# Construction and Drive System Design for a Model of a Lifter Vehicle

HAMK
UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Mechanical Engineering and Production Technology

Riihimäki 25.11.2010

*Priit Veia*

Clarification of signature.

BACHELOR'S THESIS

Degree programme Mechanical Engineering and Production Technology
Place Riihimäki

Title Construction and Drive System Design for a Model of a Lifter Vehicle

Author Priit Veia

Supervised by Timo Karppinen

Approved on 07.01.2010

Approved by Timo Karppinen

## FOREWORD

This bachelor's thesis was commissioned by HAMK University of Applied Sciences and carried out between January 2010 and November 2010.

This thesis was done in parallel with another student, Ms. Sun Xuan. This thesis is about the design and construction of the mechanical parts of a lifter vehicle model: the body, motor placements and the lifting mechanism. Ms. Sun Xuan's thesis is about designing the control system that operates the vehicle.

I would like to express my sincerest gratitude to my thesis supervisor Mr Timo Karppinen, for his guidance, insight and motivation for carrying out this thesis. I would also like to thank my colleagues: Ms Sun Xuan for her advice and good ideas about my thesis; Mr. Chew Wee Kuan in assisting me with the design and electrical arrangement; Mr. Mickael Sanial for helping keep the project on time and for designing the program for the vehicles.

However, I would not be where I am now if not for the support of my loving family: Urmas, Velda and Reemet.

Last but not least, I owe my deepest gratitude to my sweetheart Annika, who has motivated me to pick myself up when I've been down, and get this work done.

Riihimäki, Finland 17th of November, 2010

Priit Veia

ABSTRACT

Riihimäki
Degree programme: Mechanical Engineering and Production Technology
Option

**Author** Priit Veia **Year** 2010

**Commissioned by** HAMK University of Applied Sciences

**Subject of Bachelor's thesis** Construction and Drive System Design for a Model of a Lifter Vehicle

## ABSTRACT

The thesis was done for HAMK University of Applied Sciences. The purpose of the work was to design and build a vehicle that could transport cassettes, specifically designed for this purpose, between points independently. The aim of the design process was to utilize alternative design solutions to simplify production and to keep costs low, in order to produce these vehicles as easily as possible.

In the theoretical part of this thesis, different alternatives are presented to solve the problem. A detailed description is given of how the design process was done, what solutions were discarded and why the current ones were chosen. Overview will be given on the computer tools used in this thesis.

In the empirical part of this thesis, the modelling, construction and testing of the vehicles is explained in detail. The occurred problems and the solutions will be brought out. This part of the thesis required understanding of electric circuits, mechanics, component assembly, strength of materials especially in sheet metal construction.

As a result of this thesis two lifter vehicle models were constructed. They both fulfil the expected requirements of accomplishing their tasks at hand.

Future developments can be made to the vehicles in the field of lifter system design, motor types, and alternative body options, depending on the requirements.

**Keywords** Vehicle, trans-lifter, logistics, DC motor, sheet metal, 3D CAD modelling

**Pages** 57 pp. + appendices 4 pp.

# CONTENTS

1 INTRODUCTION ........ 1

2 DESCRIPTIONS OF VEHICLE VERSIONS ........ 2

- 2.1 Vehicle version 1 ........ 2
- 2.2 Vehicle version 2 ........ 3
- 2.3 Vehicle version 3 ........ 4
- 2.4 Conditions of the designs ........ 5

3 THE MAIN COMPONENTS AND TOOLS ........ 6

- 3.1 Aluminum sheet metal ........ 6
- 3.2 Aluminium profile ........ 6
- 3.3 DC motor ........ 7
- 3.4 Wheels ........ 7
- 3.5 Battery ........ 7
- 3.6 Sheet metal bending machine ........ 8
- 3.7 Milling machine ........ 8
- 3.8 DIN rail ........ 9
- 3.9 The virtual tool “ProEngineer Wildfire 5.0” ........ 10

4 THEORETICAL DESIGN ........ 11

- 4.1 The general process of design ........ 11
  - 4.1.1 The shape of the main body ........ 11
  - 4.1.2 Layout of pieces ........ 12
  - 4.1.3 Analysis ........ 12
- 4.2 MARK 1 - The first design ........ 13
  - 4.2.1 The body ........ 13
  - 4.2.2 Lifting system ........ 13
  - 4.2.3 Layout of pieces ........ 14
  - 4.2.4 Analysis ........ 14
- 4.3 MARK 2 ........ 16
  - 4.3.1 Body ........ 16
  - 4.3.2 Lifting system ........ 16
  - 4.3.3 Layout of Pieces ........ 17
  - 4.3.4 Analysis ........ 18
- 4.4 MARK 3 ........ 19
  - 4.4.1 Body ........ 19
  - 4.4.2 Lifting system ........ 19
  - 4.4.3 Layout of pieces ........ 21
  - 4.4.4 Analysis ........ 21
- 4.5 MARK 4 ........ 22
  - 4.5.1 Body ........ 22
  - 4.5.2 Lifting system ........ 22
  - 4.5.3 Layout of pieces ........ 26
  - 4.5.4 Analysis ........ 27

5 ELECTRICAL DESIGN ........ 28

5.1 Components of the circuit ..... 28
5.1.1 Relay ..... 28
5.1.2 Fuse ..... 28
5.1.3 Limit switches ..... 29
5.1.4 Inductive sensors. ..... 30
5.2 Safety circuit ..... 31
5.3 Placement of sensors and switches ..... 31
5.3.1 Lifter switches ..... 31
5.3.2 Safety bumpers ..... 32
5.3.3 Detector sensors ..... 32

6 THE CONSTRUCTION OF THE MODEL ..... 33

6.1 The main body ..... 33
6.1.1 Cutting the profile to length ..... 33
6.1.2 Milling the pockets into the profile ..... 33
6.1.3 Holes on the profile ..... 35
6.1.4 The base plates ..... 36
6.1.5 Assembling the main base ..... 38
6.2 Wheel and lifter system supports ..... 39
6.2.1 Vehicle version 2 wheel fixtures ..... 39
6.2.2 Vehicle version 2 lifter system supports ..... 40
6.2.3 Vehicle version 1 improved support pieces ..... 41
6.3 Free wheel axis bar ..... 42
6.4 Attaching the driving motors and the wheels ..... 43
6.4.1 Preparing the wheels ..... 43
6.4.2 Attaching the motor to the body ..... 44
6.4.3 Attaching the wheel to the motor ..... 44
6.5 Lifter system ..... 44
6.5.1 Manufacturing the lifter legs. ..... 45
6.5.2 Manufacturing the 'nut-bar' ..... 46
6.5.3 Manufacturing the lifter rack ..... 47
6.5.4 Manufacturing the motor support ..... 48
6.5.5 Manufacturing the lifter screw ..... 50
6.5.6 Attaching the lifter screw to the motor ..... 51
6.5.7 Attaching the motor support ..... 51
6.5.8 Assembling the lifter legs and 'nut-bar' ..... 52
6.5.9 Attaching the motor and inserting the lifter screw in place ..... 52
6.6 Carriage connector pieces for vehicle version 2 ..... 52
6.7 Top floor for front carriage for vehicle version 2 ..... 53
6.8 Placing of electric components ..... 53
6.8.1 Vehicle version 1 ..... 53
6.8.2 Vehicle version 2 ..... 54

7 CONCLUSIONS ..... 55

SOURCES ..... 56

Appendix 1 Version 1 circuit diagram
Appendix 2 Version 1 wiring list (based on diagram)
Appendix 3 Version 2 circuit diagram
Appendix 4 Version 2 wiring list (based on diagram)

# 1 INTRODUCTION

Two miniature lifter vehicle models were constructed for the HAMK (Research and Education Centre for Technological Industries. The constructed models will be used in laboratory exercises on control systems, wireless networks in industry and telematics in logistics and transportation. The goal of the thesis is to find the best solution for an independent lifter vehicle model design and the optimal construction method.

The purpose of the lifter vehicle is to ride along a pre-defined path and upon driving under a cassette, a box specifically designed for this purpose, is lifted on the vehicle’s ‘back’. Then the vehicle will continue along the path until it reaches its ‘drop-off point’, upon which, it lowers the box to the ground.

This thesis is focused on the design and construction of the vehicle: the body, the placement and use of motors, the lifting mechanism, the circuits, and safety systems.

This thesis is a tandem thesis with another student, who designed the electrical controlling part of the vehicles. The controlling part of the vehicle consists of Programmable Logic Controllers (PLC), wireless interface systems and the relevant components. It is important to bring this up, because the weight and dimensions of these components have to be taken into account when designing the lifter vehicle.

# 2 DESCRIPTIONS OF VEHICLE VERSIONS

## 2.1 Vehicle version 1

Also known as the wired vehicle version, the first vehicle version is a car that goes back and forth along a track. The wheels are directly connected to the track so that if the track turns, the wheels follow.

Power is supplied via a wire, one end connected to a power source and the other end connected to the car. Control signals are transmitted by wire also. Altogether, two wires will connect the vehicle to a ground terminal at all times. The wires will be housed in the car, in a specific 'drum', much like the wire drums in vacuum cleaners.

*Figure 1* will give a rough general idea of what components make up the entire system.

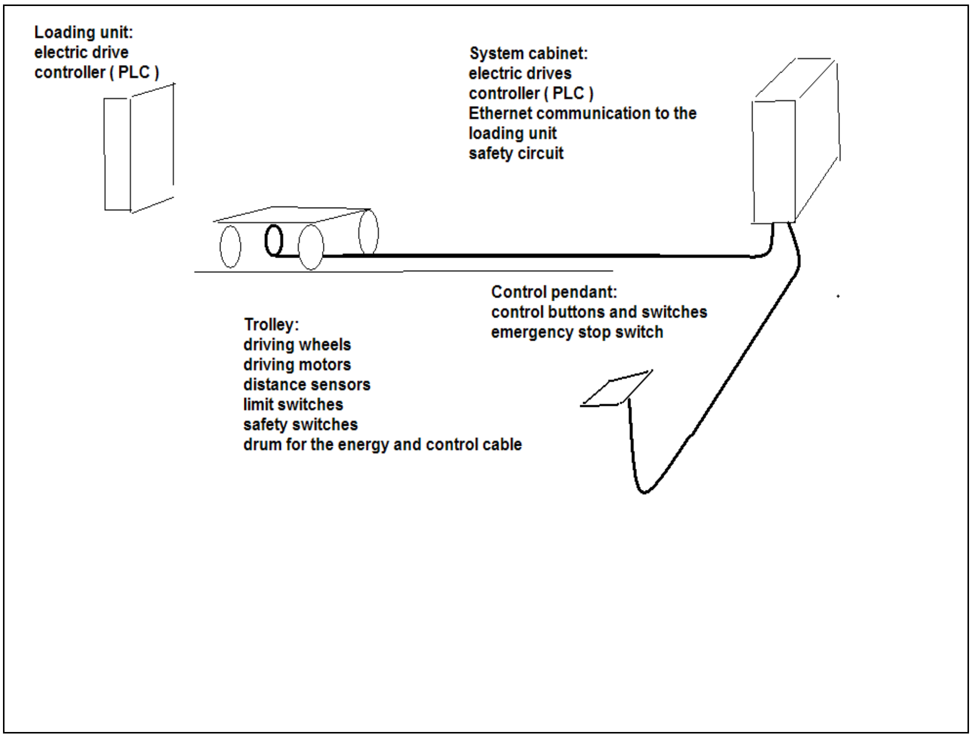



FIGURE 1 *The overall system for the first version*

The vehicle is equipped with metal detector sensors to detect whether it is under a metal box or not.

Switches will be placed to the front and rear - in case the car runs into an obstacle, a wall for example, then the switch would be pressed down and the correct action taken.

## 2.2 Vehicle version 2

The second version of the design is a wireless vehicle. This vehicle would be driving only backwards and forwards. The power would be supplied by a battery inside or on the vehicle. The car can only go backwards and forwards so the front wheels should be locked in place.

The vehicle will drive under a cassette and lift it up. Once the box is lifted, the car will continue to drive to the drop off point, where it will eventually lower the box to the ground.

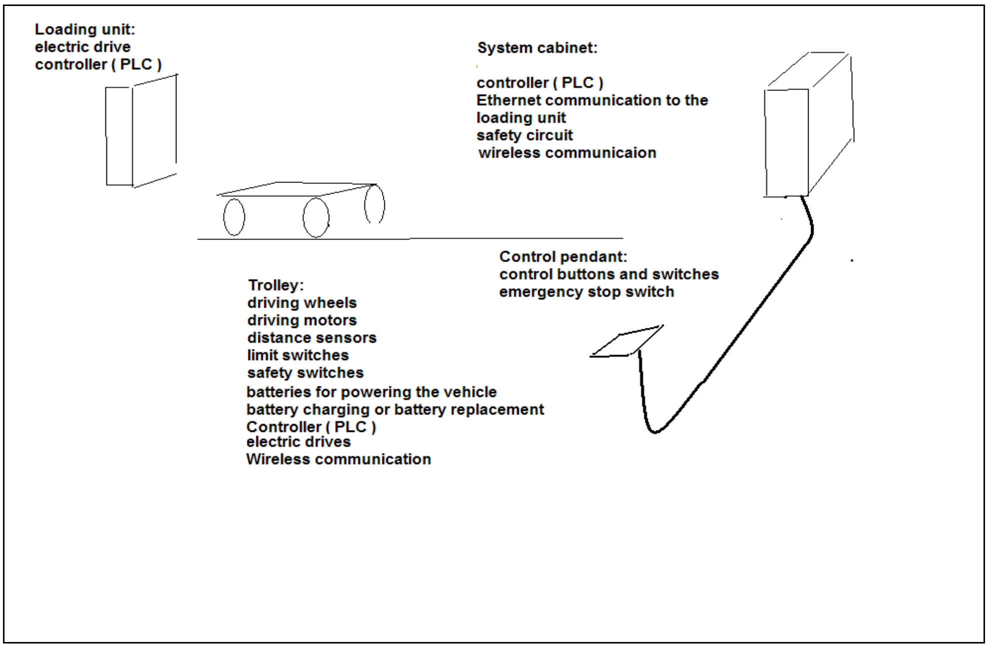



FIGURE 2 *The overall system for the second solution*

The vehicle is equipped with metal detector sensors to detect whether it is under a metal box or not.

Switches will be placed to the front and rear - in case the car runs into an obstacle, a wall for example, then the switch would be pressed down and the correct action taken.

Note: The second version project was cancelled and this will not be built nor designed.

## 2.3 Vehicle version 3

The third version will be a wireless vehicle that follows a line on the ground. Power will be supplied by a battery inside the vehicle. Instead of four wheels, this version only has three wheels. That is done as to be able to control the turning more easily. The car is designed to drive on even surface only

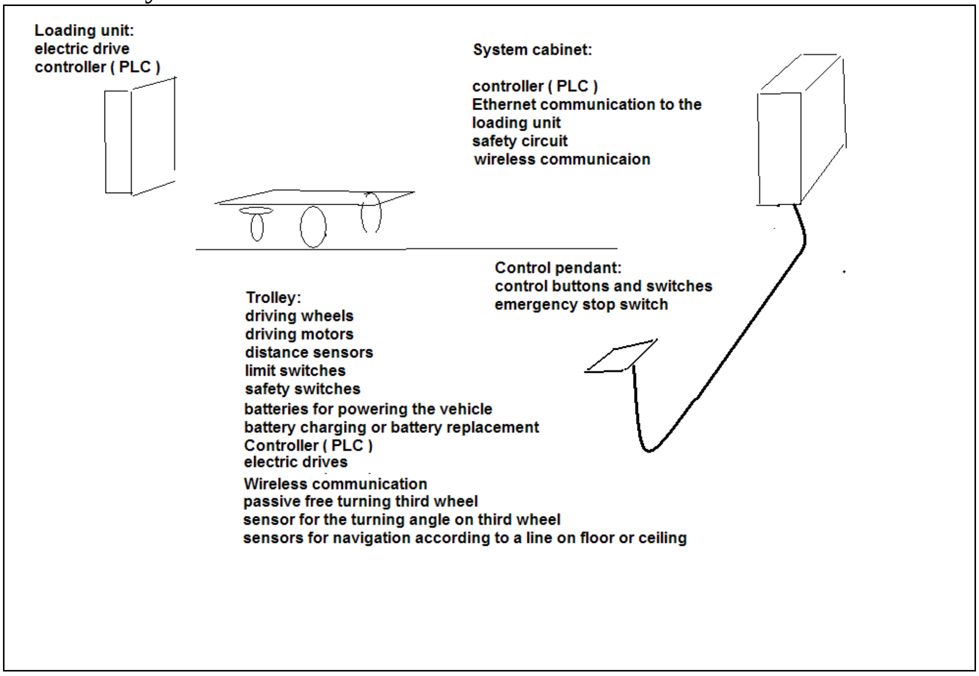



FIGURE 3 *The overall system for the third solution*

The vehicle is equipped with metal detector sensors to detect whether it is under a metal box or not.

Switches will be placed to the front and rear - in case the car runs into an obstacle, a wall for example, then the switch would be pressed down and the correct action taken.

## 2.4 Conditions of the designs

- The vehicles have to be able to lift and carry the box, specifically designed for this purpose
- The outer dimensions of the vehicles cannot exceed the inner dimensions of the box
- Bodies have to be made of aluminium metal
- The given motor will be used
- The given wheels will be used
- The vehicle must be partially autonomous

# 3 THE MAIN COMPONENTS AND TOOLS

This chapter describes the main components and tools used in this thesis. Because the same components are used in both models, they will not be mentioned separately later.

## 3.1 Aluminium sheet metal

Sheet metal is simply metal formed into thin and flat pieces. It is one of the fundamental forms used in metalworking, and can be cut and bent into a variety of different shapes. Countless everyday objects are constructed of the material. /1/

The bodies of both constructed cars are made of 3mm thick aluminium sheet metal.

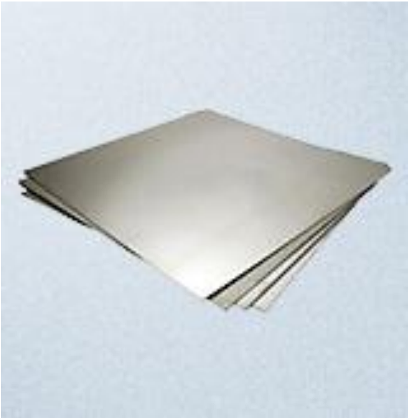


FIGURE 4 *Aluminium sheet metal /2/*

## 3.2 Aluminium profile

The profile used in this thesis is standard industrial rectangular aluminium profile. Measurements are 40x60x3 mm (Figure 5).

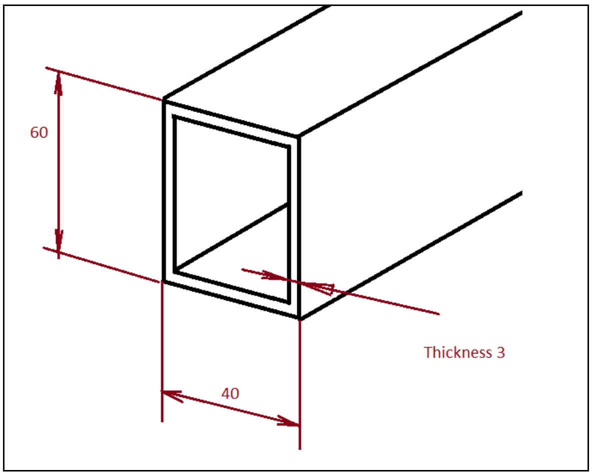



FIGURE 5 *Aluminium profile measurements.*

A 10x10x1 aluminium profile is used to manufacture the lifter system support legs.

## 3.3 DC motor

A DC Motor is an electrical motor that runs on direct current (DC) electricity. The motors used in this thesis are all of the same model: 'Bosch CHP 12 V 40 W' (Figure 6).
Nominal voltage +12V;
Nominal power 40W;
Nominal current +10A;
The attachment holes on the motor accept M6 bolts.
The screw on the revolving part accepts M8 nuts.

FIGURE 6 *The Bosch DC motor, uses worm-gear transmission inside /3/*

## 3.4 Wheels

The wheels are made of two plastic materials, a harder inside material and a softer outside material. Usually they are used on industrial furniture. The wheel is composed of two parts: the harder inside core, and the softer, rubbery outside. The outside part is softer in order to apply more resistance to the ground and to protect the core of the wheel from external forces. The outside diameter of the wheel is exactly 100mm, the inside hole diameter is 12mm, and the width of the wheel is 36mm.

FIGURE 7 *The industrial wheel used in this project.*

## 3.5 Battery

Yuasa NP7-12 7 A/H 12V Battery with Faston Terminal
Measurements: 151mm L x 65mm D x 97.5 mm H. 2.65 Kg


FIGURE 8 *Battery used in the vehicle version 2 ./4/*

## 3.6 Sheet metal bending machine

The sheet metal machine used at the workshop at HAMK University of Applied Sciences is a manual, basic design sheet metal bending machine (Figure 9). The length of the edge is 650 mm, which means that only a metal piece with the width of 650 mm or smaller can be bent.

