University of Canterbury

Direct-Drive Electric Scooter Development

ENEL400 - Third Professional Year Project Specifications Report

Project Title: Direct-Drive Electric Scooter Development
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Abstract

The Direct Drive Electric Scooter project is being developed as an alternative form of transport for short range urban transport. This uses components and findings from a previous third professional year project to essentially give electrical functionality to a children's scooter (shown in Figure 1) by fitting a brushless direct current (BLDC) hub motor to the rear wheel. Further modifications will be required to the scooter frame in order to target its use at adults. On top of this a high level controller needs to be designed to interpret user commands for the BLDC motor speed controller. As currently stands the initial mechanical specifications have been completed and the information has been relayed to mechanical workshop for design checks, however these modifications will require ongoing communication. Additionally a clear set of requirements have been established regarding the high level controller by means of examining the previous Avanti Electra project and gathering waveforms. The project appears to be on track; however significant amounts of electrical design work will be required regarding the high level controller in the upcoming weeks.

Figure 1 – Children's Scooter Purchased by the Department.

Contents

1) Project Overview

The aim of this project is convert a commercially available children's scooter into a direct drive electric scooter with the intent for adult use as form of light weight urban transport. The department is in possession of a brushless direct current (BLDC) hub motor that has been modified from an Avanti Electra road bicycle. A previous project, undertaken by Matthew Codlin and supervised by Dr. Paul Gaynor, has successfully improved the performance of the motor through increased supply voltage. This project will involve the fitting of this BLDC motor into the rear wheel of the purchased scooter, applying the electrical improvement learnt from prior experimentation.

The department has also purchased a number of high energy density Lithium Iron Phosphate ($LiFePO_2$) battery cells manufactured by A123 Systems. The cells each have a potential 3.3V and are capable of sourcing up to 100A [1]. The intention is to connect 5 of these in parallel, and then 8 sets of these 5 in parallel to achieve approximately 26.4v and a continuous current capacity of up to 500A (5 parallel cells at 100A).

An important design constraint of this project is to keep weight to a minimum. Much like the selected cells, it is for this reason that a BLDC motor is to be used. This is due to the high power density they possess, making them ideal for weight constrained situations. The motor is rated for 200W however the previous project has determined that this can be extended to 300W through greater voltage and still remain road legal without requiring registration [2]. Furthermore the motor is able to 'over-powered' for a short duration of time without damage, enabling the implementation of a 'boost' feature. An I^2t algorithm will be required to determine this duration.

The use of this motor on the scooter will require the fabrication of new rim. This is due to the diameter of the BLDC motor exceeding that of the current rim. Additionally, in order to achieve adult use of the scooter, the frame will involve a considerable amount of working particularly the positioning of the handlebars and integration of power source. Special care must be taken during these modifications to ensure that the mechanical integrity/operation remaining intact. In particular it is important that any change in height/weight distribution does not cause the scooter to become top heavy and cause difficulties for the user.

The department is also in possession of a 'Golden Motor BAC-0281' motor controller that has been used on the previous Avanti Electra project. While this controller provides an abstracted level of control of the BLDC motor a higher level embedded system will need to be developed to interpret user inputs and thus generate appropriate signals for the motor controller. These inputs include speed control, regenerative breaking and boost activation. This system should also be capable of relaying speed and battery charge information through a mounted display.

It is also important to consider the sustainability when engaging the engineering design process. For this reason triple bottom line analysis will be applied to identify the environmental, economic and social issues surrounding the project.

From here it can be established that the key areas of work on the project can split into two key categories:

- Mechanical Design – Involving the careful planning process that will be required to realize a functional lightweight electrical vehicle.
- Electrical Design – The electrical design that will be required to achieve an efficient, safe and usable system.

2) Progress to Date

a) Mechanical Assessment/Design

A large amount of the work done to date has been on the mechanical alterations required for the project. This is predominantly due to the time that will be required for these alterations to be made. In order for the project to be completed on time it is practical for these alterations to occur while other design phases are happening. The mechanical alterations consist of three key sections; battery enclosure, motor fitting, and handle bar adjustments. The following sections explain the corresponding design decisions in detail.

Battery Enclosure

The cell array, consisting of 40 cells (8 x 5 in parallel), has been modeled using solid works in order to design the appropriate casing enclosure. This can be seen below in Figure 2.

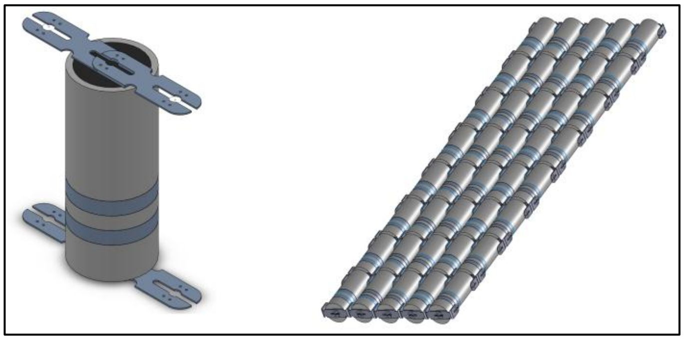

Figure 2 – Single A123 Systems LiFePO2 Cell (Left) and Proposed Cell Array (Right).

The resulting cell array will weigh approximately 2.88Kg (40 x 72g) and occupy a space, specified by the manufacturer, of (524mm x 130mm x 26mm) [3]. Casing for the cell array must also consider a thin insulating lining that will be required into electrical isolate the cells from the enclosure.

Figure 3 shows the cell array positioned under the scooter frame. As can be seen, the cell array is significantly longer than the horizontal portion of the scooter frame (By approximately one cell length - 65mm). Additionally the diameter of the cells means that placement of the array under the frame is impractical as it would not provide adequate clearance to the ground (66mm down from 92mm).

