ENGN2226 Design Portfolio

Systems Engineering Analysis of a Modern Electric Scooter System

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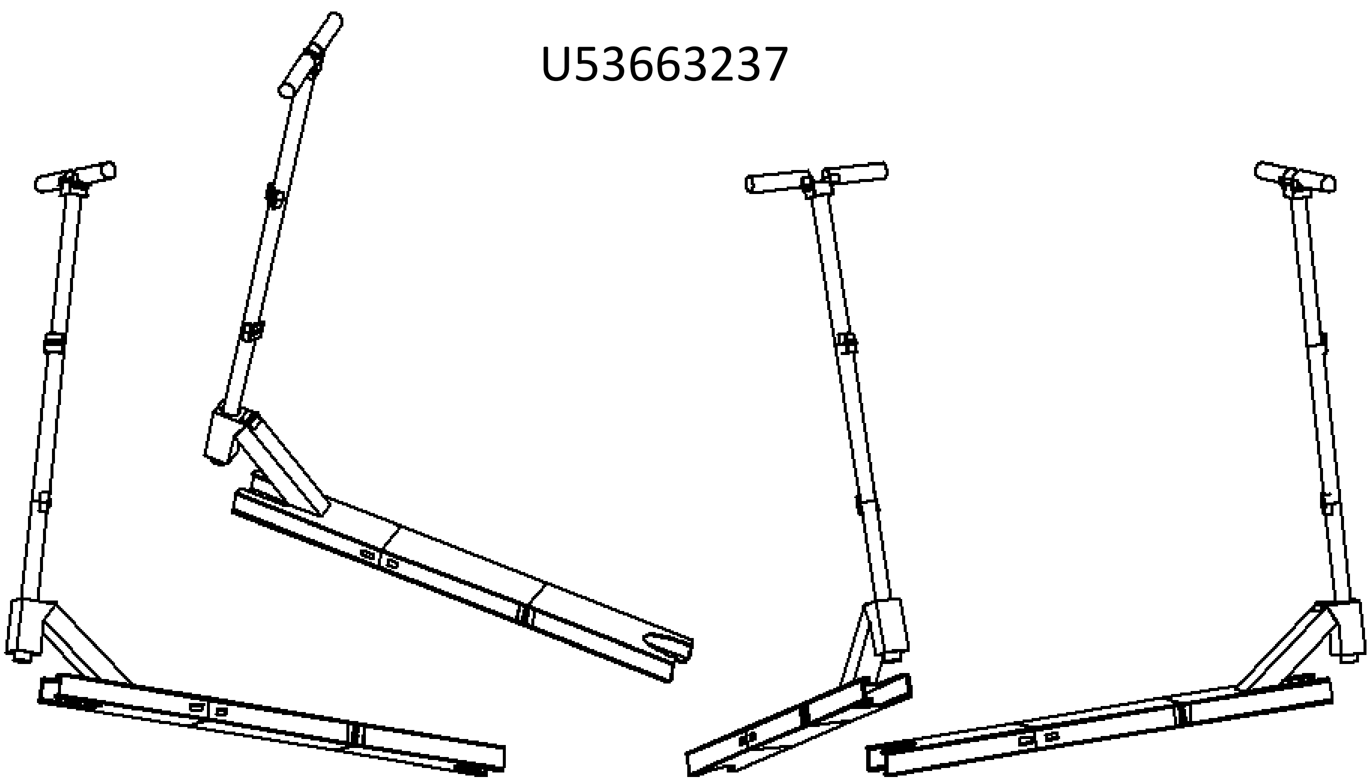

Abstract

With the rise in environmental consciousness and fuel prices, people are increasingly using alternative transportation methods. For urban and "last-mile" transport personal electric vehicles (PEVs) have the potential to play an important role in this commuting paradigm shift. Of the various PEV options available, we believe the scooter to be the most convenient for reasons of weight, storage size, speed and safety. However, for mainstream adoption to occur, there does need to be significant improvement to the design of the electric scooter. During the systems analysis process, human factors, energy and materials analyses produced recommendations to improve the function of the scooter. These recommendations were validated in the optimisation process, and became part of the final design. The final design of the scooter has been changed from the original in the following ways: The 6 MOSFETs in the motor controller were changed to IRFB4410, the battery capacity of the scooter was decreased to 6Ah, optional deck width extension plates were added and the frame was changed to one with significantly higher portability once folded. For a representative 11km commute, electric scooters were shown to have environmental and economic benefits over ICE and Electric cars.

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1. Introduction

1.1 Background

Electric vehicles (EVs) have an extensive history, the first EV was created in 1835, and throughout the late 19th and early 20th century they were significantly more popular than the Internal Combustion Engine (ICE) based car that pervades every aspect of modern life and industry (Prud'homme 2010; Glickenstein 2010). In certain niche applications; such as trains and mining vehicles, (EVs do not use up the scarce oxygen underground, and significantly reduce chances of igniting combustible underground gases) EVs remained the most popular locomotive option (Scientific American 1905; Prud'homme 2010). However their widespread consumer use has been severely limited by the battery technologies available at any given time. To illustrate this it is valuable to make a comparison between the electrical energy available in the battery of an electric vehicle and the chemical energy in the fuel tank of an ICE-driven car. The 2014 Nissan Leaf contains a 24kWh battery (Nissan 2014), it can be calculated that one litre of petrol contains $11.\dot{7}$kWh of energy able to be extracted via combustion (as in an ICE). Simple arithmetic shows that The Leaf's battery is equivalent to just over 2 Litres of petrol, and from this the challenges EVs face are made very clear (Many car fuel gauges read empty with 2 litres in the tank). For further information on the range difficulties of EVs, a more detailed energy analysis is conducted in the respective section.

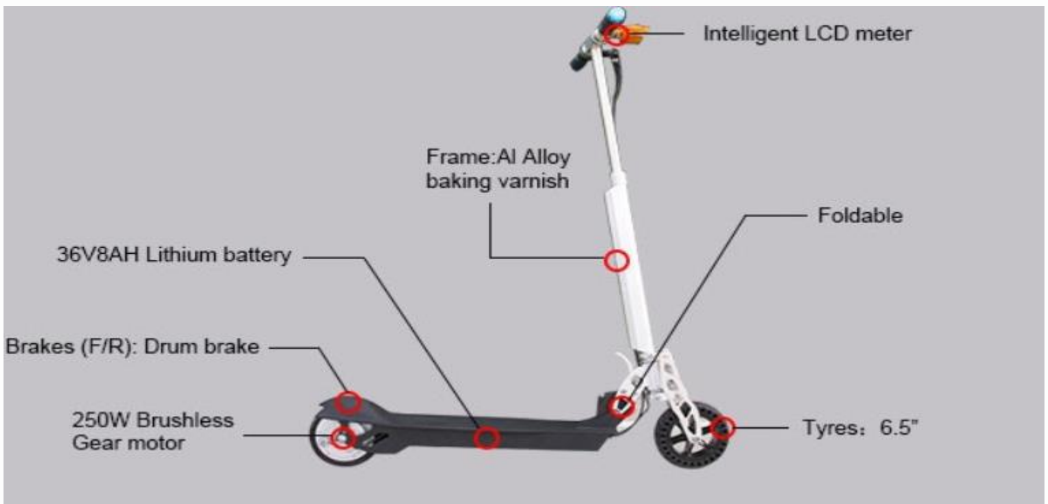
However, once the focus is shifted to smaller form-factors, electronic propulsion becomes much more appealing than using a gasoline engine. Factors such as convenience, cost, noise, the much lower weight required to be transported and powerful modern motors that are much smaller than their ICE power-equivalents, make EVs the correct choice for personal transportation. This category of EVs are thus termed Personal Electric Vehicles or PEVs. They are most suitable for distances less than 20km, or routes with dedicated bicycle paths or high-quality sidewalks (depending on the PEV in use). Another increasing trend amongst local councils is to promote mixed transportation, most commonly a mixture of cycling and public transport. The bus/train is taken the majority of the journey, and the 'last mile' at each end is traversed by bicycle. This is known as 'last mile' commuting, and has various environmental and traffic benefits (Anonymous 2010). Use of a PEV for last mile commuting over conventional small vehicles has numerous inherent benefits, most importantly: it accommodates the physically disabled, does not waste an individual's energy before or after work as would a bicycle (energy expended can be entirely decided by the user), increases distances able to be covered comfortably and increases speed of transportation. Within the PEV category, we believe the scooter form factor to have superior flexibility of Use-Case, as well as a good balance of range, practicality, weight, speed and safety. Thus we begin the analysis of the most modern electric scooter system available, that which uses modern Lithium batteries and brushless motors to attain optimum performance at a minimum weight. The most popular commercial examples of this product are the Singaporean Patgear (Patgear 2014), and American EcoReco (Ecoreco 2014), however there are a plethora of other models on the market, all with similar performance and components, so a representative model will be chosen using the scooter model to which there is physical access.

1.2 Original and New Design for Analysis

Throughout the report there will be two designs mentioned, the original electric scooter pictured on the top of the front cover, and then an updated design containing a preconceived design change, a CAD model of which is depicted at the bottom of the front cover. The base components between the new and old design are very similar, the key change occurs in the aluminium frame of the scooter. For the purposes of succinctness and clarity, the original design will be discussed, and then the major design change for the new scooter will be explained. The following analysis sections will then hopefully do two things, firstly to validate the preconceived design change as a useful innovation, and then to identify and rectify any issues or shortcomings that may be revealed through the systems analysis process.

1.2.1 Original Design

The original design of the scooter uses modern PEV technologies entirely. Figure 1 shows the main breakdown of components as given by the manufacturer, a more detailed materials audit will be shown in the materials analysis section, so only what is needed to understand the design is given here. For the purposes of many analysis steps, the performance characteristics given in figure 1 will be reduced such that they can be met over the entire lifecycle of the scooter.



MOTOR	250W Brushless Gear motor	**Max speed**	<35KM/H
Battery	36V8AH Lithium battery	**Range**	35KM
Meter	Intelligent LCD	**Load capacity**	95KGS
Charger	100-240V AC 50-60HZ	**Net weight**	12.8KGS
Charge time	3-5 hours	**Gross weight**	14.5KGS
Fork	Front suspension fork	**Dimension**	970X150X1040 mm
Frame	Al Alloy baking varnish	**Carton size**	915x160x355 mm
Folding size	810x150x270mm		
Tyres	6.5"		
Brakes (F/R)	Drum brake		

Figure 1 - Original design specifications and components

1.2.2 New Design

The new design incorporates 5 additional hinge points on the deck and steering column, arranged in a novel manner that allows the scooter to fold into a much smaller and more aesthetically pleasing form than that of a regular scooter, be it electric or conventional. Figure 2 shows the hinge locations and the final folded form of the scooter. The components marked (1) refer to the aforementioned hinge locations in the scooter. Their orientation is deliberate. If they were located on the top or bottom of the deck, the weight force of the rider would be actively working to shear them, the vertical orientation allows forces to be distributed along the length of the hinge and is therefore much stronger, particularly in high-stress scenarios such as riding off kerbs. The components marked (2) in figure 2 show the locations of the spring loaded locks.

