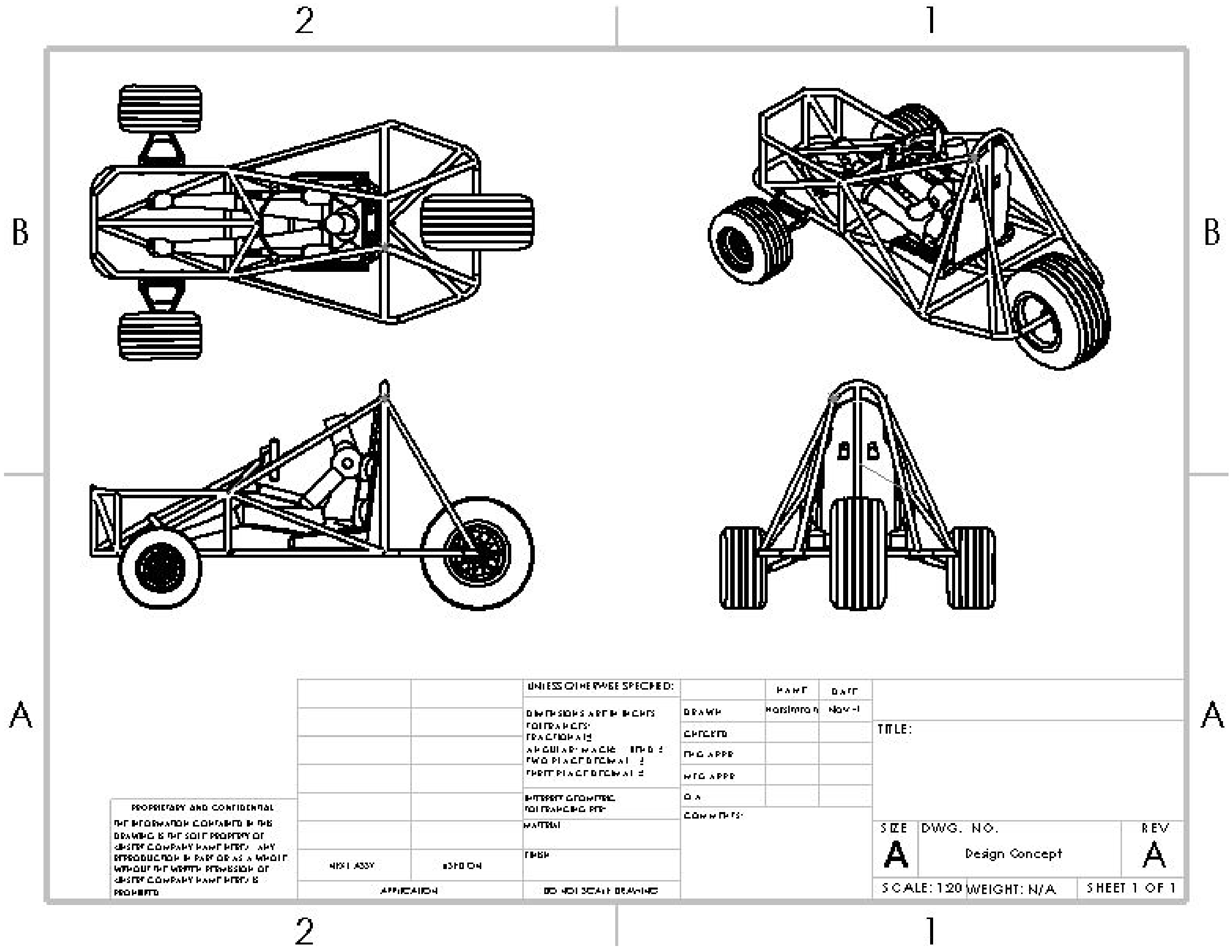

Fig X. Drawing of Trike Concept Showing All Views