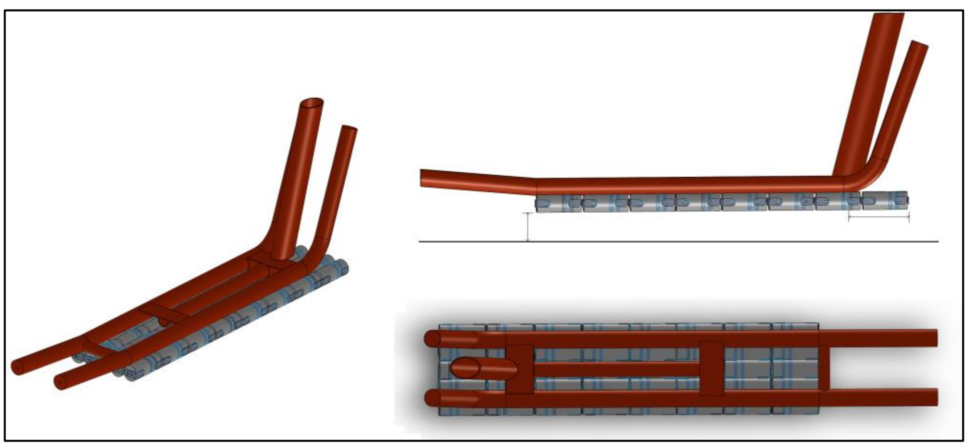

Figure 3 – Solid Works Models illustrating Issues of Placing Cell Array Under the Scooter.

To overcome these problems, the proposed solution is shown in below in Figure 4. The idea is to integrate the cell array and enclosure into the frame structure itself. This will effectively minimize the overall gain in weight while allowing sufficient ground clearance and overall length. To further reduce weight the casing will ideally be made from aluminum due to its low density nature. The design will require the removal of the middle portion of the scooter frame and the aluminum enclosure wielded as replacement.

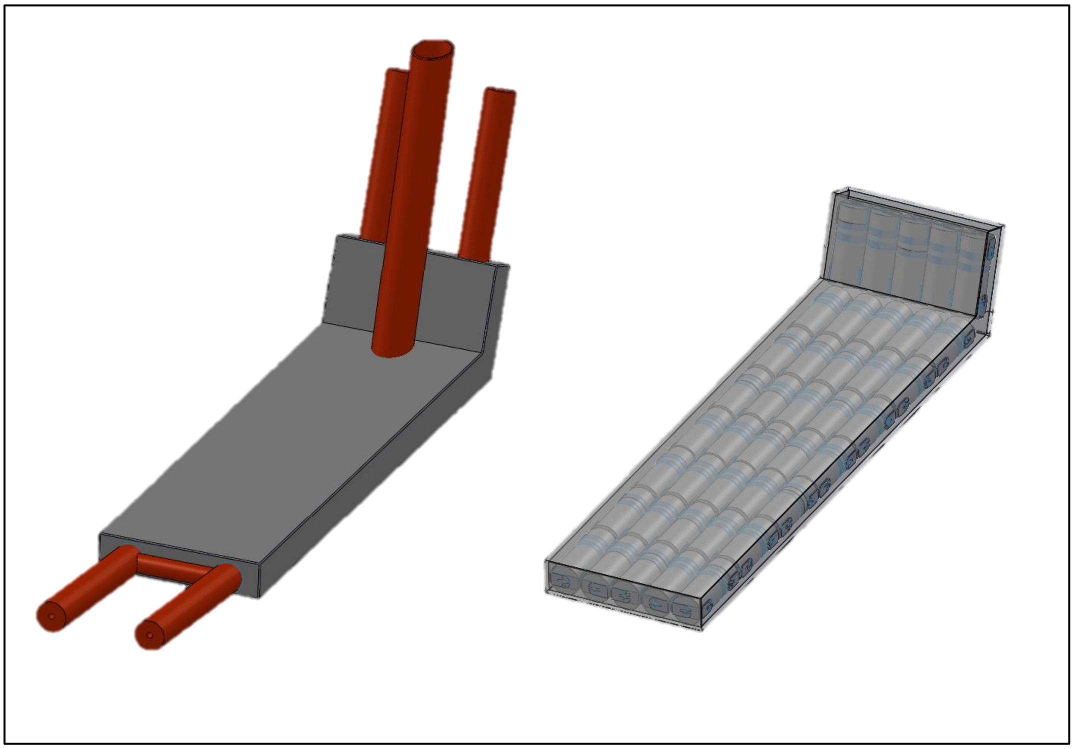

Figure 4 – Proposed Cell Enclosure Solution by Integrating with Frame. Dimension Drawing in Appendix 4.

Further modification to the orientation of each series line of eight cells is still to be considered. If they were positioned with each cell closer bunched in closer (slightly elevating the second and fourth cell columns) then the enclosure is similar dimensions to the motor controller shown in Appendix 1. This would allow the motor controller to be included in the battery enclosure and as a result be protected from external factors such as water/erosion. Furthermore the new cell orientation would allow paths for cables from the far cell terminal to be brought to the motor controller inside the enclosure.

The enclosure must also be fabricated in such a way that access is still readily available to the cells. To do this the upper layer of the casing will need to be bolted to the lower piece as opposed to being wielded. This means that the outer walls will be required to be a minimum of 4mm thick in order to support a 3 mm bolt.

Motor Fitting

Due to BLDC having a larger diameter than the rim currently on the scooter it will not be able to be used. Instead it has been arranged with David Healy, one of the technical staff in the mechanical workshop, to have a new rim fabricated for the motor to be mounted on. This solution will allow the rim to be catered specifically for the BLDC hub motor and therefore achieve a resulting rear wheel size similar to that of the front.