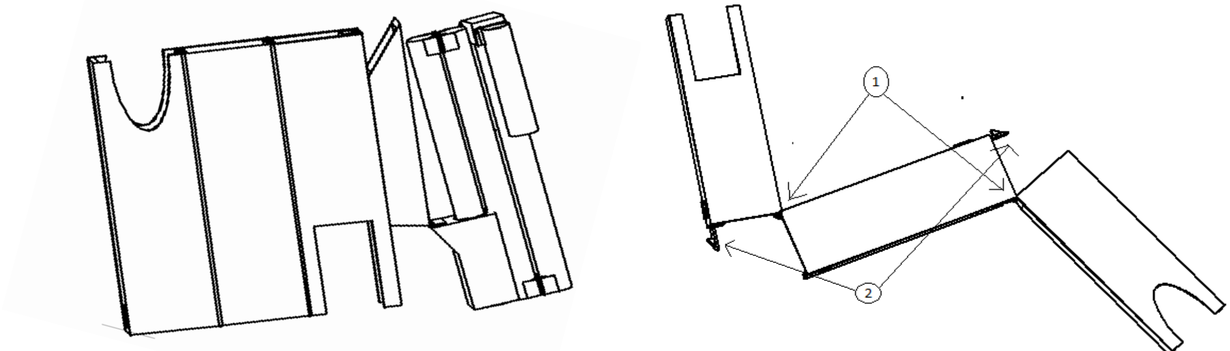


Figure 2 - Basic Folded Frame Configuration for the new design the left image depicts the entire scooter completely folded, while the right depicts the deck only, showing the folding mechanism

The locks are short spring-loaded steel tabs that fit into a notch on the adjacent section of the scooter. They activate automatically upon unfolding, and to disengage the lock, all that needs to be done is apply a perpendicular force to the deck to remove the hook from the notch, which enables the scooter to fold. Again, the orientation is beneficial, as the highest forces experienced by the deck are not working to open the lock, in fact, they apply a frictional force to the steel tab, preventing accidental disengagement during use. This design innovation gives clear aesthetic, ergonomic and storage benefits to the electric scooter. Further detail of the operation of the folding mechanism can be found in Appendix IV.

2. Human Factors Analysis

Any successful consumer device must be focused around the user experience. Thus the importance of Human Factors Analysis cannot be overstated. This is particularly true in the case of an item used in public such as the Electric Scooter. It is vital that the intangible and qualitative social complications be rigorously analysed through the established systems engineering processes (Karwowski 2007). The comfort of the product will be validated through Anthropometric and Ergonomic analysis, and a portion of the analysis will be dedicated to the aesthetic characteristics of the device. These factors will be examined for both states of the scooter, that is, when it is being ridden, and when it is being carried/stored. Data required for later sections such as Energy and Materials analysis will be gathered through surveys to determine optimum power, battery size and maximum comfortable weight of the scooter; as well as gauge social reaction to the new design put forward to combat the 'un-cool' stigma associated with kick-scooters.

2.1 Survey Result Analysis

The primary step taken in human factors analysis was to conduct a survey of ENGN2226 Students. The survey contained questions that gauged the commuting habits of each student, their interest in the two designs, and information to validate the survey participants as a valid demographic. The complete survey is available in Appendix I at the end of the report. A total of 66 responses were obtained, which while not ideal, is enough to give an indicative spread of the commute types for students in Canberra. The complete data is available in Appendix 2, with graphs formed from the data in Appendix 3. Data gathered that is mainly relevant to other analysis steps will be discussed in those sections.

2.1.1 Applicability of Electric Scooter to Commutes

Interpreting the data available in Appendix 3 shows that out of those surveyed, 59.1% of commutes are well within the range of the electric scooter, such that the individual can easily travel to and from university without having to charge the scooter or have the risk of strain discomfort from excessive use.

2.1.2 Interest in Original Design

It is clear that in the demographic surveyed, there is a strong stigma against the use of scooters, electrified or not. They are considered to be juvenile and undesirable to be seen upon. This is reflected in the interest and price data gathered for questions relating to the original scooter design. With zero responses of "Very" or "Extremely" interested, and only 17% of respondents "Interested" in the electric scooter at all, it is clear that any mainstream adoption of the vehicle is practically impossible in its current state. A similar view is given by the indicative prices given in the responses; only 3 responses gave a value of $750, while 45% responded $500 and 47% responded with $0. This is clearly insufficient to fund the cost of the scooter, which is $766 dollars without any business and freight costs considered.

2.1.3 Interest in New Design

An examination of the survey in Appendix I would reveal that that the way in which interest in the new design was gauged was not direct. Instead of presenting the concept as a scooter, it is presented as a similar object with the same dimensions as the fully-folded new design, yet with the performance of the scooter. This was done primarily to ensure that the features were judged upon their merit, not upon the social stigma of scooters, but also for intellectual property purposes. The responses showed a higher interest in the new design, with 6% of responders "Very-Interested" or above, and 26% of responders "Interested" or above. This is a 53% increase in interest compared to the results of the scooter questions in the survey. In terms of the indicative price, responses of $750 or higher were 17%, a 183% increase compared to the original design. This clearly shows a higher acceptability of the new design and that, while it does not significantly increase production cost, consumers are willing to pay more for the innovation.

2.2 User Comfort

This analysis is undertaken for both folded and unfolded states of the scooter. As the two designs are indistinguishable in un-folded performance and dimensions, the analysis for that state applies to both. Folded analysis is conducted as a comparison between the two designs.

2.2.1 Unfolded State

In order to test the current dimensions of each scooter, we must conduct an ergonomic analysis of riding the scooter. We first establish the criteria that must be met to provide a comfortable rest position on the scooter. As there has been no detailed public analysis on ergonomic kick-scooter design, the criteria will be formed from a synthesis of anthropometric analysis and injury data. The key results of this analysis are as follows, and will be addressed in order:

- The handlebars should be of sufficient height to allow the rider to maintain an upright posture in the rest position.
- Handlebars should not rise above waist height, to prevent arm cramping. This also assists balance as the handlebars will be aligned with the rider's centre of gravity.
- The deck should be wide enough to allow both feet to rest comfortably beside each other.
- The handle bars should be as wide as the shoulder-span of the rider, to allow stability during the push motion (for when the rider does not wish to use electric propulsion).

An ergonomically ideal product should work for both males and females, so parameters will be determined accordingly, for two standard deviations. The waist height range for two standard deviations has the lower bound taken from female data, and the upper bound taken from male data, and is 815mm – 1030mm (Diffrient & Tilley n.d.). The maximum shoe width, required to determine the minimum deck width for side-by-side footing, is 120mm (Diffrient & Tilley n.d.). Comparing this to the dimensions of the scooter designs, we see that the handlebar criteria is met, with maximum and minimum handlebar heights of 1040mm and 810 mm respectively.

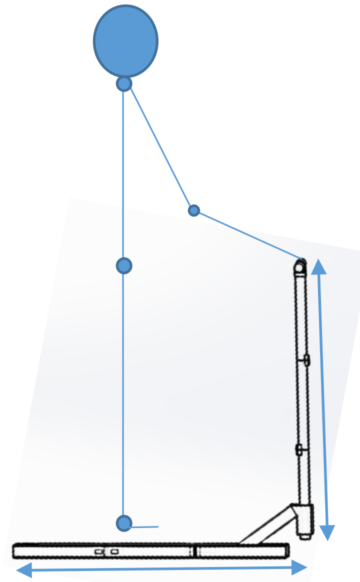


Figure 3 - Ideal rest posture on kick scooter for continued use

The deck width criteria is an entirely separate issue, however. The current deck width is only 150mm, comfortable for one foot, but far too low for two feet to be placed on the deck. This is because increasing the width of the deck has a significant impact on the overall size and weight of the scooter, while allowing more space for battery and electronic components. Thus, a Human Factors recommendation is to increase the width of the deck to 250mm to comfortably accommodate both feet, this recommendation will be evaluated against its drawbacks in the optimisation section where the final design will be determined.

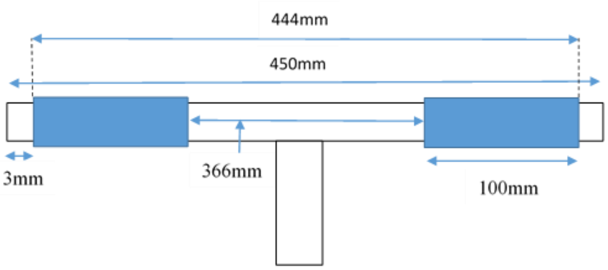


Figure 4 - Detailed Handlebar Dimensions for ergonomic analysis

The shoulder width range for 95% of the population is 365mm to 495mm (Diffrient & Tilley n.d.). While ideally custom or adjustable width handlebars would be available to the rider, this is not practical due to extra complexity, and is not part of the design under analysis. Therefore the mean value will be taken, as taking a high value would have a negative impact on those with a small shoulder span, and taking a low value would have a negative impact on those with a high shoulder span. The mean value is 430mm, which is slightly below the 450mm handlebar width of the scooter, however the grips do not extend to the end of the handlebars. The detailed handlebar measurements are shown in figure 4, and show that the grips allow a minimum hand separation of 336 mm and a maximum of 444mm (taking into account hand-width itself), which fits the requirements to a degree. Even for the worst case, where a rider with a shoulder width of 495mm but an arm length two-standard deviations below the mean (630mm - very unlikely) has to use the handlebars, their arms would only be at a 5.4° angle from the ideal. Hence no design change recommendation is made for the handlebars.

2.2.2 Folded State

The ergonomics of carrying objects have been extensively investigated in the literature. As this area of analysis varies between load forces, we will be considering loads of approximately 10kg. In the simplest sense, the ideal carrying device allows an object's centre of mass to be parallel with, and as close to, your spine as possible, reducing torques applied to your joints and transmitting all forces down via your centre of gravity (Action, RSI 2011). For this reason, well-fitted backpacks are considered the best option for loads under 20kg (Nichols et al. 2011). However so that the scooters are available for use quickly, a briefcase style is chosen for the new design, this requires that the centre of gravity be well aligned. Figure 5 shows the centre of gravity lines of the two scooter designs. The line for the old design was determined experimentally, and that of the new design was determined using CAD software. The old design has a large amount of weight at the rear wheel, where the hub motor and handlebars are, in fact the ideal carrying position based on centre of mass would have the carrier's hand right up against the folded handlebars, which is not ideal. We can see that in the new design, the handle is located correctly. The main ergonomic difference is in the carrier's comfort when there is a small force applied to the scooter (e.g. wind). The length that the new design projects forward from the carrier's hand means that forces will become amplified as torques applied

Figure 5 - Comparison of balance points of the new (left) and old) scooter designs when folded

to their wrist. This length is over three times longer than that at the front of the new design, which means the new design is easier to carry in a range of environments. For both scooters, there is a severe weight issue. The weight of the old design is 12.8kg and the new design is 13.2kg, this is slightly too high for comfort. Handle ergonomics are a critical factor in determining maximum comfortable weight (Jung & Jung 2003), but the handle is only part of the new design. For applicability to even one standard deviation of lifting capacity, the weight must be brought down to below 10kg. The self-proclaimed 'lightest electric scooter in the world' is the Singaporean *ZoomAir 2*, which weighs 10.7kg (Lai 2014), so this problem is obviously a major one faced by electric scooters in general. Therefore the key design recommendation from human factors is either a reduction of weight to below 10kg, or the addition of a shoulder strap to allow greater comfort at higher weights. This recommendation will be addressed through materials analysis to determine how much the weight of the scooters can be reduced.