FIGURE 9 *Manual sheet metal bending machine*

## 3.7 Milling machine

The milling machine (Figure 10) is used to create pockets, holes and grooves into metal work-pieces. The milling machine allows for the use of a variety of tools, tooltips, spinning speeds and processes. In order to manufacture a work-piece, the piece is fixed on the base of the milling machine. The spinning part of the machine stands still, while the user manipulates the placement of the base of the machine. The placement can be determined by a numerical display screen that shows the relative motions of the base with an accuracy of 0.01 mm. The milling machine is used repetitively in this thesis, because of its accurate numerical measurements.

FIGURE 10 *Milling machine*

## 3.8 DIN rail

The electrical control system components will be fixed on the vehicle by a DIN rail. The DIN rail keeps all the components tightly in place.

"DIN, an acronym for "Deutsche Institute von Normen" or "German Institute of Standards", is a worldwide standard ensuring dimensional uniformity for products regardless of the manufacturer. DIN rail is the metal rail used to mount various electrical components (for example, terminal blocks, motor starters, relays, circuit breakers, contactors, remote I/O, power supplies, etc..) in a control cabinet. Since the rail is manufactured to DIN standards, end users can select DIN rail mountable product from different manufacturers (for example, terminal blocks from XYZ Corporation and contactors from ABC Corporation) and mount them on the same rail."/5/

FIGURE 11 *A short piece of a DIN rail /6/*

## 3.9 The virtual tool "ProEngineer Wildfire 5.0"

The Pro Engineer Wildfire 5.0 is a 3D Computer Assisted Modelling program. It is a tool that many professional companies and individuals use every day. The program enables engineers to create visual demonstrations of their ideas and then manipulate them via the program to:

- Use as a mechanism, and see if all the pieces move as intended
- Assemble the pieces to other pieces
- Animate impact and shock on the body and view the results in forms of graphs and images
- Create visual animations of their concepts.

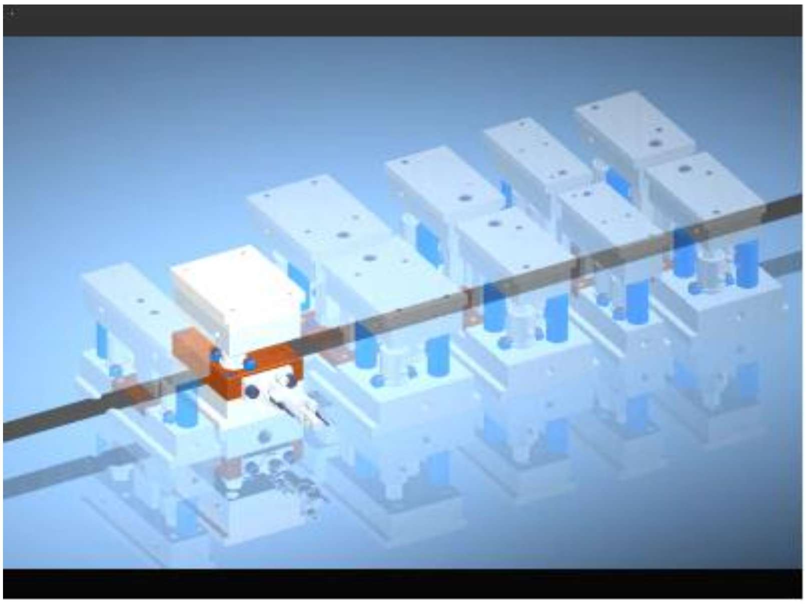


FIGURE 12 *ProEngineer manufacturing animation /7/*

# 4 THEORETICAL DESIGN

The first basic specifications for the vehicle were as follows:

- Use the windscreen wiper motors
- Use the already existing wheels
- Aluminum sheet metal body
- Car will drive under a metal box and lift it onto its 'back'

The first stage of the design process was to find out, what requirements the car had to fulfill. A list of questions was put down for finding more details for the specification.

- What shape does the car need - how many wheels, how many motors, approximate dimensions?
- How will the car turn – whether a controlled turning wheel or two motors that control the turning by driving at different speeds?
- How to tell the car that there is a box on top of it, so it would know when to lift it up?
- How does the lifting mechanism work?
- What pieces are needed in order to control the electric motors?
- How much space will be needed to house the control components and the drive battery?
- What are the power requirements?
- Do we need to equip the car with safety switches, in order not to crash it into anything? How?

## 4.1 The general process of design

The work was done by analyzing alternative solutions for each of the questions. During the course of this work, the design changed many times down to the basic type of the car.

In order to get a rough idea of the car models, they were made in the Pro-Engineer Wildfire 5.0 program.

### 4.1.1 The shape of the main body

The body is the main support structure of the vehicle. It holds all the components and the load of the carried goods. In the following designs, various options of the body will be presented and analysed.

The initial sketches for the shape and wheel placements of the main body were as shown in figure 13.

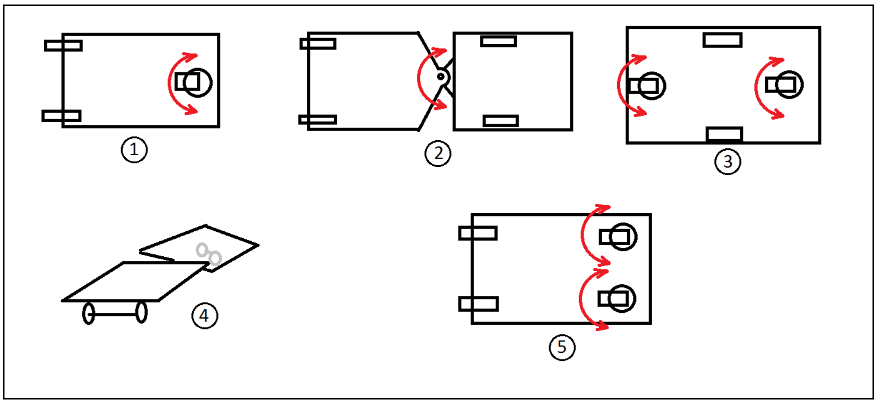


FIGURE 13 *5 first sketches. The red arrow shows the turning wheel.*

Out of those sketches option number 1 was chosen. Upon this sketch, the structuring of the pieces and their layout was built. The dimensions were added, and thus the size of the car got its overall parameters.

### 4.1.2 Layout of pieces

One of the key elements of the designs is that the pieces should fit onto the body, so that the overall size would not exceed the specified dimensions. All the components of the vehicle have to be fitted so that they would have enough space and air flow in order to keep them from overheating. Also avoiding damage to the components in case of a collision should be considered.

### 4.1.3 Analysis

In this chapter, the vehicle is analysed. Is it an acceptable design? Does it meet the standards and pre-given dimensional tolerances? Are the components placed well? What could be improved? Future development options will be presented here after analysis is done.

## 4.2 MARK 1 - The first design

In this design, the two rear wheels will be motorized, since one motor cannot run the car forward on its own. Another, a third motor will be working the lifting mechanism. The two front wheels are freely spinning for version 2 but fixed in place for version 1.

The power will be supplied by a power line dragging along behind the car in the rail. The car will move backwards and forwards by using relays, to change the direction of the current going to the motors, thus changing the rotation direction of the motor.

### 4.2.1 The body

The body is made of a 3mm thick sheet metal, shaped to resemble a box facing ground. To reinforce against buckling the ends will be folded in, and riveted to the 'ceiling' of the vehicle (Figure 14).

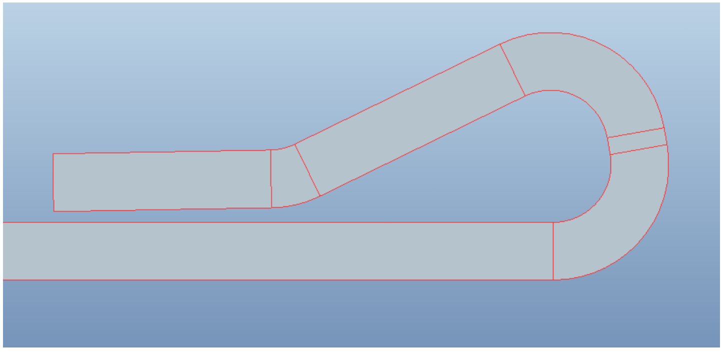


FIGURE 14 *The metal is bent around and riveted to the underside, thus creating a supporting bend, that will not allow the metal to buckle easily.*

### 4.2.2 Lifting system

Two long rails, made of steel, will be situated on top of the car. They are connected via legs from both ends of the vehicle to one of the electrical motors. When the motor rotates 90 degrees, the legs rotate, this lifting the rails up (Figure 15). The length of the legs will determine the lifting height.

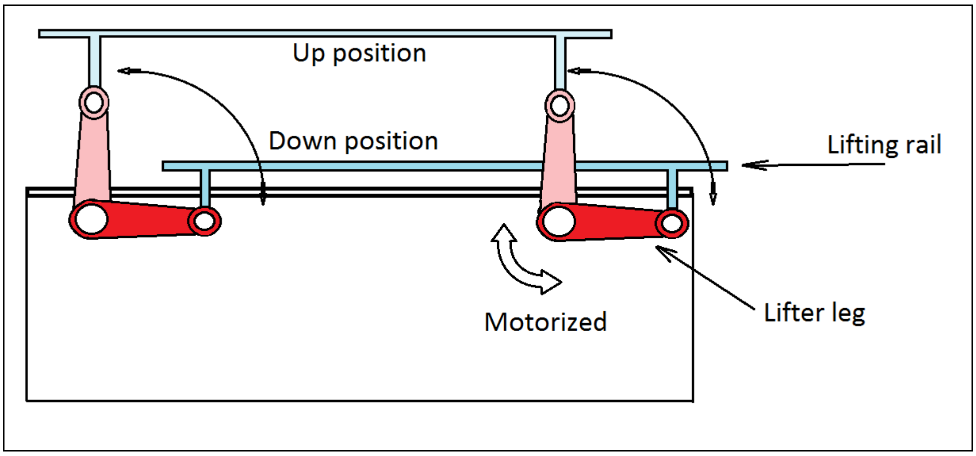



FIGURE 15 *Lifting system for MARK 1. The red legs, support the blue rails. A 90 degree turning motion of the legs lifts the rail to maximum height.*

### 4.2.3 Layout of pieces

Two motors will be directly connected to the rear wheels. The safety bumpers will be on both ends connected directly to switches.

All the components will be on the ceiling of the main body. The electrical components will be fit on the ceiling separately.

The first vehicle will be guided along the rail by two connecting rods (Figure 16).

### 4.2.4 Analysis

The lifting system proved to be problematic: there was too little room in the design for the lifting system parts. The control system components don't have enough room to be fit onto a DIN rail.

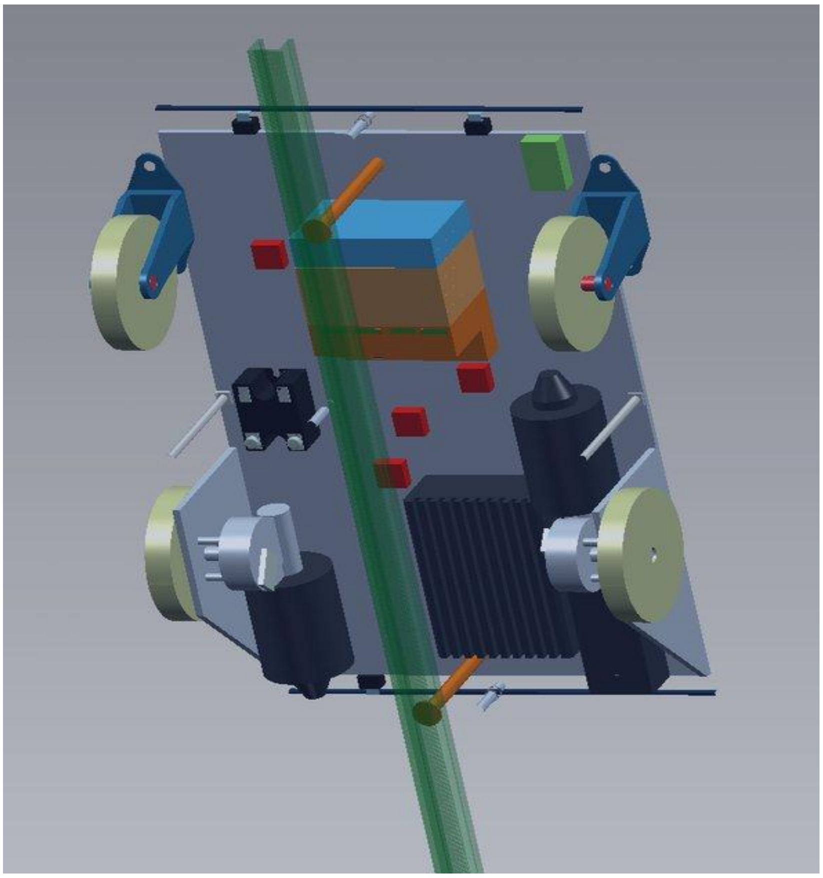


FIGURE 16 *The first design of vehicle version 1*

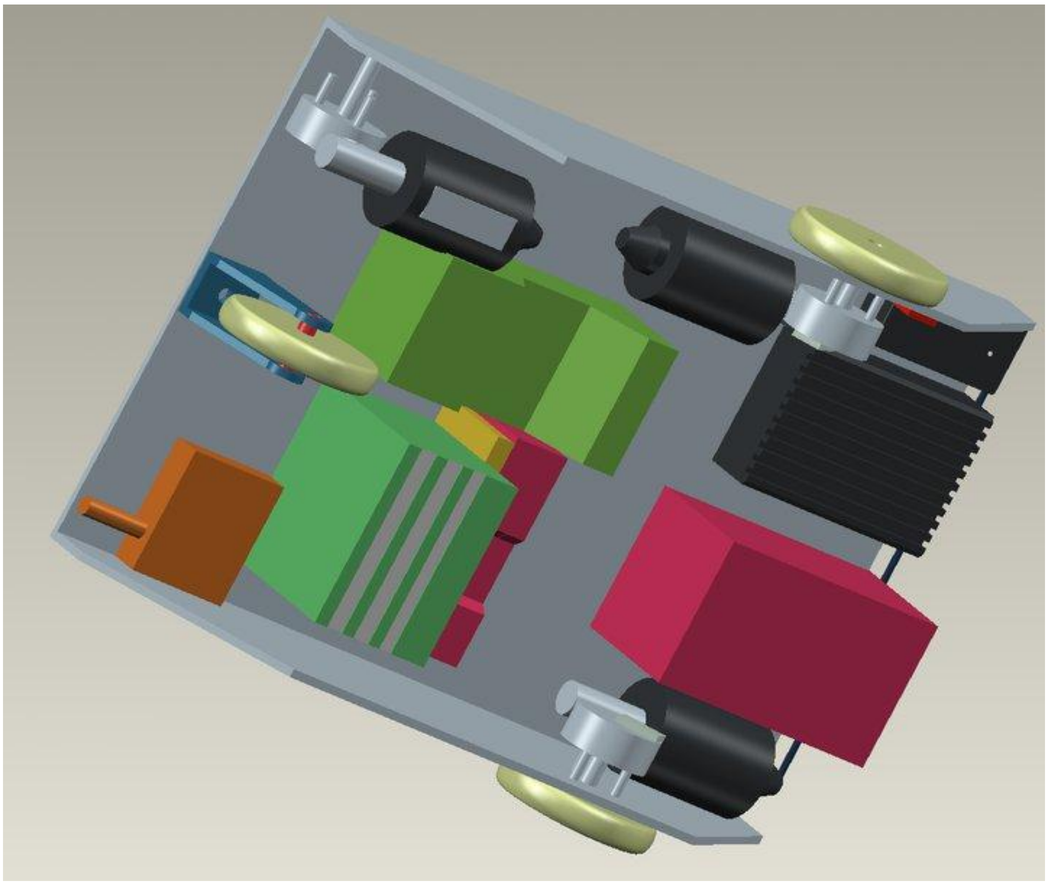


FIGURE 17 *The first design of the vehicle version 2*

## 4.3 MARK 2

Another option for the design was put on the table. This design focuses more on solving the lifting system problem.

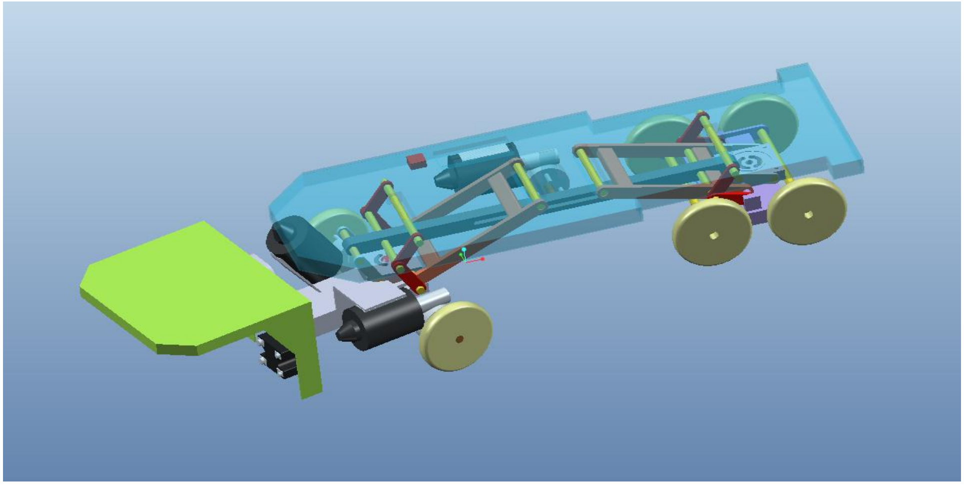


FIGURE 18 *General overview of the second design generation.*

### 4.3.1 Body

The body of the second vehicle was made to resemble a lorry car, to improve turning and to better the layout of the pieces. The front of the lorry, or the 'head' would be connected to the driving motors. Rotating the motors at different speeds allows the controller to turn the head while driving or while standing still. The head of the vehicle would be connected to the main body via a turning connection. The turning connection has a hole going through the entire piece, allowing wires to be transported through the turning piece between the 'body' and 'head'.

### 4.3.2 Lifting system

The lifting system in the second vehicle was incorporated directly into the wheel supports. A slider bar, moved by the lifter motor (Shown on figure 19 as red), flexes/un-flexes the 'knees' of the lifter system, on both the rear and front end.

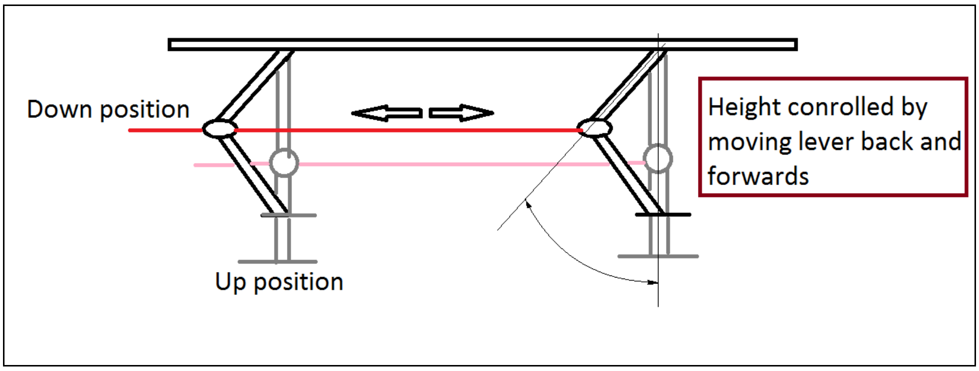



FIGURE 19 *The rough principle of the lifting system for MARK 2 vehicles.*

When incorporated into the model

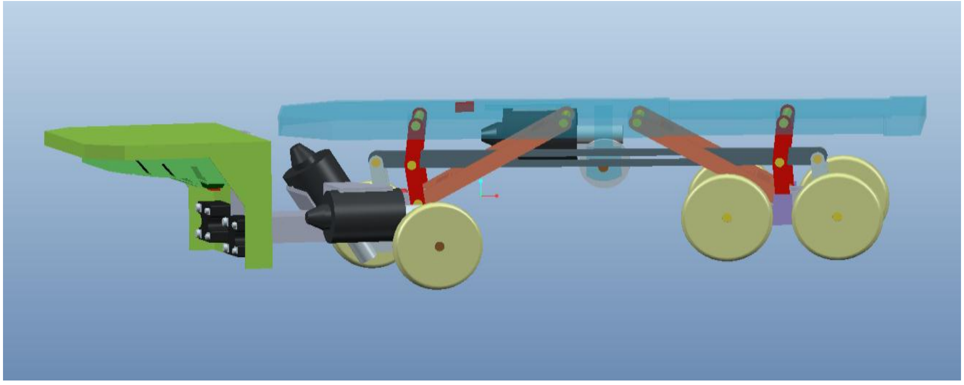


FIGURE 20 *Lifter system, straight 'knees'.*

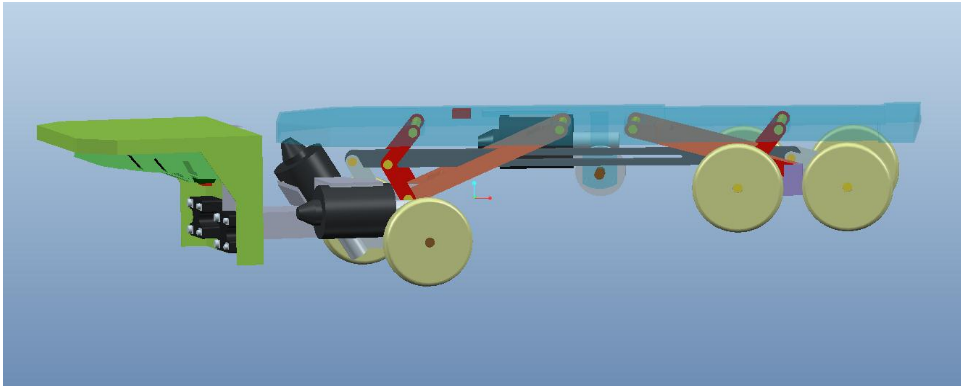


FIGURE 21 *Lifter system, folded 'knees'.*

### 4.3.3 Layout of Pieces

The head of the lorry vehicle would house the motor controllers and the PLC. This way, the PLC is protected, and is relatively close to the motors it controls (2 driving motors are very close, and the third, lifting motor is only half way to the other end of the vehicle).