The outer dimensions of the rim will still need to be fabricated to match that of a desired tire. Unfortunately the standard sizes of commonly manufactured tires are discrete and very limited. The BLDC hub motor, shown below in Figure 5,   has a diameter of 240mm. There are two standard tire sizes either side of this in New Zealand, 317.5mm (marketed as 12 - 12 ½ inch) and 406.4 mm (marketed as 16 inch) however these values refer to the outer dimensions of the tires. The insider diameter, concerning the fitting of the motor, will depend on the profile of the tire itself. While a very low profile tire in the 12 ½ inch range may be possible, all 16 inch tires are simply too large.

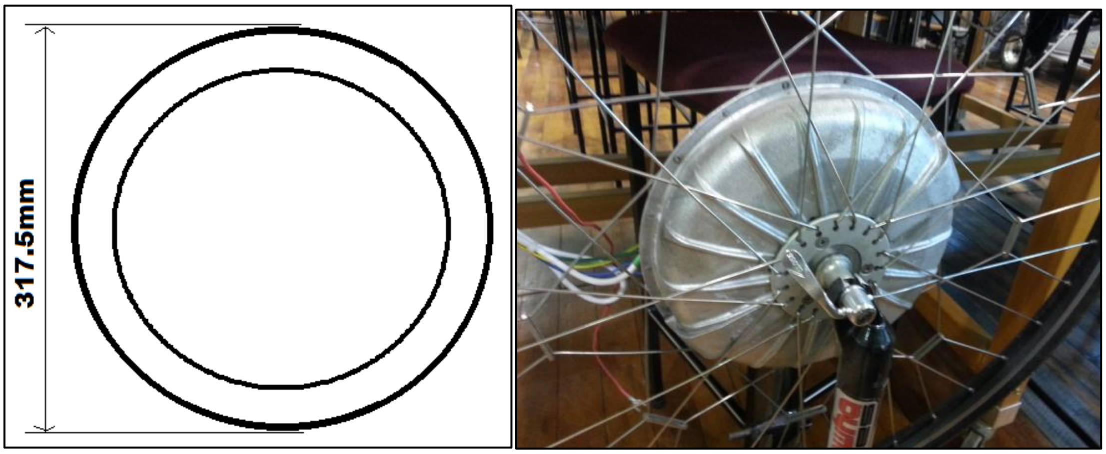

Figure 5 – Region of the Outer Tire Dimension (Left) and the Purchased Avanti Electra BLDC Hub Motor (Right)

A low profile 12 ½ tire has been purchased and the feasibility of this is still to be finalized. An alternative to this could be a tubeless tire or some other means of reducing the thickness of the outer portion of the tire.

Handlebar Adjustments

In order for the scooter to be safely and effectively used by an adult, the positioning of the handlebars will need to be modified. In particular it has been decided that the piece that extends from the frame will need to be extended. The exact magnitude of this increase is still to be finalized.

Figure 6 – View of the Handlebar Region of the Scooter.

b) Electrical Specifications

Work and research on the electrical aspects of the electrical has been undertaken first by setting up and examining the previous projects work on the power modification to the Avanti Electra's BLDC hub motor. From this set up and the documentation provided of the Avanti Electra project a number of beneficial observations can be made. The requirements for the high level controller have been identified as follows.

Current Transducer – The system will require a Hall Effect current transducer. Care should be taken to ensure the swing voltage from is close to the ADC sampling range of the selected microcontroller unit (MCU) in order to maximize resolution. The current is required in order to implement both battery management and the motor boost function. It is known that the PWM currents for the motor can produce a very noisy environment therefore some form of filtering will need to be applied to the signal.

Motor Speed - The BLDC hub motor has eight teeth positioned on the hall sensor target wheel producing a square wave between 0V and 5V with a frequency of eight times the wheel frequency. There is known noise in the signal that can be linked to jittering effects caused by the mechanical loads and electrical interference from the motor currents. Like the current transducer the motor speed signal will require filtering before being interfaced with a digital input on the MCU. An interrupt can then be configured to detect state changes and durations between pulses in order to acquire the signal frequency and thus motor speed. Figure 7 shows the recorded signals from the sensor. Noise can be seen in the high voltage state, particularly at higher frequencies. This can be expected to worsen with a changing mechanical load.