2.3 Aesthetic and Social Considerations

Any analysis that attempts to take into account Aesthetic and Social Considerations must be sure to justify every arising recommendation as applicable to the vast majority of society. This is vital to avoid simply projecting the author's own tastes in a positive light and sweeping the actual social issues under the proverbial carpet. To this end, this analysis will be simply looking at survey data and attempting to provide possible solutions based on specific issues raised. One of the survey questions sought to gain an insight into the social issues faced by electric scooters among today's youth. The data was processed somewhat, with similar responses grouped into a category based on the main issue raised, and this data is presented in a word cloud in figure 6 (word size is based on frequency of response).

Figure 6 - Word Cloud showing Electric Scooter problems.

The responses show that the new design has great promise, as the largest issue, 'Awkward-to-Carry' will certainly be removed by the completely changed carrying experience. The second largest issue 'Heavy' is something that will be addressed during materials analysis. It is a positive indication that the actual performance / experience given by the scooter was deemed more important than the social considerations, however the large 'Embarrassing' category is an issue with a much less clear solution. A large number of proposals could be made to address this, however it is hoped that as the experience of carrying and using the scooter improves with the new design, they will become more mainstream and the social stigma will fade away. While this may be optimistic, further social engineering/marketing options are considered outside the scope of this analysis due to space limitations.

3. Time Analysis

Queue theory plays an interesting role in the analysis of the Electric Scooter, as the users are moved from the roads onto the paths - and in the case of last mile commuting, public transportation infrastructure - of their city. However calculating the impact of traffic reduction is a whole report's worth of work in itself, and the city of Canberra is not the best case study for this, and therefore it is considered beyond the scope of this report (which is focused on the scooter itself). A Gantt chart will be used to show the speed of collapsing and unfolding the scooter to determine whether it needs to be improved. A PERT chart will be used for the more complex example of last mile commuting and will be multi-layered with a comparison to a conventional vehicle easily visible. These will display both the benefits and areas for improvement of the Electric Scooter system. The Gantt chart showing a very conservative time estimate of the simple folding process of the old design is displayed in figure 7.

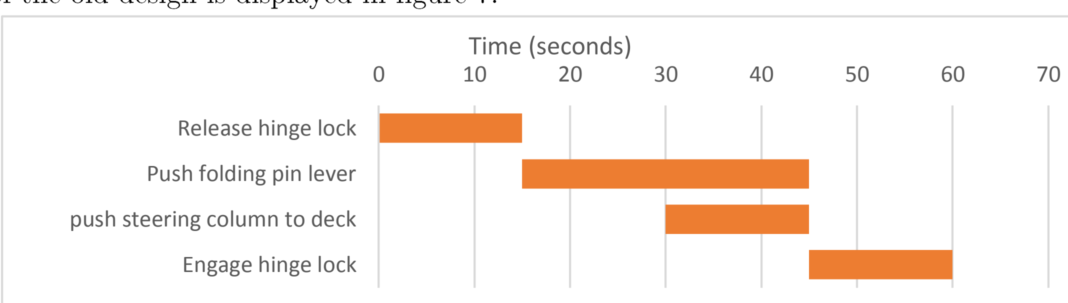


Figure 7 - Gantt chart of scooter folding process for old design

The new design has five hinge points as opposed to the old design, however they do not all require strong locks, due to the way the force acts perpendicular to all hinges, there is no major force attempting to open them during use. Hence the new design is the same as the old design, but with five instances of steps 2 and 3 in the Gantt chart, for a very conservative total folding/unfolding time of 3 minutes.

3.1 PERT Chart Analysis

Figure 8 contains three PERT charts showing different transportation options for a representative Canberra commute, from Woden to the city-centre. In order to cover a range of locations, a 2km distance from home to the bus stop is assumed, and then 1km from the bus stop to the individual's place of employment. It is clear that Driving is the fastest transportation method, however the PERT chart shows that the addition of the electric scooter to a bus-based commute can provide a significant time reduction. The environmental and financial benefits of public transport are well understood already (Woodcock et al. 2009; Huwer 2004), so they will not be determined from first principles here. As use of the electric scooter has negligible environmental impact, it is concluded that supplementing a bus-based commute with a scooter can save a significant amount of time (24% in the above example) while keeping all of the benefits compared to a driven commute. The PERT charts also show that the folding time of the scooter does not have a major impact on its usefulness, and therefore no changes to the new design need to be made in that regard. Time Analysis of the electric scooter system has shown that no major design changes are required, rather it has validated some positive aspects of the design and use of the electric scooter.

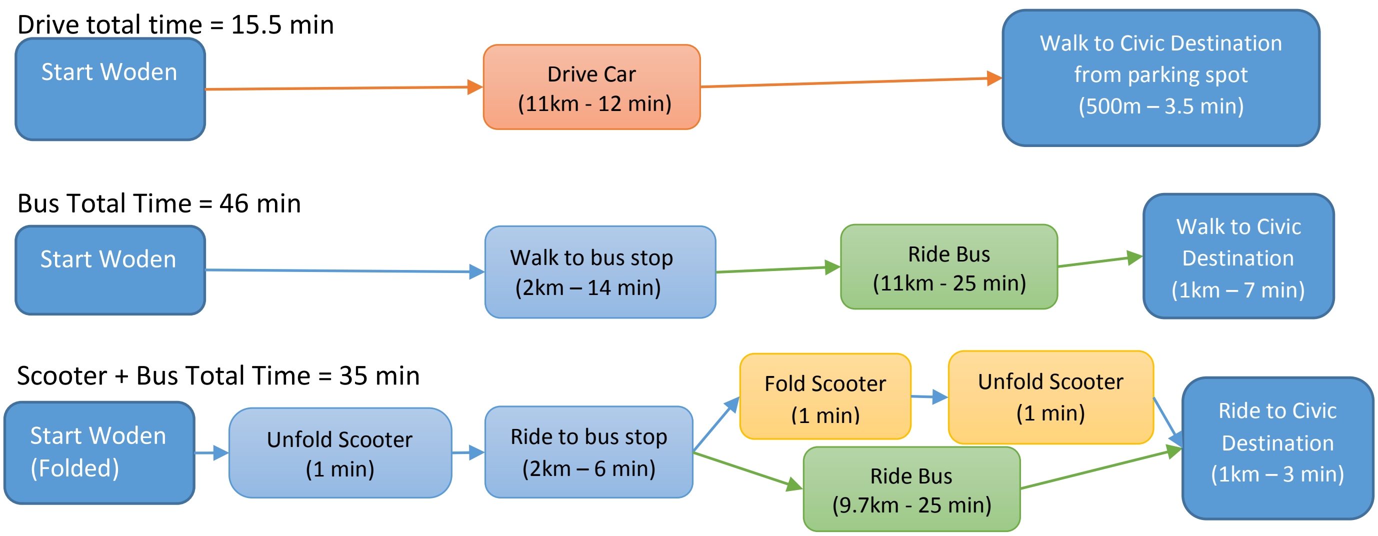


Figure 8 - Pert charts for use of electric scooter in typical 'Last-Mile' commute from Woden to Civic

4. Energy Analysis

There are straight-forward energy conversions in an electric vehicle system, these will be shown in a detailed Sankey Diagram. The IPAT equation will be used to analyse the extensive environmental benefits of PEV adaptation, with a detailed comparison made between last mile PEV commuting and travelling via car, for the Time Analysis use-case, to determine the potential emission reduction. The performance of the scooter will also be looked at in this section, however materials analysis will affect the performance greatly through its impact on the scooter's weight, and therefore more detailed performance analysis is left for the Optimisation section of the report. Energy-Mass Balance is not considered important for scooter analysis, as the inflows and outflows of energy/mass are the same as those for all electric vehicles, and EMB's don't take into account the quantity of each in/out-flow, therefore the significantly more useful and complex Sankey diagram is used.

4.1 Sankey Diagram and Analysis

Electric vehicles are much more simple devices than their ICE brethren, and this is particularly true of a PEV like the scooter. From figure 9 the efficiency of the scooter can be seen, and calculated as over 76%. Compared to a typical ICE car's efficiency of less than 25%, the energy savings of the scooter are obvious.

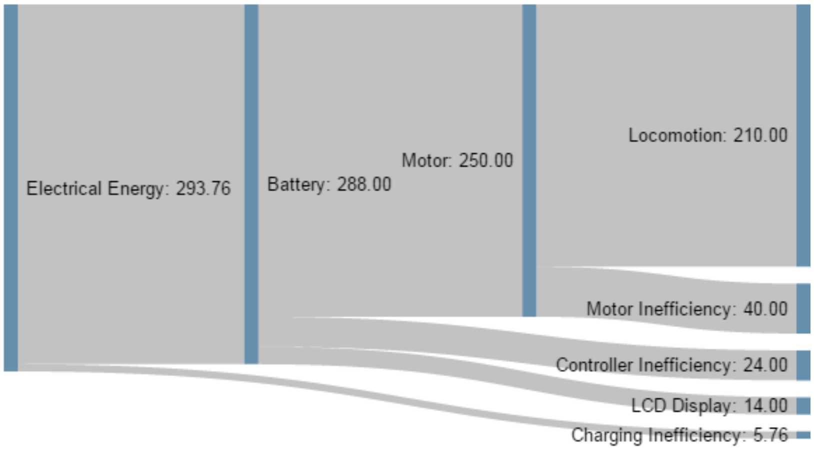


Figure 9 - Sankey Diagram for one complete charge/discharge battery cycle of Electric Scooter Use.

Furthermore, even when compared to an 80% efficient electric vehicle, the significantly lower mass that is needed to be moved by the scooter means that far less energy is required. For instance, using the most generous measurements available, the Nissan Leaf has an electricity usage of 120Wh/km (Nissan 2014), while the electric scooter has an electricity usage of just 9.6Wh/km, more than 12.5 times less. Although the efficiency of the scooter is already high, it is still important to identify areas of improvement. The charging inefficiency is inevitable, every battery chemistry has some loss while charging, and the lithium batteries used in the scooter designs actually have a very high charge efficiency. The motor inefficiency is the largest and most obvious one, however as a hub motor is used, this encompasses the motor and transmission losses. By far the most reasonable inefficiency to reduce is that of the controller.

