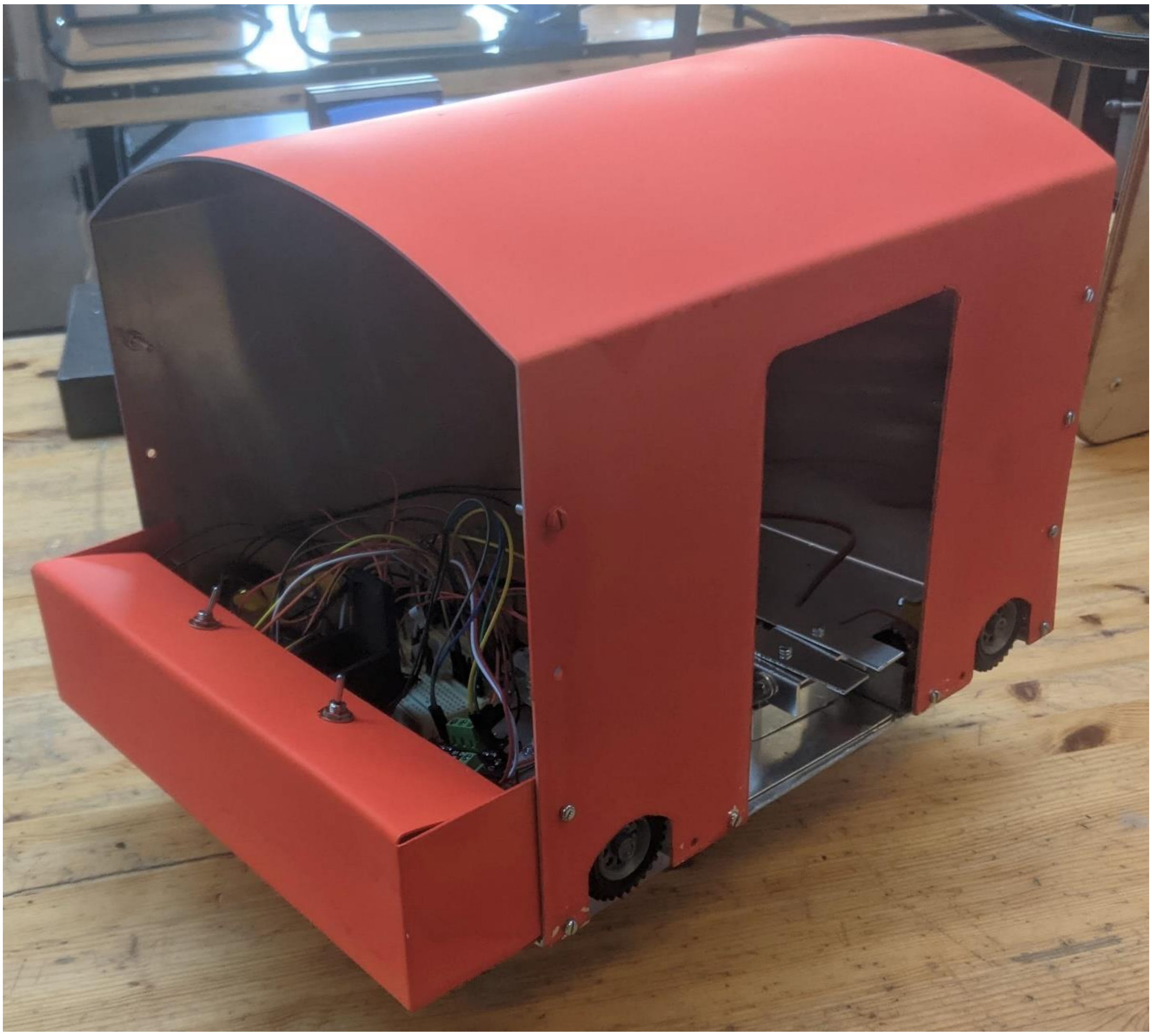
Leaving Certificate Engineering

Design Task 2021

Examination Number: 108051



Contents

Acknowledgements

Many thanks to my Leaving Certificate Engineering teacher, Philip Devereux, for being a fantastic mentor over the last few years as well as throughout the course of this project; who's guidance has enabled me to complete this project.

Many thanks to Micheal Griffin and Michael Forrestal for teaching me skills in Junior Certificate Coding and Technology which allowed me to succeed in your classes as well as in Engineering today.

Instructions to Examiner

My project allows for two modes of operation: automatic and remote.

Ensure a wide area and no sudden drops.

Automatic

1. Activate vehicle with switch on right hand side of Driver's console.
2. Allow minute for start-up then press button on left hand side of console.

Vehicle will demonstrate basic functionality of self-propulsion and ability to load and unload cargo.

Remote

Bluetooth-enabled device required.

I recommend the free download of Serial Bluetooth Terminal from the Google Play Store. Unfortunately, I cannot verify the functionality of any non-paid apps for iOS.

1. Activate vehicle with switch on right hand side of Driver's console.
2. With Bluetooth turned on *(on your device)* open Serial Bluetooth app and search for "108051 Engi Project" in Devices: Bluetooth Classic.
3. When connection is confirmed, the vehicle can be controlled by entering the following commands in the Terminal.

Action	Command
Move Forward	f
Move Backwards	b
Turn Right	r
Turn Left	l
Stop Moving	s
Extend Platform	ext
Retract Platform	ret
Lift Cargo	up
Lower Cargo	down

Design Brief

Urban freight distribution is the system and process by which goods are collected, transported, and distributed within urban environments. It is essential to supporting international and domestic trade, as well as the daily needs of local businesses and consumers, in a sustainable manner. Progressive technological determination of low emissions vehicles for urban usage in this sector has been notable. Central to the research is the European Commission Funded Furbot Project which developed the concept architecture of a light duty, fully electric vehicle, to transport two cargo boxes. Following a sustainable and efficient mobility approach, a robotic handling device has been designed and positioned on-board the vehicle. The handling device realizes the loading-unloading operations on the right side of the vehicle and from the ground to the vehicle platform.

Design a model Urban Freight Vehicle to the general specifications outlined below. The Vehicle should be your own unique design and should:

a) Be a four wheeled, single seat vehicle.
b) Have a forward propulsion unit.
c) Feature an on-board lift mechanism to enable loading/unloading of a single cargo box.

Presentation of the completed project should ensure that:

a) All main operating features are clearly visible without dismantling.
b) The longest dimension of the vehicle does not exceed 400 mm.
c) Electric power does not exceed 9 volts.

Special Note: (i) A cargo box need not be included in the final solution.

(ii) Modified toys or recycled projects are not acceptable.[1]

[1] https://www.examinations.ie/misc-doc/EN-EX-6761835.pdf

Analysis of Design Brief

- ❖ **Urban Freight Distribution:** The system by which goods are collected, transported, and distributed within urban environments.
- ❖ **Fully Electric:** Powered entirely by electrical energy, generally stored in batteries.
- ❖ **Furbot Project:** The project proposes novel concept architectures of light-duty, full-electrical vehicles for efficient sustainable urban freight transport and will develop FURBOT, a vehicle prototype, to factually demonstrate the performances expected.[2]
- ❖ **Loading-Unloading…Right Side:** As an EU initiative the Furbot loaded and unloaded to suit most European roads. In an Irish road context this should be adjusted to Left Side.
- ❖ **Four Wheeled:** These vehicles should run on four wheels, presumably to ensure stability and suitability for urban spaces.
- ❖ **Single Seat:** The vehicle should be operated by, and only accommodate, a single driver.
- ❖ **Forward Propulsion Unit:** The vehicle must be able to move forwards under its own power.
- ❖ **On-Board Lift Mechanism:** Loading-Unloading should be completed by mechanical, rather than manual, means.
- ❖ **Single Cargo Box:** This mechanism should accommodate at least one cargo container.

[2] https://cordis.europa.eu/project/id/285055

Urban Freight Vehicles Today

Freight Vehicles are currently found in a wide range of forms and sizes, as shown bel ow, and are a ubiquitous sight in day- to-day life.

Since I began working in a local shop last summer, I have had the chance to experience first-hand some of the issues inherent in these forms of delivery vehicles. The largest issues stemming from the fact that, in general, these vehicles do not make use of built-in loading-unloading mechanisms. This leaves the job of unloading to human manual handling, which creates multiple hazards in both the long and short term for individuals in these jobs. Along with the possibility for injury I notice that damages to certain products due to either transport or mishandling are more common than I would have previously expected. Finally, after a large delivery is brought into our storeroom, we are left with the job of sorting through a pile of disorganised products stacked on top of each other.

These issues clearly show the need for, on-board lift mechanisms in future urban freight vehicles. A well-designed mechanism could address every one of these current issues one by one.

- A fully electro-mechanical system could completely eliminate the need for delivery drivers to risk their health by giving them responsibility of operating the mechanism not unloading manually.
- An efficient and smoothly acting mechanism would remove harsh shocks from mishandling decreasing the risk of product damage.
- Standardising storage crates could save recipients a lot of time unpacking deliveries.

Where lift mechanisms are currently in use, they are generally only found at the rear exit of larger transport vehicles. These "tailgate lifts" are poor solutions to the problems outlined above for several reasons. To begin with they reduce but do not eliminate the need for manual handling and many hazards. A human must still load the cargo onto the lift then move it inside the storage compartment. Additionally, these lifts vary greatly in size and in many cases are not large enough to grant those in danger room for error. When error occurs, the best possible result is often damaged cargo with the worst being serious injury.

To achieve this, I believe that this mechanism must be fully contained within the vehicle. Where possible, the cargo should not require any human contact when loading, unloading, or being stored within the vehicle. The process should not require complex or fine readjustments, instead relying on standardisation of cargo containers to allow for mostly automatic loading and unloading.

An even greater issue with current urban transport vehicles then I have mentioned so far is the environmental damage the continued use of internal combustion engines is having on our current and future lives.

Global warming and climate change aside the presence of air pollutants alone is already attributed to a massive number of deaths every year. Research has recently found that in 2018, air pollution may have caused 8.7 million deaths globally.[3]

Due to the short distance and low speed nature of Urban Freight the steppingstone of hybridisation would have no effect on air quality and public health, as these vehicles would not have a chance to charge their batteries, and would therefore be futile and unsuitable.

For this reason, I believe the only sustainable and moral option is for Urban Freight Vehicles to move to fully electric power.

Safety

Aspects currently found in Urban Freight Vehicles which should be maintained and continually improved on over time are safety features protecting the driver.

The drive compartment must be separated from the cargo hold by a sturdy backstop to ensure that in the case of a rough stop unsecured cargo is not able to continue its momentum and cause the driver injury. Seat belts, being just as if not more important, work off a similar principle only they prevent the driver becoming the projectile.

Modern technology is making personal vehicles vastly safer but has not spread to freight vehicles as rapidly.

Fully electric vehicles do not require bulky engines so much larger crumple zones can and should be incorporated in these new solutions, as they will protect both drivers and all other road users.

[3] https://www.sciencedirect.com/science/article/abs/pii/S0013935121000487

The introduction of computer systems and X-By-Wire[4] control into urban transport will greatly reduce the potential for human error on roads and over time may remove it completely.