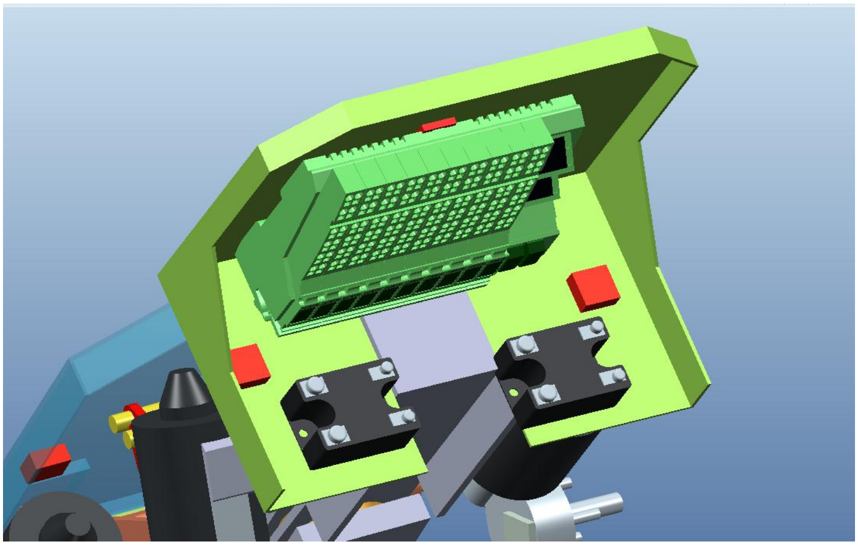


FIGURE 22 *The PLC (green), 2 relays (red) and 2 motor controllers (black) are located in the 'head' of the vehicle.*

#### 4.3.4 Analysis

Problems: Having solved the lifting mechanism problem, instantly some other problems emerged. The lifting mechanism, if constructed, would be shaky, and the threat of buckling or uneven lifting sides would remain. Another problem is the component attachment – all the components would be connected to one face of the main body, which would result in the pieces all being too close together and vulnerable to extremely uneven driving surface and the maintenance of the vehicle would be complicated due to the fact that moving and static pieces would be mixed.

## 4.4 MARK 3

This design addresses the elimination the component space problem and allows the vehicle to be built of one body part.

### 4.4.1 Body

The body was made of a single aluminium sheet, laser-cut into two dimensional shape and then forged into a three-dimensional product. Being made of a single metal sheet allowed for more durable design. At the ends of the body, several layers of sheet metal overlapped, thus reinforcing each-other (Figure 23).

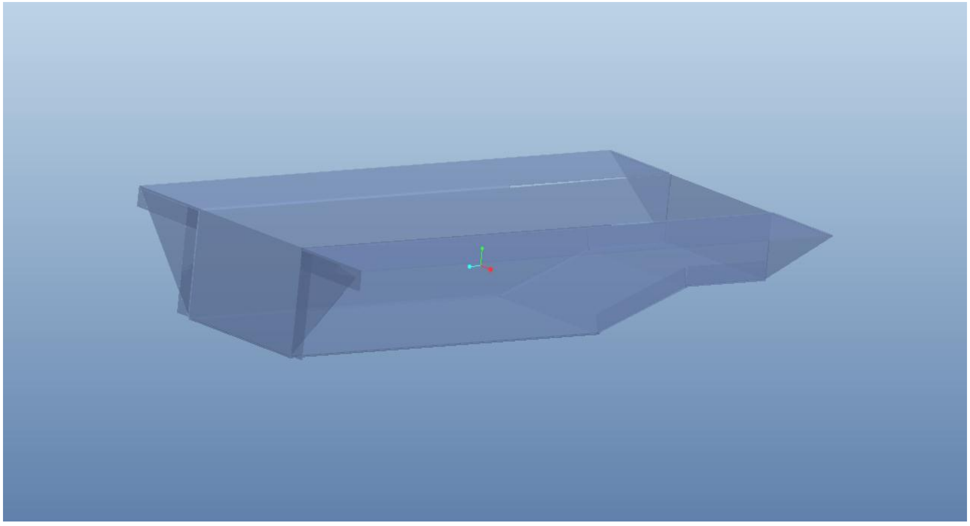


FIGURE 23 *Mark 3 vehicle chassis overview*

### 4.4.2 Lifting system

The lifting system of this version resembles that of the previous version, but it is more space conserving. As seen on figure 24 the lifting motor is situated at the rear end of the vehicle. The purple part is an extension of the body, as the motor would otherwise have little room to be fixed to the body.

The motor is connected to a long screw, shown on the image as light-green. The long screw goes through the 'nut-rod' which in essence is a nut welded to the middle of a rod. When the motor is activated, it spins the screw around, thus moving the nut forwards or backwards. The motion is slow, but the gear ratio also allows for a high torque lifting force.

The yellow arm connects the 'nut-rod' of the rear (motorized) end to the front end 'nut-rod'. The front end doesn't need a nut in the rod, but it could be used as a mobile backup (in case the rear end 'nut-rod' gets damaged, it can be replaces with the rod from the front end, and the front end can be replaced with any bar.

The force applied on the yellow arms is of stretching nature. There is no compression, since the 'pushing' is done by gravity pulling the vehicle downwards.

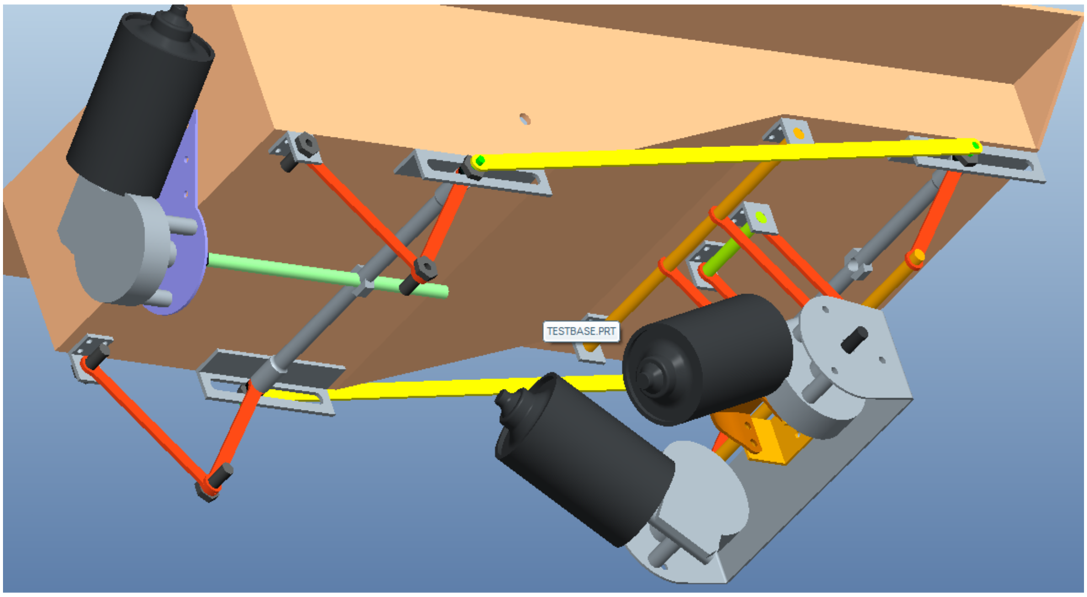



FIGURE 24 *The principle of the lifting system*

There appeared to be problems in the functionality of the connection pieces, that connect the orange 'legs' to the main body of the vehicle. If made of too weak material it might result in unwanted bending.

This problem was addressed by redesigning the separate pieces into one sheet metal piece, that is bent into shape. The sheet metal piece shown in Figure 25 has all the same dimensions as the previously separate components, but also is reinforced by riveted corners (marked as green in the figure). This construction is to be connected to the main body by rivets going through top-side holes marked on figure as red.

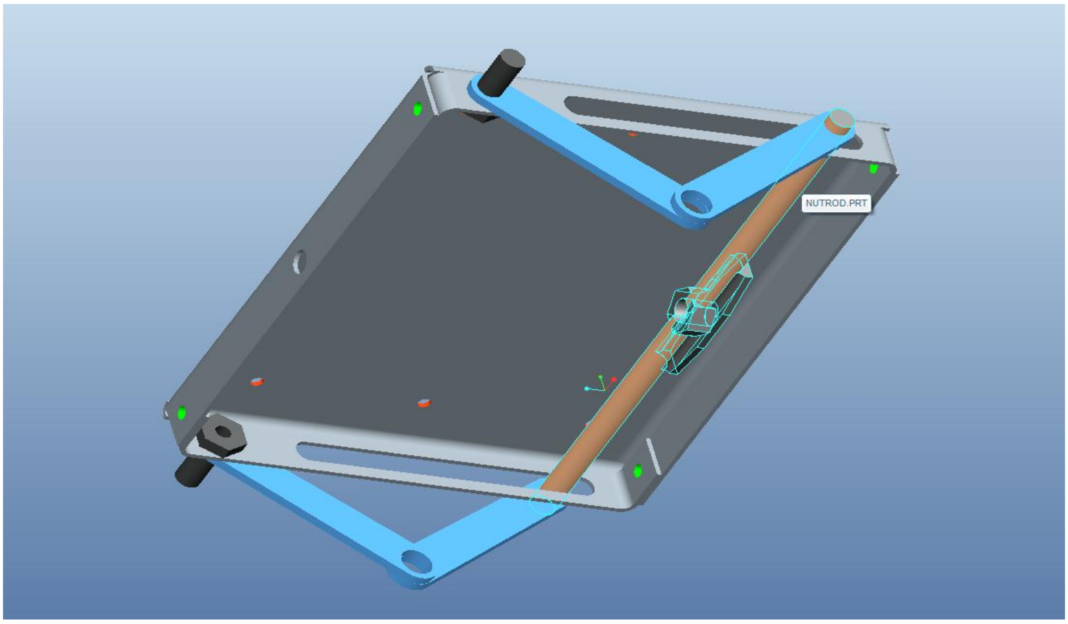



FIGURE 25 *Lifting system sheet metal frame.*

The front and rear systems were replaced by the sheet metal racks. They are still inter-connected by long 'arms', that run on the side of the vehicle and regulate the unison motion of lifting (purple legs on Figure 26).

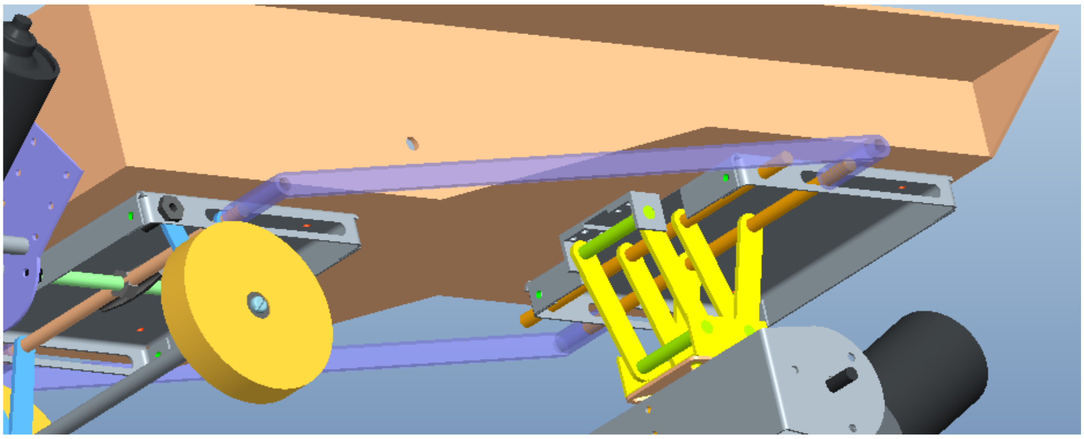


FIGURE 26 *Front and rear lifting system sheet metal racks connected*

The lifting system, compared to the previous version (MARK 2) takes up less space and is more functional than before - only selected areas at the front and at the back end (outer surface) are used, the inside of those areas is left to hold the control system pieces and power sources.

### 4.4.3 Layout of pieces

The inside of the main body, is completely reserved for components. Even if they do not fit there, the undersides of the top plate are still free for component housing. The room for the components is sufficient to allow air flow and clear wiring.

### 4.4.4 Analysis

The one-piece body design proved to be difficult to manufacture (Figure 27). Were this design to go into mass production, it would result in high costs and low production rates (long production times).

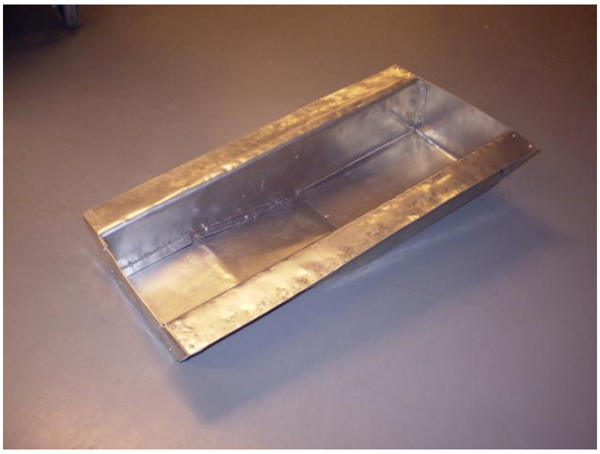


FIGURE 27 *Problems at manufacturing*

## 4.5 MARK 4

To compensate for the difficulties in building the body constructions, the folding of the aluminium sheet metal was replaced by industrial aluminium profile.

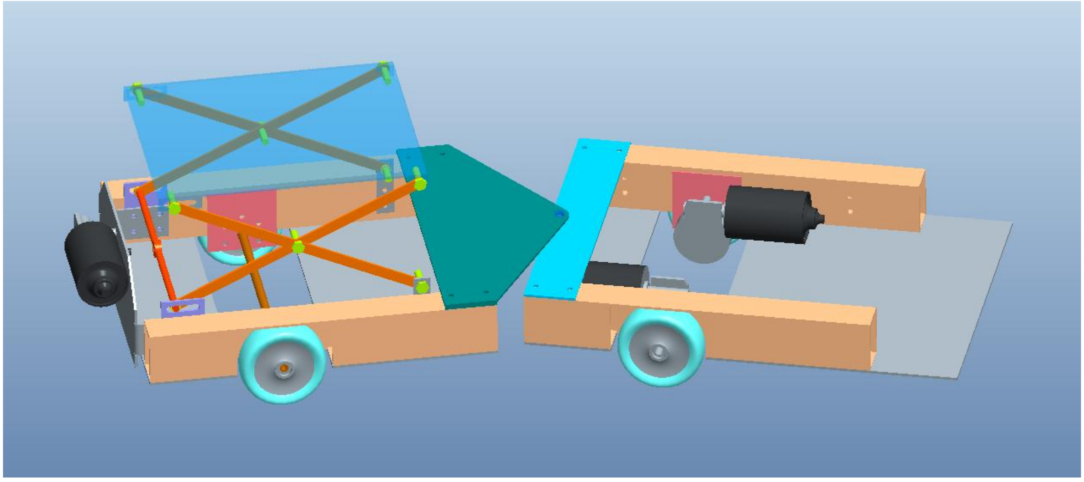


FIGURE 28 *Mark 4 vehicle version 2*

### 4.5.1 Body

The body for the first version is a single rigid assembly of two aluminium profile pieces, connected on the underside by aluminium sheet metal pieces. In the places of wheels the sheet metal discontinues. Four bolts connect each of the aluminium plates to the profiles.

On both the vehicles the wheel fixtures are identical:

- The freely spinning wheels are carried by a 12mm diameter steel bar. At the end of the steel bar there are holes with grooves, meant for screws to be inserted, to keep the wheels in place, but giving enough clearance for easy spinning.
- The motorized wheels are connected directly to the motor. A 25 mm long nut is inserted into the wheel. The nut fits tightly, but due to the plasticity of the material of the wheel, adhesive was added to keep the nut tightly locked.

### 4.5.2 Lifting system

The lifting system is in essence a scissor system. With one end of the system remaining fixed (later called 'static') and the other end sliding on a rail (later called dynamic), thus closing/opening the scissors some length, thus raising the top area up. Figure 29 shows the concept model of the lifting system at its 'down' position and figure 30 shows the concept model of the lifting system at its 'up position.

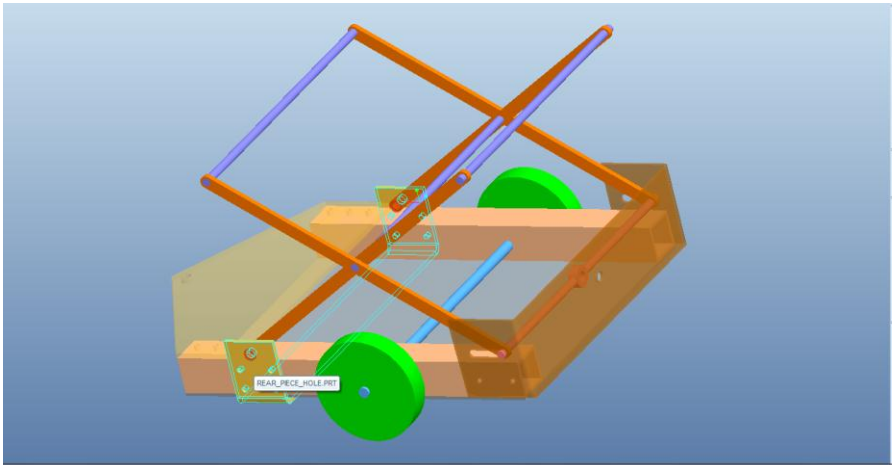



FIGURE 29 *Lifting system down position. The connection to the carriage on the left side is static, and the connection on the right side is dynamic.*

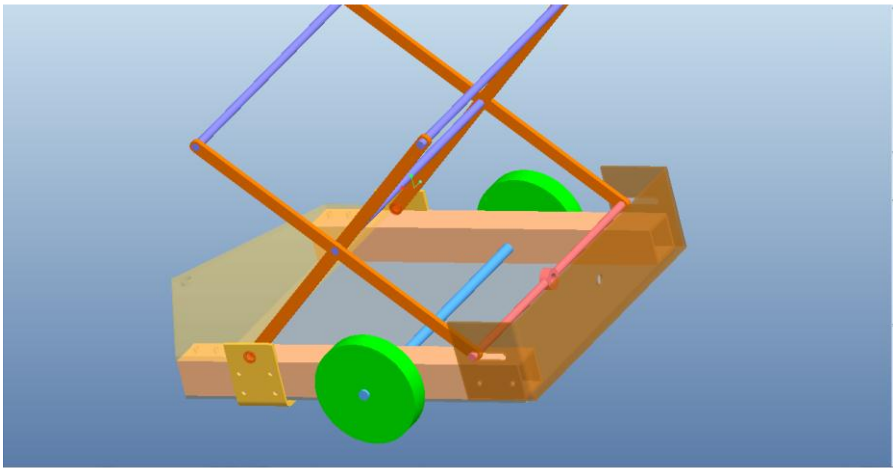


FIGURE 30 *Lifting system up position. On the rear end of the carriage, there is a motor support plate, where the lifting system motor will be fixed.*

The dynamic end of the lifting system is moved by a lifter 'nut-bar' which is essentially a bar, with a nut welded in the middle of it. A screw will go through the nut, and is connected to a motor, which is fixed on the rear side. The work principle of the system is: The motor will be spun in either direction, turning the screw relatively, which in turn will move the 'nut-bar' backwards or forwards, thus lifting or lowering the lifting system (Figure 31).