4.1.1 Increasing Controller Efficiency

Hands-on analysis has determined that the controller uses International Rectifier IRFB4115 MOSFETS in a TO-220 form-factor shown in figure 10. These MOSFETs have an $R_{DS(on)}$ value of $9.3m\Omega$ (International Rectifier 2009). As all current that goes to the motor must pass through these FETs – and only through these FETs and then wire - decreasing this MOSFET resistance value is the only way to significantly decrease controller inefficiencies. It is recommended that IRFB4110 TO-220 MOSFETS are used instead, the 4110's have a typical $R_{DS(ON)}$ value of $3.7m\Omega$, significantly less than the 4115 FET (International Rectifier 2014). They are normally used in higher current applications such as electric bicycles, and electric motorcycles. They come at an increased cost, but it would only cost 9AUD to replace all 6 MOSFETS in the scooter motor controller. The Gate characteristics are the same for both MOSFETS and therefore this would be a simple drop-in replacement that would improve the efficiency and reliability of the controller. This is the main design recommendation arising from the Energy Analysis of the Electric Scooter system and will be looked at again in the optimisation section to determine the final design.

Figure 10 - IRFB4115 TO-220 MOSFET as used in the scooter

4.2 IPAT Analysis

The I=PAT equation can have many manifestations. In this analysis we will be focusing upon the reduction in environmental impact for the use-case described in the Time Analysis section, a commute from Woden to Civic. However now we will assume the electric scooter is ridden for the entire trip. Thus the IPAT used is:

$$\boldsymbol{Impact} = \sout{\boldsymbol{Population}} * \textbf{Consumption (km)} * \textbf{Technology (Wh/km)}$$

As this analysis is a comparison between multiple options, the population would be constant between them, and therefore the population factor is removed from the analysis. Table 1 shows the environmental impact of the commute in kilograms of Carbon-Dioxide-Equivalent for various commute options.

Table 1 - IPAT calculations for different commuting options for Woden-Civic in Canberra.

	Consumption (km)	Technology (Wh/km)	T (Lifecycle)	Impact
Nissan Micra (ULP)	11	513	+1.32kg $CO_{2\text{-}e}$	2.695kg $CO_{2\text{-}e}$
Nissan Leaf (Plugin)	11	120	+0.825kg $CO_{2\text{-}e}$	0.825kg $CO_{2\text{-}e}$
Electric Scooter	11	9.6	+0.046kg $CO_{2\text{-}e}$	0.046kg $CO_{2\text{-}e}$

Here it is clear that even compared to a 100% electric vehicle, the scooter is far more environmentally friendly. To stress the point, the Electric Scooter Impact value is just 1.7% of that for the ICE vehicle, and 5.5% of that for the electric vehicle. The electricity generation lifecycle impact was determined using the mix of energy sources in the Canberra power-grid. The materials analysis will also show that the embodied energy of the scooter is understandably miniscule compared to the cars. This alludes to a common point among supporters of PEV adoption, "Why do you need to carry 1 ton of metal with you whenever you travel?"

5. Materials Analysis

As the electric scooter design has the aim to provide environmental benefits to the community, a complete Life-Cycle Assessment taking into account both production and end-of-life considerations must be conducted to justify this claim. A materials audit is constructed to assist in this, with the supplementary metric of material weight being used to address the results of the survey in the Human Factors section of the analysis. Clearly there needs to be a balance struck between minimal environmental impact and best performance materials, and this will be dealt with in the Optimisation and Reliability section. Due to having physical access to the original scooter design, and small material difference between the new and old design, an in-depth materials audit was able to be conducted, and is shown in table 2. The Scooter was completely disassembled and the weight of each part recorded directly such that the materials audit can be considered highly accurate. The total mass of the scooter from the materials audit is 12.74, very close to the specified mass of 12.8kg. This minor discrepancy can be attributed to the small array of components not included in the audit, such as the grips and side stand. As masses were measured directly, there is no need for the "Volume" and "Density" Columns normally found in a materials audit. The resolution of the mass scale was $\pm 0.0001kg$, and is therefore more than accurate enough for this purpose. Embodied Carbon data was not available for Lithium and Phosphate, therefore the CSIRO standard conversion of $1MJ = 0.098kg_{CO_2}$ was used (CSIRO 2011).

Table 2 - Materials Audit of the Electric Scooter System. Embodied Energies/Carbons from (Hammond & Jones 2011)

Function	Component	Embodied Energy Density (MJ/kg)	Embodied Carbon Density (CO_2/kg)	Mass (kg)	Embodied Energy (MJ)	Embodied Carbon (kg)
Frame	6061 Al alloy	155	9.16	4.60	713	42.136
Hub Motor	Stainless Steel	56.7	6.15	3.27	185.409	20.1105
Controller	Aluminium	159	9.22	0.33	52.47	3.0426
Front Wheel, Tyres	Rubber	91	2.85	0.96	87.36	2.736
Bolts, Nuts etc.	Stainless Steel	56.7	6.15	0.57	32.319	3.5055
Wires	Copper	42	2.71	0.38	15.96	1.0298
Battery ($LiFePO_4$)	Lithium	853	83.6	0.18	153.54	15.048
	Iron	25	2.03	1.41	35.25	2.8623
	Phosphate (PO_4)	6.96	0.68	0.78	5.4288	0.5304
Throttle, Display	ABS Plastic	95.3	3.76	0.26	24.778	0.9776
Total				**12.74**	**1305.515**	**91.98**

5.1 Environmental Payback Period

The total value for embodied energy and carbon is high compared to an un-powered scooter, but if the scooter was used in place of a Car, be it EV or ICE, the savings are immense. The embodied carbon of the scooter is 293 times lower than the Nissan Leaf (Hawkins et al. 2013). Although it may seem like an unfair comparison, for many purposes a car can be entirely replaced by a PEV like the electric scooter. But what if the car is still required for long-distance trips, and only the commute is replaced by the scooter? We can calculate the payback period for such a case, and this is displayed in figure 11. The exact use-case is the same as that used in the Time Analysis and IPAT Analysis sections, an 11km commute to-and-from work 5 days a week. Figure 11 combines data from tables 1 and 2 in order to calculate the total CO_2 equivalent impact of each commuting option.

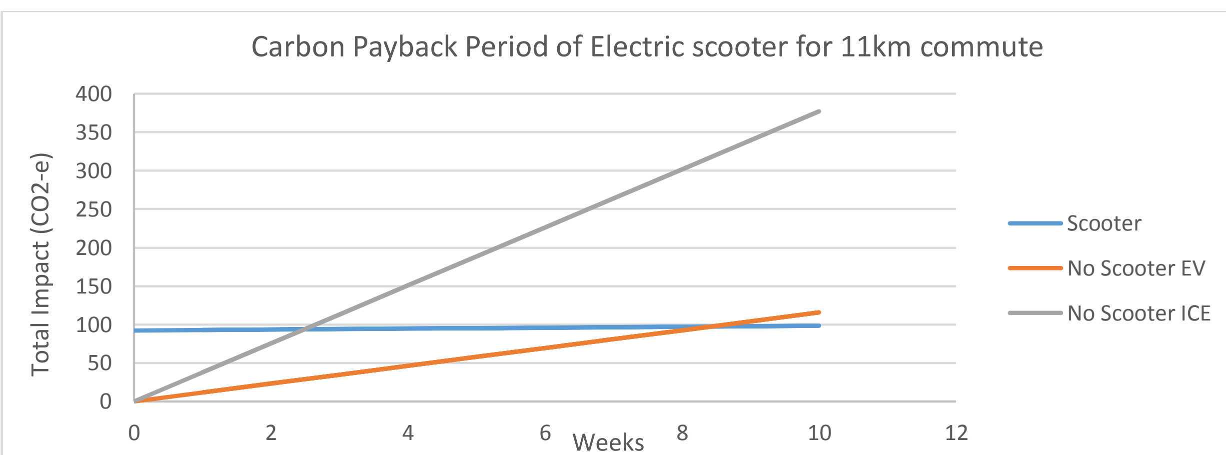


Figure 11 - Carbon Impact Payback Period for the purchase of an electric scooter to replace an 11km car commute.

From figure 11, it is evident that, even if the scooter is purchased in addition to a car (the most likely case, as most people will still own a car even if they do not use it to commute) and even if the scooter is only used for the commute, the initial Embodied energy impact pays itself off very quickly. The time of 3 weeks if replacing an ICE driven car, and just over 8 weeks for replacing an EV, show that this change is well worthwhile environmentally. Both of these payback periods are incredibly short. Any individual who passes this payback period, or uses the scooter to replace more than 375 kilometres of ICE travel (calculated from tables 1 and 2) has cancelled out the impact of producing the electric scooter, and from then-on is saving carbon emissions and thereby reducing their carbon footprint.

5.2 Weight Considerations

A major outcome of the Human Factors section was that the weight of the scooter was too high to be carried comfortably by most people. The target mass was set at 10kg, while the original mass of the scooter is 12.8kg, meaning that a 2.8kg drop in mass needs to be taken from somewhere in the scooter. As the materials used in the scooter's construction are modern and already quite light, it is not as simple a matter as replacing the frame material. We suggest that the original range (35km) is in excess of what could be comfortably travelled at any one time on a scooter, as it would take an hour at top speed to traverse. Therefore, the battery size can be decreased to a more practical level. This would also allow the size of the frame to be decreased, as the volume of the inner compartment is not needed to be as high. As they are the main contributors to the embodied energy of the scooter, reducing the battery and frame size would also have environmental benefits. A maximum range of 25km is deemed to be sufficient. To lower the range to that value correlates to a 28.5%, or 0.7kg decrease in battery mass. We propose that the battery thickness is reduced by the corresponding 19.2mm that this capacity decrease would allow. Propagating this change to the frame, this would remove 6mm*19.2mm*850mm of aluminium, a decrease of 0.264kg. This means that the choice is between an extra 10km of range or a 0.964kg decrease in the weight of the scooter. This recommendation is an outcome of the materials analysis process, and it is left to the optimisation section for the final design choice to be made.

6. Optimisation and Reliability

This section is arguably the most important and difficult, with many critical design choices needing to be made. As the life-cycle of the scooter is undefined, Bathtub Curve analysis is conducted to determine the likelihood of various possible failures in the scooter system. The failures are then divided into those caused by user-error and general wear, and those caused by manufacturing defects. But first the final scooter design will be determined through optimisation processes

6.1 Optimisation

First we will list the main recommendations for design change from each analysis step: Human Factors recommends increasing Width of deck to 250mm such that feet can be placed side-by-side. Energy Analysis recommends a change of MOSFETS from to IRFB4110 to improve Controller Efficiency. Materials Analysis recommends a decrease in Battery size and Scooter deck to save weight and reduce Embodied Energy. These recommendations will be addressed in order, with all reasonable impacts considered.