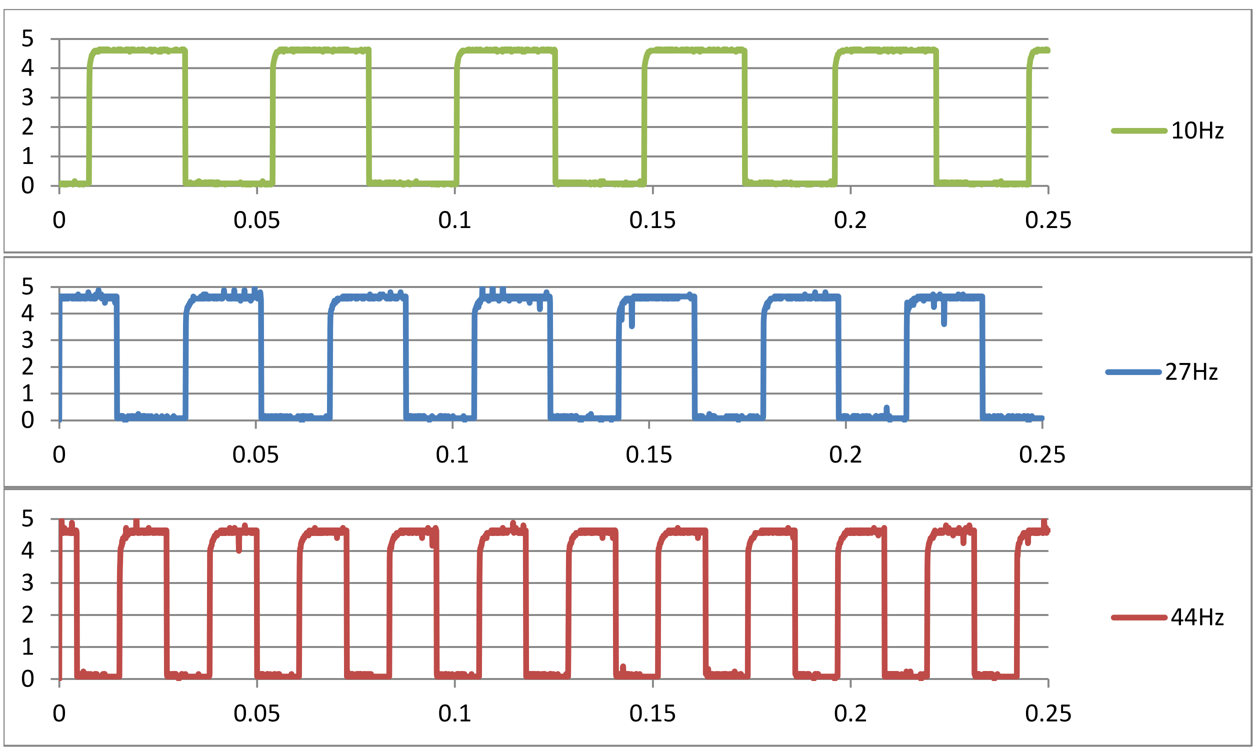

Figure 7 – Unfiltered Signals from Motor Position Hall Effect Sensor at Varying Speeds.

Throttle – The throttle needs to be capable of generating an analogue signal from a user input to be sampled from a MCU analog to digital convertor (ADC). Once again this signal should be designed to achieve a range equal to the sampling range in order to maximize resolution.

Boost Activation – Boost Activation will require a soft push button to activate a boost feature, giving the ability to overpower the motor momentarily.

Regenerative Breaking – The regenerative breaking will also require a soft push button to activate regenerative breaking. An additional hard switch could also be considered to permanently activate regenerative mode should added resistance be desired for fitness or mechanical charging.

Display – A small display will need to be interfaced with the selected MCU in order to relay motor speed and battery charge information back to the user.

From these specifications a distinct set of requirements regarding MCU choice and circuit design can be established as follows,

MCU Requirements –

- JTAG /SWD programming interface.
- ADC, for current transducer sampling) ideally 12 bit for higher resolution sampling of signals.
- Multiple GPIO for display interfacing, supporting API would be beneficial.
- DAC or PWM, preferably an on chip DAC peripheral to reduce hardware filtering associated with PWM.
- Supply voltage that can be obtained with no additional source.
- USB/UART Communication break out for debugging would be an advantage.

Circuit Requirements –

- Use surface mount components in order to minimize size and increase mechanical integrity
- Make use of department two layer printing, again to reduce circuit size.
- Be mountable on handlebars perhaps stacked and encased under the display.
- Include relevant overcurrent protection through a fuse.
- Relevant power decoupling and regulation.
- Appropriate filtering and good PCB practice in order to increase signal integrity.

3) Remaining Tasks

A number of tasks still remain, particularly in the design and development of the high level controller to interface with the motor speed controller. Tasks relating to this include;

- Microcontroller and Component Selection; Current transducer, Voltage Regulation, additional IC's etc.
- Circuit Design.
- PCB layout.
- Hardware Assembly/Testing.
- Software Design/ Development.
- Investigation into performance parameters involved with golden gate motor controller.

Remaining mechanical tasks include:

- Finalizing of Mechanical Design Decisions.
- Investigate possibility of disc breaks
- Confirmation of the channel piece required for battery housing and commencement of the integration with scooter frame.
- Confirmation of tire feasibility and commencement of the rim fabrication and BLDC fitting.
- Specific Details on the required extension length of the handle bar region of the scooter.
- Connecting the Battery Cell Array

A Gantt chart showing a projected project schedule, considering other academic responsibilities, can be seen below in Figure 8.

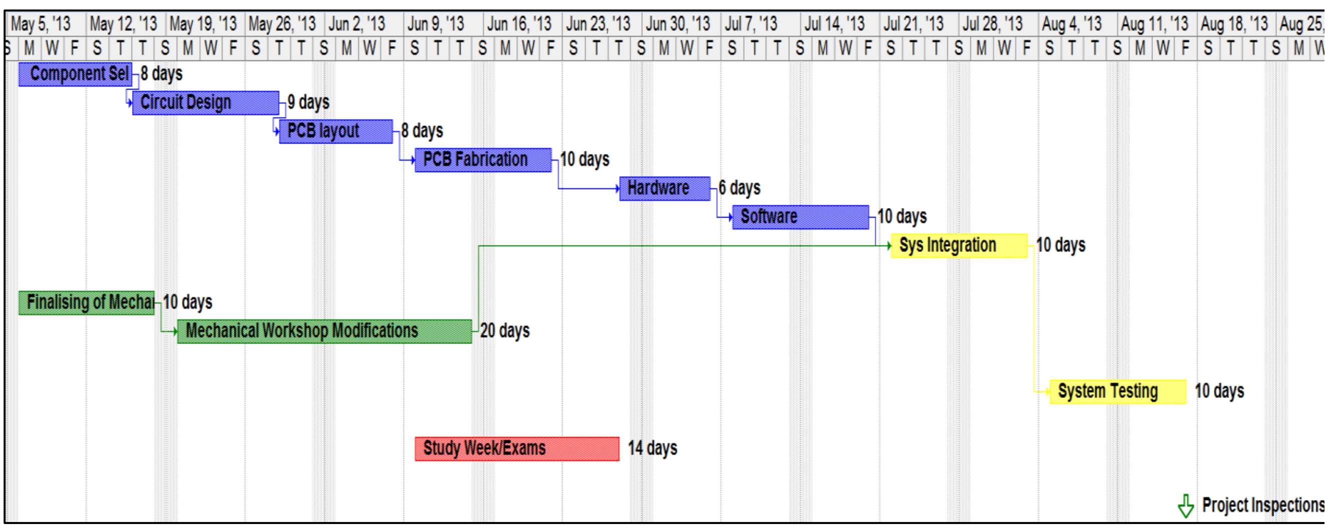

Figure 8 – Gantt Chart Projecting Project Schedule. Full Size Chart in Appendix 2 and Appendix 3

4) Sustainability Analysis

The Direct Drive Electric Scooter project is targeted at being an alternative form of short range urban transportation. By applying triple bottom line analysis, the key effects of the project can be established and critically assessed. Triple bottom line analysis focuses on the major issues regarding in terms of environmental, social and economic sustainability.