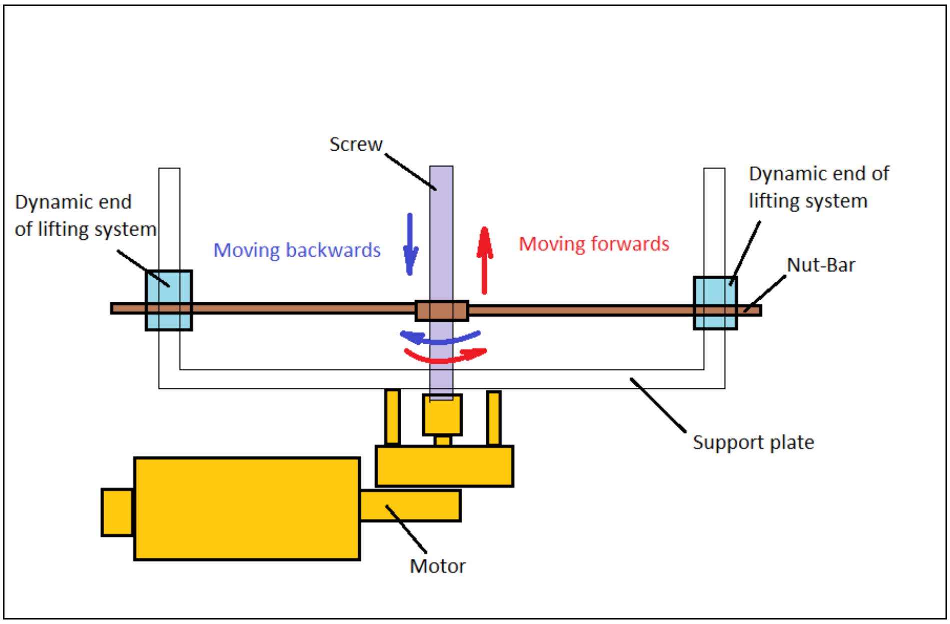



FIGURE 31 *Showing the lifting system movement principle. Viewed from top.*

The next step is to calculate the lengths of the sliding motion and lifter legs. For this assignment a basic drawing was created to show the necessary variables and constants (Figure 32)

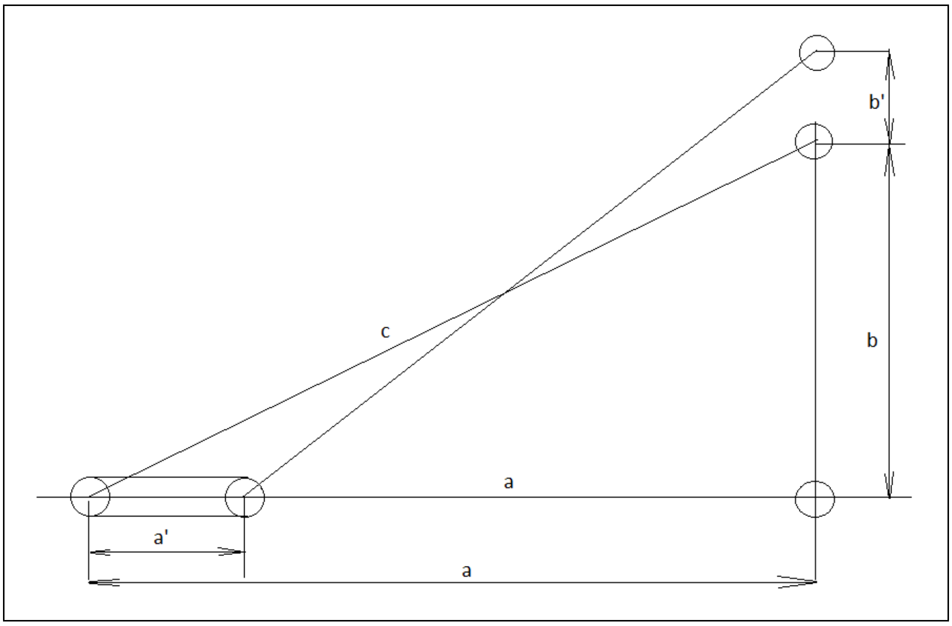



FIGURE 32 *The calculating constants and variables*

On figure 32 the distance "a" is the maximum distance of the lifting base connections. The distance "a' " is the sliding length of the dynamic lifter base connection. The distance "b" is the initial height of the lifting system. The distance "b' " is the distance between the top of the lifting system and the bottom of the box, thus displaying the necessary lifting distance. Distance "c" is the distance between the end holes of the lifter leg.

Beginning information for this task is the derivation of the existing measurements. The bottom of the box is 250mm. The lifting holes are situated already at height 120mm. From this we can deduce the maximum height of the lifter system. In the case of this height the upper end hole of the lifter system will already touch the box. This is too high (Figure 33), because the lifter system hole will have material around it, and on top of the lifter leg, there will be fixed a rack to support the box evenly. There should be at least a tolerance of 10 mm between the box and the rack, when the lifter system is at its down position, so the vehicle could drive under the box undisturbed. The distance between the lifter rack and the lifter leg upper hole is estimated to be also 10mm, to allow connection via M6 bolts.

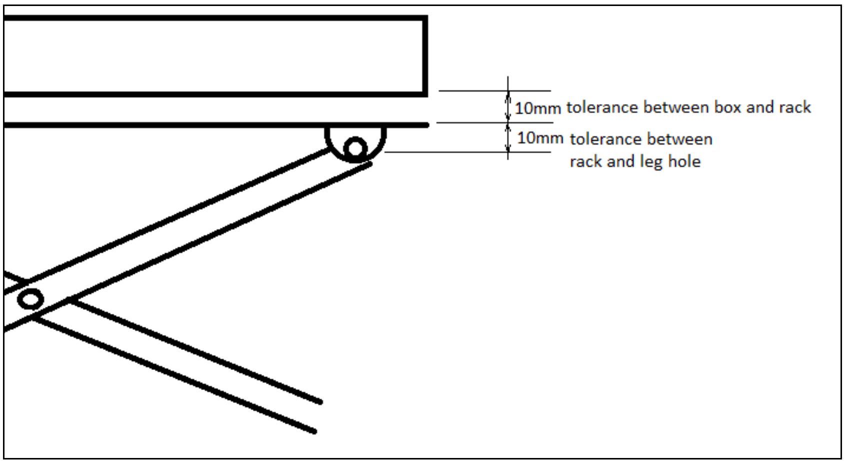



FIGURE 33 *Tolerances necessary for measuring lifter system measurements*

= 250mm - 120mm - 10mm tolerance - 10 mm tolerance = 130mm

Based on the design of the vehicle version it was decided that the holes should be situated 290mm apart (the distance "a". This way the lifting system supporting pieces do not interfere with the wheel supporting pieces.

The tolerance between the box and the rack is also the needed minimum lifting distance "b' ".

Having the two dimensions we can use the Pythagoras theorem of a right angle triangle to calculate the needed length of the lifter leg.

$$a^2 + b^2 = c^2$$

FORMULA 1 *Pythagoras theorem of a right angle triangle*

From the theorem we can derive the equation $c = \text{sqrt}(a^2 + b^2)$
Substituting numbers it is $c = \text{sqrt}(290^2 + 110^2) =$ 310,16 (approx. 310)

The preliminary distance between the end holes of each lifter leg must be 310 mm.

The next step is to calculate the optimal lifting distance "b' " again, but this time, additional lifter height should be added, so as to actually lift the box up from the ground, not just make the rack and the box touch together. The estimated lifting height is taken to be 20mm.

b' = 10mm (tolerance) + 20 mm (lifting box 20 mm off the ground)
b' = 30mm

The new value of b', 30 mm is the total distance the lifting system has to be able to lift up.

The final step is to calculate the distance of the sliding movement "a' ".

From the Pythagoras theorem we derive the following equation:

$(a - a') = \mathrm{sqrt}\ (c^2 - (b+b')^2)$

In this equation the sum of "b" and "b' " are the total desired height of the lifting system. The answer should be less than the value of "a", to show how much it has to decrease (a - a') (how much the slider has to move forwards for the system to reach the needed height).

Substituting numbers we get:

$(290 - a') = \mathrm{sqrt}\ (310^2 - (110 + 30)^2)$

(290 - a') = 276,586

a' = 290 - 276,586

a' = 13,414 (approx. 13.5)

The slider has to move forwards 13,5 mm in order for the lifting action to reach the desired height 140mm.

The slider hole should be 13,5 mm long. However in order to prepare for any unforeseen errors, the lifting hole will be made 30 mm long (In case the lifter legs later need to be replaced with shorter ones, the system could still be able to rise to the necessary height, by sliding more forward).

### 4.5.3 Layout of pieces

All the electrical components will be fit onto a DIN rail, that will run through the centre of the vehicle. This can be done, because the lifting system takes very little actual space on the floor on both vehicles.

On vehicle version 1, a single DIN rail will run through the vehicle, where all the components will be attached. The length of the vehicle is sufficient for all the components.

On vehicle version 2, majority of the components will be fit to the front carriage. Also a second level will be added on top of the first one, which will be easily-removable, to make repairing and adjustment-making easier. Some components, like the battery will be placed in the second part of the vehicle.

### 4.5.4 Analysis

- The lifting system is sufficiently simple to be easily manufactured. It also leaves room on the floors of the vehicles for component placement.
- All the components have enough room to be fit in place, while leaving room for wiring and air flow.
- Motors are fixed with support pieces securely onto the side of the profile.
- There is enough room on the design for safety switches, to stop the car before it can crash into an obstacle.

# 5 ELECTRICAL DESIGN

## 5.1 Components of the circuit

This chapter will introduce all the main components of the electrical circuits. The components will be shown and their main work principles explained.

### 5.1.1 Relay

A relay is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism mechanically, but other operating principles are also used. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. The first relays were used in long distance telegraph circuits, repeating the signal coming in from one circuit and re-transmitting it to another. Relays were used extensively in telephone exchanges and early computers to perform logical operations. /8/

Nowadays relays are used in control circuits to convert signals into different voltage levels.

FIGURE 34 *A relay fixed in a DIN-rail mountable relay holder* /9/

### 5.1.2 Fuse

Fuse is a safety device that protects an electric circuit from excessive current. Fuses consist of or contain a metal element that melts when current exceeds a specific amperage, thereby opening the circuit. */10/*

FIGURE 35 *Typical examples of fuses* /11/

Fuse-holders are used to keep the fuse fixed and to protect users from electrical contact (Figure 36).

FIGURE 36 A DIN rail mountable fuse holder. /12/

### 5.1.3 Limit switches

In electronics, a switch is an electrical component that can break an electrical circuit, interrupting the current or diverting it from one conductor to another. The most familiar form of switch is a manually operated electromechanical device with one or more sets of electrical contacts. Each set of contacts can be in one of two states: either 'closed' meaning the contacts are touching and electricity can flow between them, or 'open', meaning the contacts are separated and non-conducting. */13/*

FIGURE 37 *Examples of limit switches /14/*

5.1.4 Inductive sensors.

An inductive sensor is an electronic proximity sensor, which detects metallic objects without touching them.

The sensor consists of an induction loop. Electric current generates a magnetic field, which collapses generating a current that falls asymptotically toward zero from its initial level when the input electricity ceases. The inductance of the loop changes according to the material inside it and since metals are much more effective inductors than other materials the presence of metal increases the current flowing through the loop. This change can be detected by sensing circuitry, which can signal to some other device whenever metal is detected. /15/

FIGURE 38 *An inductive sensor /16/*

## 5.2 Safety circuit

All 3 motors are controlled by the same safety circuit. The safety circuit is cutting the power from the motor control relay coils, thus cancelling all other control signals.

On each end of the vehicle, there will be 2 mechanical push-down switches (2 per end). These are the actuators for the safety circuit. When the vehicle runs into an obstacle, the ‘bumper’ will touch the object first, the switches will be pressed down and a circuit will be broken (opened). This is a safety circuit, and it will be controlling a relay on the main power supply circuit. If at any time somehow the switch is pressed down, the power supply will be disconnected from the motors, but will kept in other systems on the car. When the switch is released the car will continue on its course.

## 5.3 Placement of sensors and switches

Detailed description of where the sensors/switches will be placed and what their task will be.

### 5.3.1 Lifter switches

The task of the lifter switches is to determine, whether the lifting system is at the up position or at the down position.  The actuators used are limit switches and they will be placed on the dynamic lifter support, as show on figure 39.

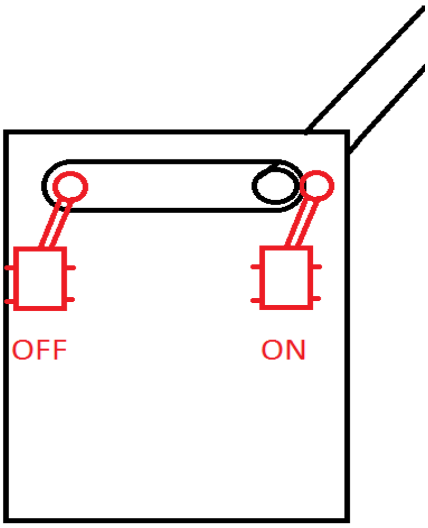



FIGURE 39 *The placements of 2 limit switches on the dynamic lifter system support.*

### 5.3.2 Safety bumpers

To prevent the vehicle from driving into an obstacle, the safety bumper will turn off the motors when there is an obstacle in the way. The safety bumper limit switches have long pendants attached to the button, allowing the switches to be pressed from a further distance than usual. Two of these safety switches will be placed on either end of the vehicle (Figure 40). The switches will be controlling the relay that allows the current to run into the motors. If the switches are pressed, the motors will stop.

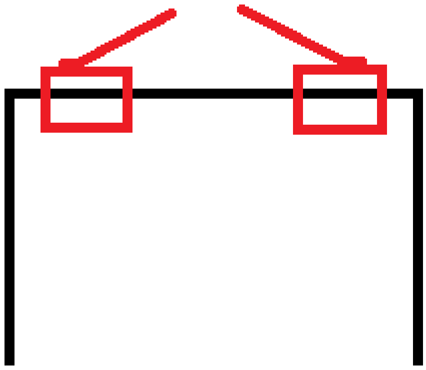


FIGURE 40 *Two limit switches acting as a safety bumper on the end of the vehicle.*

### 5.3.3 Detector sensors

The inductive sensors will be used to detect whether the is a box above the car and whether the car is still on the track.

One of the sensors will be placed on the lifter rack, directed upwards. When the car drives under the box, the sensor will detect the box.

On the vehicle version 1 another sensor will detect whether there is a track for the wheels. When the track ends and the sensor does not detect it, the car stops - in case there is no cassette, the car will not keep running forev-er, but will stop when the track ends.

On the vehicle version 2 there will be 3 sensors to make the car follow the metallic tape on the ground (Figure 41).

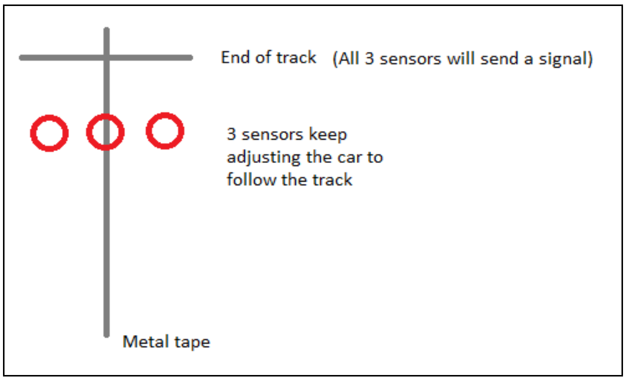



FIGURE 41 *The functionality of the sensors on the vehicle version 2.*

# 6 THE CONSTRUCTION OF THE MODEL

This chapter will go over the construction of the lifter vehicle models step-by-step.

## 6.1 The main body

The main reinforcing structures of the vehicles are the aluminium profiles. The default measurements are width 40mm, height 60mm, thickness 3mm.

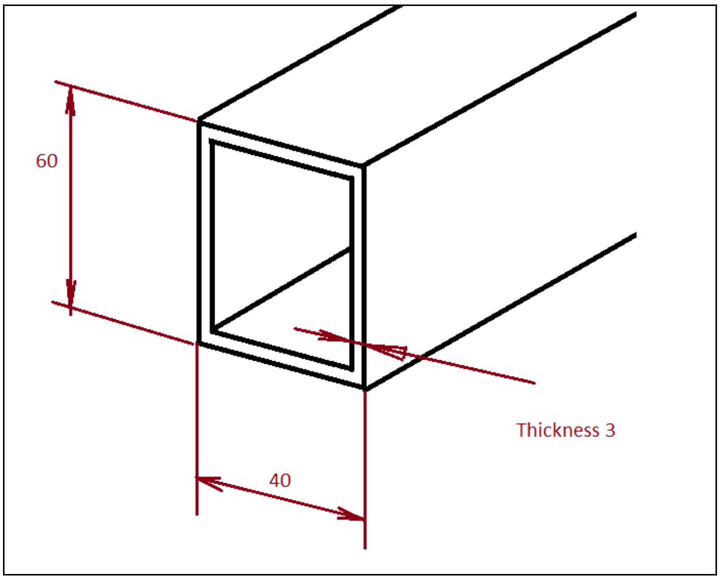



FIGURE 42 *Aluminium profile measurements.*

### 6.1.1 Cutting the profile to length

Using the metal cutter saw, the pieces are cut to the necessary lengths: four pieces of length 400mm for the second vehicle and 2 pieces of 500mm for the first vehicle.

The edges of the cut profile remained sharp, so they were filed smooth, to ease the handling of the pieces, during the measurements and fitting of the pieces.

### 6.1.2 Milling the pockets into the profile

Using the milling machine, pockets were cut into the profiles, to allow the fitting of wheels inside the profile. Also a semi-circular hole was cut to 155mm from the closest edge, where the wheel axis would later be. The tool used to cut the holes was 10mm diameter pocket mill.