6.1.1 Human Factors – Deck Width Increase

This design change recommendation was an outcome of the ergonomic analysis of the scooter using anthropometrics. The recommendation was that the width of the scooter deck be made 250mm wide, such that the rider can comfortably stand on the deck with both feet facing forward. The ergonomic benefits of this recommendation must be weighed against the adverse effects this would have on weight and cost. In order to ensure the correct decision is made, the relevant literature must be found, and the ergonomic difference between a front-on and a side-on posture determined. The main reasons raised why both feet should be on the deck facing forward are: to equalise pressure in each leg, to assist in balance at speed and to ensure that there is no natural predisposition to turning the handlebars (Ulrich 2014; Little 2011). However the final two points were directed towards the body's position while 'kicking' the scooter to propel it forward. For the electric scooter, we will assume no kicking will be done and therefore that these two points are unimportant. The major reason to equalise pressure in both legs is to delay leg strain for extended rides, and as electric scooter rides will be longer than kick-scooter rides, this is an important issue to address. Therefore a solution that meets this need with a minimum weight and size impact is proposed in figure 12. The solution consists of an optional attachment to the new scooter design: two 50mm wide 3mm thick aluminium panels bolt on to the original deck using Allen key screws. This means that riders who wish to extend the deck width have this option, although it severely impacts the main advantage of the new design which is its compact size and weight. The solution is also only required for one folding section of the new scooter design, as the length of each section is sufficient for an individual's foot. These weight saving measures mean the extensions only have a weight of 60 grams each. The final design will incorporate this outcome of the Human Factors Analysis Process.

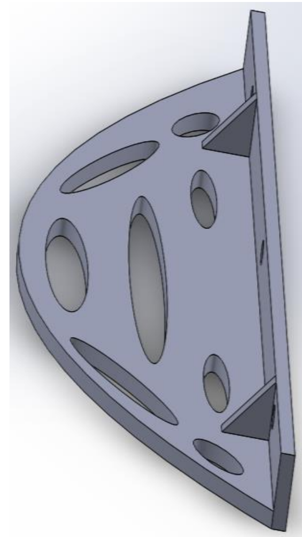


Figure 12 - CAD Drawing of Deck Extension

6.1.2 Energy Analysis – MOSFET Change

The recommendation to change from IRFB4115 MOSFETs to IRFB4110 MOSFETS was made based on information from the Sankey diagram in the energy analysis section. The relevant data for each MOSFET is given in that section. Based on the lack of major drawbacks to implementing this change in the design, the huge reduction in controller resistance is considered well worth it. The final design will incorporate this outcome of the Energy Analysis process. The Pareto principle certainly applies to this change, as the MOSFET is one component of a complicated controller, yet as it is the only component that sees full motor current, it has the largest impact on controller resistive heat losses.

6.1.3 Materials Analysis – Decrease of Battery size and Scooter Deck

The recommendation was made to reduce range by 10km in order to achieve a 0.964kg decrease in scooter mass. Even with this change, the mass is still higher than is ideal, tipping the scales at 11.84kg. As can be seen in the materials audit it is difficult to find other areas where mass can be reduced, the other major weight is the hub motor, but as it consists of motor, transmission and braking all-in-one, it is hard to reduce its mass safely. Therefore the significance of the 10km range decrease is the determining factor. In a practical sense, a 35km range is not strictly necessary for the electric scooter and its urban purpose. We suggest that the large ranges found on the electric scooters arise from a crowding online marketplace where each product tries to attract customers without them being able to have physical interaction with the product. Hence a large range is an attractive characteristic when choosing between two models, even if it will not be useful. However, the new design's folding innovation already provides significant advantages over its competitors, so from a business sense, this marketing of high range is no longer required. Therefore it is concluded that the 0.964kg weight decrease is more important, and the design is changed accordingly to a battery with 6Ah of capacity instead of the original 8Ah. In this way, the final design has been changed by the materials analysis process. As it does not significantly impact cost, or environmental impact, a shoulder strap which clips into the notches for the hinge locks in the new design will be sold with the scooter. Furthermore the new design can reasonably fit inside a medium-sized messenger bag for further carrying comfort.

6.2 Reliability

The most important process in analysing the reliability of the system is to determine its Early, Wear-out and Random failures, and to draw the bathtub curve. The ideal bathtub curve is as flat as possible for as long as possible. As there is no work in the literature about electric scooter failures, the following results are based upon original testing and interpretation. Due to the lack of data on scooter failures, an accurate bathtub curve cannot be drawn. However, for a system like the electric scooter where the majority of failures arise from user-error or accidents, it is clear that the bathtub curve would unfortunately be dominated by random failures. The scooter could be strengthened to resist damage in a crash-scenario, but the impact this would have on the overall mass of the scooter would be massive, and therefore the main recommendation is for the scooter to be operated with the same care as any larger powered-vehicle would be. As adoption increases, studies may be done and information received from manufacturers' warranty centres to determine the spread of failures more accurately.

Table 3 - Possible failure causes for the Electric scooter system

Early Failures	Wear-out Failures	Random Failures
Controller Defect	Brake Pad Wear-Out	Crash that breaks scooter
Folding Mechanism Defect	Hinge Lock Wears Loose	Excessive speed causing brake failure
Battery Failure	Hinge Jam	Water Damage to Throttle
Charger Defect	Motor/Controller Corrosion	Battery Over-discharge
	Battery capacity loss over time	

7. Cost Analysis

The cost of the electric scooter and its use are vital factors impacting consumer uptake of the system. Although the environmental benefits have been well-established even in inefficient use-cases, the cost of an electric scooter system may be prohibitive to consumers. To examine this, a payback period will be conducted for the same use-case as the Time and Materials analysis sections. The scooter will be priced at 1000AUD; a fuel price of $1.50 per litre and an electricity price of 18c per kWh will be used in calculations. As was done previously, the scooter is considered an addition to an ICE car or an EV that is already owned, and therefore its initial purchase cost is considered, while that of the cars are not. The most common situation will be that where an individual already owns an ICE-driven vehicle. For this situation the payback period is a reasonable 76 weeks at current fuel prices. For someone who already owns an electric vehicle, changing to a scooter makes sense environmentally as shown previously, but economically it is impractical as the payback period is over 8 years. An interesting outcome of the analysis is that it costs more to fuel the ICE-driven car for a month than it does to power the electric scooter for 10 years, in the use-case under analysis. However, for other use-cases such as where there is more than one person in the car, both the carbon and cost payback periods increase proportionally, as the individual passenger's masses have negligible impact on the amount of fuel used to travel. Therefore it is important for an individual to examine their own circumstances before determining whether the scooter is beneficial for them. Environmentally, the scooter is beneficial even compared to 4-person carpooling, as the original carbon payback period is only 3 weeks. Cost-wise, however, it would take 304 weeks for the fuel savings to pay for the scooter.

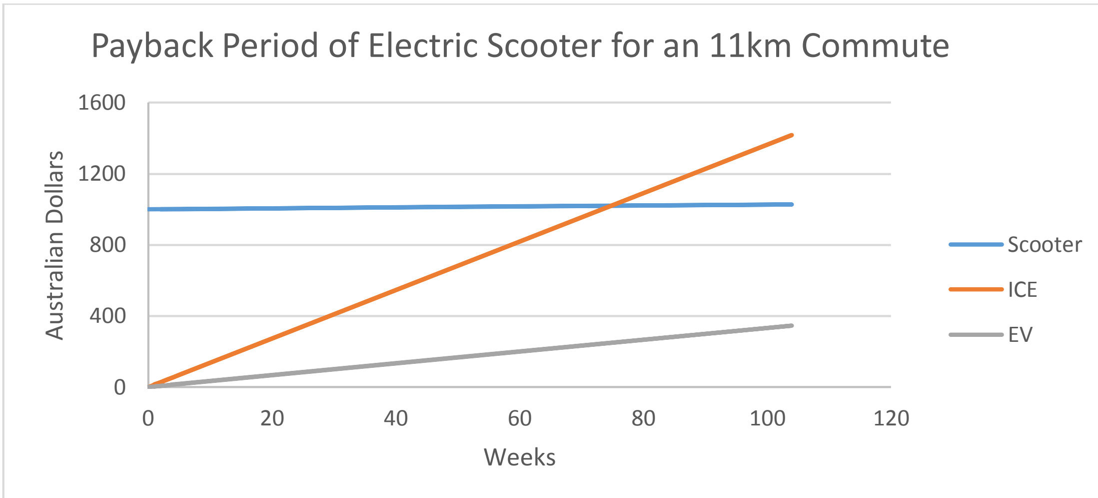


Figure 13 - Payback Period of an Electric Scooter for a Woden-Civic commute

As the scooter has already been highly optimised according to the metrics of ergonomics and weight, optimising with respect to cost is difficult. The above payback period analysis did not raise any significant issues with the cost of the scooter, and the $1000 price used was one that is also reasonably able to cover the new design, which incorporates the innovative folding mechanism. Therefore it is deemed that the performance and significant environmental benefits of the design more than justify the cost, and that no changes are recommended out of the cost analysis process.

8. Conclusions

The systems engineering analysis process strongly validated the preconceived design change to the electric scooter system through Human Factors analysis. Upon this validation, a draft patent was written with regards to the folding mechanism in the new scooter design, and this is shown in appendix IV. Furthermore, key design recommendations were made in the ergonomic, energy and materials analysis sections; and without exception these changes proved useful and became a part of the final design, showing the value of undertaking rigorous systems analysis. The significant environmental benefits of the electric scooter system were also shown, even when compared to a modern electric car. The only area where the electric scooter system does not excel is cost, with the 1000AUD price above what 98.5% of survey respondents were willing to pay. However, this did not incorporate the new design. As electric scooters are currently a niche product, there is certainly room for price reduction if there is increased adoption, as mass production and competition will drive down prices. The final design is arguably an ideal electric scooter system, based on current technologies, at a reasonable price point. Overall, the systems analysis process has shown the potential that electric scooters, and PEVs in general, have to help individuals significantly reduce their carbon footprint in a cheap, effective and convenient way.

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Appendices

Appendix I – Commuting Habits Survey

The purpose of this survey is to determine the applicability of alternate transportation methods to students and workers in Canberra. The later questions seek to establish the budget/criteria for the design of such an alternative transportation solution. Please complete the survey in order, without changing your response to earlier questions upon reading later questions. Please direct all queries regarding this survey to u5366327@anu.edu.au. This survey should take < 10 minutes.