I should attempt to include technologies such as collision avoidance sensors and autonomous breaking in my design. Such technologies will both make my vehicle safer in today's world and open the possibility of eventually moving to fully autonomous Urban Freight Vehicles.

Drivetrain

While only forward propulsion is required under the provided brief, I believe that it is worth exploring this system further. The vehicle must be four wheeled which is logical for the use case, it provides the stability that is clearly required in a freight vehicle. While a track system could improve stability, the tracks would take up valuable space and limit options for loading.

This is not to say tracks should not be used as inspiration in any way. On narrow city streets their ability to make on the spot turns is an advantage over the wide turning angles of traditional drivetrains.

A fully electric vehicle however can make similar low angle turns much more feasible as each wheel can be controlled separately if desired and wired as such. Pairing wheels along the vertical axis rather than horizontal, for instance, would facilitate near on the spot turns with four wheels.

Constraints on my Design

Presentation of the completed project should ensure that:

a) All main operating features are clearly visible without dismantling.
b) The longest dimension of the vehicle does not exceed 400 mm.
c) Electric power does not exceed 9 volts.

[4] https://www.electronicdesign.com/markets/automotive/article/21797531/xbywire-for-power-x-marks-the-spot

Investigation of Solutions

Origin of the Electric Motor

The future of road vehicles, Urban Freight Vehicles included, is undoubtedly fully electric vehicles (EVs). As a result, I believe it is important that this be represented in my own design. To fully understand modern EVs it is important to explore the development of the electric motor itself and the vehicles which followed it.

Early Developments

While the electric motor would not be seen till the early 19th century the main principles of their operation were being researched as much as a century earlier. In the 1740s, Andrew Gordon (a Scottish monk) and Benjamin Franklin each experimented with simple electrostatic devices.

In the 1820s and 30s DC motors developed rapidly, starting with Michael Faraday's experiment to convert electric current into rotary motion using electromagnetism. By 1832, William Sturgeon invented the first DC motor that could turn machinery. His work was further improved by Thomas and Emily Davenport who together developed a battery-powered DC motor capable of powering tools and a printing press; but the limitations of battery power led to its commercial failure.

Technology developed over the rest of the century and in 1886 Frank Julian Sprague introduced the first DC motor which was well suited to industrial use. Unlike previous iterations, this motor could run at a constant speed under variable loads. Sprague used his motor to power the world's first Electric Trolley System; the first time a fully electric mass-transit system was seen.[5]

[5] https://www.parvalux.com/news/when-was-the-electric-motor-invented/#:~:text=1834%20%E2%80%93%20The%20first%20electric%20motor,a%20small%2Dscale%20printing%20press

AC Induction Motors

Two years after Sprague released his DC motor, Nikola Tesla patented his AC Induction Motor, though it was not wet particle. Westinghouse licenced Tesla's patents and had a particle design on market in 1892.

In order to further improve on the induction motor Westinghouse later partnered with General Electric to produce a three-phase motor.[6]

Application to Electric Vehicles

The development of Electric Vehicles closely followed electric motors for much of the 1800s. Many crude and simplistic vehicles were developed as early as the 1830s, but current technology and economics did not allow for widespread production or adoption.

William Morrison found some success in 1889, with an electrified field wagon. While his product was not yet suitable for general use it did spark a public interest in the idea.[7]

Just a few years later Westinghouse's Induction Motor was found to be capable of powering vehicles relatively efficiently and an early golden age of electric vehicles soon followed; unfortunately, lasting less than two decades.

Modern Electric Vehicles

Today's electric vehicles have built on past technologies and continued to push development to design vehicles that are now vastly outperforming not only the electric vehicles of the past but internal combustion vehicles of the present.

Tesla are currently the gold standard for electric vehicle design. They design not only cutting-edge electric vehicles but also the "safest car

[6] https://ieeexplore.ieee.org/document/1454598
[7] https://www.energy.gov/timeline/timeline-history-electric-car

ever built"[8] according to the American National Highway Traffic Safety Administration. This extraordinary achievement is undeniably a result of designs only possible in fully electric vehicles. The lack of an engine allows the entire front of the vehicle to act as a crumple zone. By arranging the battery cells in a flat sheet along the bottom of the chassis the car's centre of gravity is both centralised and lowered, greatly adding to stability, and providing structural rigidity against side-on collisions. When used incorrectly, Tesla's autonomous driving features have led to controversy but when used responsibly and in collaboration with common sense the all-around sensors, early warning systems, and autonomous breaking are highly effective in preventing accidents.

Early Tesla vehicles have made use of AC induction motors, following on from those of Nickola Tesla and Westinghouse. With these motors they could deliver strong performances, with a starting torque and acceleration greater than internal combustion can deliver; all while remaining incredibly silent. These motors used three-phase power to produce a four-poll magnetic field around the rotor. The speed of this motor is proportional to the frequency of the power supply. This allowed a 0-18000 RPM without need for a transmission and without sacrificing torque. These motors also act in reverse, as generators, allowing for effective regenerative breaking greatly improving power efficiency and range of these vehicles.[9]

Not to remain complacent Tesla have already moved away from induction motors with the release of their Model 3's. Induction motors suffer from back-emf due to the requirement for induced magnetic fields, at cruising speeds this caused a 3-4% power loss in previous vehicles. To counter this Tesla have begun using permanent magnet motors, specifically IPM-SynRM motors. These motors retain all functionality of the previously used induction motors without the need to induce a magnetic field, greatly reducing back-emf. A six-poll magnetic field is now used rather than four poll which has and added benefit of even higher torque. Tesla's new motors have an approximate efficiency of 96% an improvement on the 94% efficiency of induction motors.[10]

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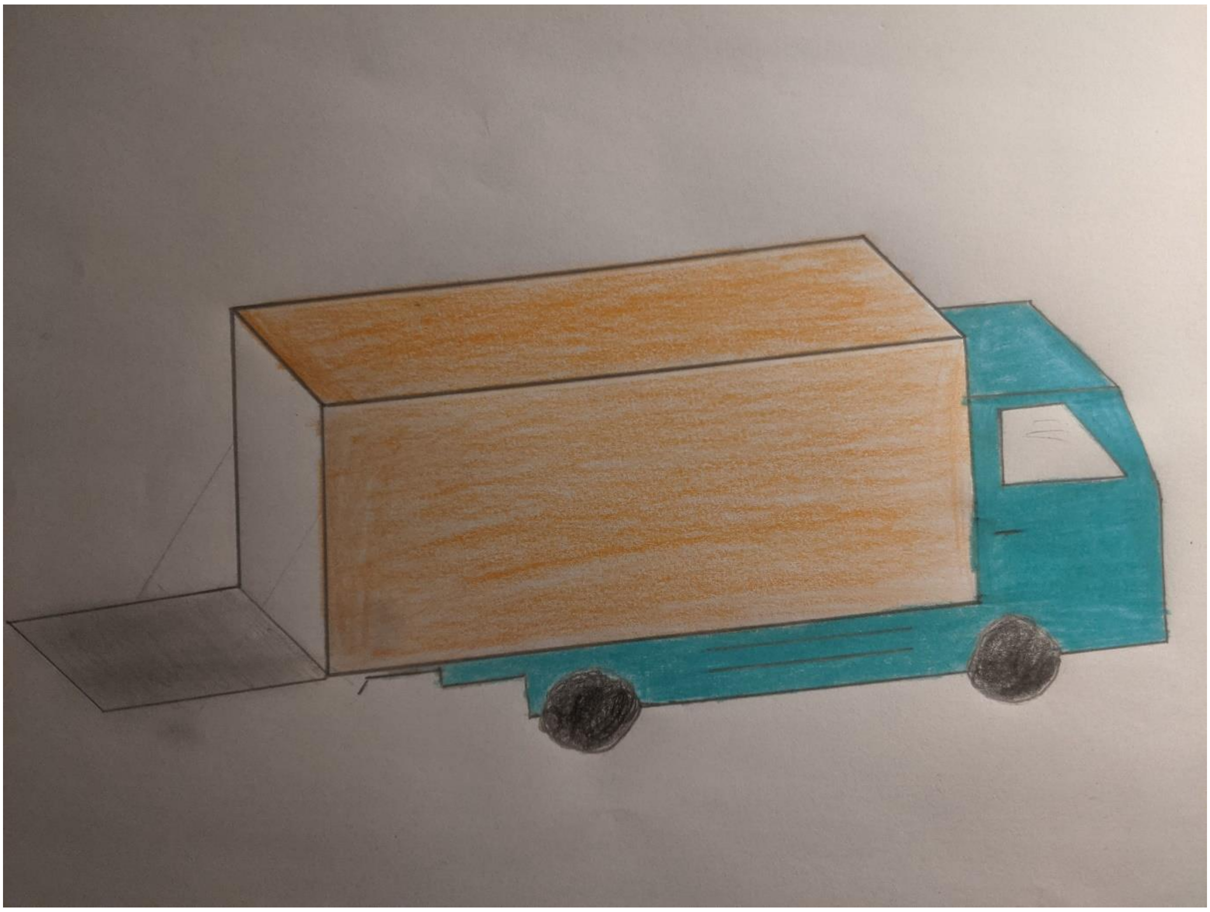
[8] https://www.tesla.com/en_IE/blog/model-3-lowest-probability-injury-any-vehicle-ever-tested-nhtsa
[9] https://www.youtube.com/watch?v=3SAxXUIre28
[10] https://www.youtube.com/watch?v=esUb7Zy5Oio

Existing Solutions

Box Trucks



Pros:

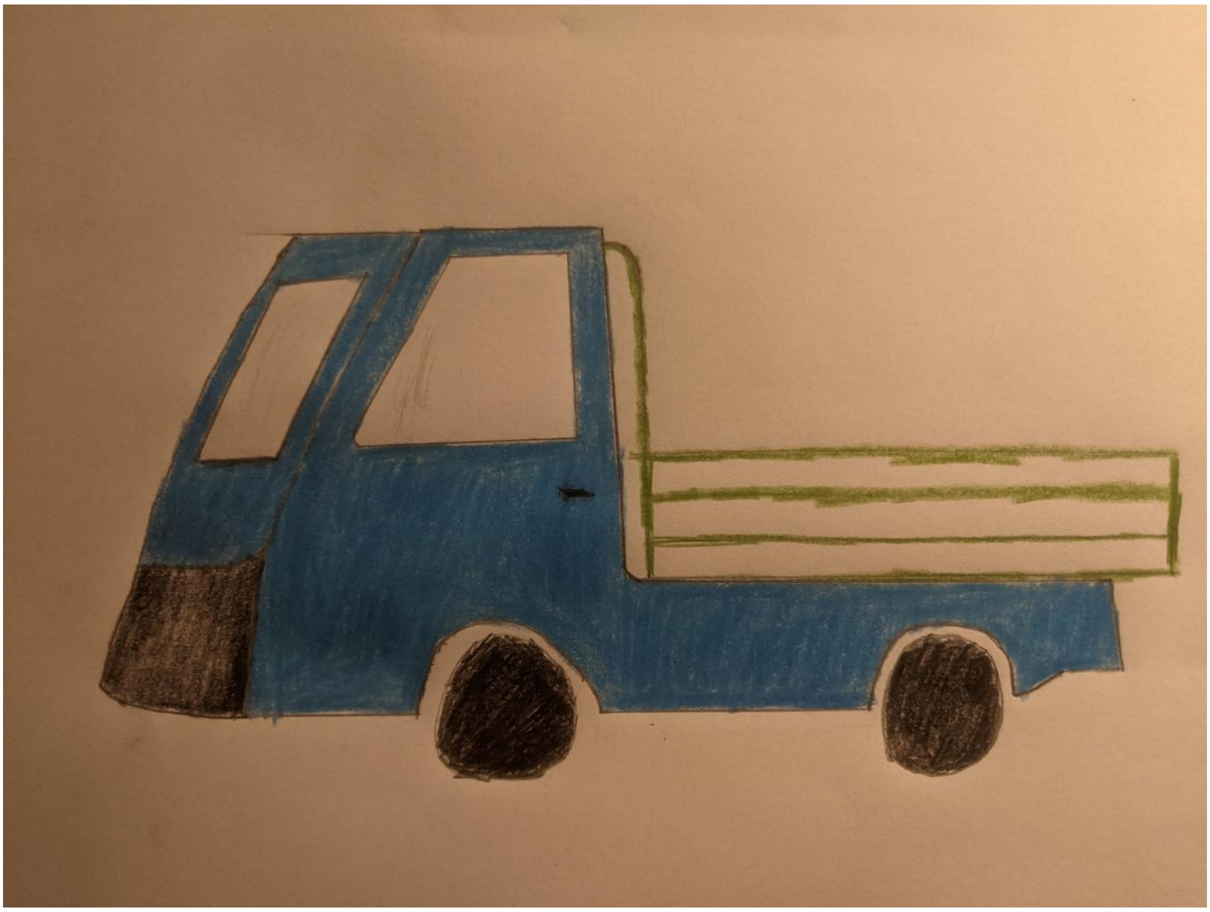
- High capacity allows for transportation of larger volumes of goods.
- Lift at back reduces risks when loading and unloading.

Cons:

- Still heavily reliant on manual labour.
- Larger size and low manoeuvrability is a liability on urban streets.
- Only allow for offloading from the back

While these delivery vehicles are very common today, I believe their downsides out way their benefits. They are well suited to transport across large areas but not within urban environments. They require large areas to be able to manoeuvre and would block narrow streets for a long time if unloading.

Flatbed Trucks



Pros:

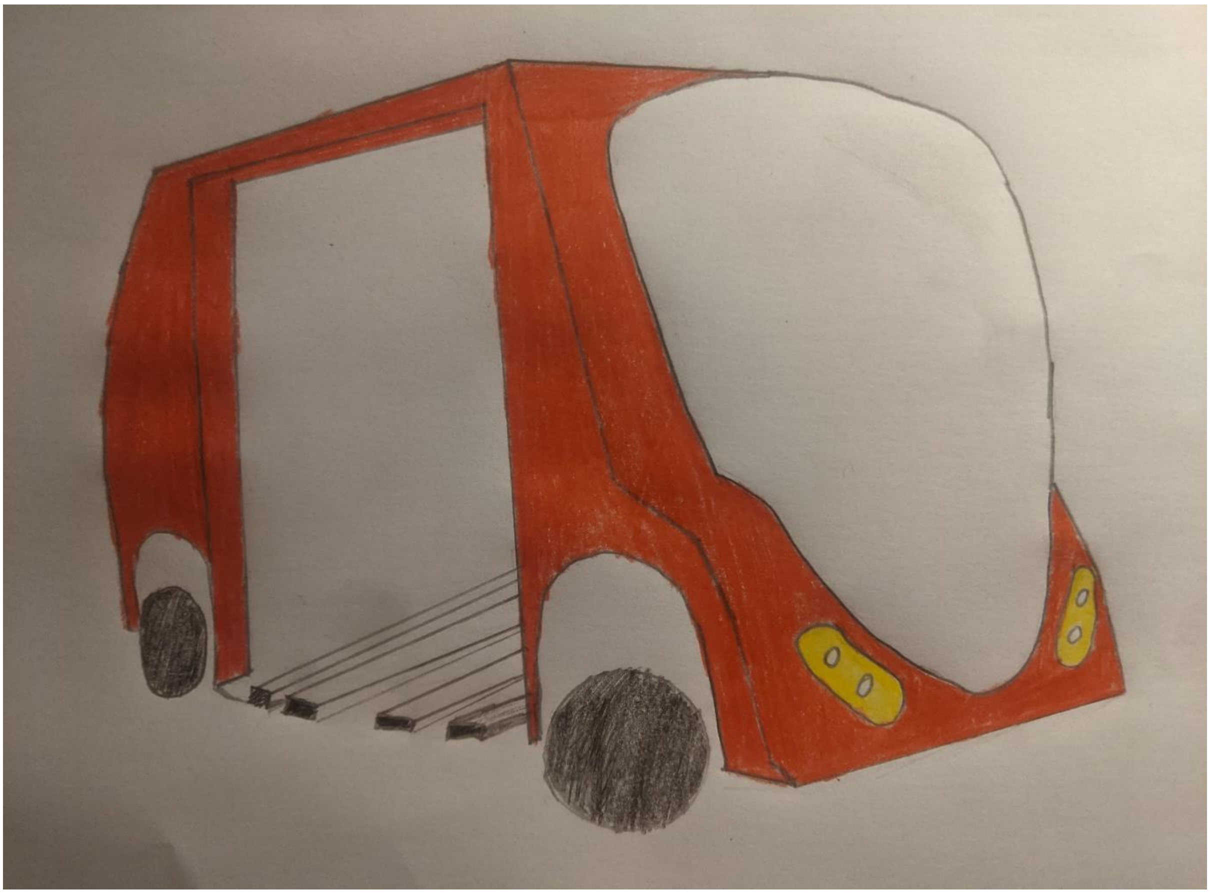
- Reasonably high capacity.
- Able to unload from three sides.

Cons:

- Completely reliant on manual labour.
- Open storage offers no protection against weather.
- Unsecured loads become serious hazards.

These vehicles are generally more appropriately sized for urban streets and their flexibility in offloading is highly advantageous, but this flexibility is at the expense of greatly increased risk to those unloading. Their cargo is also limited in size and shape as if it is taller than the side railings there is a risk of the cargo being lost. Additionally, cargo is limited as to eliminated anything that cannot be adequately protected against water damage due to the lack of rain cover.

Furbot



Pros:

- Fully autonomous loading-unloading mechanism.
- Small profile well suited for urban streets.
- Fully electric design allows for low weight-high efficiency design.

Cons:

- Relatively low capacity.
- Only allows for unloading on one side.

The EU Furbot project has many benefits; it successfully addresses the main issues I see in current designs. The loading-unloading mechanism protects workers, cargo, and saves time overall. The smaller vehicle is better suited to urban environments. The main downside is the low capacity which is why the project also impressed the need for these vehicles to be used within a wider fleet.[11]

[11] https://cordis.europa.eu/article/id/92707-futuristic-freight

Autonomous Control Solutions

Although not strictly necessary to control the most basic functionality required for this project, I believe a microcontroller to be necessary to fully realise my vision for this project. I would like the option of including features such as autonomous, remote, and x-by-wire control as well as a more advanced drive train.

I have person experience with the two main options for these applications: The Raspberry Pi[12] and the Arduino Uno[13]. Each of these options offer their own advantages and disadvantages which will factor into my choice for this project.

In my research into these solutions, I also discovered the ESP developer boards which are based off Arduino architecture while offering some potential additional benefits. I will compare these options together against the Pi and Arduino Uno.[14]

In my consideration of these solutions, I will focus mainly on price, power requirements, programming, relevant functionality, and overall suitability.

[12] https://www.raspberrypi.org/products/raspberry-pi-4-model-b/specifications/
[13] https://store.arduino.cc/arduino-uno-rev3
[14] https://makeradvisor.com/esp32-vs-esp8266/

Raspberry Pi

Price: €35-60 (Ram dependent)

Power Requirements: 5V 2A input recommended.

Direct battery power also unrecommended due do architecture and high base power draw.

Programming: Fully functioning computer operating Linux, supports most languages but Python generally offers the best balance between functionality and ease of use.

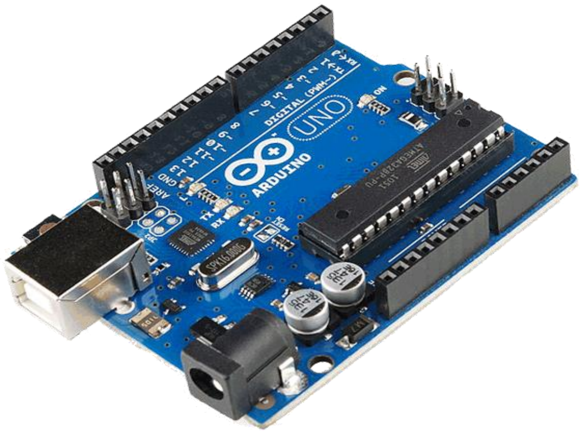
Relevant Functionality:

- 40 GPIO (General Purpose Input Output) pins, digital only
- 5V max output
- Built-in WiFi
- Built-in Bluetooth
- Greatest processing power on this list

Overall Suitability: The Raspberry Pi is a very attractive choice for the brain of my project. The operating and output voltage are within my 9V maximum. Both WiFi and Bluetooth offer effective remote-control capabilities.

Unfortunately, I can see several factors of this device which would be problematic in my project. While the Pi has an expansive number of GPIO pins they are limited to digital input-output. This limits sensor and motor control capabilities greatly. The board also has a very high base current draw which only increases with every functionality used, this is an issue if I intend to make use of battery power as they would have very short operating times, which would be impractical and wasteful.

Arduino Uno



Price: €20

Power Requirements: 6-12V input recommended, numerous supply options.

Programming: C++ through the Arduino IDE. Generally, more complicated than Python but much less resource intensive.

Relevant Functionality:

- 14 GPIO pins, Analogue and Digital
- 5V max output
- Many optional "shields" further expand on functionality
- Only limit on sensors and components is power requirement

Overall Suitability: The Arduino Uno is in many ways the reverse of the Raspberry Pi. It makes use of the bare minimum and offers the same in return. This is a strong advantage when it comes to power consumption, where battery power is both much simpler and more sustainable. The GPIO pins offer both digital and analogue input-output which is very advantageous even if it has almost only a quarter of the Pi's pins.

Of course, bare minimum also means sacrificing functionality, potentially very useful features such as on-board WiFi and Bluetooth are not possible with the base Uno and expensive to replicate with dedicated components.

ESP Developer Boards

ESP-8266[15]	**ESP-32**[16]
Price: €5	**Price:** €9
GPIO: 17 pins	**GPIO:** 34 pins
Bluetooth: No	**Bluetooth:** Yes

Past this point I will focus on the ESP-32 as it is a clear improvement on the ESP-8266 for very little price difference.