FIGURE 43 *Displaying a pocket mill tooltip. A similar tool with a 10 mm diameter was used to mill the pockets into the profile. /17/*

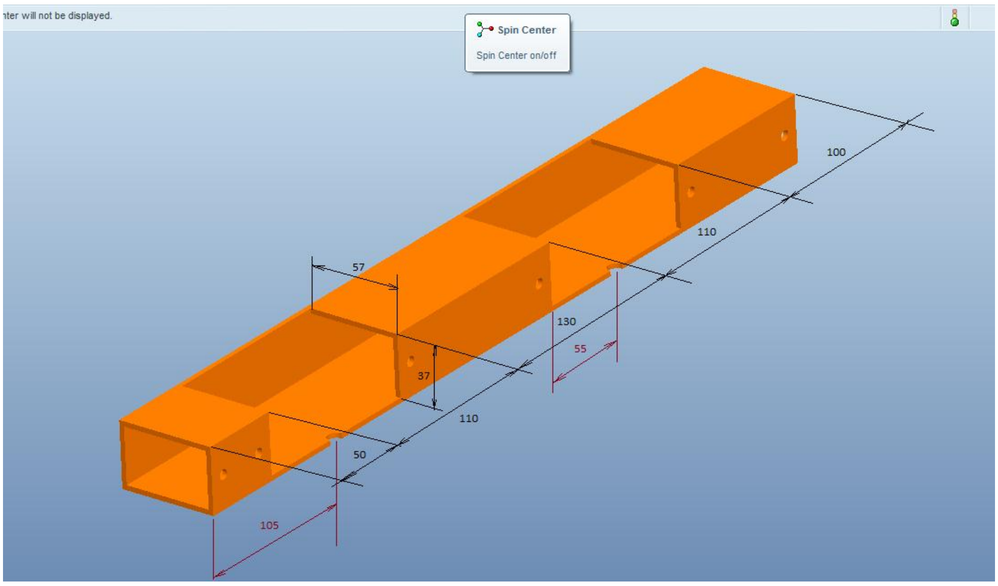



FIGURE 44 *The placement of the pockets for milling operation for vehicle 1. The pocket measurements are marked in black. The placements for the holes for the vehicle axis are marked in red*

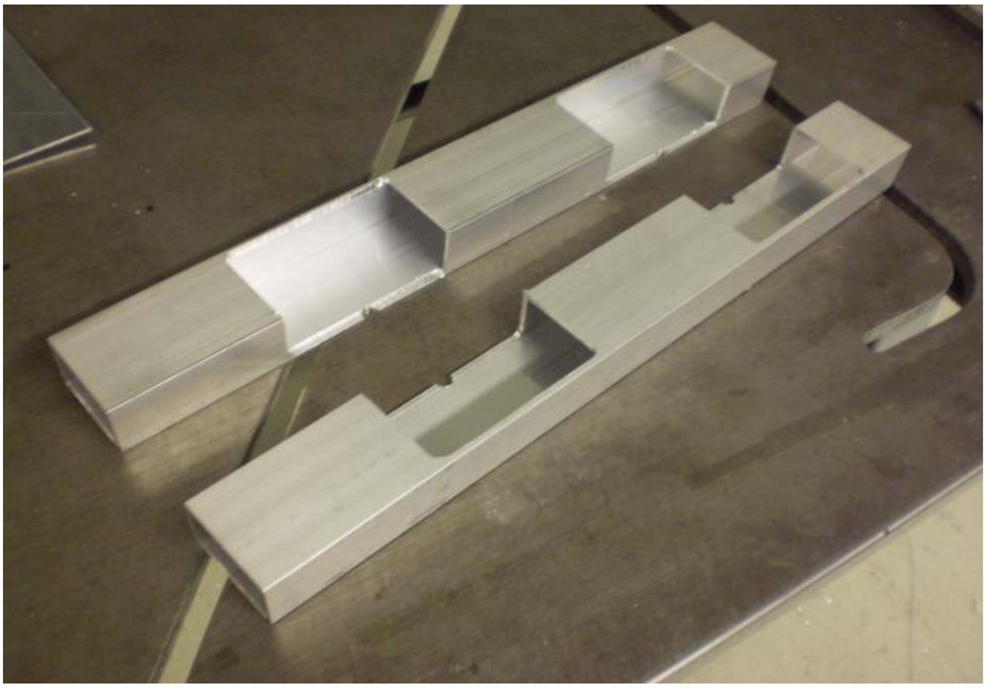


FIGURE 45 *The profiles of the vehicle version 1 after the milling operation.*

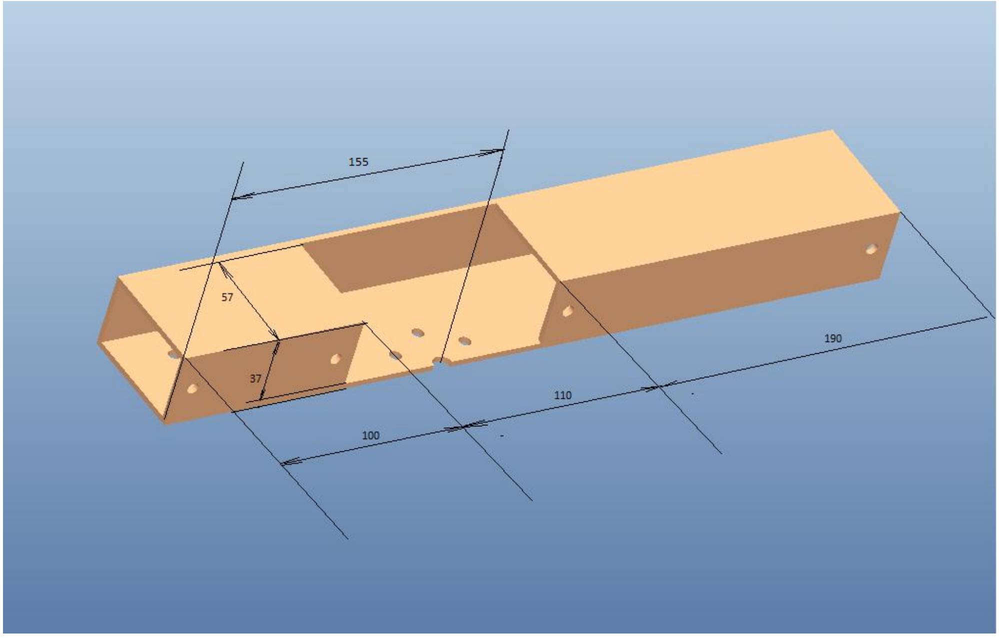



FIGURE 46 *The placement of the pocket for the milling operation for vehicle 2.*

### 6.1.3 Holes on the profile

The next step is to make the holes, to fix other components of the profiles. All the holes used for fixing are 6 mm in diameter, to allow the use of standard M6 bolts while attaching the pieces.

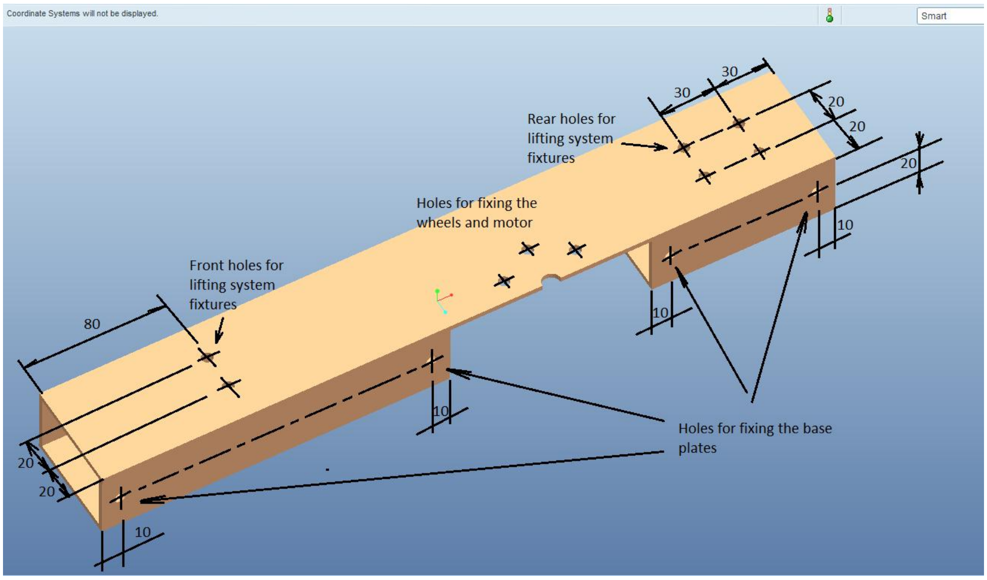



FIGURE 47 *The placement of the holes on the bottom side and the in-side of the vehicle 2.*

First the holes for the lifting sytem fixtures were made first, then the holes for fixing the bottom plates.

The holes for fixing the motor and wheels were done last. Since the measurements required a different reference point, they were labeled as "Hole set 1". The 'Hole set 1' is used in all the vehicle versions, where a motor is attached to a surface.

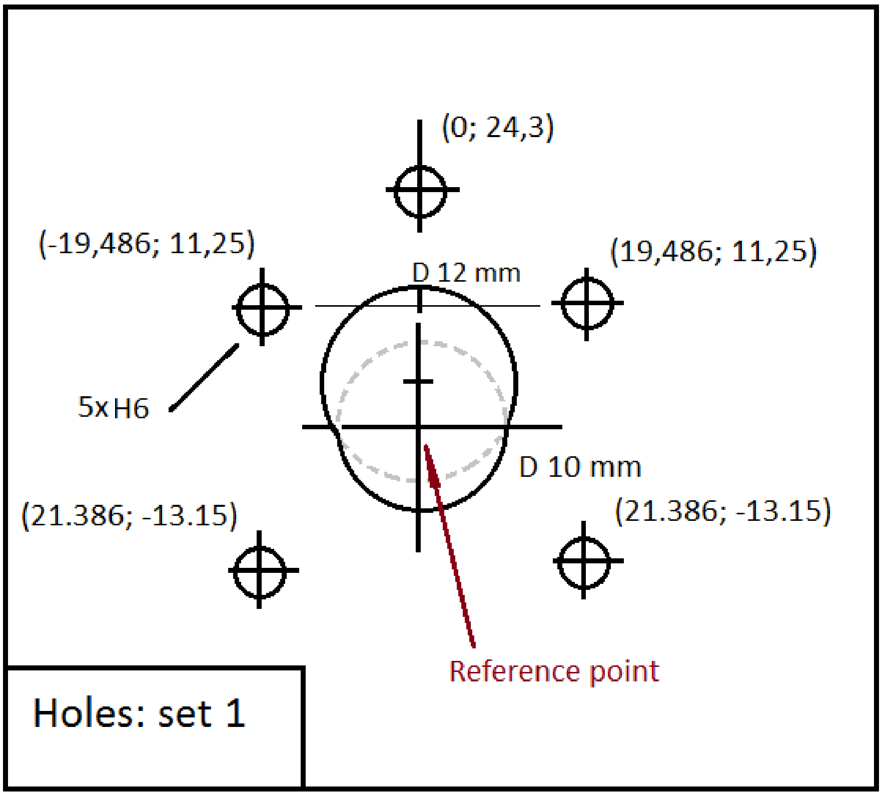



FIGURE 48 *The "Hole set 1" layout with a reference point in the middle circle (The referent point is the 'zero point' for all the surrounding hole coordinates). The top-most hole and the two bottom holes are to fix the motor. The two parallel top holes are to fix the current surface to any other surface. All the holes are radially around the reference point.*

### 6.1.4 The base plates

Using the sheet metal cutter, the 3 mm thick aluminium sheets were cut into the correct measurements. Since the vehicle necessary width is 350 mm and the plates reach from side to side, the plates are all 350 mm wide.

For vehicle 1 three plates were cut, with the lengths of 50, 100, 110 mm (Figure 49).

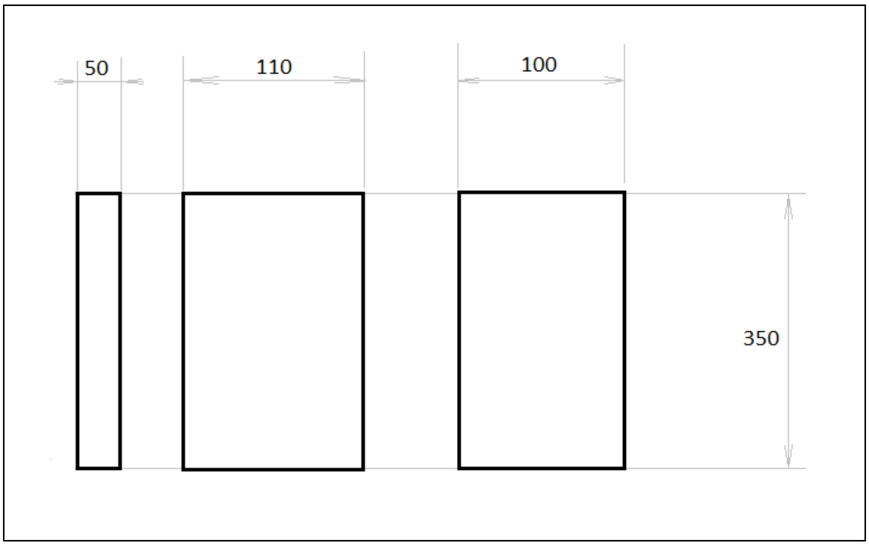


FIGURE 49 *Plate measurements for vehicle 1.*

For vehicle version 2, four plates were cut, with the lengths of 290, 190, 100 and 100 mm (Figure 50).

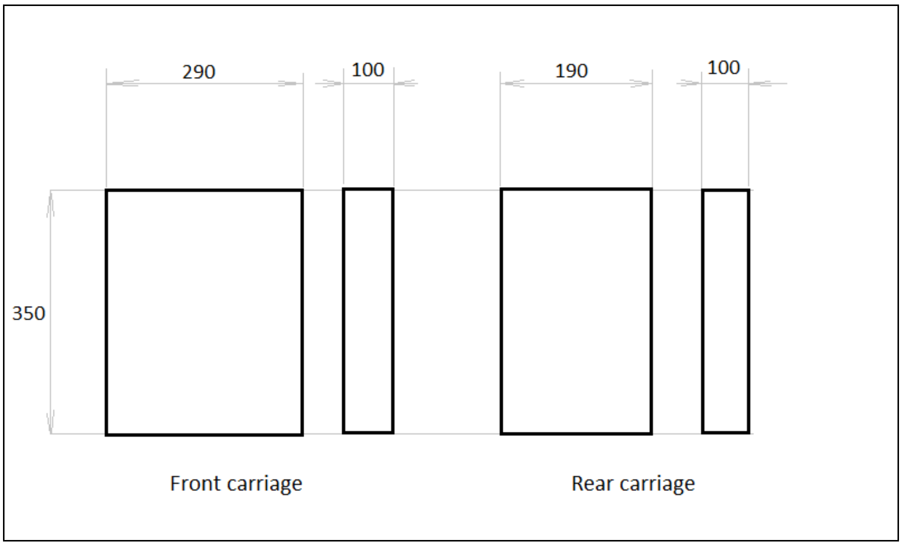


FIGURE 50 *Plate measurements for vehicle 2.*

Using a hand drill and a 6 mm drill tool, 4 holes were drilled into all the base plates. For all the plates, the holes were drilled according to the same parameters: on the 350 mm side 20mm in from both ends, and 10 mm in from the varying distanced side (Figure 51).

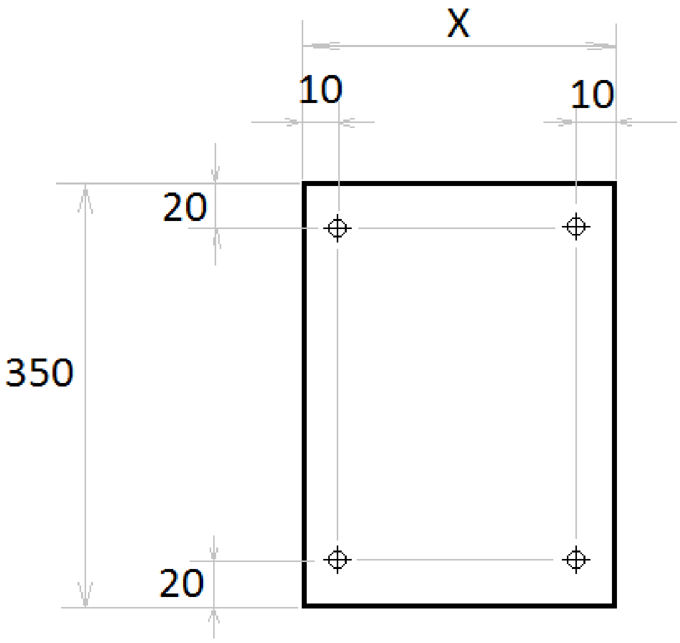



FIGURE 51 *The placements of the holes on the base plates. X is the variable measurement of the base plate.*

### 6.1.5 Assembling the main base

Now all the components for the main base are manufactured and can be assembled. M6x14mm bolts (industrial standard, meaning 6mm in diameter, and the main body of the bolt is 14 mm long) are used to connect the profile to the base. The bolts are inserted from the inside of the profile, to enable easier tightening of the nuts (Figures 52 and 53).

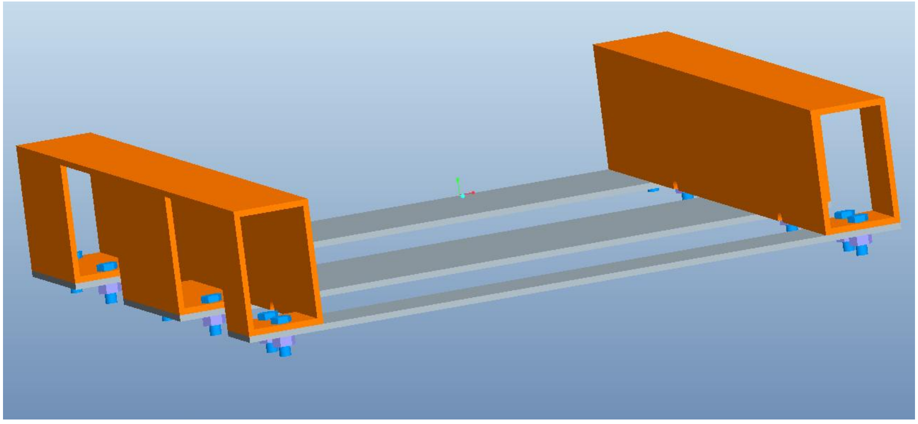


FIGURE 52 *The assembled base components of vehicle version1.*

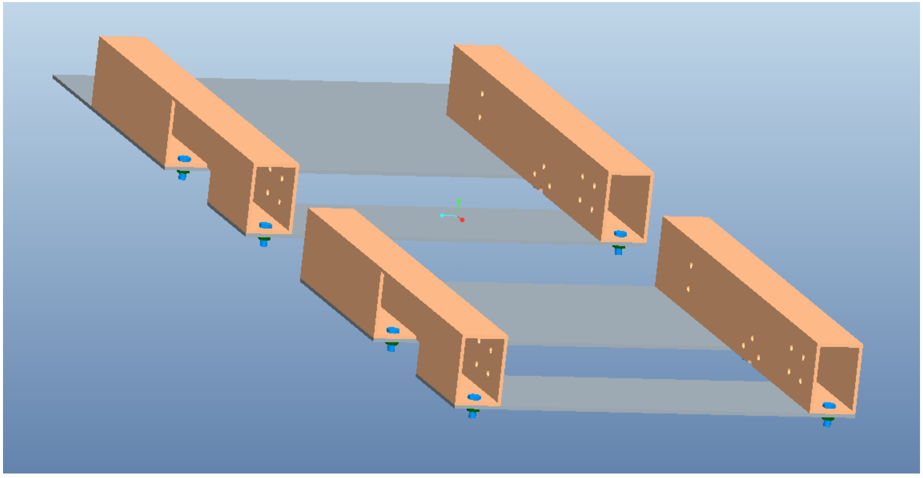


FIGURE 53 *The assembled base components of vehicle version 2*

## 6.2 Wheel and lifter system supports

For the vehicle version 2, which was originally constructed first, the components will be brought up first. Later some improvements were made on the pieces, and those improved pieces were used in the first vehicle version.

### 6.2.1 Vehicle version 2 wheel fixtures

For the freely spinning wheel axis, two support plates were created. Each plate is fixed to the inside of the profile on the rear carriage, and the task is simply to hold a wheel axis bar in place (Figure54). For precision hole-making, the milling machine was used to achieve a better accuracy on the placements - any minor deviation might cause misalignment of the axis and thus the carriage would constantly try to go in a different direction.

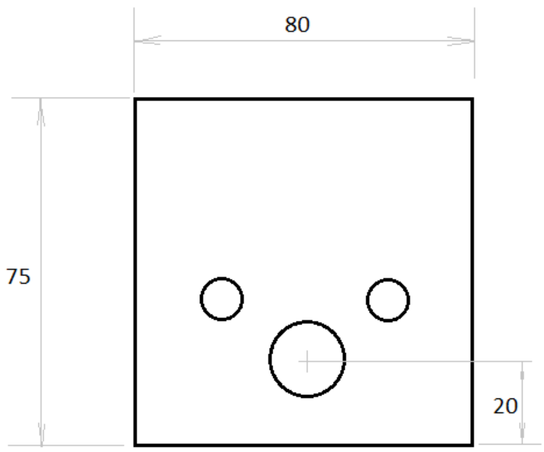



FIGURE 54 *Free wheel plate. The holes on the picture do not have measurements attached, because they are a partial representation of the 'Hole set 1' - only the axis hole and the fixing holes to the profile.*

For the motorized wheels, similar plates were made, but with additional holes for fixing the motor to the plate. As such the plate has the full complement of the 'Hole set 1' (Figure 55). The holes on the motorized wheel plates were made also with the milling machine.

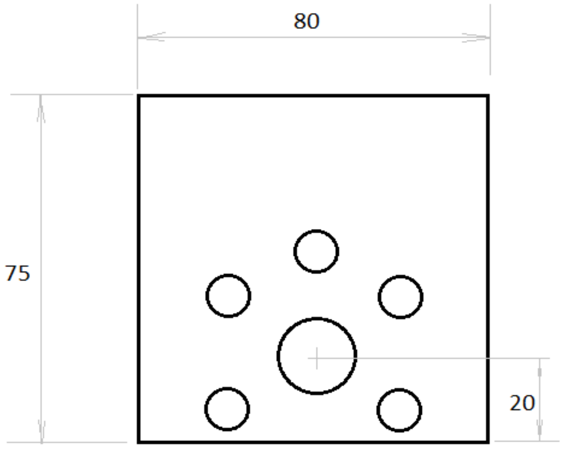



FIGURE 55 *The support plate for the motorized wheel, with holes according to the 'Hole set 1'.*

### 6.2.2 Vehicle version 2 lifter system supports

Figure 56 shows the measurements of the vehicle version 2 lifter system supports. Two sets of those supports were created, so that one piece would be fit on both sides. The sheet metal pieces were measured and cut from the sheet metal, and the holes done with the milling machine.