1. **Please check the box which best describes the length of your travel from your primary place of residence to your place of education or employment (Your Commute).**

   ☐ $< 1km$ ☐ $1km - 2km$ ☐ $2 - 5\ km$ ☐ $5 - 10km$

   ☐ $10km - 20km$ ☐ $20km - 50km$ ☐ $50km +$

2. **Please select your primary mode of transportation for this commute.**

   ☐ *Car (Alone)* ☐ *Car (Carpooling)* ☐ *Bus* ☐ *Walking*

   ☐ *Bicycle* ☐ *Scooter* ☐ *Other (Please Specify) … … … … … … … …*

3. **If you combine multiple different modes of transportation in your commute, please select your secondary mode of transportation.**

   ☐ *Car (Alone)* ☐ *Car (Carpooling)* ☐ *Bus* ☐ *Walking*

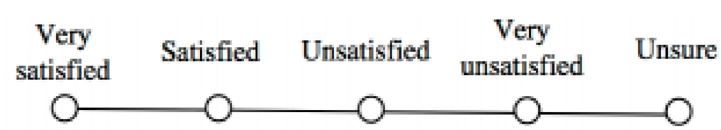
   ☐ *Bicycle* ☐ *Scooter* ☐ *Other (Please Specify) … … … … … … … …*

   ☐ *I do not use a secondary form of transportation in my commute*

4. **Please provide a rough estimate of the distance travelled using your SECONDARY mode of transportation.**

   Your Response: ____

5. **Overall, how satisfied are you with your current commuting transport arrangements?**



QUESTIONS 6 – 8 ARE CONCERNED WITH A HYPOTHETICAL PRODUCT

IMAGINE you have a messenger bag sized vehicle (physically similar to bag in figure 1) that allows you to travel up to 30km/h using walking/cycling routes for 30km a day. For each kilometre of walking distance in your commute, this could save you up to 10 minutes of travel time. The bag lasts for five years and there are no ongoing costs. (Consider Parking, Petrol and Registration/Insurance savings).

Figure 14 - Example of Messenger Bag

6.

a. **How interested would you be in such a product?**

Not Interested | Somewhat Interested | Interested | Very Interested | Extremely Interested

b. **What is the Maximum you would pay for such a product?**

$0 | $500 | $750 | $1000 | $1500

7.

a. **The messenger bag now has some drawbacks (all other specifications remain the same):**

☐ It weighs 12kg when carried.

☐ It needs to be charged for 3 hours a day (negligible CO_2 emissions).

☐ Moving in this way is seen as unfashionable by some.

Using the squares provided next to each drawback, please rank the above drawbacks from 1 to 3, where ‘1’ is the worst drawback and ‘3’ is the most minor drawback.

b. **With these drawbacks in mind, how interested would you be in such a product?**

Not Interested | Somewhat Interested | Interested | Very Interested | Extremely Interested

c. **What is the Maximum you would pay for such a product?**

$0 | $500 | $750 | $1000 | $1500

8. The pictures below show a modern electric scooter in its folded and unfolded states. The scooter has the same characteristics of the device described in questions 7 and 8, except for the change in shape.

a. **What makes this option less appealing than the product described in Question 8? (If multiple reasons, please list from most unappealing aspect to least unappealing aspect).**

____

____

b. **How interested are you in such a product?**

Not Interested | Somewhat Interested | Interested | Very Interested | Extremely Interested

c. **What is the maximum you would pay for such a product?**

$0 | $500 | $750 | $1000 | $1500

Appendix II – Raw Survey Response Data

Commute Length	Primary Type	Secondary Type	Secondary Distance	Satisfaction	Ideal Interest	Ideal Price	Real Interest	Real Price	Scooter Interest	Scooter Price
20-50	BUS	CAR	20-50						N/A	N/A
20-50	CAR	OTHER	20-50	VS	VI	1000	NI	500	SI	500
10-20	CAR	NONE		S	SI	500	SI	500	NI	0
1-2	BIKE	NONE		S	SI	500	NI	0	NI	0
10-20	CAR	NONE		S	SI	500	SI	500	I	500
10-20	CAR	NONE		S	EI	1500	EI	1500	SI	500
0-1	WALK	NONE		VS	SI	500	VI	50	SI	500
0-1	WALK	BIKE	0-1	VS	I	750	I	750	NI	500
20-50	CAR	NONE		S	I	1000	I	1000	I	500
2-5	CAR	NONE		VS	VI	500	I	500	I	500
20-50	BUS	NONE		S	SI	500	NI	0	NI	0
10-20	BUS	WALK	0-1	VU	I	500	SI	500	NI	0
10-20	BUS	CAR	10-20	S	SI	500	SI	500	SI	500
20-50	CAR	NONE		S	NI	500	NI	500	NI	0
10-20	CAR	NONE		VS	I	1000	NI	500	SI	500
10-20	BUS	NONE		US	I	500	SI	750	SI	500
10-20	CAR	BUS	10-20	VS	SI	750	SI	500	I	500
10-20	BUS	CAR		VS	I	500	SI	500	SI	500
10-20	BUS	WALK	1-2	S	I	500	SI	0	NI	0
10-20	CAR	NONE		S	NI	0	NI	0	NI	0
0-1	WALK	NONE		S	NI	0	NI	0	NI	0
1-2	CAR	BUS	1-2	S	I	0	SI	0	SI	0
0-1	WALK	NONE		S	NI	0	NI	0	NI	0
0-1	WALK	NONE		VS					N/A	N/A
0-1	WALK	BUS	0-1	S	SI	500	SI	500	NI	500
5-10	BUS	NONE		US	NI	0	NI	0	NI	0
0-1	WALK	BIKE	0-1	S	I	500	SI	500	I	750
20-50	CAR	NONE		S	SI	500	SI	500	NI	0
10-20	CAR	WALK	1-2	VS	SI	1500	I	1500	I	500
10-20	OTHER	NONE		VS	NI	0	NI	0	NI	0
1-2	WALK	BIKE	2-5	S	SI	0	SI	0	SI	0
2-5	BIKE	NONE		US	SI	500	NI	0	NI	0
2-5	BIKE	NONE		VS	SI	500			N/A	N/A
10-20	CAR	BUS	10-20	S	I	500	NI	0	NI	0
0-1	WALK	NONE		VS	NI	0	NI	0	SI	500
10-20	CAR	NONE		S	VI	500	I	500	SI	500
2-5	CAR	NONE		VS	I	500	SI	0	SI	0
1-2	BIKE	NONE		S	NI	0	NI	0	NI	0
0-1	WALK	BUS	1-2	VS	VI	500	VI	500	I	500
1-2	WALK	NONE		S	I	500	I	500	I	500
0-1	WALK	CAR	1-2	VS	EI	750	I	500	SI	500
5-10	CAR	BIKE	1-2	US	I	750	SI	500	SI	500
20-50	CAR	NONE		S	I	750	I	1000	SI	500
1-2	BIKE	NONE		S	I	500	SI	500	SI	500
5-10	BUS	NONE		S	SI	500	SI	500	NI	0
55-10	BUS	NONE		S	SI	750	NI	750	NI	750
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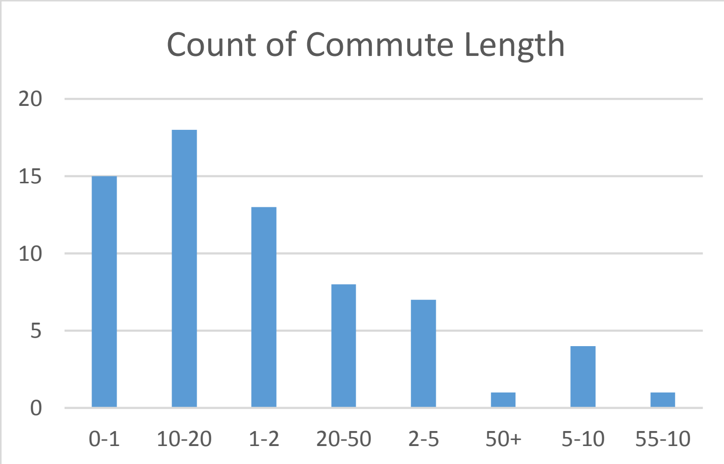
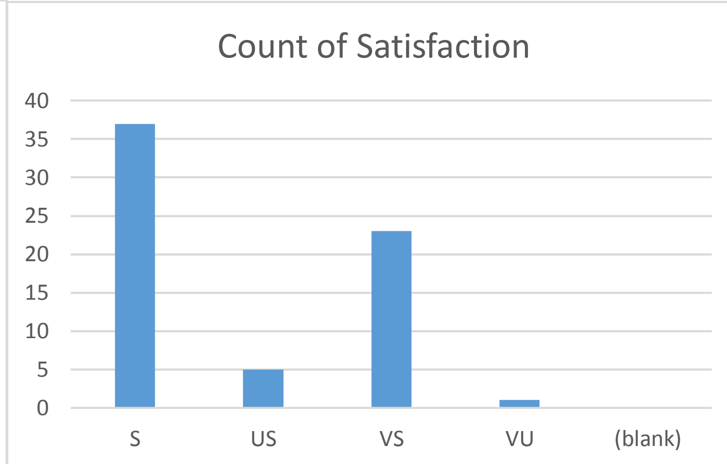
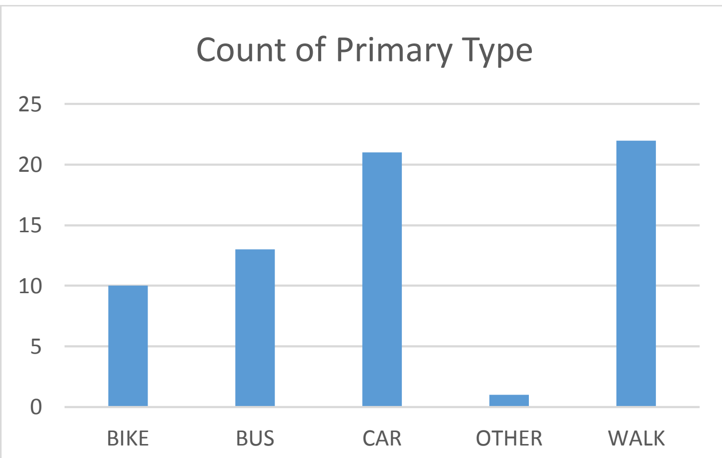
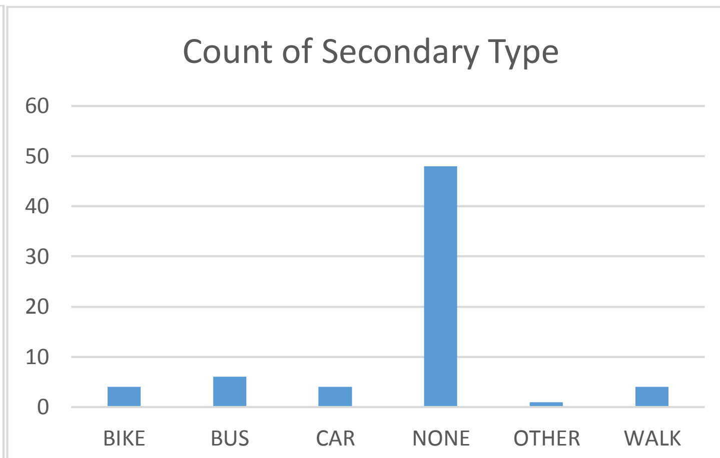
0-1	WALK	NONE		S	SI	500	SI	500	SI	500
2-5	BIKE	NONE		S	NI	0	NI	0	NI	0
1-2	WALK	NONE		S	I	750	I	1000	I	500
50+	CAR	NONE		S	NI	0	NI	0	NI	0
20-50	CAR	BUS	10-20	VS	VI	1000	NI	1000	NI	0
1-2	WALK	NONE		VS	SI	500	SI	500	NI	0
1-2	WALK	NONE		S	I	500	SI	500	SI	500
10-20	CAR	NONE		S	I	500	I	0	NI	0
1-2	BIKE	NONE		VS	I	500	SI	500	NI	0
0-1	WALK	NONE		VS	EI	500	NI	0	NI	0
1-2	WALK	NONE		VS	I	500	NI	0	SI	0
1-2	WALK	NONE		VS	I	1000	I	1000	I	750
2-5	BIKE	NONE		VS	SI	500	NI	0	NI	0
5-10	BIKE	WALK	0-1	S	I	500	SI	500	SI	500
2-5	BUS	NONE		S	SI	500	NI	500	SI	500
1-2	WALK	NONE		VS	NI	0	NI	0	NI	0
10-20	BUS	NONE		S	NI	750	NI	750	NI	0