Power Requirements: 5-7V input, many options available.[17]

Programming: C++ through the Arduino IDE with "esp32 by Espressif Systems" installed through board manager. Generally, more complicated than Python but much less resource intensive.

Relevant Functionality:

- 34 GPIO pins, Analogue and Digital
- 5V max output
- Only limit on sensors and components is power requirement
- WiFi built-in
- Bluetooth classic and low energy built-in

[15] https://makershop.ie/Microcontrollers/ESP/Lolin-V3-soldered
[16] https://makershop.ie/Microcontrollers/ESP/ESP32-DevKitC
[17] https://techexplorations.com/guides/esp32/begin/power/

Overall Suitability: I was very surprised to find the ESP Developer Boards when researching potential solutions for this project. Not only do they expand on the GPIOs offered by most Arduino Boards and include both WiFi and Bluetooth as standard but they both do this at a lower price than an Arduino Uno.

These boards offer the extra features of the Raspberry Pi which I see as useful in this project contained on a board which is as power efficient as an Arduino and in a smaller form factor than both.

Loading Mechanisms

In order to satisfy the requirements of this brief I believe at least two separate mechanism working in series will be needed. An IN-OUT mechanism, that will convert rotational motion to linear motion. An UP-DOWN mechanism that will lift the cargo box off the ground.

IN-OUT Solutions

Rack and Pinion

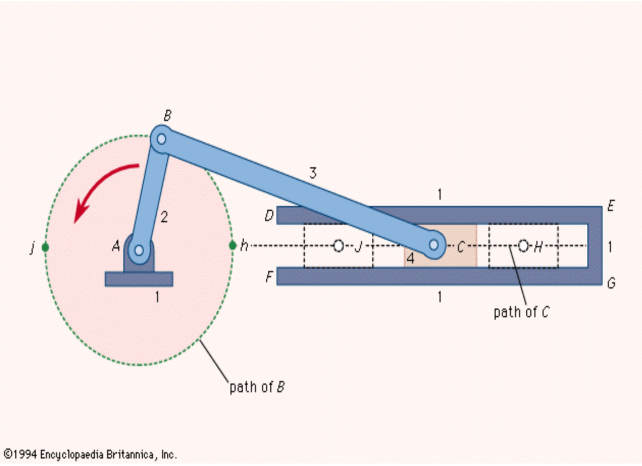
Advantages:

- Compact
- Cost Efficient
- Very Simple R-L Motion conversion

Disadvantages:

- Particularly vulnerable to the effects of friction.

Crank and Slider



Advantages:

- Good degree of power conversion
- Convert to Reciprocating motion
- Less vulnerable to Friction

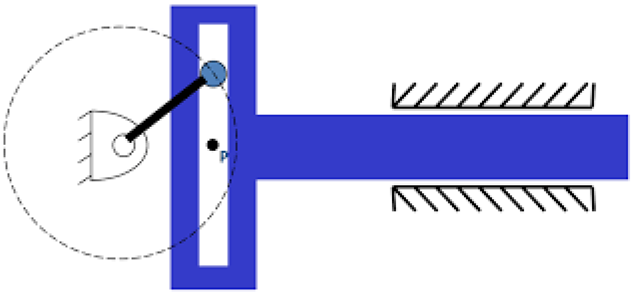
Disadvantages:

- Linear force is variable based on current position
- Requires a large space

Scotch Yoke

Advantages:

- As with Crank and Slider
- Power output less variable

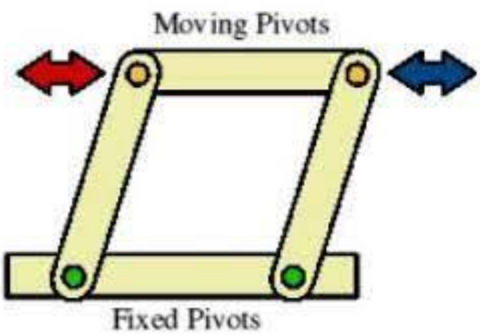


Disadvantages:

- Large space required
- Very Little extension for large Circles

UP-DOWN Solutions

Parallelogram Linkage



Advantages:

- Simple, Reliable Design
- Many options for raising and lowering

Disadvantages:

- Limited lift height

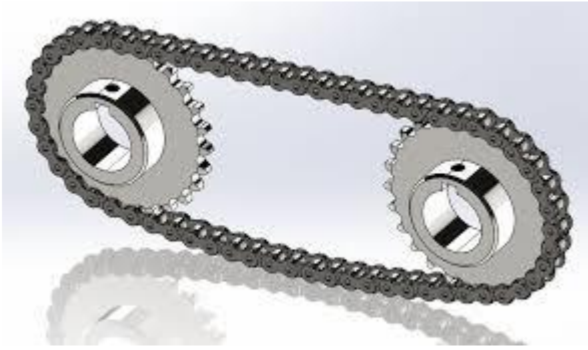
Chain Drive

Advantages:

- Precise
- Allows for greater heights

Disadvantages:

- Chain prone to failure
- Not compact



Prototyping

In my research I decided to test an augmented Cam and Slider. I replaced the usual slider with a double rack and pinion, where one rack is fixed, and both the pinion and the second rack are movable. Theoretically, this allows for greater extension in a smaller space.

I found this mechanism to work as I intended, although there were some potential issues to be kept in mind. The rack had a tendency to drift and at certain angles the downward force was limiting the outward force.

Criteria for Selection of Solution

General Model

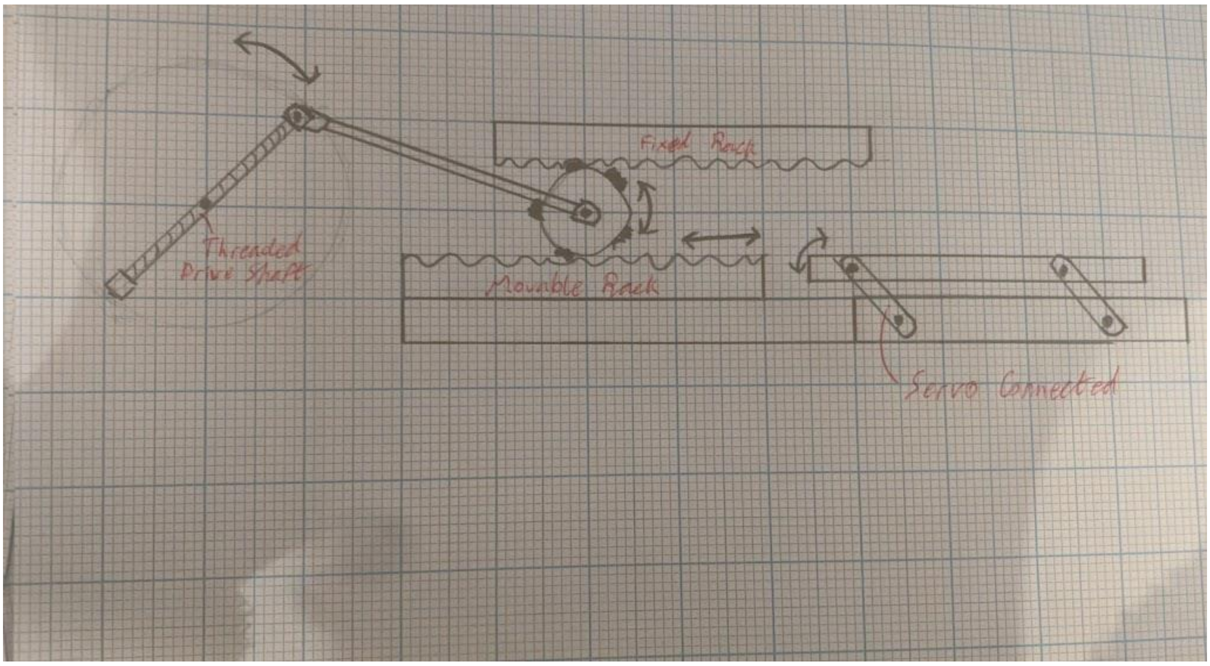
I will be basing my solution off the general design of a Furbot. It is unlikely that these vehicles will become ubiquitous soon and it will take even longer to replace vehicles currently used in urban freight. Despite this, I believe focusing on the vehicles that are currently in use would be a failure to follow this brief of designing a modern urban freight vehicle. Today's freight vehicles may be contemporary, but they are in no way modern, unlike the Furbot.

The body is could not be counted as stylish, instead being designed from a purely utilitarian point of view. The Furbot is compact enough to be highly manoeuvrable in narrow urban environments but designed with a taller body then is standard for vehicles to maintain a good cargo capacity. This lack of aerodynamic design would be a hindrance to both performance and energy efficiency in most vehicles, but not in this case. These urban freight vehicles should not be making use of high speeds or long travel times meaning aerodynamics are of limited functionality.

Autonomous Control System

I will make use of an ESP-32 micro-controller for my control system in my solution. Cost efficiency alone is a strong selling point for this over both the Raspberry Pi and Arduino, but the vast array of features makes it highly suitable for this project. With more GPIO pins than the Arduino, and the ability to use these pins for Analogue input/output unlike the Pi, I will not be limited by this board. The additional features of both WiFi and Bluetooth will be useful to control my vehicle and would be applicable to a Modern Urban Freight Vehicle on a large scale.

Loading Mechanism



I will develop my prototyped Crank and Rack and Pinion mechanism. This will extend a Parallelogram Linkage mechanism out of the side of my vehicle. This platform would move under the pallet-like slots in the bottom of a cargo box. A servo will raise the Linkage mechanism, lifting the cargo box off the ground. This will allow the full mechanism to retract, carrying the cargo with it.

I had considered using a chain linkage for a forklift style UP-DOWN mechanism but decided on the Linkage Mechanism as I believe it is better suited to an urban freight vehicle. The chain linkage would use up room that could be used for cargo storage. Additionally, the forklift operation would be both redundant and dangerous in an urban environment, as cargo should not be left above ground level and due to the lack of any counterbalance, a heavy load could turn the vehicle on its side.