Environmental

In New Zealand, transportation accounts for "about 40% of our carbon dioxide (CO2) emissions, or 15% of all greenhouse gas (GHG) emissions" [3]. This is a significant issue that has prompted concerned groups and authorities to create long term visions to mitigate the problem. It is understood that the nature of modern transportation is essential to everyday life; however in urban areas there are often alternatives to transportation that, collectively, has a large carbon footprint. In light of these facts the government has made the decision that New Zealand should be one of the first countries to widely use electric vehicles in its fleet [4].

The Direct Drive Electric Scooter fits well into this vision however the environmental benefits are not limited to its electric nature. The NZ transport strategy has concluded "the predominant users of roads, accounting for about 80 percent of road traffic, are people in cars" and "About 90 percent of people travelling to work in cars do so alone" [4]. This is an issue of efficiency as much as infrastructure as similar quantities of energy that could potentially traffic up to five people to their destination are instead only being used to traffic a single commuter. Forms of transport such as the Direct Drive Electric Scooter, which are designed for single occupancy, are considerably more efficient in this regard. Additionally it is now common to see dedicated lane for busses and high occupancy vehicles in urban areas. These areas encourage more efficient use of road space and it can be expected that modes of transport such as this will fit into this scheme.

Another key concern is the common misconception that electric vehicles do not cause CO2 emissions. The reality is that electric energy is only as clean as the form of generation it comes from. Fortunately the New Zealand Energy Strategy (NZES) has adopted a target that by 2025, 90% of electricity will come from renewable resources such as wind, hydro and geo thermal [4]. This will support the decision for electric vehicles in reducing New Zealand's carbon footprint. This future, however, will still be subject to generation and distribution rising to meet the increased electrical load needed to charge such vehicles.

Efficiency is paramount when it comes to both renewable and non-renewable generation. Electric vehicles offer an energy conversion that is about four times higher than regular combustion engine vehicles [5]. This means that for the same task an electrical vehicle will consume significantly less resources than that of a combustion engine. Furthermore, in cases such as this one, electric motors are capable of using 'regenerative breaking' in order to convert the kinetic energy of the vehicle back into electric charge to be again used by the vehicle. While not all of the energy is again restored to the batteries, it is considerably better when compared to more traditional breaking methods. These methods simply convert the kinetic energy of the vehicle into heat by means of brake pads. Not only is this method wasteful but also consumes break pad materials that in electric vehicles, rarely need to be used.

It is clear that the single user electric nature of the electric nature of the direct drive electric scooter delivers many benefits that coincide with current environmental trends however it, along with other electric vehicles is not without drawbacks. In particular these issues stem from the various battery chemistries and both their inability to store charge and environmental impact when not correctly disposed of. Many batteries, such as ones that are Lead and Cadium based, when dumped in landfills can permeate into the soil and groundwater and even release toxin into the air when burnt in furnaces. As the direct drive electric scooter makes use of a relatively new technology Lithium Iron phosphate ($LiFePO_4$) this is not as much of a problem. The cell structure still requires that the batteries are disposed of correctly due to the lithium, however since the long life nature of the cells is projected at 5-7 years the cells do not need frequent replacement. The problem could be further mitigated by educating users with the knowledge of environmental hazards associated with the batteries and correct disposal procedures.

Economic

Alternative forms of transport such as the Direct Drive Electric Scooter come with a range of economic advantages for a number of stakeholders. The first of these applies to the user themselves. The amount of energy that can be stored in the proposed cell array can be calculated by,

$$Energy_{Cells} = V_{nominal} \times Charge\ Capacity\ Per\ Cell \times Number\ of\ Cells \quad \textbf{(Equation 1)}$$

$$Energy_{40\ Cells} = 3.3V \times 2.3Ah \times 40 = 303.6\ Wh$$

The cost for this much electricity in New Zealand (Assuming the typical price of around 26.5 cents per kWh for a normal residential electricity supply) is approximately 8.05 cents [6]. A comparison with the average Christchurch commute times, distances and costs against other forms of transport can be seen in below in Table 1

Table 1- Estimated Single Occupant Commute Times and Associated Costs for a Range of Transportations in Urban Christchurch.

Christchurch Single Occupant Commuting	One Way			Two way					
Means of Travel:	Dist. to Work (km)	Time to Work (mins)	Avg. Speed to Work (km/hr)	Cost per km ($/km)	Cost per day ($)	Cost per week ($)	Cost per month ($)	Cost per year ($)	Scaled to Scooter Dist. ($)
Direct Drive Electric Scooter	5.00	16.60	14.60	0.02	0.08	0.40	1.75	20.93	20.93
Public Transport (Bus)	8.20	33.30	14.70	0.56	4.60	23.00	99.82	1196.00	729.27
Small Vehicle (0-1500cc)	7.90	17.40	24.30	0.59	9.32	46.61	202.29	2423.72	1534.00
Compact Car (1500cc - 2000cc)	7.90	17.40	24.30	0.64	10.10	50.48	219.09	2625.01	1661.40
Medium Car (2000cc - 3000cc)	7.90	17.40	24.30	0.79	12.50	62.49	271.20	3249.43	2056.60
Large Car (2000cc - 3000cc)	7.90	17.40	24.30	1.08	17.02	85.08	369.26	4424.32	2800.20

The economic estimations uses data from NZ government statistics on commuting data [7], road costs from AA [8] and inner zone bus fares of $2.30 per trip [9]. The cost of charging the scooter is calculated above in equation 1 and its sufficiency for a 10km journey is assumed with commute distance and time taken from cycle statistics. The model does not include the additional costs of inner city parking which are set at $65 per month by the city council. Finally it assumes that the costs can be scaled linearly with distance. It is also worthwhile noting that the operating costs of diesel engine are reported by AA to comparable to similar sized petrol engines after road costs.