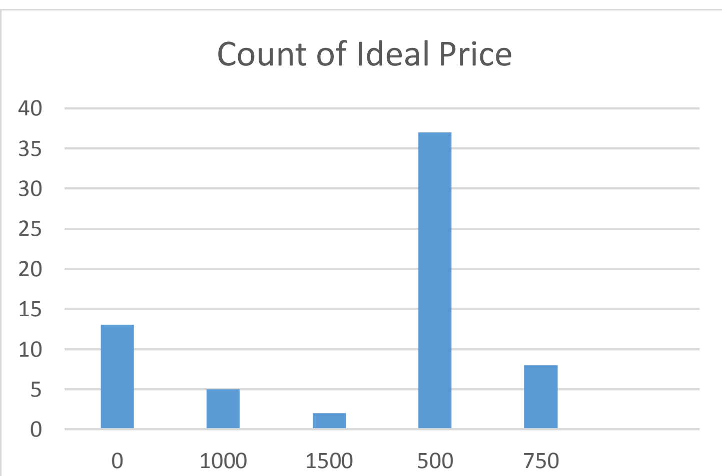
Appendix III – Graphical Representations of Survey Data

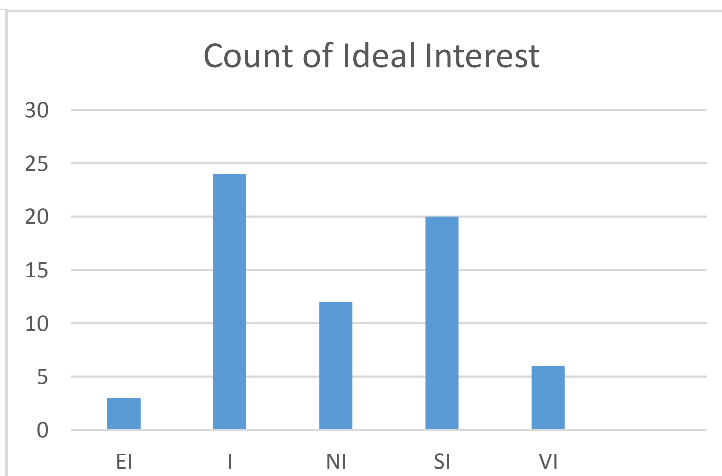


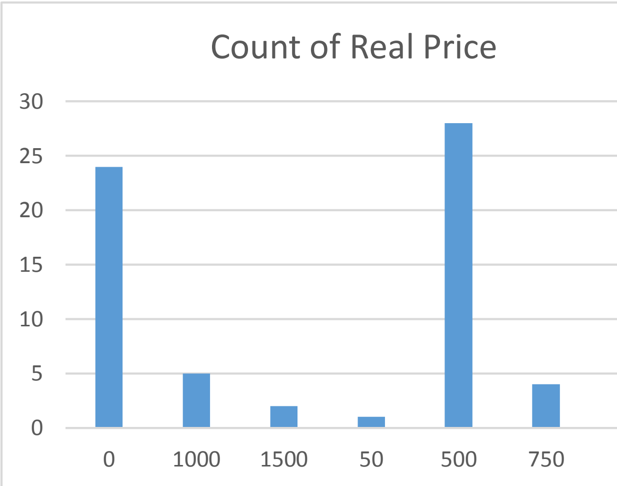


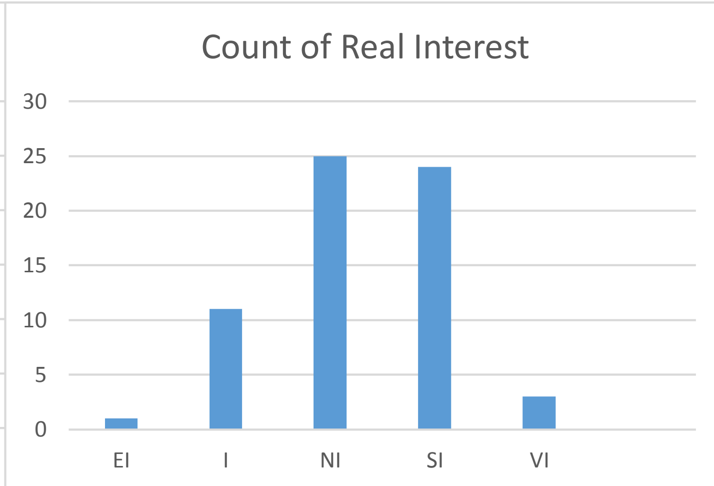


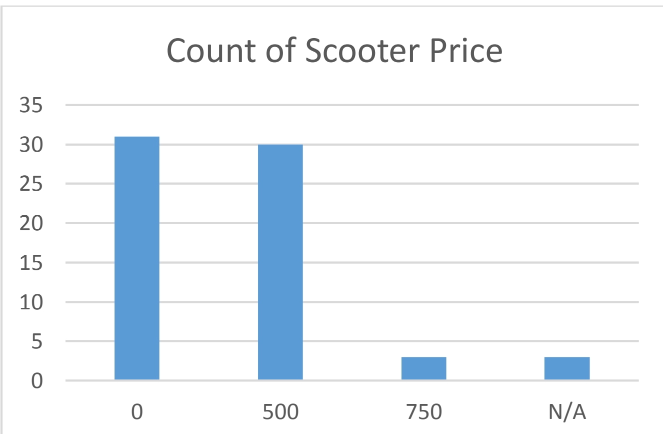







Count of Real Price
30
25
20
15
10
5
0
0
1000
1500
50
500
750


Count of Real Interest
30
25
20
15
10
5
0
EI
I
NI
SI
VI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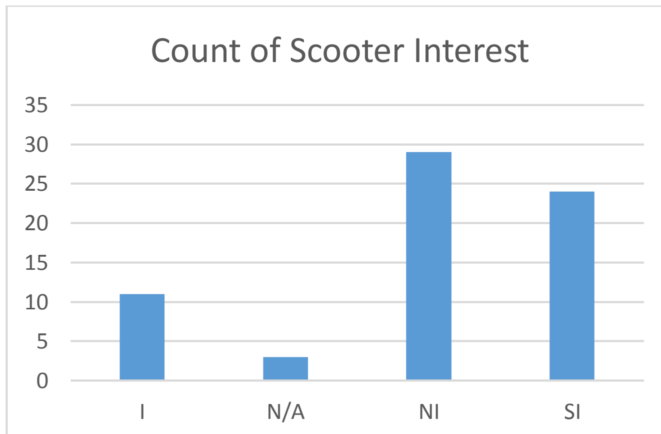
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Australia

Patents Act 1990

Complete Specification

Innovation Patent

COLLAPSIBLE SCOOTER WITH ELECTRIC PROPULSION

The following statement is a full description of this invention, including the best method of performing it known to me:

COLLAPSIBLE SCOOTER WITH ELECTRIC PROPULSION

Push or kick-scooters (herein: "scooters") have been a technology for many years, however due to their cumbersome shape, they are uncomfortable to carry when not in use. This has been reduced through the use of a folding steering column in most designs, however still the scooter is very un-ergonomic. This invention has been designed in order to increase the comfort and ease of which a scooter can be carried and stored by altering the shape such that it is more compact. Various methods have been attempted previously, however this design differs in its method and execution, and is unique in that this goal is achieved, with the added feature that the hollow space within the scooter deck is preserved such that it may be used to safely house batteries and electronics involved with the electric propulsion of the scooter. The use of a scooter is accepted to be an effective form of exercise, and the provision of electric propulsion increases the range of people for whom scooter transportation would be practical, as well as the enjoyment derived from such use.

The term scooter in accordance with this invention comprises of a strong deck that supports the rear wheel as well as a freely-rotating steering shaft used to turn the front wheel, and thus steer the scooter in the intended direction.

The innovation occurs in the deck itself, which, usually a simple piece of steel, is replaced by three sets of four pieces that form a hollow tube when in used, with hinges and locks placed strategically at the junctions between the sets, such that when said locks are released and hinges folded, the scooter collapses into a very practical rectangular prism shape. When unfolding the scooter, the locks also have the ability to automatically extend and latch at the junction, increasing the ease and speed of the transition from the folded form to the unfolded form.

The locks operate using a latching mechanism, and are spring-loaded such that they automatically create the lock when the scooter is unfolded, and maintain it while the scooter is in use. The scooter is collapsed by pressing the latches inward against the spring pressure, such that they lose contact with the outer deck. This breaks the connection and thus allows the hinges to rotate and the scooter to be manipulated into the shape of a rectangular prism. This process is shown at various stages in figures 1, 2 and 3.

Once the scooter is fully folded, the locks are able to be pushed inwards and latch in a position such that they do not protrude from the folded scooter, this negates any risks involved with pointed protrusions, as well as improving the collapsed shape.

The same process is used to collapse the steering column, however in this case the placement of hinges is such that the steering column and handle-bars folds to join the deck in an extension of its rectangular prism shape This is shown in figure 4 with an a view of the collapsed system in figure 5.

To achieve the most compact design, the steering column detaches from the deck, and is placed in another location along one edge of the folded deck. This is shown in figure 5. The method used to fasten the steering column to its primary and secondary locations is arbitrary.