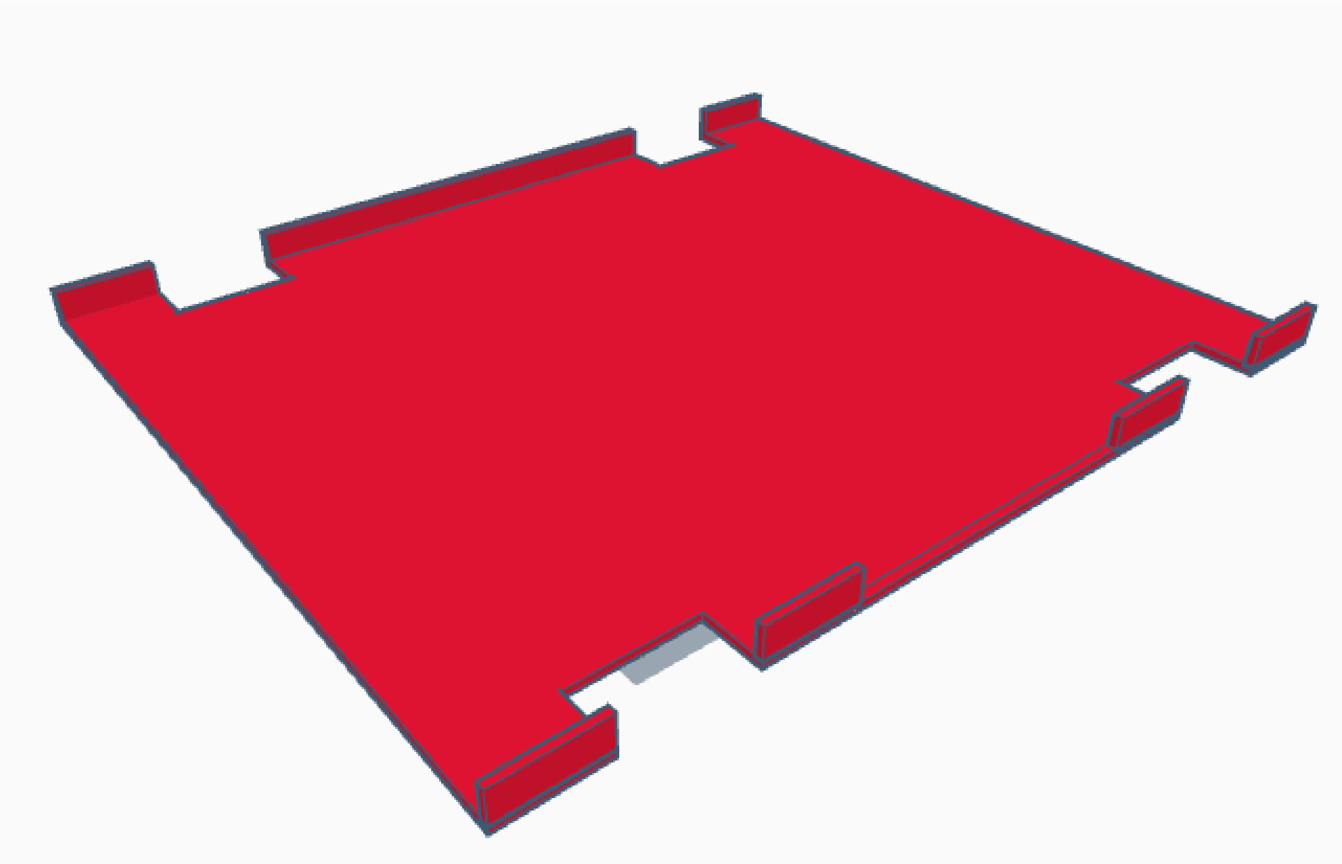
Materials

I will use Aluminium for most of my project. The high workability is highly desirable. The lightweight, durable, and anti-corrosion properties of this metal are very desirable in a vehicle.

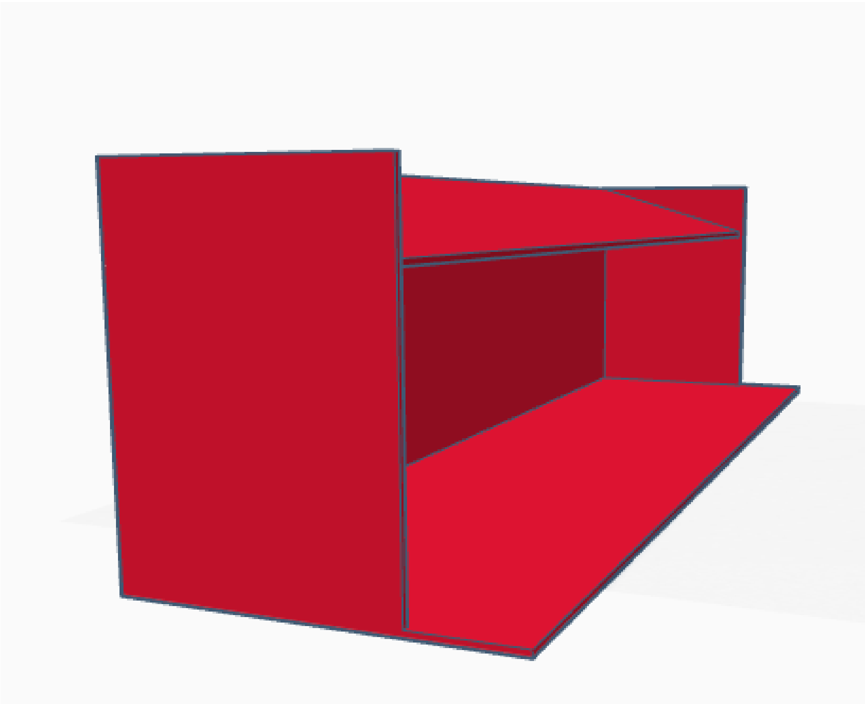
I will also vacuum form a windscreen out of clear ABS.

Production Drawings[18]