Table 1 therefore shows the substantial financial advantages when compared to combustion based vehicles both private and public. With rising petroleum prices anticipated, these forms of transport can only be expected continue to increase.

Another key economic stakeholder that stands to benefit from small electric vehicles such as the Direct Drive Electric Scooter is the city council and by extension the rate payers. More efficient use of the road as can be expected with smaller vehicles meaning less stain on city traffic infrastructure. This means less that less city finances will be required for roading and can be diverted into other quality of life sectors or rate reduction. City infrastructure is also a key factor when weighing up living conditions. A less congested city can thus attract and support a greater population leading to an assortment of wider economic gains.

Social

The reason many people choose to cycle, walk or take some other non-motorized form of transport to their destination is often for fitness and the health benefits. A study from the UK Sustainable Development Commission has found that “exposure to natural spaces – everything from parks and open countryside to gardens and other green space – is good for health” [10]. In particular this can be beneficial to morning commuters who have issues stimulating the mind and relieving themselves of drowsiness.

Small electric vehicles also have the potential to relieve stress though traffic congestion methods previously discussed. The Department of Psychology of York University, Canada has found a strong link between traffic congestion and everyday stress irrespective of gender and age. [11].The ability to move to past struggling full sized cars would likely go a long way to alleviate driver stress/road rage. Perhaps most importantly however are the relationships that are common between stress and declining productivity [12].

Another key advantage that light weight urban transport has over public transport is the ability to manage one’s own time. This can be seen clearly in commute time for busses in Table 1. In fast paced urban lifestyles, often being late is simply not an option and thus some commonly unreliable public transport systems cannot suffice. This also applies to the fixed time slots available for public transport and the added total commute time associated with it.

Deduction

By applying triple bottom line analysis it can be said that the Direct Drive Electric Scooter will affect stakeholders in many ways more positively than it would negatively. Minor issues that can be associated with battery toxins are able to be mitigated assuming that care it taken to educate users when battery replacement is required.

5) Budget Summary

While a number of purchases have already been made, there are still some part purchases required for the high level controller. The two groups of purchases can be seen below in Table 2 and Table 3.

Table 2- Costs of purchases already made by the department.

Item Name:	***Cost:***
40 x A123 $LiFePO_2$ Cells	$ 170.20
Motor Speed Controller	$ 75
BLDC Hub Motor	$ 220
Scooter	$ 50
12 ½ Inch Tire	$ 15.29
Total:	$ 527.49

Table 3- Estimated costs of items that still need to be purchased.

Item Name:	***Estimated Cost:***
MCU	< $5
PCB Fabrication	~ $20
Current Transducer	$10
Other Electrical Components	< $10
Throttle	$35
Total:	$ 80

6) Conclusion

In conclusion the progress that has occurred on the direct drive electric scooter to date has proved to be successfully placing the project on good tracking to be completed before inspections. This will depend heavily on the successful of the circuit design and PCB layout as laid out in the Gantt chart in Table 1.

A good assessment has been made on the mechanical aspects of the project that should yield a successful design. There is still some finalizing of design considerations that needs to be completed however frequent communication with Dave Healy will continue until the mechanical aspects have been completed.

The electrical design will commence in the upcoming weeks and will consist of the circuit and PCB layout. Given such a particularly nosing system from motor currents it will be critical filtering and PCB layout techniques are used. The intention is to have these two tasks complete before the end of term two, so that fabrication can commence over study and exam periods.