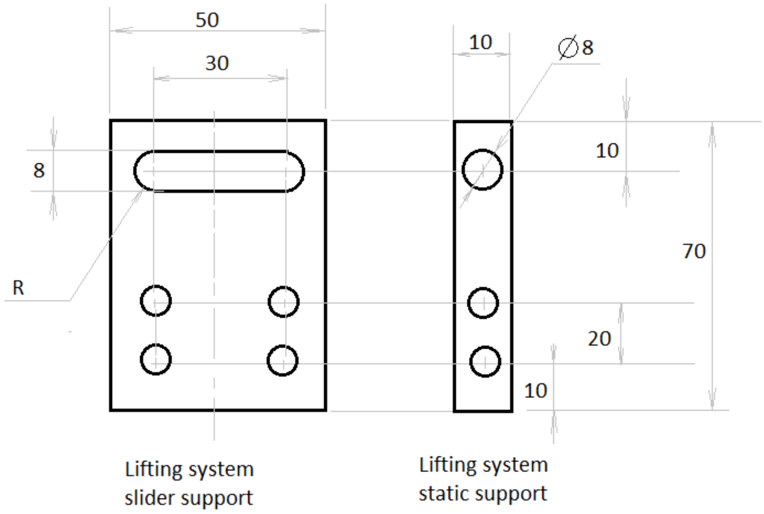



FIGURE 56 *The lifter system supports for the vehicle version 2, measurements. Unmarked holes are standard holes for this design, diameter 6mm.*

After the manufacturing of the pieces they were attached to the vehicle, as shown on figure 57.

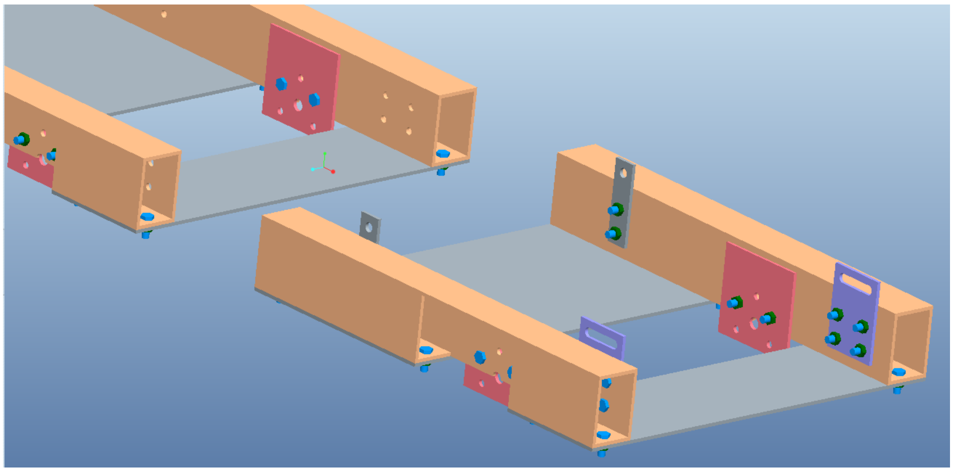


FIGURE 57 *Vehicle version 2 lifter support pieces and wheel connector plates added to the assembly.*

### 6.2.3 Vehicle version 1 improved support pieces

Since the measurements of vehicle version 1 are smaller, and the components more pressed together, it seemed reasonable to try to merge the wheel support plates and the lifter system support pieces.

The front wheels are the motorized wheels, the entire 'Hole Set 1' had to be fit into the combined support piece. The front part of the lifter system is the static part, just a hole, that needs to be fit to the design as well (Figure 58).

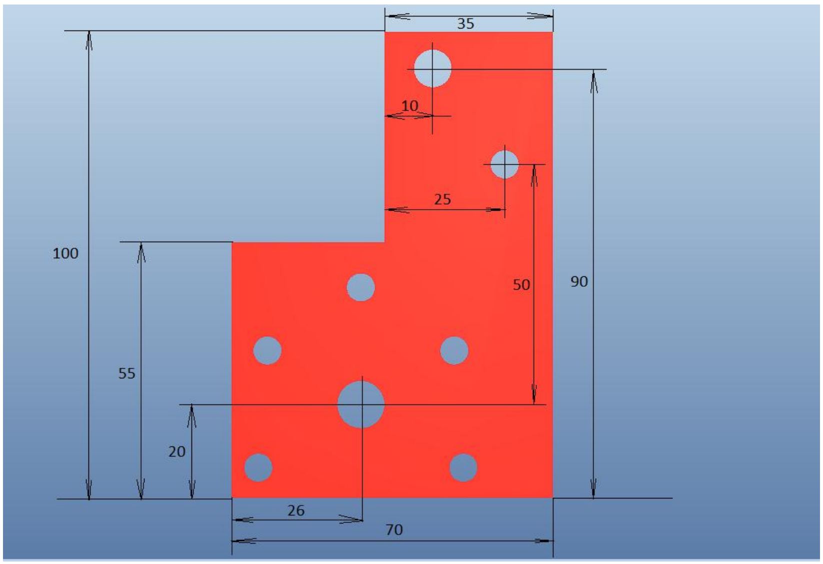



FIGURE 58 *Vehicle version 1 combined wheel and lifter support for the front (motorized) end. Unmeasured hole is the standard fixing size for this design 6mm.*

The rear wheels are the freely spinning wheels, so no holes will be needed to fix the motor, a partial 'Hole set 1' will be used. The design and measurements are shown in figure 59. Since the important part of the design is the hole placements, the measurements all are based on measurements..

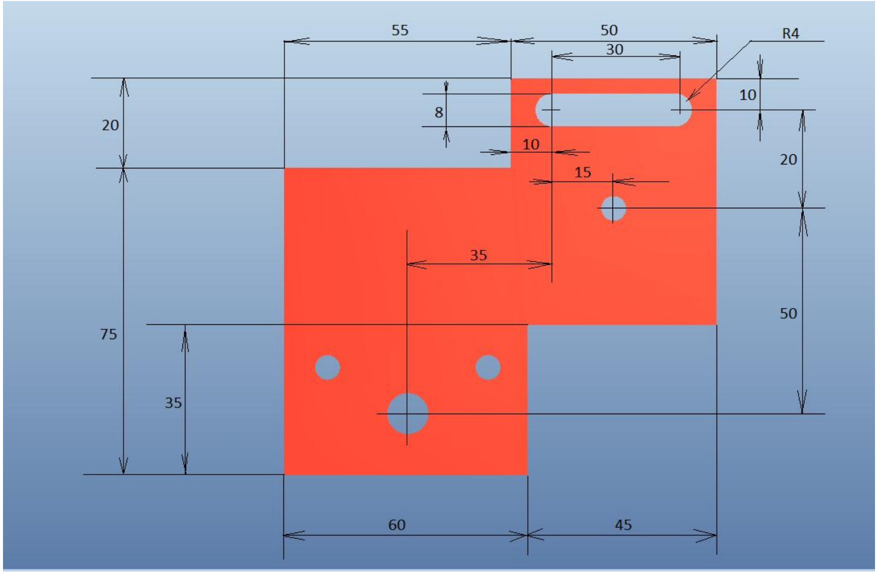



FIGURE 59 *Rear support piece for the vehicle version 1.*

After the manufacturing of the components, the pieces can be assembled onto the main base of the vehicle version 1 as shown on figure 60.

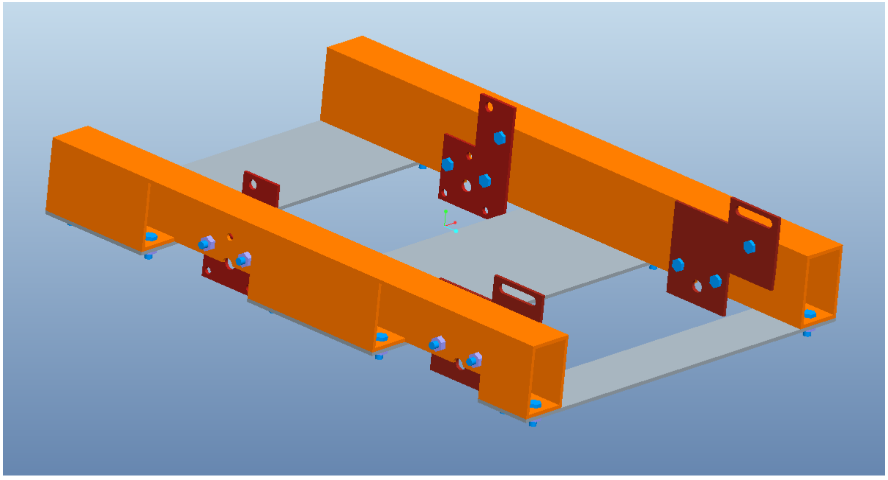


FIGURE 60 *Vehicle version 1 support pieces are assembled to the main base.*

## 6.3 Free wheel axis bar

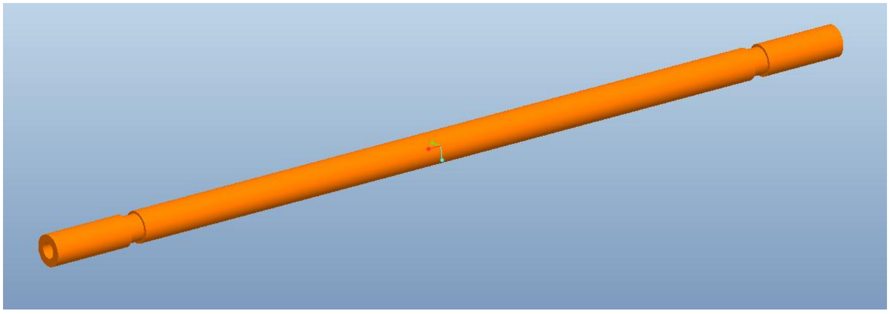


FIGURE 61 *Free wheel axis bar*

Both vehicles will have the same kind of axis to support their free wheels. The bar is made of steel, to ensure it resists possible shocks

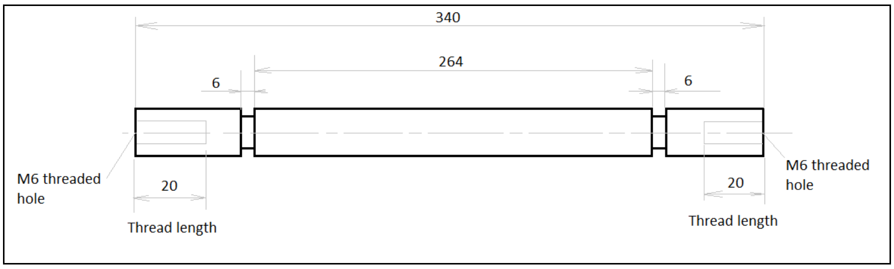



FIGURE 62 *Free wheel axis bar drawing with measurements*

Figure x, shows the manufacturing measurements for the axis bar. Using the turning machine 2 bars specified in the drawing were created, one for each vehicle version.

Fixing the bar will be using the support pieces. The thinner areas of the bar are 6mm because they will be through the support plate (thickness 3mm) and profile (thickness 3 mm). The holes on the ends will be fit to house M6 bolts. The wheel spins on the bar feely, but is kept in place by a bolt at each end. There is a washer between the bolt and the wheel as shown on figure x.

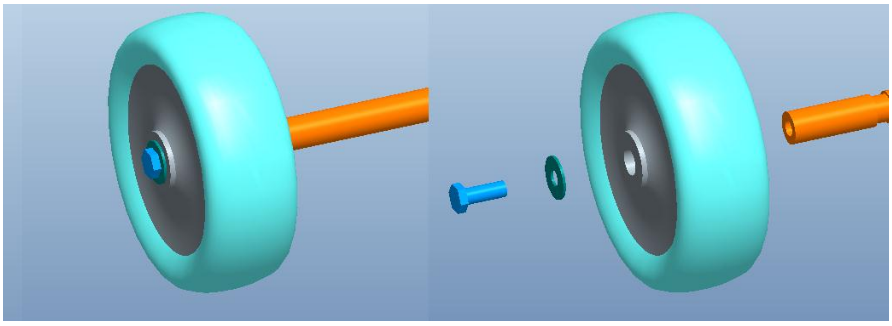


FIGURE 63 *Representing the fixing of the wheel on the bar. Left image shows the assembled view. The right side image shows all the components in an exploded view style.*

In order to fix the wheel bar, the support pieces must be taken out, the wheel bar put into place, and then the support pieces put back. This should be done in the current state of construction. Also the wheels should be attached (Figure 63).

## 6.4 Attaching the driving motors and the wheels

### 6.4.1 Preparing the wheels

An M6 nut fits the motor screw. To connect the wheel to the motor, a nut is to be placed inside the wheel. Adhesive is used to fix the nut permanently in the wheel. For both designs, a total of 4 such wheels are prepared (Figure 64).

FIGURE 64 *A 25mm long nut is embedded in the wheel.*

### 6.4.2 Attaching the motor to the body

Using three M6 bolts, the motors are attached to the support plate and the profile (Figure 65).

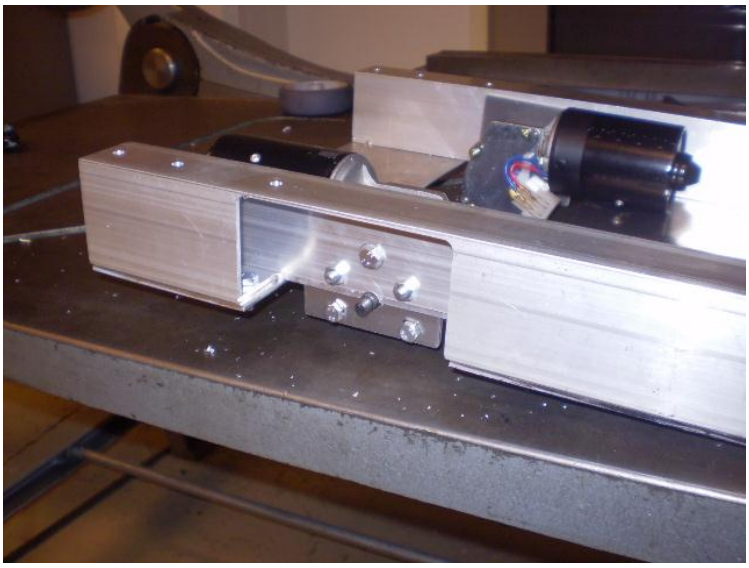


FIGURE 65 *Showing the attached motor and bolts in place, vehicle version 2.*

### 6.4.3 Attaching the wheel to the motor

To prevent the wheel from unscrewing while the vehicle is in motion, a drip of "Locktite" is added on the screws of the motor, and then the wheel is rolled on. The "Locktite" takes a few seconds to harden, and then the wheels are set securely into place.

## 6.5 Lifter system

The Construction of the lifter system will be explained in detail in this chapter.

FIGURE 66 *Lifting system on the vehicle version 1*

### 6.5.1 Manufacturing the lifter legs.

A 10x10 mm square aluminium profile, with a thickness of 1 mm is used for the lifter legs. Since the out-most holes on the lifter legs are at a distance of 310 mm from each other, 324 mm pieces of the profile are cut out, to also leave some material covering the holes on both ends. The holes at the ends and in the middle are all with a diameter of 8 mm, as shown in figure 67. A total of 8 pieces are manufactured, four pieces for each vehicle version.

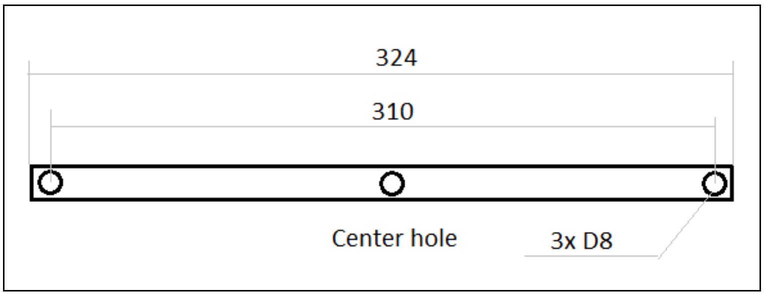



FIGURE 67 *Measurements of lifter leg holes*

At one end of the lifter leg, the excess material is ground off, to give it a smooth round corner (Figures 68 and 69). This corner needs to be smooth not to interfere with the rack on top of the lifter system.

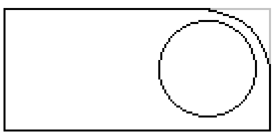


FIGURE 68 *Ground lifter leg end.*

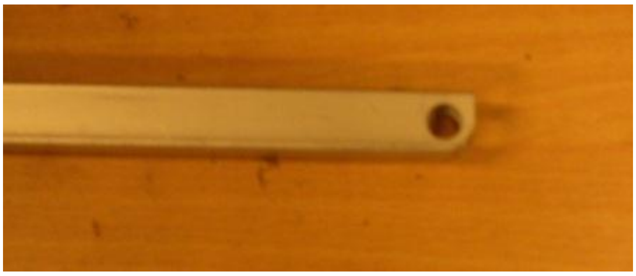


FIGURE 69 *The aluminium profile with round end.*

### 6.5.2 Manufacturing the 'nut-bar'

Using the metal saw machine, a piece is cut from a standard L-shape steel profile, and 140 mm long pieces are cut from the M8 industrial screw-bar (Figure 70).

FIGURE 70 *Industrial screw being cut on the metal saw machine*

Using the milling machine, cavities are cut into the steel L-profile (Figure 71).

FIGURE 71 *Milling cavities into the steel profile.*

The nut is placed into the hole and welded to place. Then one at a time the screw pieces are welded together (Figure 72). The weld type is gas arc welding.

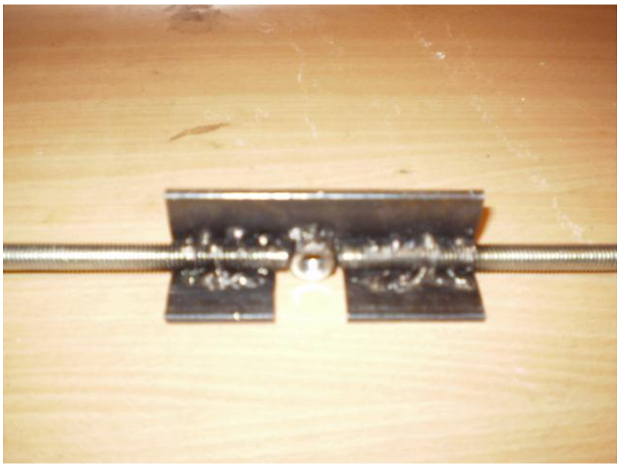


FIGURE 72 *Welded assembly*

### 6.5.3 Manufacturing the lifter rack

The sheet metal was cut into approximately the correct size. Two layers of sheet metal were fixed to a wooden support. Using the milling machine, the shape, pockets and holes are cut into the metal sheets (Figure 73).

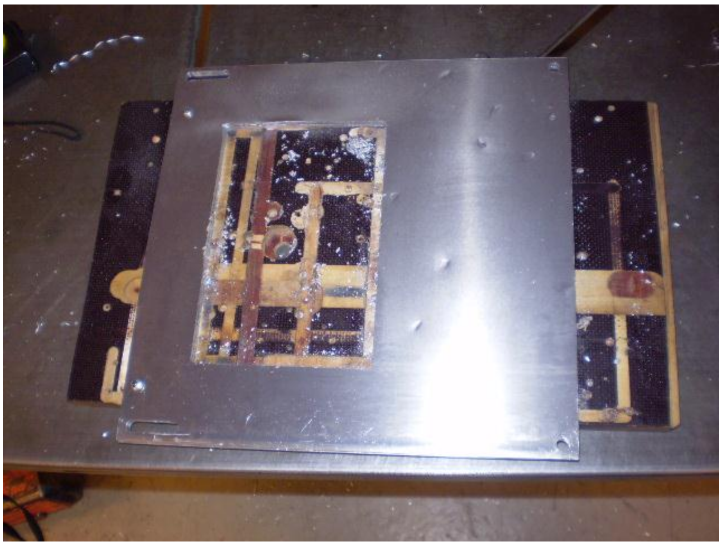


FIGURE 73 *Profile of the lifter rack is milled*

Using the bending machine, the sides are bent to a 90 degree angle.
The final result is shown on figure 74.

FIGURE 74 *After the piece is bent into shape, it can be attached.*

### 6.5.4 Manufacturing the motor support

The motor support is made of 3 mm thick sheet metal. The support is fixed to the lifter system support piece on vehicle version 2, and to the combined support piece on the vehicle version 1. Because the support pieces on the versions are different, the motor support pieces will be different as well. Figure x shows the motor support system for the vehicle version 1. Figure 75 shows the motor support system for vehicle version 2.
Figure 76 shows the motor support system for vehicle version 1.