Chassis

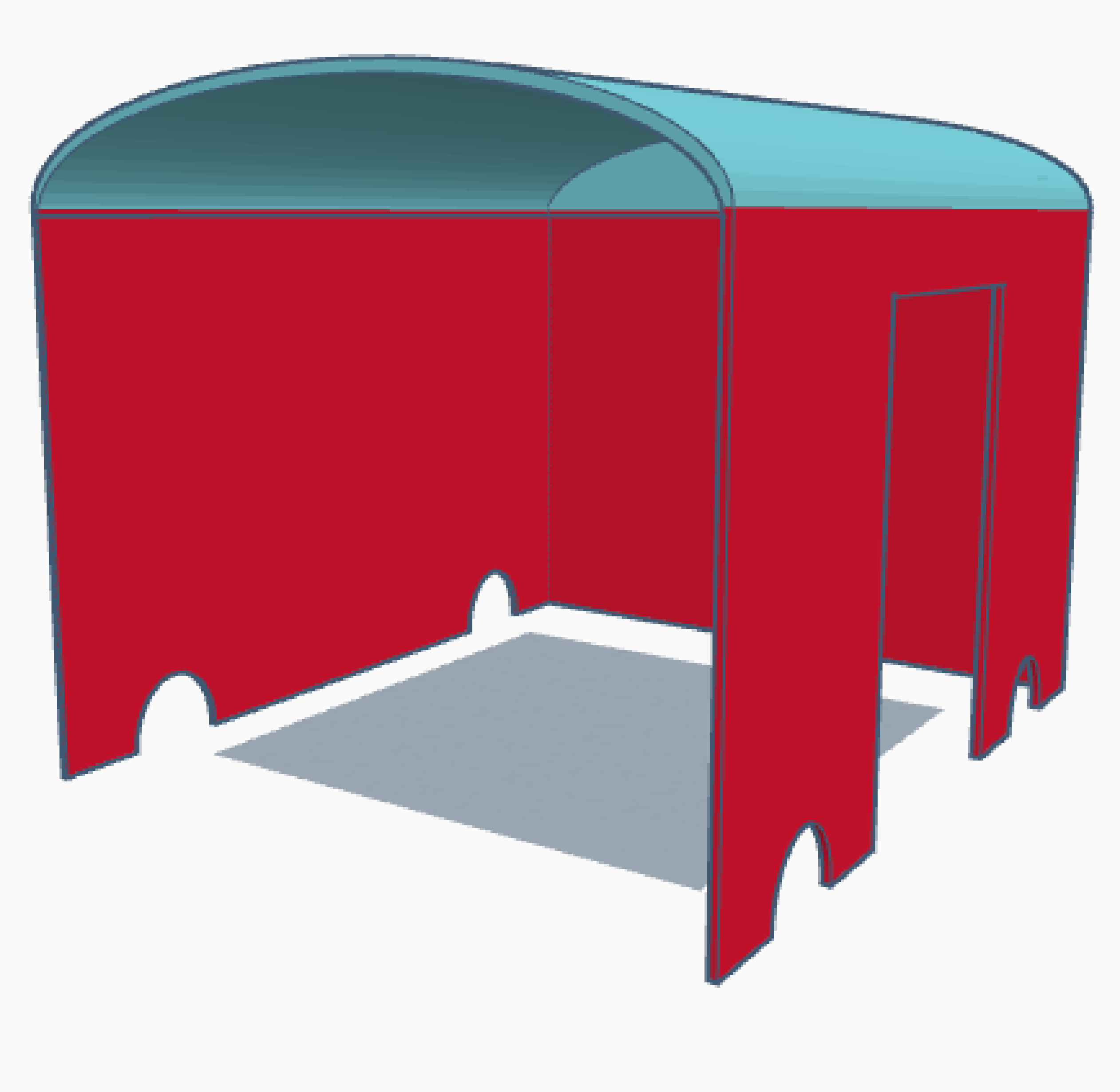


Front

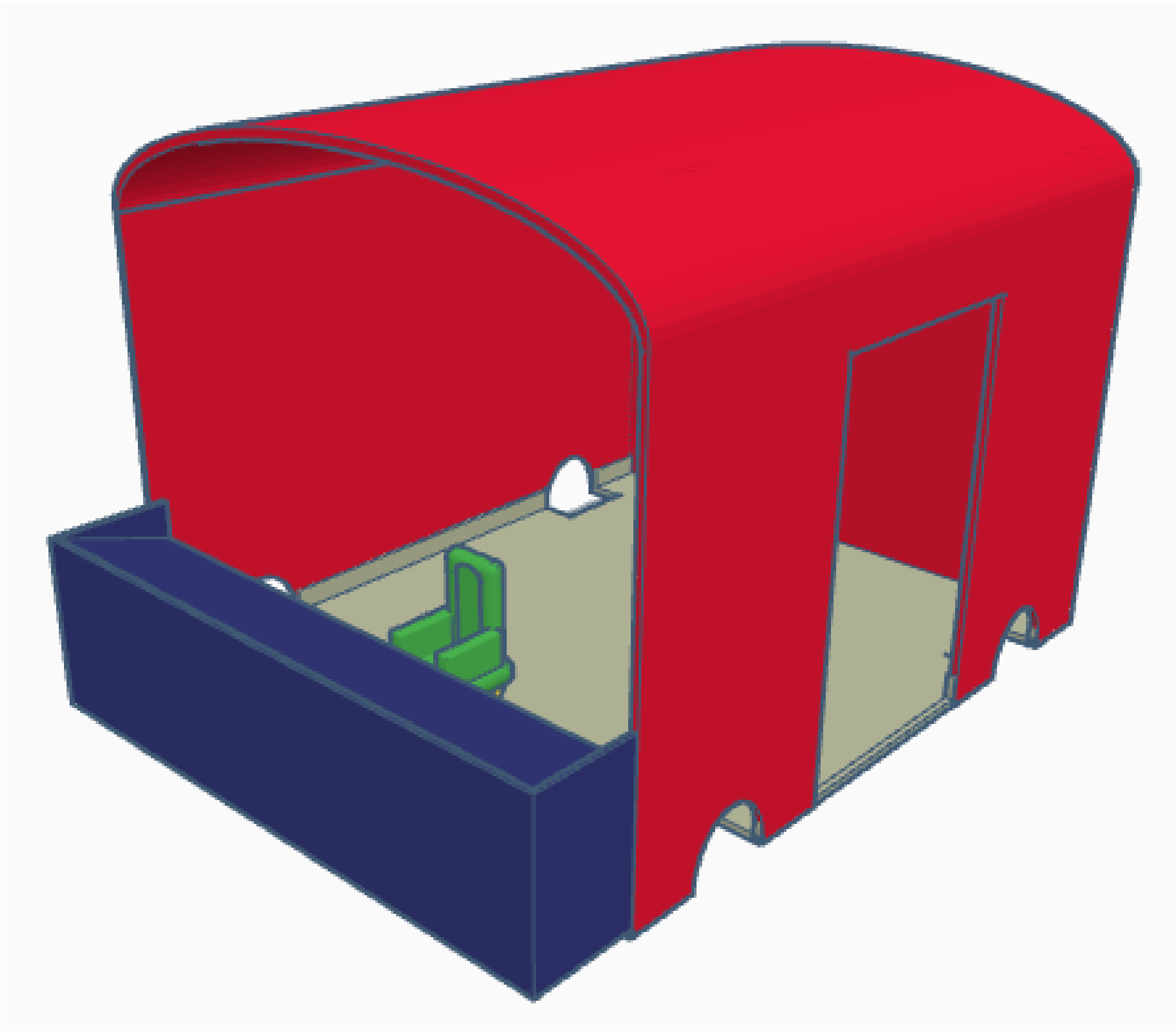


[18] STL Files on included USB stick

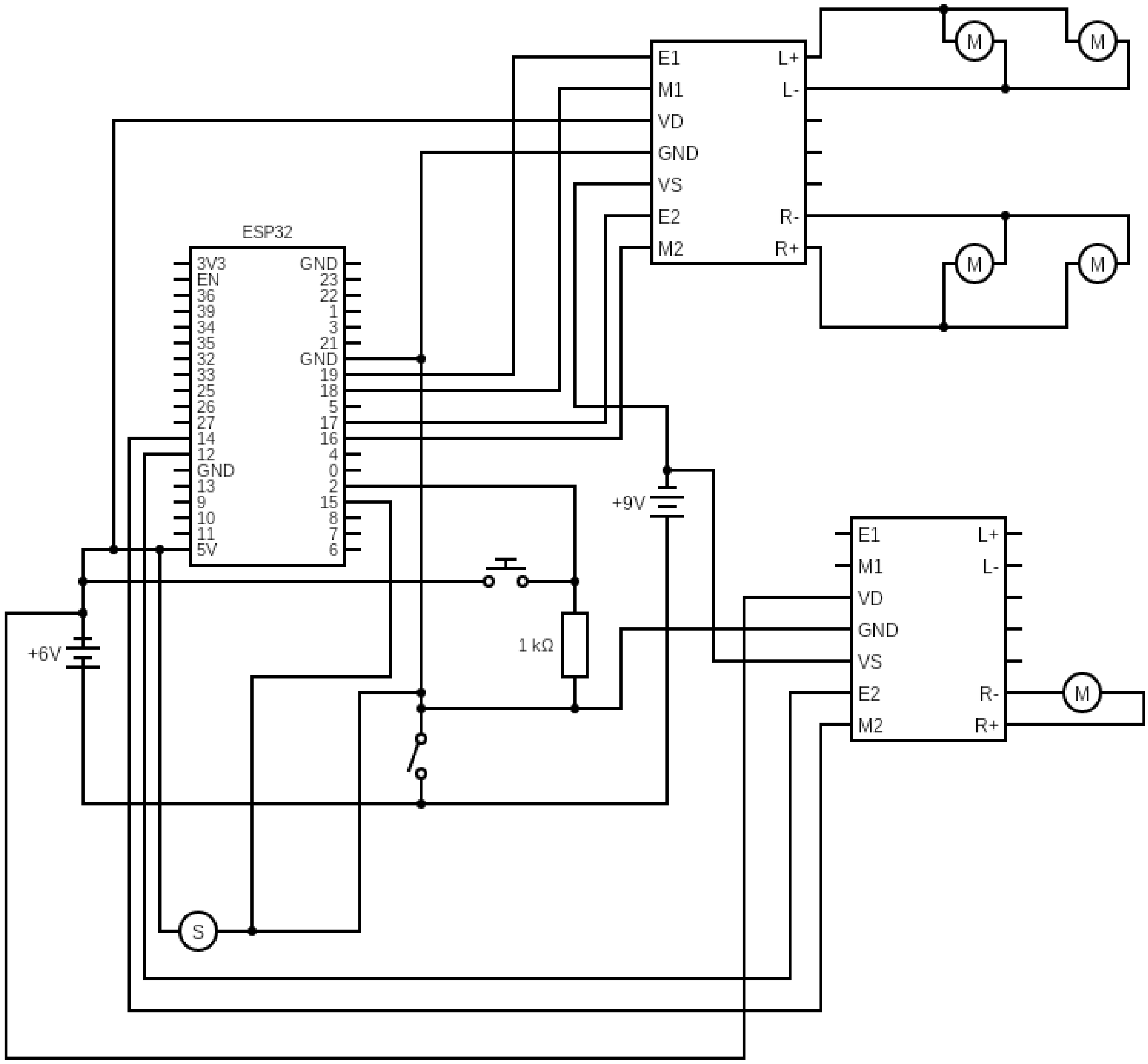
Body



Full Model



Circuit Diagram



Manufacture

Chassis

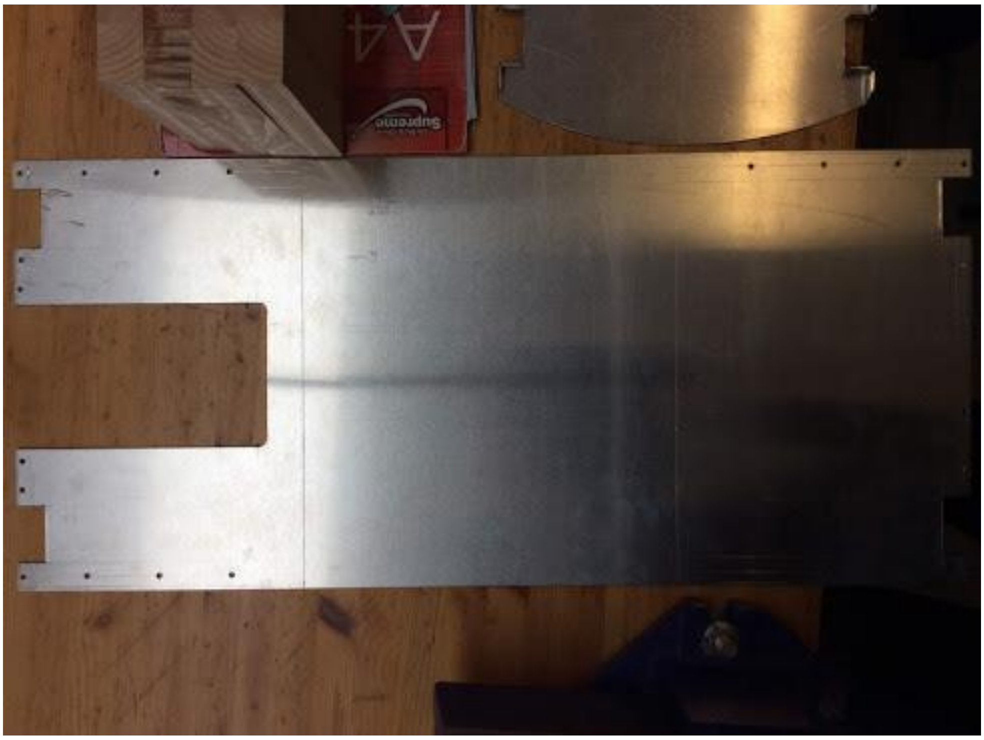
My original plan for my vehicle involved a curved back and front.

I bent up the sides of my chassis to create wheel wells and mounts for the body.

As I also wanted to curve the roof of my vehicle, I soon found this to be impractical as joining these sections would be near impossible due to the elliptical shape.

I considered shaping an approximate shape in wood and vacuum forming a solution. Due to time constraints and the lack of functionality in curving the back and front I instead decided to cut these curves away.

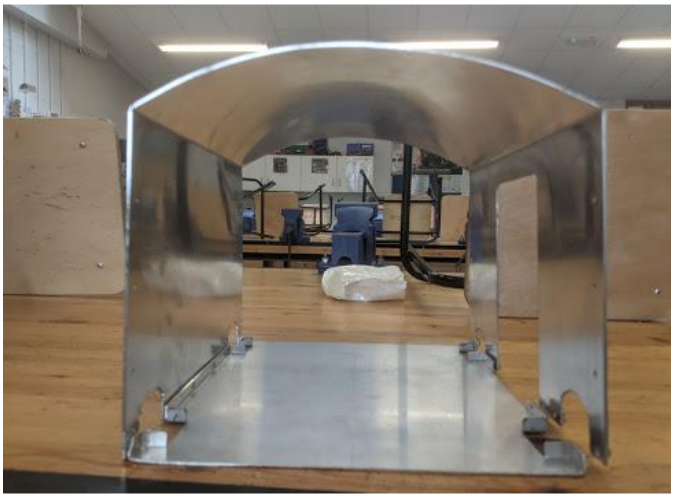
Body



I planned out and cut the sides and top from a large sheet of aluminium.

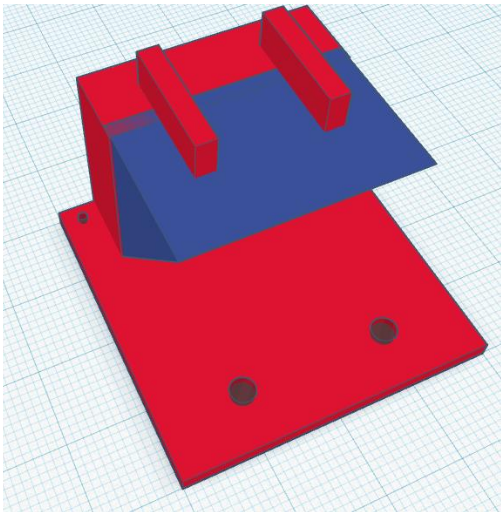
I then bent the sides to 30° before rolling the roof into a curve.

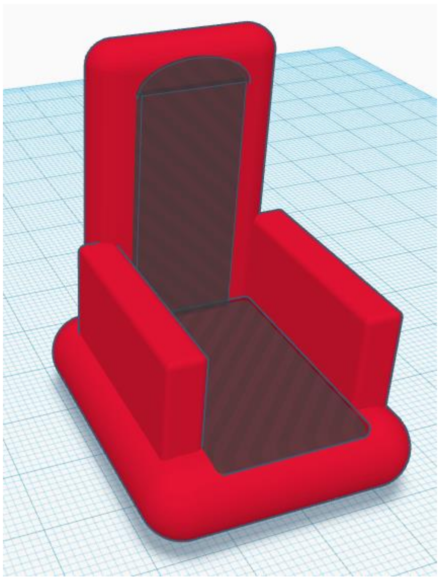
I then attached this section to my chassis and added a back plate.