7) References

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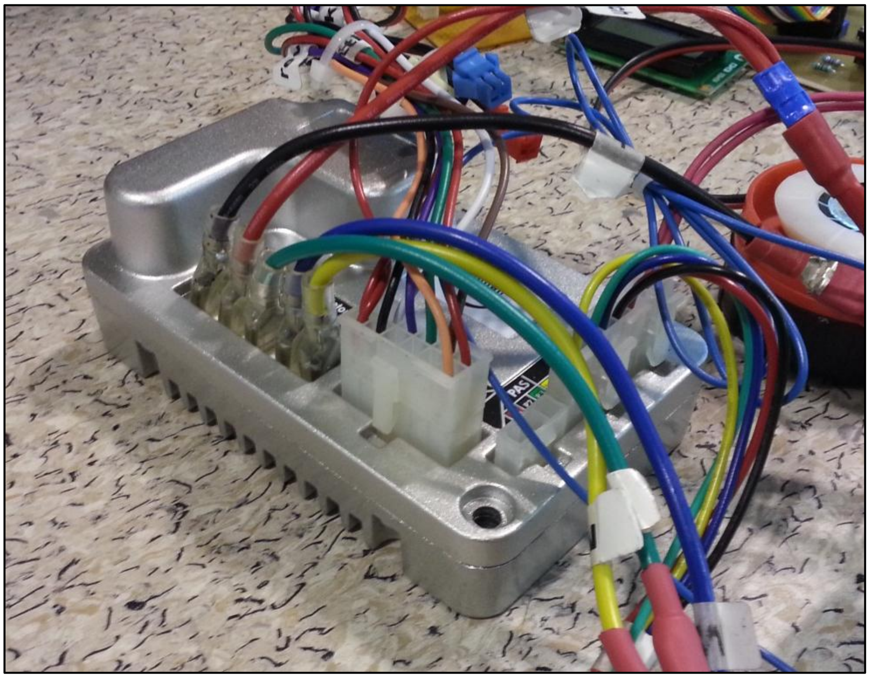
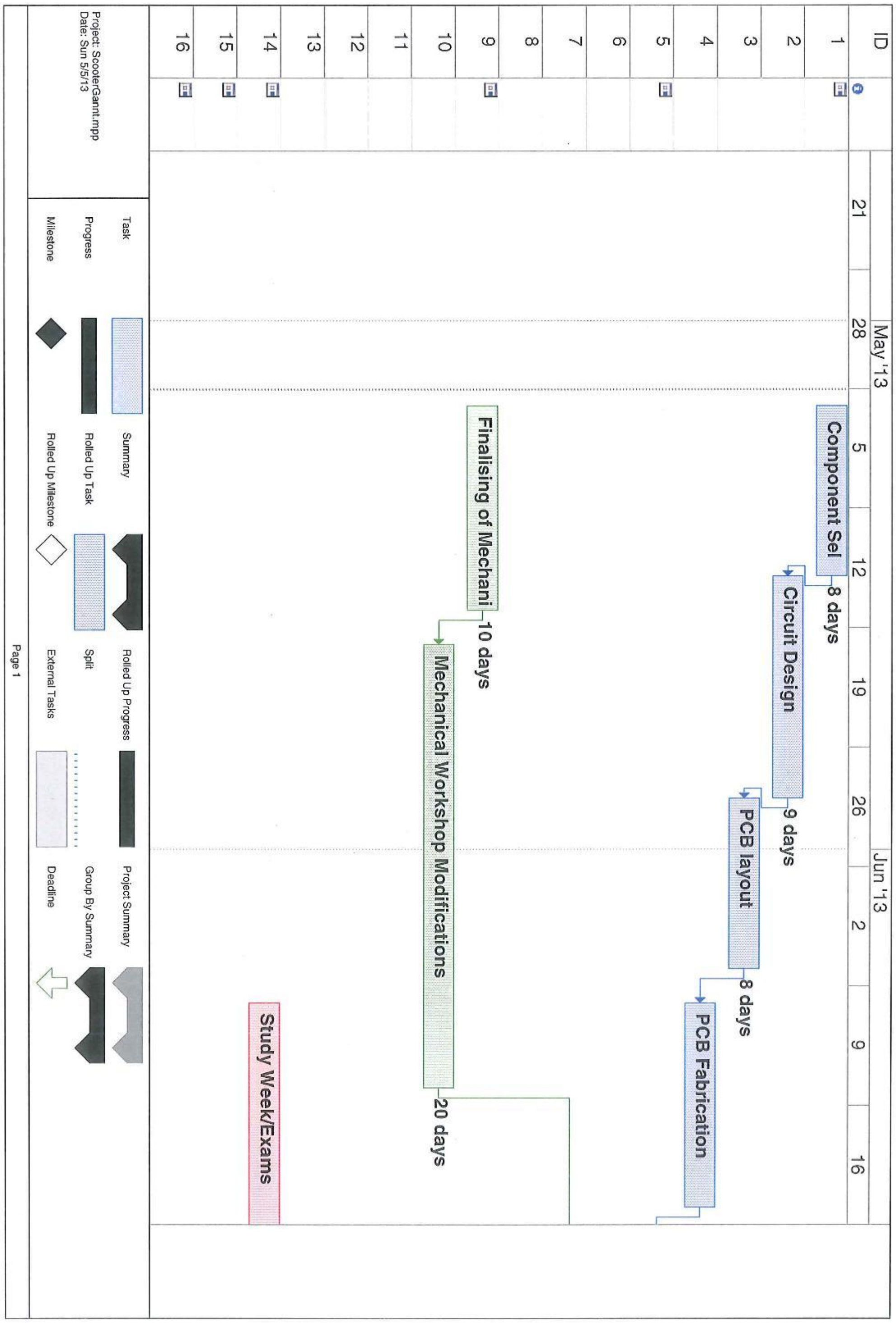
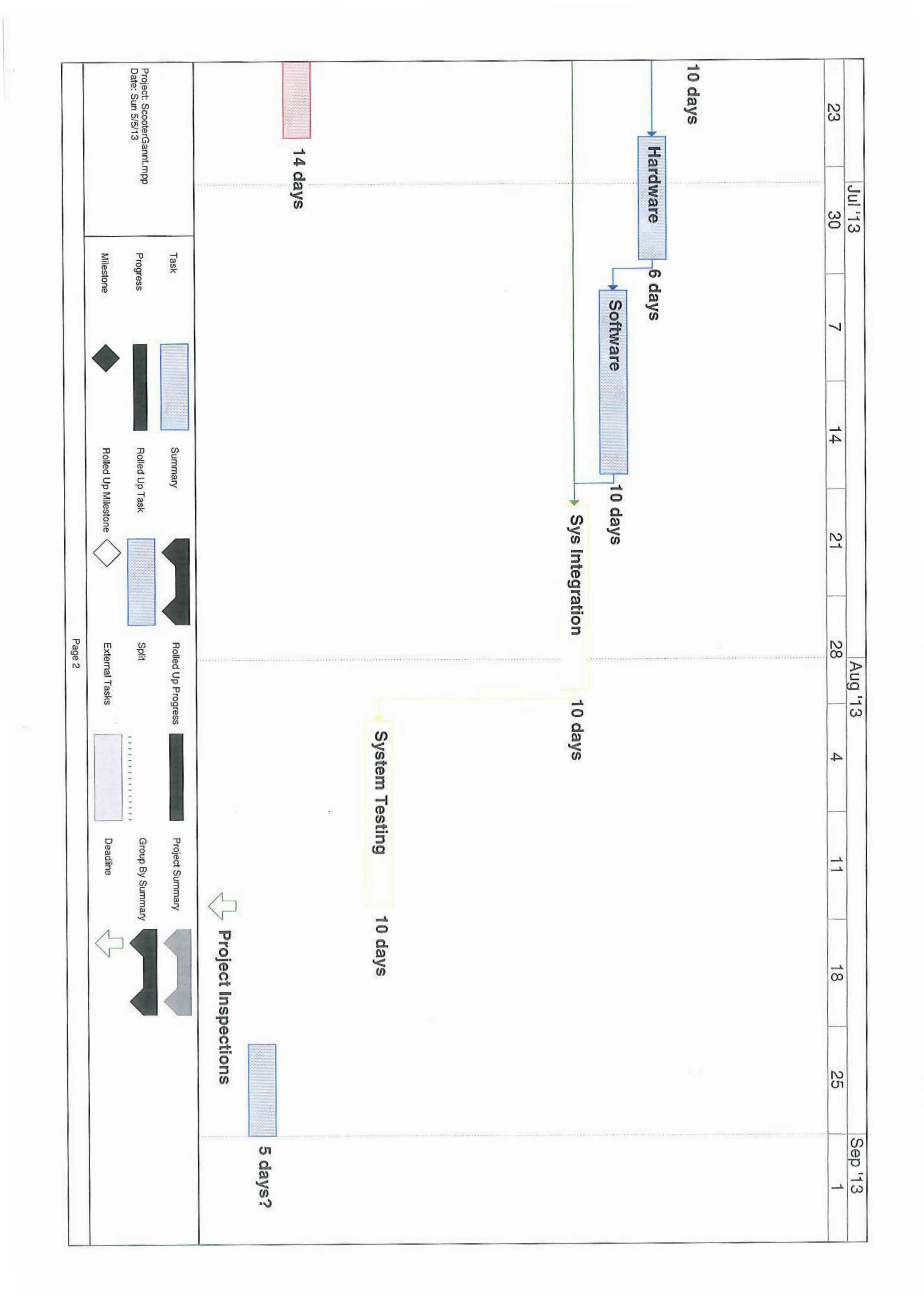
8) Appendices