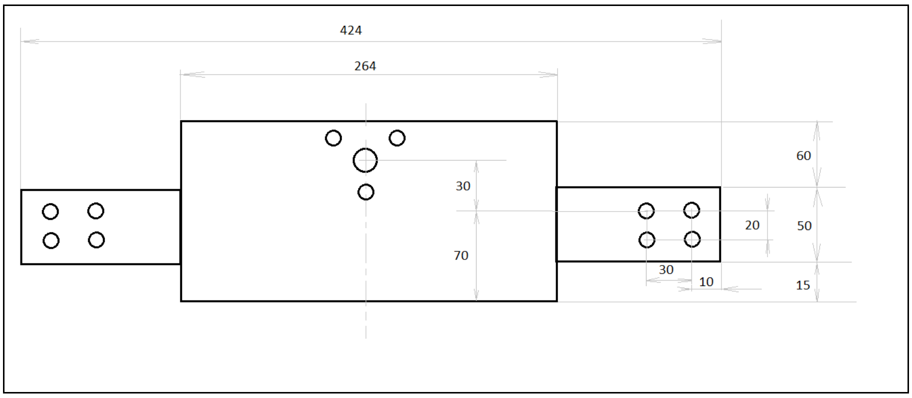



FIGURE 75 *Vehicle version 2 motor support piece layout drawing.*

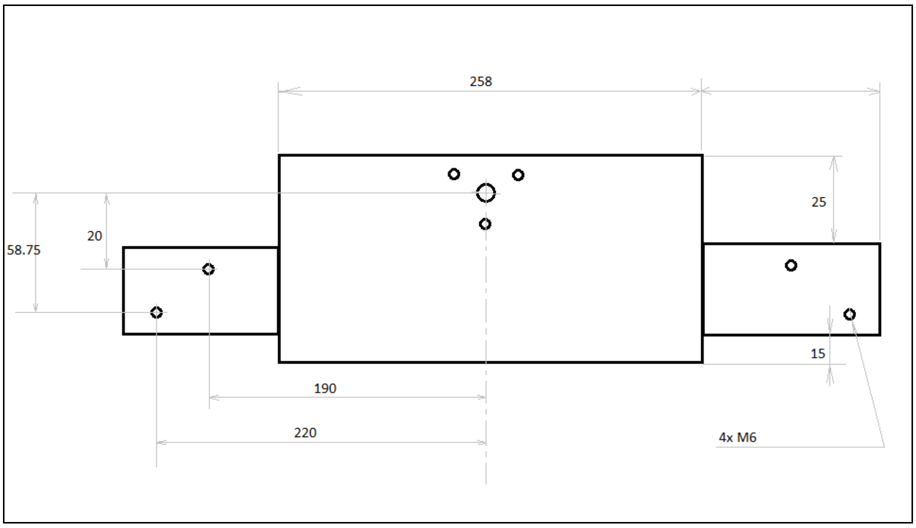



FIGURE 76 *Vehicle version 1 motor support piece layout*

Both the drawings are layout drawings. After the pieces are cut out, the edges will be bent to a 90 degree angle, using the sheet metal bending machine.

The holes are done via milling, because the numerical measuring system allows for great accuracy. In order to mill a sheet metal piece, it needs to be fixed to a wooden plate, so that the mill can actually go through the sheet metal, while not hitting the milling machine base. The wood piece also keeps the sheet metal piece straight and prevents bending.

Then the holes are milled into the plate (Figure 77).

FIGURE 77 *Sheet metal piece fixed to the wood plate. Holes have been already milled.*

The excess sheet metal is removed by using the sheet metal cutter for straight cuts from en-to-end-cutting and a grinding cutter, to make smaller incisions.

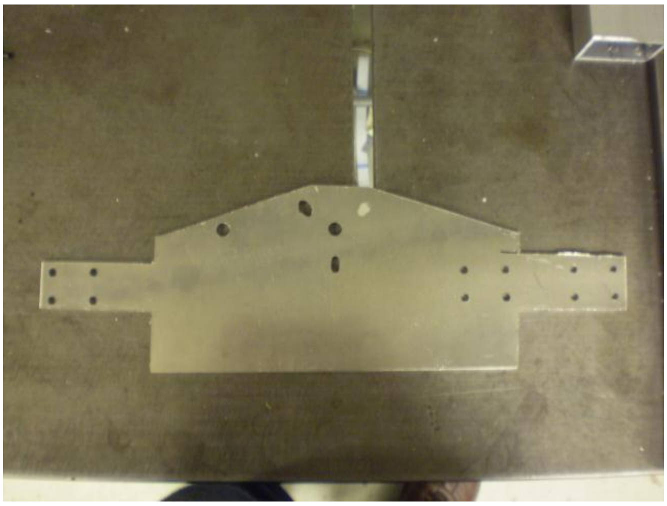


FIGURE 78 *Motor support plate is cut out from the surrounding material.*

Using the bending machine, the flanges (smaller edges on both sides) are bent to a 90 degree angle (Figure 79).

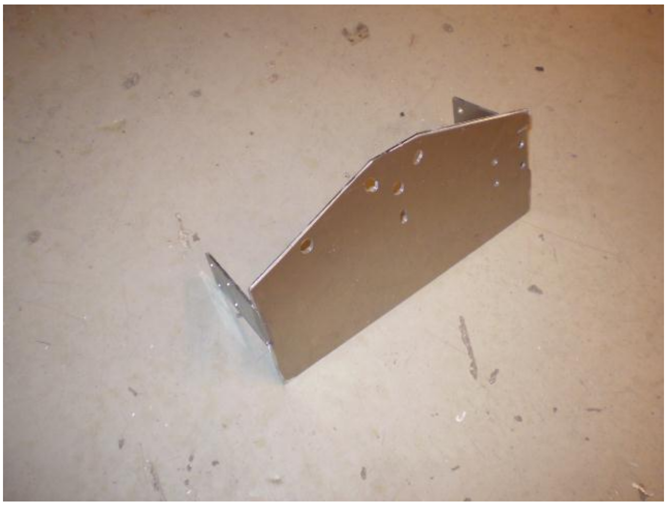


FIGURE 79 *The ready lifter motor support piece*

### 6.5.5 Manufacturing the lifter screw

From a standard industrial screw bar, size M8, a 80 mm piece is cut using the metal saw machine (Figure 80).

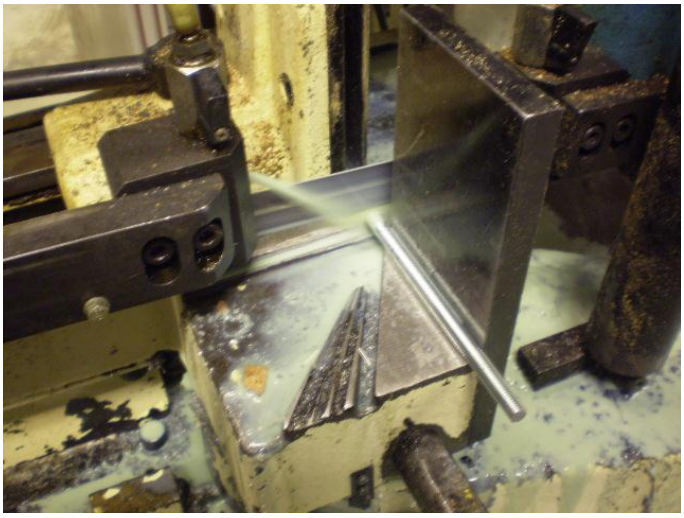


FIGURE 80 *Cutting the screw*

### 6.5.6 Attaching the lifter screw to the motor

A drop of "Locktite" is added on the screw of the motor, and a 25 mm long industrial M8 nut is screwed on. Another drop of "Locktite" is added onto the lifter screw, which is screwed into the other end of the 25mm long M8 nut. Note: only a drop of "Locktite" is needed, because the screwing motion will distribute the adhesive evenly through all the grooves.

### 6.5.7 Attaching the motor support

The sets of holes designed into the motor support pieces coincide with the screw placements of the lifter support piece on version 2 and support piece on version 1. Using the already placed screws, the motor support pieces are fixed in place (Figure 81).

FIGURE 81 *Fixing the motor support*

### 6.5.8 Assembling the lifter legs and 'nut-bar'

Two nuts are put onto the 'nut-bar', one from each end, followed by the lifter legs, and washers. The bar is put in place. The nuts, now situated in the innermost side of the 'nut-bar' are used to tighten the lifter legs to the lifter support, but applying force from inside to out (Figure 82).

FIGURE 82 *The fixing in place of the nut-bar is done with nuts on the nut-bar.*

### 6.5.9 Attaching the motor and inserting the lifter screw in place

Using three M6 bolts, the motor is fixed to the motor support plate. A 25mm long M8 nut is fixed, using 'Locktite' onto the motor screw. The lifter screw is first manually run through the nut in the 'nut-bar', then the tip is covered with the adhesive, and turned into the other end of the 25mm nut (Figure 83).

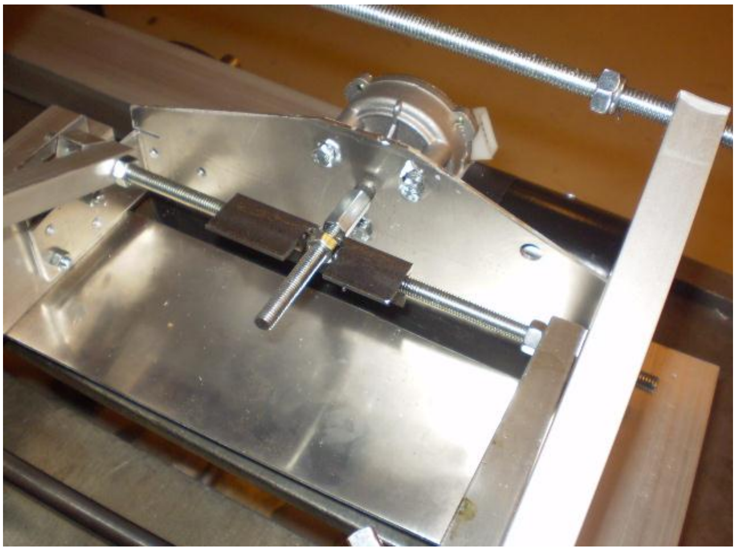


FIGURE 83 *Assembled lifting system motor on vehicle version 2*

## 6.6 Carriage connector pieces for vehicle version 2

The two vehicle carriages of version 2 are connected by a two-piece joint.

On the first carriage, there is a rectangular plate with a hole in the middle. On the second carriage, there is an envelope shaped plate, with a hole at the tip of the 'envelope'. The pieces are connected via a bolt (Figure 84).

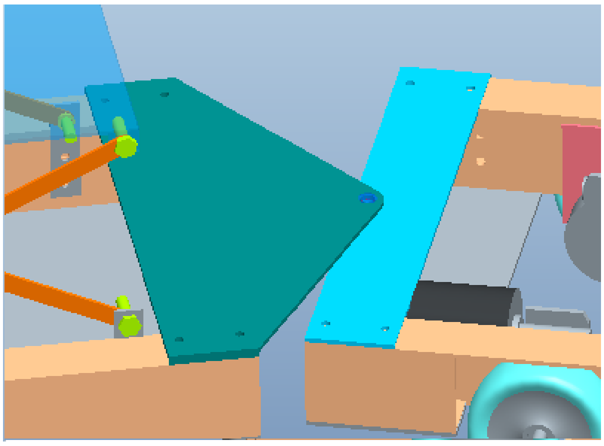


FIGURE 84 *Representing the connection assembly.*

## 6.7 Top floor for front carriage for vehicle version 2

In order to fit all the components on vehicle version 2, a second floor had to be placed on top of the first carriage, to house all the components. The material used for the floor is the 3mm thick sheet metal. Holes were cut to each corner, based on the hole system for the base plates (6.1.4).

## 6.8 Placing of electric components

### 6.8.1 Vehicle version 1

The electric components are pre-assembled onto the DIN-rail, and wires are connected between the components (Figure 85).

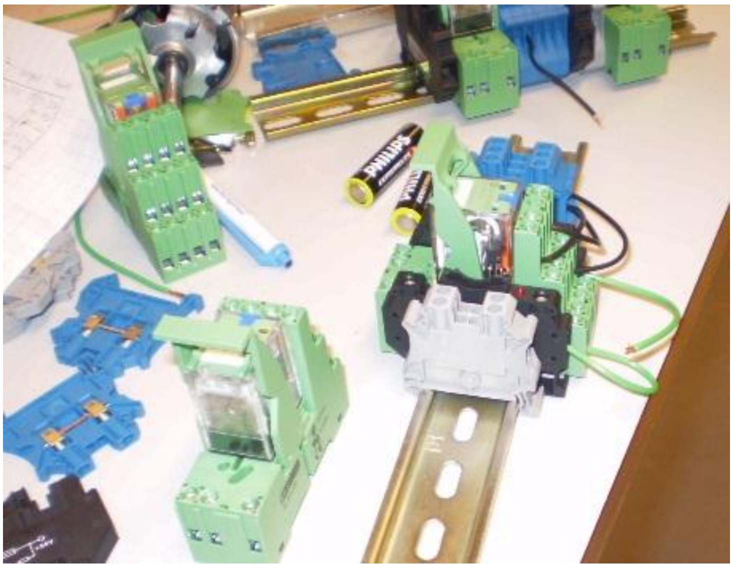


FIGURE 85 *Preassembled electronics*

The pre-assembled components are fit onto the car. Using a hand drill, holes are drilled onto the base of the car, and the DIN-rail is fixed via bolts (Figure 86).

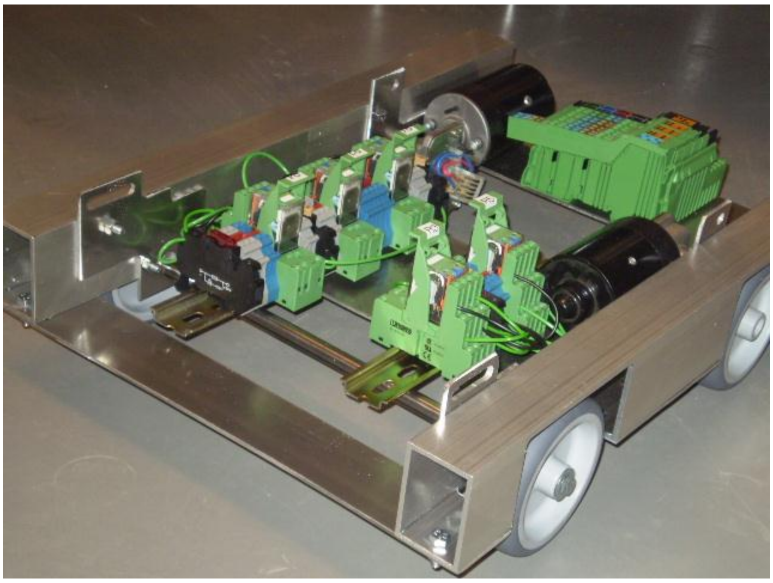


FIGURE 86 *Electrical components are placed and fixed.*

### 6.8.2 Vehicle version 2

The components are placed in the same manner as those of version 1, but in this case wires are used to connect the electronic components on the top floor of carriage 1 to the lower floor of carriage 1 and between the front and rear carriages (Figure 87).

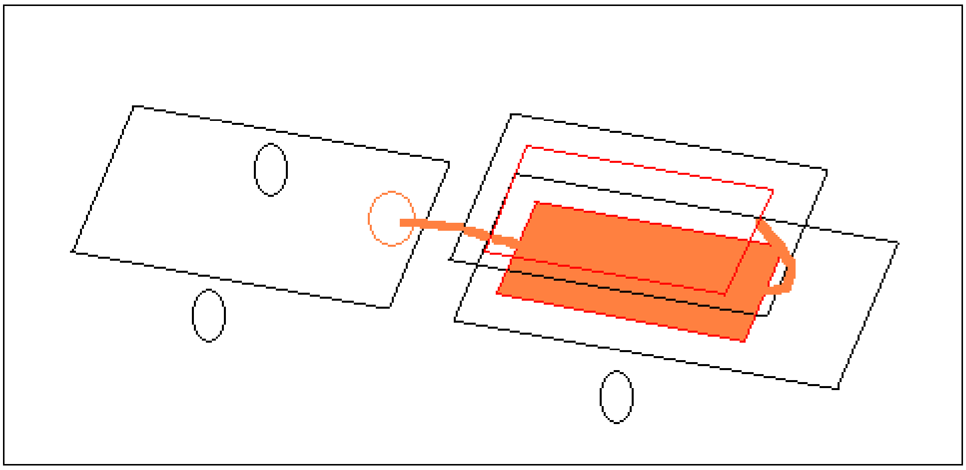


FIGURE 87 *The main electronics areas of vehicle version 2, and cable placements*

# 7 CONCLUSIONS

When first the decision came to design the lifter vehicle, the design process seemed very easy. But as the process progressed and as the design became more and more clear, the level of detail started mattering more and more. Questions about whether all the components would fit, and what kind of pieces should we use, were determining the main course of the design process. It is one thing to start designing a piece with no constraints, but an entirely different matter to design your part to already existing components. The design process took so many turns because the problems were about component placements and lifting the vehicle.

The main problems during the thesis were the choice of the correct model to manufacture, and then the manufacturing itself. I couldn't decide which model to manufacture - every better solution brought new complicated problems. Even the simplest things turned out to be more complicated than expected, e.g. fixing wheels on a bar, so that the wheels could spin.

However I was able to turn the minuses into plusses by learning a few new skills about manufacturing and designing. I learned how to use many of the machines, how to weld, grind and use the workshop tools. A whole new department of knowledge about electrical devices opened up to me - the work principles of relays, sensors, fuses, PLC's and more.

During the course of my thesis I got a lot of help from strangers, who just wanted to give me their advice, e.g. the project manager at the company LaserPro OY, who spent an hour showing me different techniques of laser welding and 3D sheet metal constructions. The knowledge may not have been necessary in this project, but I may be able to use it later in life.

# SOURCES

/1/ "Sheet metal" 27.09.2010
< http://en.wikipedia.org/wiki/Sheet_metal#Aluminium>

/2/ “Sheet metal image” 16.11.2010
<http://www.metals-unlimited.com/images/aluminumsheet.jpg>

/3/ "Bosch motor" 17.11.2010
<http://www.boschmotorsandcontrols.co.uk/elektromotoren/gleichstrommotoren/mit-getriebe/index.htm>

/4/ "Yuasa battery" 17.11.2010
<http://www.vps-ups.co.uk/product/379/yuasa_np7_12__7_a_h_12v_battery_faston_terminal>

/5/ "DIN rail" 28.9.2010
<http://www.designnews.com/article/12007-DIN_rail_basics.php>

/6/ “DIN rail image” 16.11.2010
<http://rocky.digikey.com/weblib/American%20Electrical/Web%20Photos/ADR3575-S7874.jpg>

/7/ "ProEngineer image" 17.11.2010
<http://communities.ptc.com/community/creo-elements-pro/assembly_management?view=video>

/8/ "Relay description" 16.11.2010
<http://en.wikipedia.org/wiki/Relay>

/9/ "Relay image" 16.11.2010
<http://eshop.phoenixcontact.fi/phoenix/treeViewClick.do?UID=2834643&parentUID=&reloadFrame=true>

/10/ "Fuse" 16.11.2010
<http://www.yourdictionary.com/fuse>

/11/ "Typical examples of fuses" 16.11.2010
<http://www.electronicrepairguide.com/how-to-test-a-fuse.html>

/12/ "Fuse Holder" 16.11.2010
<http://parts.digikey.com/1/parts-kws/mta-fuse-terminals>

/13/ "Limit switch" 16.11.2010
<http://en.wikipedia.org/wiki/Switch>

/14/ "Examples of limit switches" 16.11.2010
<http://www.annpurnaelectricals.com/jaibalaji.html>