3D Printing Driver Seat

I used TinkerCAD to design a single driver's seat.[19] In order to avoid "drooping" due to overhangs I designed it in two parts, with joints as part of the models, allowing for adhesive-free and bolt-free connection.





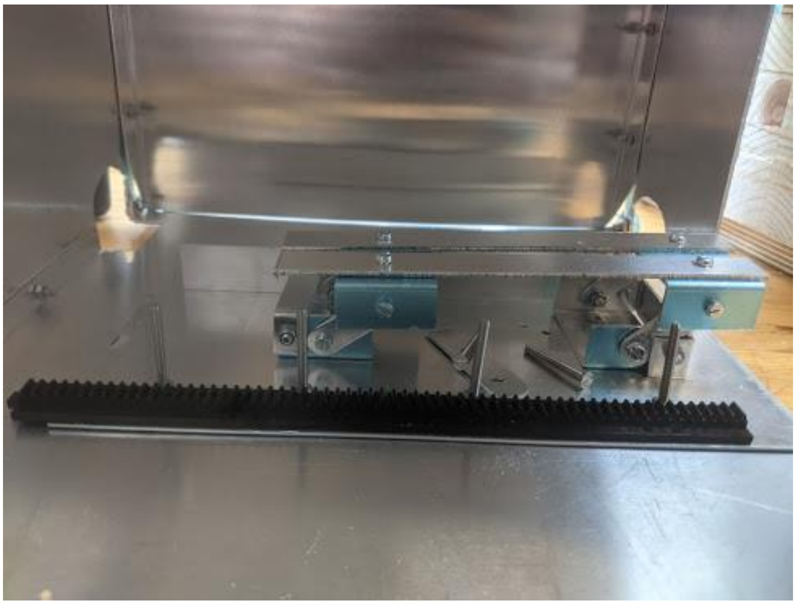
[19] STL files on included USB drive

Mechanism

I began designing my desired mechanism supported by a polycarbonate sheet. The durable and shock resistant nature of polycarbonate makes it perfect for both holding the mechanism and acting as a bulkhead to protect the driver.

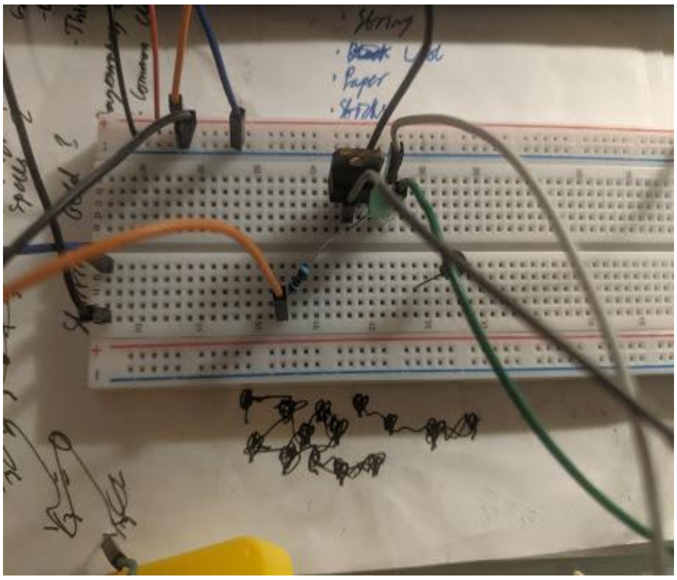
At this point I found resistance to movement and rack-drift to be far from ideal and greatly increased from my prototype. I do not believe these problems to be insurmountable. A very slight incline on in fixed rack should decrease resistance. Attaching the rack to the extending platform should also decrease or eliminate drift. This said I also had to be conscious of workshop time lost due to the coronavirus, with this in mind I decided to replace this IN-OUT mechanism with a motorised rack and pinion. With remaining time this will be less, needlessly complex, and potentially more reliable.

My UP-DOWN mechanism worked out even better than planned. It is reliably raised by a single servo motor moving through a 90° angle.



I considered adding a thin nylon sheet to the bottom of this platform to create a very low coefficient of friction, but it moves fluidly with a small amount of WD40.

Electronics and Programming

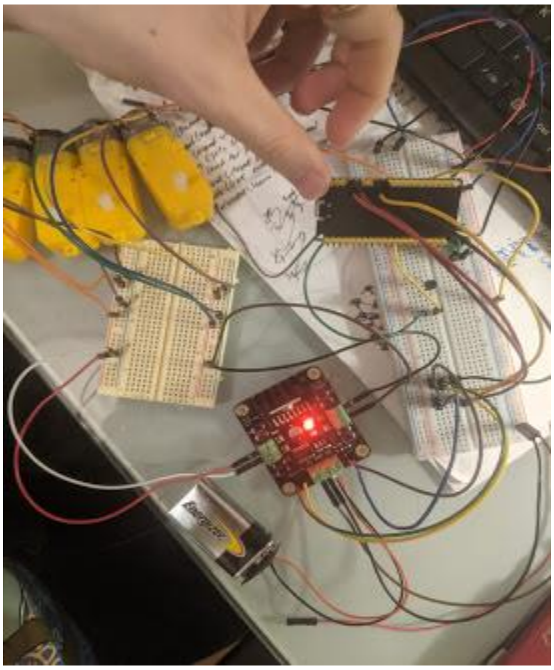


I tested using a transistor to control my motors without burning out my microcontroller.

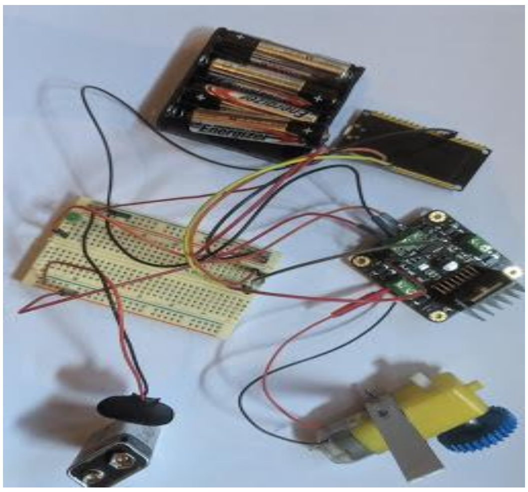
I used a TIP121 Darlington Pair as my D331's could not handle the supplied load.

I found this process highly informative, such as learning to place a diode between the Motor and the Transistor to protect against momentary back EMF when voltage to the Base is cut.

While informative, this transistor control system was impractical. Many transistors would be needed to implement directional control and the same PSU would be needed for both the ESP32 and the motors which would limit speed and power.



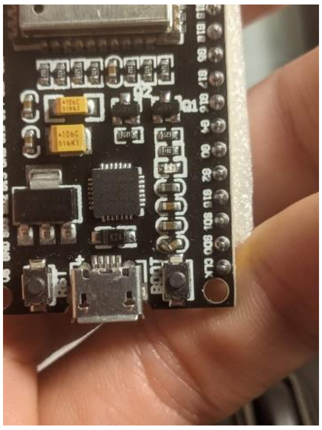
Instead, I decided to use an L298N Dual H-Bridge. One of which is sufficient to control all four motors in my drivetrain. It also allows me to run the motors off a 9V battery without damaging my microcontroller.

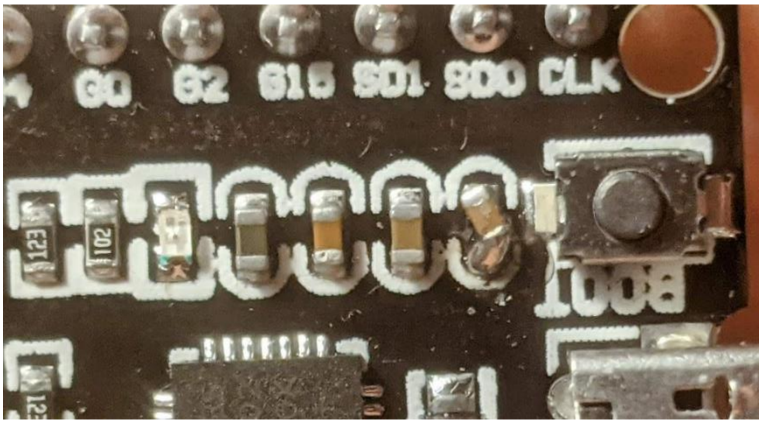


I will use a second L298N to control the pinion motor.

Broken Microcontroller

While assembling my electronics I made the disastrous mistake of miswiring my ESP32 which led to a short-circuit.

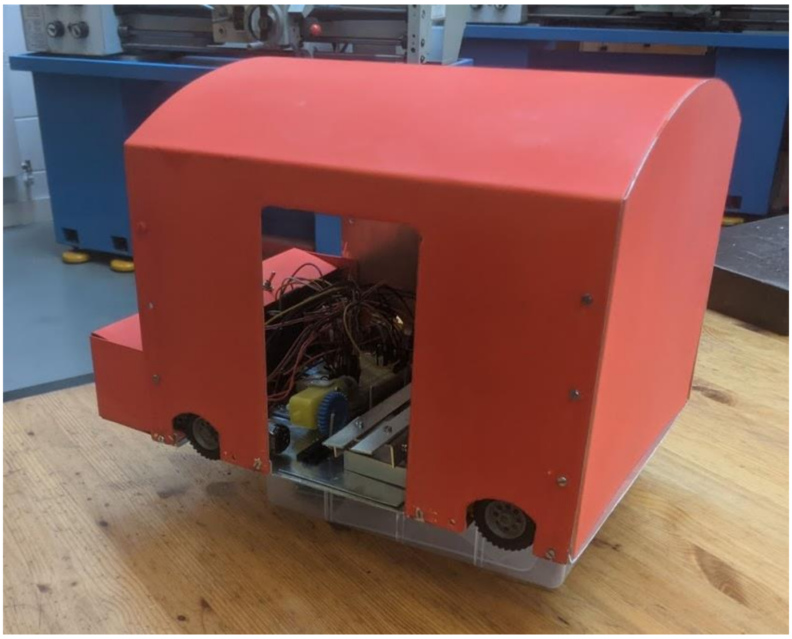




At least one ceramic capacitor was clearly fried, and the damage meant the ESP32 would no longer run or flash any code. Fortunately, I was able to acquire a replacement a few days before the deadline.

Spray Painting

As a finishing for my model, I decided to spray paint the body. I used a luminous red colour. This bright, eye-catching, colour would be an important safety feature on urban streets.