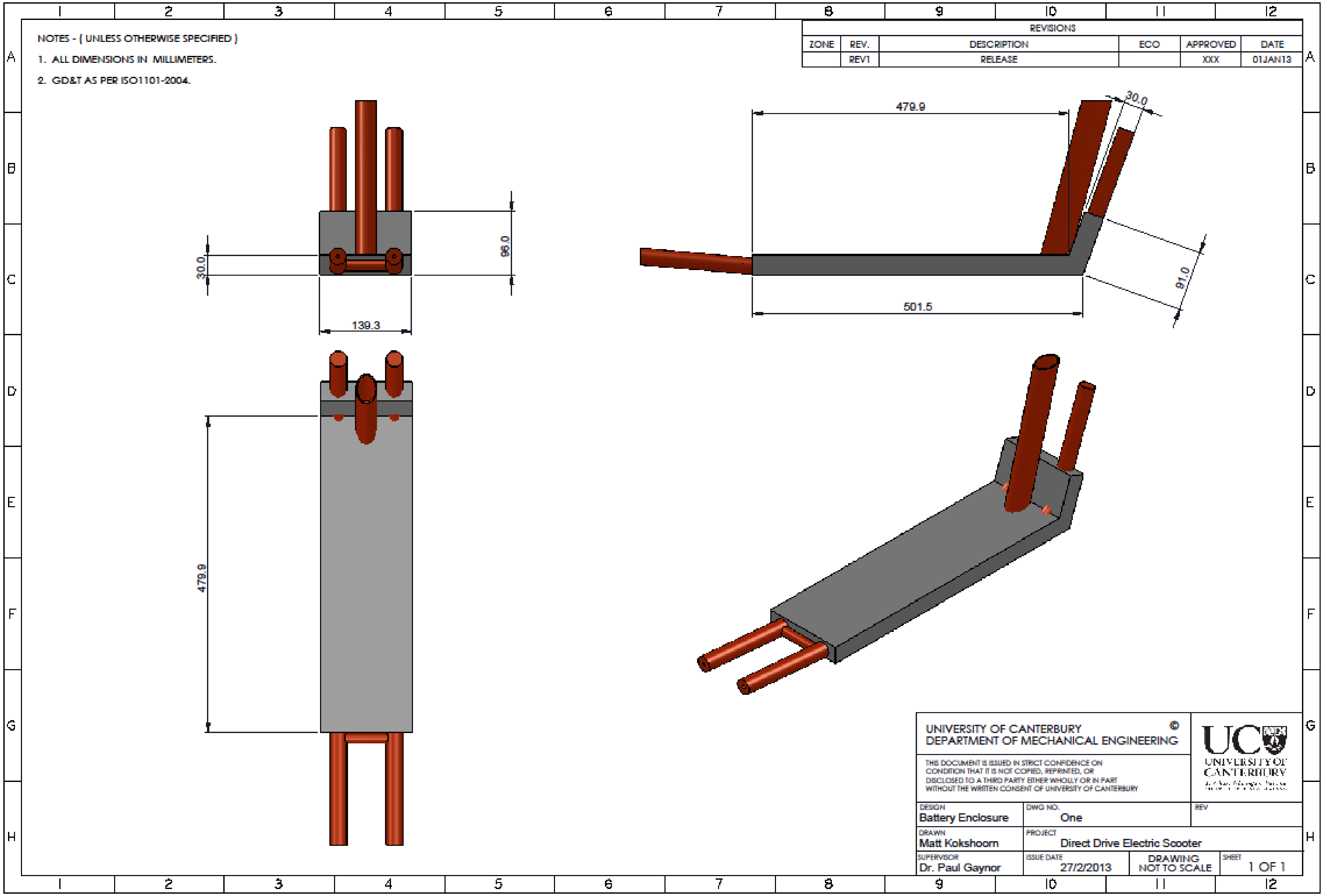
Appendix 1 – GoldenMotor Speed Controller



Appendix 2 - Projected Gantt Chart Page 1/2.



Appendix 3 - Projected Gantt Chart Page 2/2.



Appendix 4 – Dimensioned Mechanical Drawing for Battery Enclosure.