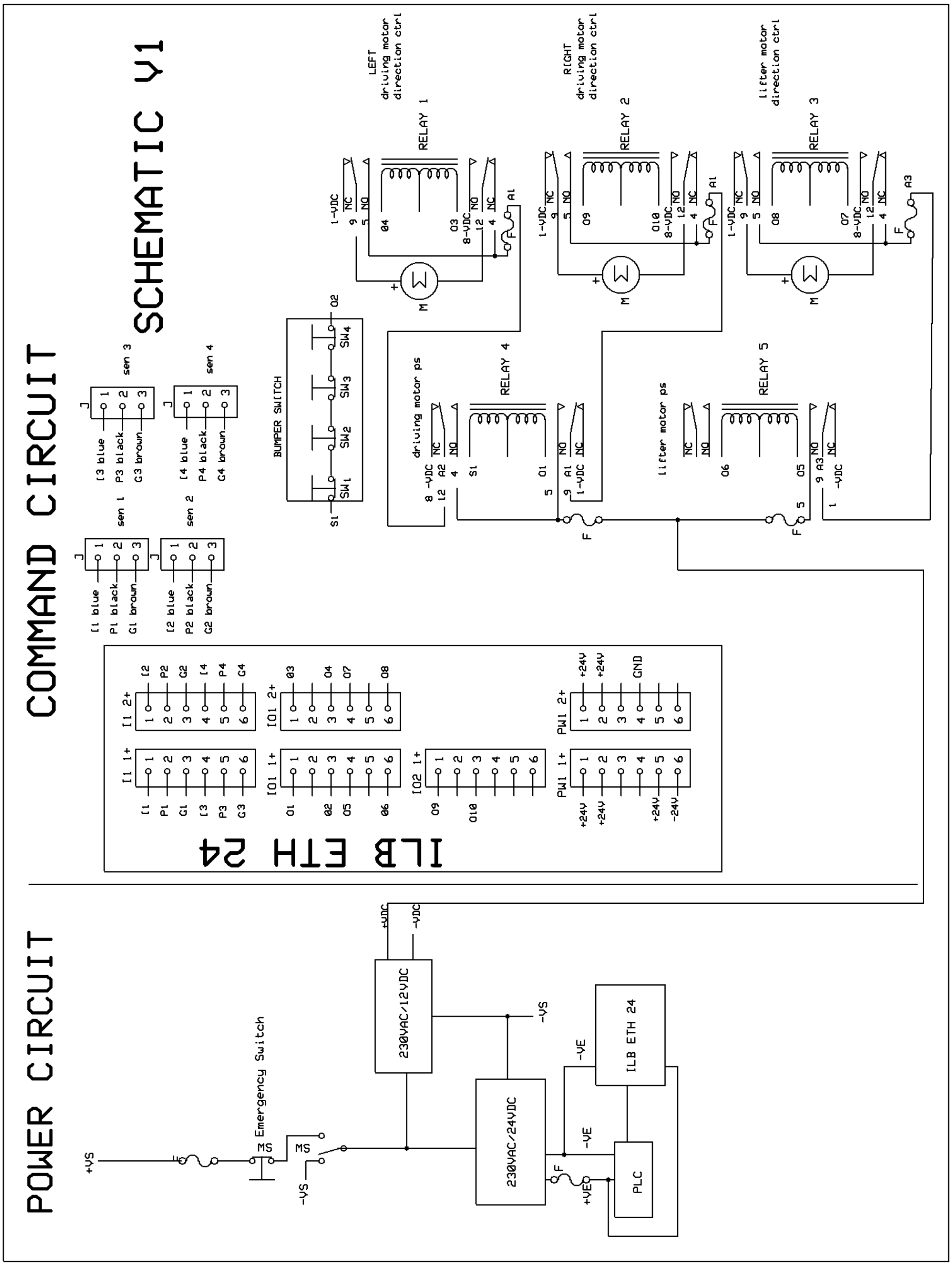
/15/ “Inductive sensor” 16.11.2010
<http://en.wikipedia.org/wiki/Inductive_sensor>

/16/ “Inductive sensor image” 16.11.2010
<http://www.alibaba.com/product-gs/215639091/M8_Non_Flush_2mm_sensing_inductive.html>

/17/ "Pocket milling tool" 7.11.2010
<http://maford.com/Products/Index.aspx?cell=Endmill>

APPENDIX 1

VERSION 1 CIRCUIT DIAGRAM



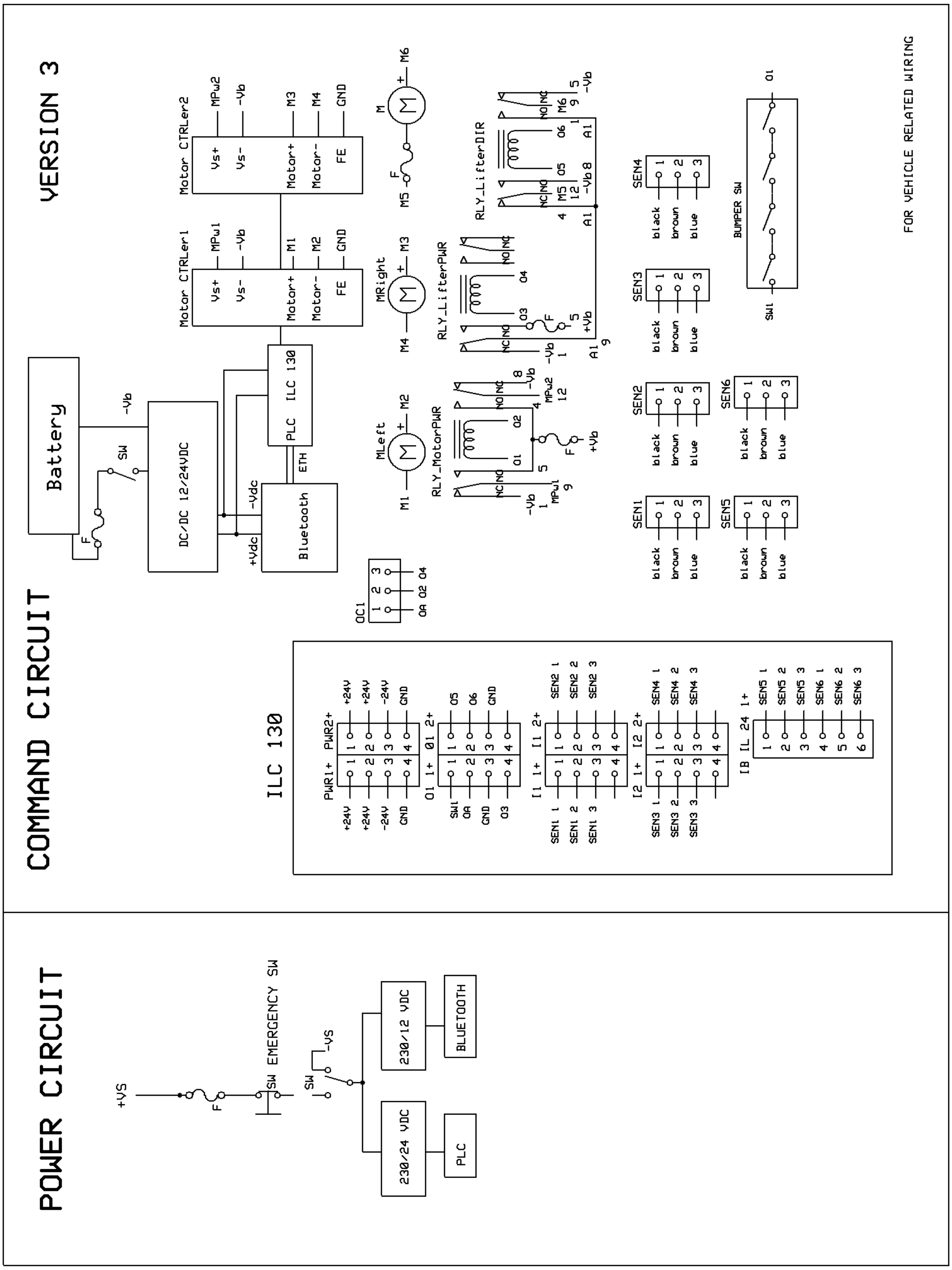
APPENDIX 2

# VERSION 1 WIRING LIST (BASED ON SCHEMATIC)

| Wire no | From | | To | | Wire col. | | |
|---|---|---|---|---|---|---|---|
| (Sensors) | Component | Port | Component | Port | | | What it does |
| 1 | PLC | I1 1.1 | Sensor 1 | 1 | Blue | Signal | Sensor 1 ("CASSEN") is for detecting whether there is a cassette next to the car |
| 2 | PLC | I1 1.2 | Sensor 1 | 2 | Black | 24V | |
| 3 | PLC | I1 1.3 | Sensor 1 | 3 | Brown | V neg | |
| 4 | PLC | I1 2.1 | Sensor 2 | 1 | Blue | Signal | Sensor 2 is for detecting whether the lifter sys is at its 'down' pos. or not |
| 5 | PLC | I1 2.2 | Sensor 2 | 2 | Black | 24V | |
| 6 | PLC | I1 2.3 | Sensor 2 | 3 | Brown | V neg | |
| 7 | PLC | I1 1.4 | Sensor 3 | 1 | Blue | Signal | Sensor 3 is for detecting whether the lifter sys is at its 'up' pos. or not |
| 8 | PLC | I1 1.5 | Sensor 3 | 2 | Black | 24V | |
| 9 | PLC | I1 1.6 | Sensor 3 | 3 | Brown | V neg | |
| 10 | PLC | I1 2.4 | Sensor 4 | 1 | Blue | Signal | Sensor 4 is for detecting whether the track is ending |
| 11 | PLC | I1 2.5 | Sensor 4 | 2 | Black | 24V | |
| 12 | PLC | I1 2.6 | Sensor 4 | 3 | Brown | V neg | |
| (Bumper) | | | | | | | |
| 13 | PLC | IO1 1.1 | Relay 4 | IN | Green | 24V | Relay 4 command circuit |
| 14 | Relay 4 | OUT | Switch 1 | IN | Green | 24V | (Each relay set is composed of 2 relays, both controlled by same command circuit) |
| 15 | Switch 1 | OUT | Switch 2 | IN | Green | 24V | Connecting the relay 4 to the safety bumper switches |
| 16 | Switch 2 | OUT | Switch 3 | IN | Green | 24V | All the safety bumper switches are connected in a single line formation |
| 17 | Switch 3 | OUT | Switch 4 | IN | Green | 24V | |
| 18 | Switch 4 | OUT | PLC | IO1 1.3 | Green | 24V | |
| (MAIN) | | | | | | | The main power circuit 12V |
| 19 | 230V-> 12VDC | 12V end | Wire 21 | (T-connection) | | | |
| 20 | Fuse 5 | OUT | Fuse 4 | IN | | 12V | |
| 21 | Fuse 4 | OUT | Relay 4-2 | NO | | 12V | NO stands for 'Normally Open' |
| 22 | Relay 4-1 | OUT | Fuse 2 | IN | | 12V | |
| 23 | Relay 4-1 | NO | Wire 22 | | | 12V | |
| 24 | Relay 4-1 | NC | V neg | | Black | 12V | V neg' - Negative voltage (usually grounded) |
| 25 | Relay 4-2 | OUT | Fuse 1 | IN | | 12V | |
| 26 | Relay 4-2 | NC | V neg | | Black | 12V | NC stands for 'Normally Closed'. (Connect to relay 4, set 2, NC pin) |
| 27 | Fuse 5 | IN | Relay 5-1 | NO | | 12V | |
| 28 | Relay 5-1 | NC | Vneg | | Black | 12V | |
| 29 | Relay 5-1 | OUT | Fuse 3 | IN | | 12V | Note: Relay 5-2 is not used at all |
| 30 | Fuse 3 | OUT | Relay 3-2 | NO | | 12V | Fuse, Motor and Relay set: 3 |
| 31 | Wire 31 | | Relay 3-1 | NC | | 12V | |
| 32 | Relay 3-1 | OUT | Motor 3 | neg end | | 12V | |
| 33 | Relay 3-1 | NO | V neg | | Black | 12V | |
| 34 | Relay 3-2 | OUT | Motor 3 | Pos end | | 12V | |
| 35 | Relay 3-2 | NC | V neg | | | 12V | |
| 36 | Fuse 2 | OUT | Relay 2-2 | NO | | 12V | Fuse, Motor and Relay set: 2 |
| 37 | Wire 37 | | Relay 2-1 | NC | | 12V | |
| 38 | Relay 2-1 | OUT | Motor 2 | neg end | | 12V | |
| 39 | Relay 2-1 | NO | V neg | | Black | 12V | |
| 40 | Relay 2-2 | OUT | Motor 2 | Pos end | | 12V | |
| 41 | Relay 2-2 | NC | V neg | | | 12V | |
| 42 | Fuse 1 | OUT | Relay 1-2 | NO | | 12V | Fuse, Motor and Relay set 1 |
| 43 | Wire 43 | | Relay 1-1 | NC | | 12V | |
| 44 | Relay 1-1 | OUT | Motor | neg end | | 12V | |
| 45 | Relay 1-1 | NO | Vneg | | | 12V | |
| 46 | Relay 1-2 | OUT | Motor | Pos end | | 12V | |
| 47 | Relay 1-2 | NC | V neg | | | 12V | |
| CTRL | | | | | | | Control signals between PLC and relay 1,2,3,5 control coils. |
| 48 | PLC | IO1 1.4 | Relay 5 | IN | | 24V | |
| 49 | Relay 5 | OUT | PLC | IO1 1.6 | | 24V | |
| 50 | PLC | IO1 2.4 | Relay 3 | IN | | 24V | |
| 51 | Relay 3 | OUT | PLC | IO1 2.6 | | 24V | |
| 52 | PLC | IO2 1.1 | Relay 2 | IN | | 24V | |
| 53 | Relay 2 | OUT | PLC | IO2 1.3 | | 24V | |
| 54 | PLC | IO1 2.1 | Relay 2 | IN | | 24V | |
| 55 | Relay 2-2 | OUT | PLC | IO1 2.3 | | 24V | |

APPENDIX 3

VERSION 2 CIRCUIT DIAGRAM



# APPENDIX 4

## VERSION 2 WIRING LIST (BASED ON SCHEMATIC)

| Wire nr. | From | | To | | Wire color | Wire voltage | Description |
|---|---|---|---|---|---|---|---|
| (Power) | Component | Port | Component | Port/pin | | | |
| 1 | ILC 130 | PWR1.1 | 230VAC/24VDC | | Green | 24V | |
| 2 | ILC 130 | PWR1.2 | 230VAC/24VDC | | Green | 24V | |
| 3 | ILC 130 | PWR1.3 | 230VAC/24VDC | | Black | 24V | |
| 4 | ILC 130 | PWR1.4 | GND | | Black | 24V | |
| 5 | ILC 130 | PWR2.1 | 230VAC/24VDC | | Green | 24V | |
| 6 | ILC 130 | PWR2.2 | 230VAC/24VDC | | Green | 24V | |
| 7 | ILC 130 | PWR2.3 | 230VAC/24VDC | | Black | 24V | |
| 8 | ILC 130 | PWR2.4 | GND | | Black | 24V | |
| (Sensors) | | | | | | | |
| 9 | ILC 130 | I1 1.1 | SEN 1 | 1 | BLACK | 24V | |
| 10 | ILC 130 | I1 1.2 | SEN 1 | 2 | BROWN | 24V | |
| 11 | ILC 130 | I1 1.3 | SEN 1 | 3 | BLUE | 24V | |
| 12 | ILC 130 | I1 2.1 | SEN 2 | 1 | BLACK | 24V | |
| 13 | ILC 130 | I1 2.2 | SEN 2 | 2 | BROWN | 24V | |
| 14 | ILC 130 | I1 2.3 | SEN 2 | 3 | BLUE | 24V | |
| 15 | ILC 130 | I2 1.1 | SEN 3 | 1 | BLACK | 24V | |
| 16 | ILC 130 | I2 1.2 | SEN 3 | 2 | BROWN | 24V | |
| 17 | ILC 130 | I2 1.3 | SEN 3 | 3 | BLUE | 24V | |
| 18 | ILC 130 | I2 2.1 | SEN 4 | 1 | BLACK | 24V | |
| 19 | ILC 130 | I2 2.2 | SEN 4 | 2 | BROWN | 24V | |
| 20 | ILC 130 | I2 2.3 | SEN 4 | 3 | BLUE | 24V | |
| 21 | ILC 130 | IB IL 24 1.1 | SEN 5 | 1 | BLACK | 24V | |
| 22 | ILC 130 | IB IL 24 1.2 | SEN 5 | 2 | BROWN | 24V | |
| 23 | ILC 130 | IB IL 24 1.3 | SEN 5 | 3 | BLUE | 24V | |
| 24 | ILC 130 | IB IL 24 1.4 | SEN 6 | 1 | BLACK | 24V | |
| 25 | ILC 130 | IB IL 24 1.5 | SEN 6 | 2 | BROWN | 24V | |
| 26 | ILC 130 | IB IL 24 1.6 | SEN 6 | 3 | BLUE | 24V | |
| (Bumper) | | | | | | | |
| 27 | ILC 130 | O1 1.1 | Switch 1 | IN | Green | 24V | |
| 28 | Switch 1 | OUT | Switch 2 | IN | Green | 24V | |
| 29 | Switch 2 | OUT | Switch 3 | IN | Green | 24V | |
| 30 | Switch 3 | OUT | Switch 4 | IN | Green | 24V | |
| 31 | Switch 4 | OUT | RLY_Motor_PWR 1 | IN | Green | 24V | |
| 32 | RLY_Motor_PWR 1 | OUT | RLY_Motor_PWR 2 | IN | Green | 24V | |
| 33 | RLY_Motor_PWR 2 | OUT | OC1 | 2 | Green | 24V | |
| (RLY CTRL) | | | | | | | Relay control circuits |
| 34 | OC1 | 1 | ILC 130 | O1 1.2 | Green | 24V | |
| 35 | OC1 | 3 | RLY_LifterPWR 2 | OUT | Green | 24V | RLY_LifterPWR set |
| 36 | ILC 130 | O1 1.4 | RLY_LifterPWR 1 | IN | Green | 24V | |
| 37 | RLY_LifterPWR 1 | OUT | RLY_LifterPWR 2 | IN | Green | 24V | |
| 38 | ILC 130 | O1 2.1 | RLY_LifterDIR 1 | IN | Green | 24V | RLY_LifterDIR set |
| 39 | RLY_LifterDIR 1 | OUT | RLY_LifterDIR 2 | IN | Green | 24V | |
| 40 | RLY_LifterDIR 2 | OUT | ILC 130 | O1 2.2 | Green | 24V | |
| 41 | ILC 130 | O1 1.3 | GND | | Black | 24V | |
| 42 | ILC 130 | O1 2.3 | GND | | Black | 24V | |
| (RLY MAIN) | | | | | | | Relay main circuit |
| 43 | RLY_MotorPWR 1 | NC | Vb(-) | | Black | 12V | Relay Motor Power set 1 |
| 44 | RLY_MotorPWR 1 | OUT | Motor CTRLer1 | Vs(+) | Green | 12V | |
| 45 | RLY_MotorPWR 1 | NO | Fuse M_PWR | IN | Green | 12V | |
| 46 | RLY_MotorPWR 2 | NO | Wire 44 | | Green | 12V | Relay Motor Power set 2 |
| 47 | RLY_MotorPWR 2 | OUT | Motor CTRLer2 | Vs(+) | Green | 12V | |
| 49 | RLY_MotorPWR 2 | NC | Vb(-) | | Black | 12V | |
| 50 | Fuse M_PWR | OUT | Vb (+) | | Green | 12V | |
| | | | | | | | RLY_LifterPWR and RLY_LifterDIR |
| 51 | RLY_LifterPWR 1 | NC | Vb(-) | | Black | 12V | |
| 52 | RLY_LifterPWR 1 | OUT | RLY_LifterDIR 2 | NO | Green | 12V | |
| 53 | RLY_LifterPWR 1 | NO | Fuse L_PWR | IN | Green | 12V | |
| 54 | Fuse L_PWR | OUT | RLY_LifterDIR 2 | NC | Green | 12V | |
| 55 | RLY_LifterDIR 1 | NC | Wire 54 | | Green | 12V | |
| 56 | RLY_LifterDIR 1 | OUT | Fuse LiftMotor | IN | Green | 12V | |
| 57 | Fuse LiftMotor | OUT | Motor Lifter | IN | Green | 12V | |
| 58 | Motor Lifter | OUt | RLY_LifterDIR 2 | OUT | Green | 12V | |
| | | | | | | | Motor controller circuit |
| 59 | Battery 12V | (+) | Fuse Battery | IN | Green | 12V | |
| 60 | Fuse Battery | OUT | Switch Conv. | IN | Green | 12V | |
| 61 | Switch Conv. | OUT | 12VDC/24VDC | (+) | Green | 12V | |
| 62 | Battery 12V | (-) | 12VDC/24VDC | (-) | Black | 12V | |
| 63 | 12VDC/24VDC | (+) | Bluetooth | (+) | Green | 24V | |
| 64 | 12VDC/24VDC | (-) | Bluetooth | (-) | Black | 24V | |
| 65 | Wire 63 | | PLC ILC 130 | (+) | Green | 24V | |
| 66 | Wire 64 | | PLC ILC 130 | (-) | Black | 24V | |
| 67 | Bluetooth | | PLC ILC 130 | | Green | Ethernet | |
| 68 | PLC ILC 130 | | Motor CTRLer 1 | | Green | Ethernet | |
| 69 | Motor CTRLer 1 | | Motor CTRLer 2 | | Green | Ethernet | |
| 70 | Motor CTRLer 1 | Vs(-) | Vb (-) | | Black | | |
| 71 | Motor CTRLer 1 | Motor (+) | Motor right | IN | Green | | |
| 72 | Motor CTRLer 1 | Motor (-) | Motor right | OUT | Black | | |
| 73 | Motor CTRLer 1 | FE | GND | | Black | | |
| 74 | Motor CTRLer 2 | Vs(-) | Vb (-) | | Black | | |
| 75 | Motor CTRLer 2 | Motor (+) | Motor left | IN | Green | | |
| 76 | Motor CTRLer 2 | Motor (-) | Motor left | OUT | Black | | |
| 77 | Motor CTRLer 2 | FE | GND | | Black | | |