Part List

Part	Quantity	Price (each)	Picture
ESP 32	1	€9	
L298N	2	€10	
Geared Motor	5	€2	
Gear Rack	2	€0.50	

30mm Gear	1	€1.10	
MG90S Servo	1	€5	
9V Battery	1	€5	
AA (1.5V) Battery	4	€1.25	
		Total Price	€56.10

Code

Compiled in Arduino IDE with "esp32" by Espressif Systems v.1.0.6 installed through Board Manager and ESP32 Servo Library included.

```
//02 05 2021 Ex Number: 108051

#include "BluetoothSerial.h"
#include <Servo.h>

BluetoothSerial SerialBT;
Servo servo;

//Autonomus
const int Auto = 2;
int reading;

//Extender
const int M3 = 14; //M variables control direction
const int E3 = 12; //E variables control speed

//BT Commands
String message = "";

//Drive Train
const int M2 = 16;
const int E2 = 17;
const int M1 = 18;
const int E1 = 19;

```

```

void setup() {
  Serial.begin(115200);
  SerialBT.begin("108051 Engi Project"); //Device Name

  pinMode(Auto, INPUT);

  pinMode(M3, OUTPUT);
  pinMode(E3, OUTPUT);

  pinMode(E1, OUTPUT);
  pinMode(M1, OUTPUT);
  pinMode(E2, OUTPUT);
  pinMode(M2, OUTPUT);

  servo.attach(15);
  servo.write(0);
}

```

```
void loop() {
  reading = digitalRead(Auto);
  if (reading == HIGH){
    //This section is the automatic routine
    SerialBT.println("Automatic Begin");
    delay(2000);
    forward();
    delay(4000);
    halt();
    delay(200);
    left();
    delay(2000);
    halt();
    delay(200);
    back();
    delay(3000);
    halt();
    delay(200);
    extend();
    delay(250);
    servo.write(90);
    delay(1000);
    retract();
    delay(250);
    servo.write(0);
  }
```

```
if (SerialBT.available()) {
  //This section is Bluetooth Control
  char incomingChar = SerialBT.read();

  if (incomingChar!= '\n'){
      message += String(incomingChar);
    }
    else{
      message = "";
    }
    Serial.write(incomingChar);

  if (message == "ext"){
    extend();
  }
  else if (message == "ret"){
    retract();
  }
  else if (message == "up"){
    servo.write(90);
  }
  else if (message == "down"){
    servo.write(0);
  }
```

```
    }
    else if (message == "f"){
      forward();
    }
    else if (message == "b"){
      back();
    }
    else if (message == "r"){
      right();
    }
    else if (message == "l"){
      left();
    }
    else if (message == "s"){
      halt();
    }
    delay(20);
  }
}

```

```
//Functions
void extend() {
        digitalWrite(M3, LOW);
        digitalWrite(E3, HIGH);
        delay(800);
        digitalWrite(E3, LOW);
}
void retract() {
        digitalWrite(M3, HIGH);
        digitalWrite(E3, HIGH);
        delay(800);
        digitalWrite(E3, LOW);
}
void forward() {
        digitalWrite(E1, HIGH);
        digitalWrite(M1, HIGH);
        digitalWrite(E2, HIGH);
        digitalWrite(M2, LOW);
}
void back() {
        digitalWrite(E1, HIGH);
        digitalWrite(M1, LOW);
        digitalWrite(E2, HIGH);
        digitalWrite(M2, HIGH);
}
```

```
void right() {
        digitalWrite(E1, HIGH);
        digitalWrite(M1, HIGH);
        digitalWrite(E2, HIGH);
        digitalWrite(M2, HIGH);
}
void left() {
        digitalWrite(E1, HIGH);
        digitalWrite(M1, LOW);
        digitalWrite(E2, HIGH);
        digitalWrite(M2, LOW);
}
void halt() {
        digitalWrite(E1, LOW);
        digitalWrite(M1, LOW);
        digitalWrite(E2, LOW);
        digitalWrite(M2, LOW);
}
```

Testing and Evaluation

This year's Engineering Design Brief called for me to design and create a model Urban Freight Vehicle that fulfils the following requirements.

a) Be a four wheeled, single seat vehicle.
b) Have a forward propulsion unit.
c) Feature an on-board lift mechanism to enable loading/unloading of a single cargo box.

My solution has clearly succeeded in fulfilling each of these specifications. I designed and 3D printed a single driver seat which is located at the front of the vehicle. In addition to forward propulsion, my four-wheel vehicle should also be capable of turning and reversing. My model uses a rack and pinion to extend and retract a parallelogram linkage mechanism which enables the loading/unloading of a single cargo box.

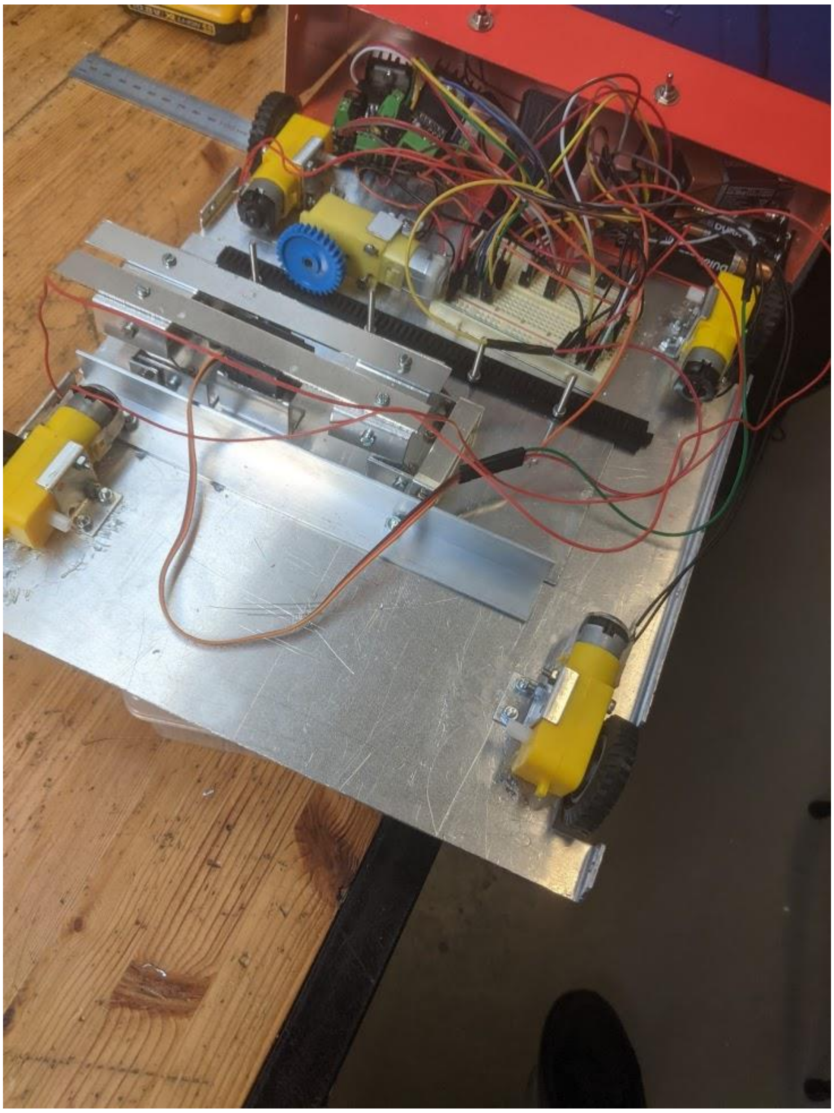
Apart from the above requirements I also made use of an ESP32 microcontroller to enable simple and affordable Bluetooth control of all operations of my Urban Freight Vehicle.

I was also conscious to ensure that:

a) All main operating features are clearly visible without dismantling.
b) The longest dimension of the vehicle does not exceed 400 mm.
c) Electric power does not exceed 9 volts.

Testing

The main areas of my project that I tested were:



- Driving
- IN-Out Mechanism
- UP-DOWN Mechanism
- Automatic Routine
- Bluetooth Control

Method

I tested of these areas alone throughout my designing and manufacture of this Urban Freight Vehicle. After bringing everything together and assembling I could feel very confident about every area with exception for driving. As a precaution, I tested the driving under both ideal and working conditions; ideal having no load on the wheels; working involving the model's full weight.

Results

In my driving test under ideal conditions, I verified that all motors functioned as desired, following all commands correctly to provide motion forwards, reversing, turning left and right. However, with the body attached for the working test, some functionality was lost. Forward and reverse motion is still fully functioning but when commanded to turn left or right the motors are unable to move. I believe this is a symptom of both my models' small wheels and my motors being insufficient for such a heavy model. Larger wheels and motors of higher torque would be a must if I where to undertake this project again or improve on my design.

Testing of all other areas was the same under both conditions and yielded the same results. The IN-OUT rack and pinion mechanism functions well, although it experiences slight drift which I would fix by placing guides on both sides of the platform. I am particularly pleased with my UP-DOWN parallelogram linkage mechanism which I have found to be completely consistent and dependable in operation. Functioning efficiently and exactly as planned.

The automatic routine, activated by pressing the normally off switch on the left side, works as programmed with exception for the turning when under load. When under load, there appears to be a momentary pause after driving forward, after which it reverses, if turning where functioning the vehicle would rotate in this time.

Bluetooth control is generally responsive in my testing, allowing each function to be controlled individually. In saying this, I do believe the use of text commands to be unintuitive when used for driving. With more time to dedicate to gaining experience and research I would have used MIT App Inventor to program a graphical drive controller.

Additional Observations

In the course of testing, I had to change out the four AA batteries once and the 9V twice. In each case the batteries where still held most of their original charge, but the high current draw of my circuit meant they were not sufficient at this point. In future projects I should look at using Lithium-Ion cells over Alkaline cells as they offer greater current supply and, being rechargeable, would be more environmentally friendly over time.

Concluding

Overall, I am satisfied with these results and with my work on this Urban Freight Vehicle. I have satisfied all the brief's specifications and added some features in addition to these. The impact of Covid-19 led to a great disruption in work and forced me to limit some of my ambitions, but I am proud of what I have achieved regardless.

What would I change?

Under ideal circumstances, there are several improvements I would make. As I have previously discussed, I originally wanted to curve the back of my vehicle. I believe the issued of an elliptical opening could have been solved with a vacuum formed filler. On the other end of my model, I would definitely vacuum form a windscreen out of clear plastic. Each of these additions would be a great improvement to the overall aesthetic of my Urban Freight Vehicle.

I would also like to clean up my electronics by replacing the breadboard with a PCB and reducing the overall number of cables. This would greatly increase space in my model and would reduce the risk of short-circuits such as the one that destroyed my first microcontroller. With this extra space, and time in general, I would also add some more passive components. Some LEDs to act as lights for the vehicle, a buzzer that would beep when reversing, and a bulkhead to protect the driver against hazards associated with freight cargo.

On the topic of electronics and programming, in my analysis I discussed X-by-wire control which I believe to be an essential safety component in modern transport. I did not have the time to implement any such system but had hopped on placing an Ultra-sonic sensor on the front of the vehicle. This would alert the microcontroller when an obstacle is close. I would condition that when this occurs all forward motion would stop; allowing the obstacle to move or the vehicle to reverse away.

Looking back, I can see ways much of this could have been achieved, even with the disruption to Covid-19. I was not decisive enough at the start of this project, instead focusing on small details in the manufacture of my solution which wasted valuable workshop time. Ultimately, this is what I have learnt to change. If I had worked at the pace I have worked since returning to in school learning, before the Christmas break, I would have been able to implement a number of the above changes and I would have saved myself a world of stress. This is a truly valuable lesson I plan to carry forward with me after this project has been submitted and after I have moved on to third level education.