The exact size and weight of each deck and steering-column section, and the scooter as a whole, is subject to the cosmetic design of various models, and thus variable between units. The scooter utilizes electric motor technology to drive the rear wheel, such that it provides the ability to propel the scooter forward, however the scooter also is able to operate manually in the same way as one with no propulsion. The specific design of the motor, such as: location, turn count, magnetic field, and pole count is arbitrary and will vary between scooter models, all practical combinations are able to be used.

A particular feature of novelty that is found in this invention is that a space within the scooter deck is available to be used for storage of batteries and electronic equipment involved with the propulsion of the scooter, this is advantageous in that the equipment is safely protected by the metal (or other material) shell of the deck, and thus enhances the robustness and usefulness of the invention, particularly when used as an electric product.

Ultimately the scooter provides a complete personal transportation platform which is able to be collapsed into a small unit that is easy to carry and store when it is not in use.

A greater understanding of the operation of the scooter may be derived from the attached figures, which are described below:

Figure 1 is three views of the scooter deck with arbitrary design choices such as the shape of the wheel well. This figure gives an overview of the innovation, with points labelled “1” being the hinges, and points labelled “2”, being the location of the locking mechanisms.

Figure 2 is a view of the scooter deck, now in the situation where the locks have been released and the scooter is partly folded, this shows the mechanism of folding.

Figure 3 is the same scooter deck as figures 1 and 2, however now the scooter is completely folded and the locks are latched into their secondary positions.

Figure 4 shows three views of the collapsed steering column.

Figure 5 shows two views of the complete collapsed scooter system in its compact form, this example not containing electric propulsion components, however that does not change any of the function of the invention.

Figure 6 shows multiple views of the unfolded scooter.

The claims defining the invention are as follows:

1. A scooter deck comprising of multiple sections, connected by hinges on alternating sides which use a locking system to form one rigid deck when extended, and fold into a more compact shape similar to a rectangular prism when collapsed.

2. A steering column and handle-bars comprising of multiple sections, connected by hinges, which use a locking system to form one rigid steering system when extended, and collapse into a more compact form similar to a rectangular prism when folded.

3. A scooter according to any claims 1 and 2 by which an internal space of the deck is preserved for use of storage of batteries, electronics or otherwise.

4. A scooter according to any claims 1, 2 and 3 by which propulsion is achieved via electric motors, in-wheel or otherwise.

5. A scooter substantially as herein before described with reference to figures 1-5 of the accompanying drawings.

Thomas James McMenamin 15 September 2014

Figure 1

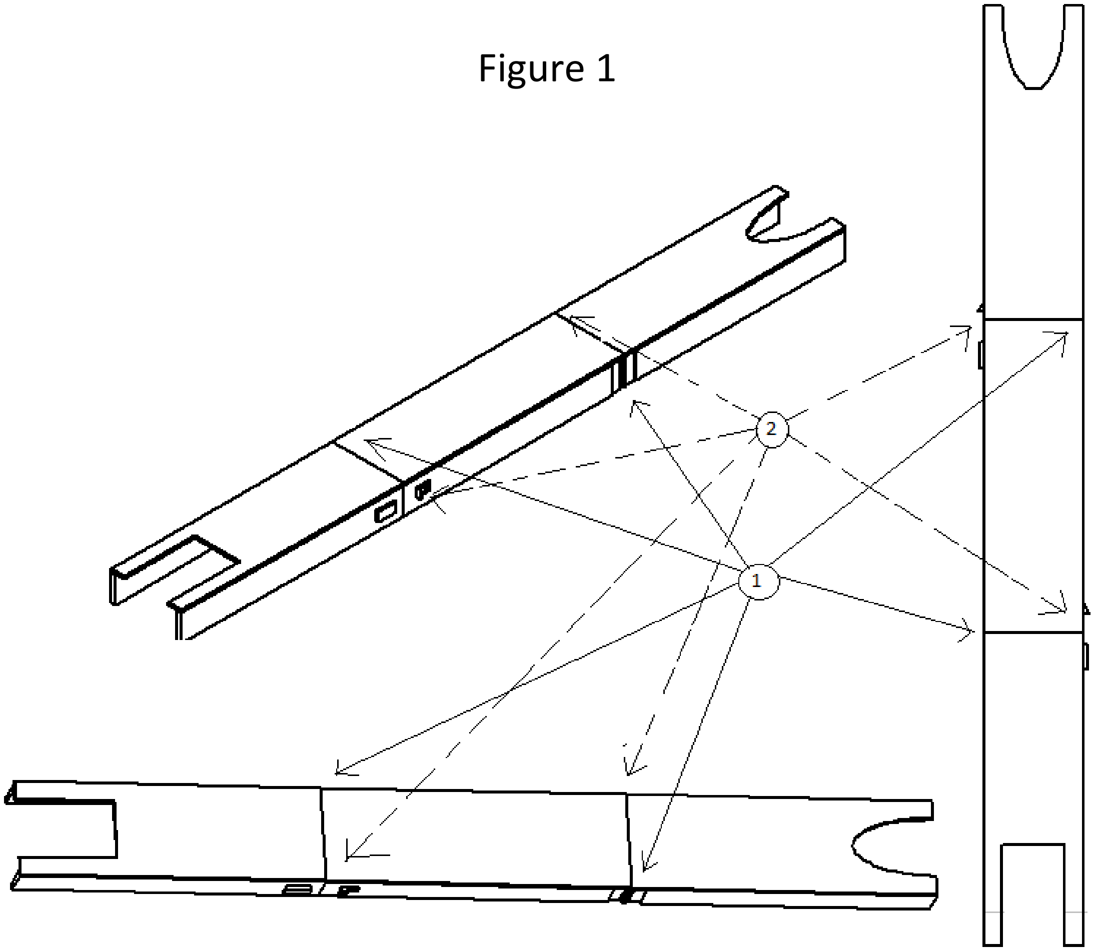


Figure 2

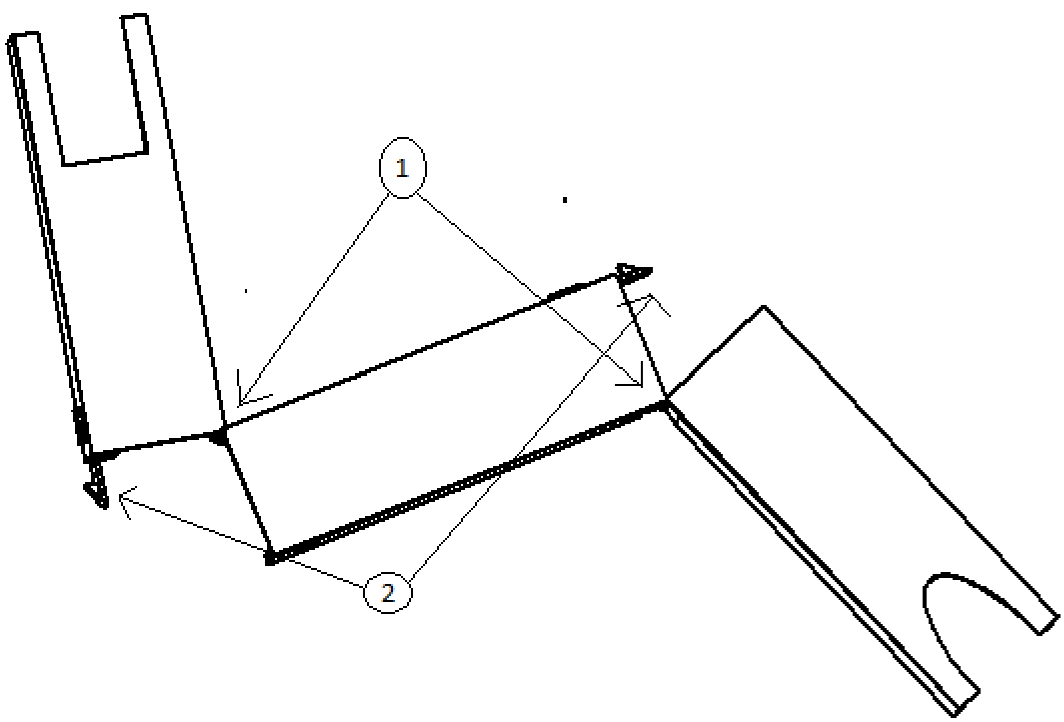


Figure 3

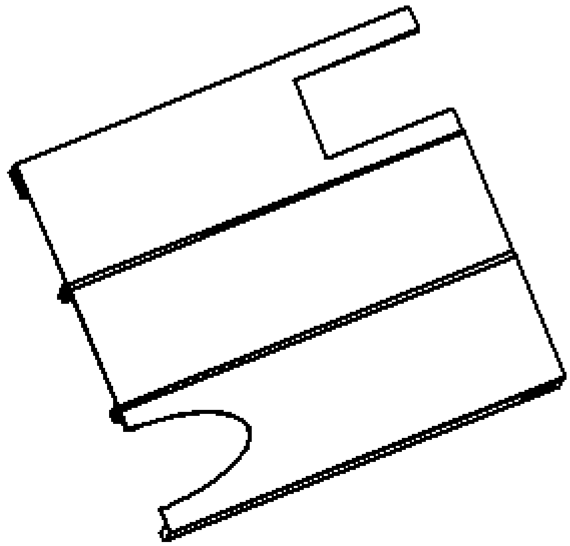


Figure 4

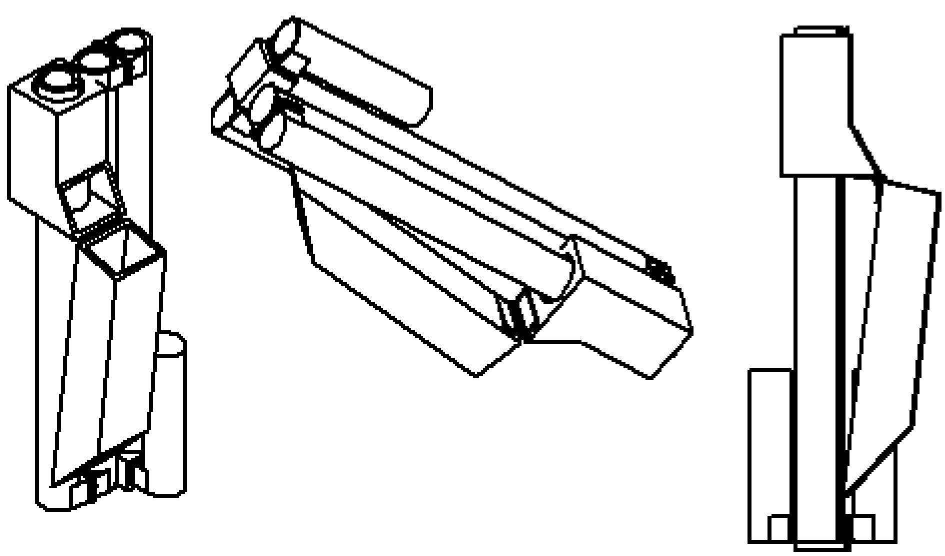
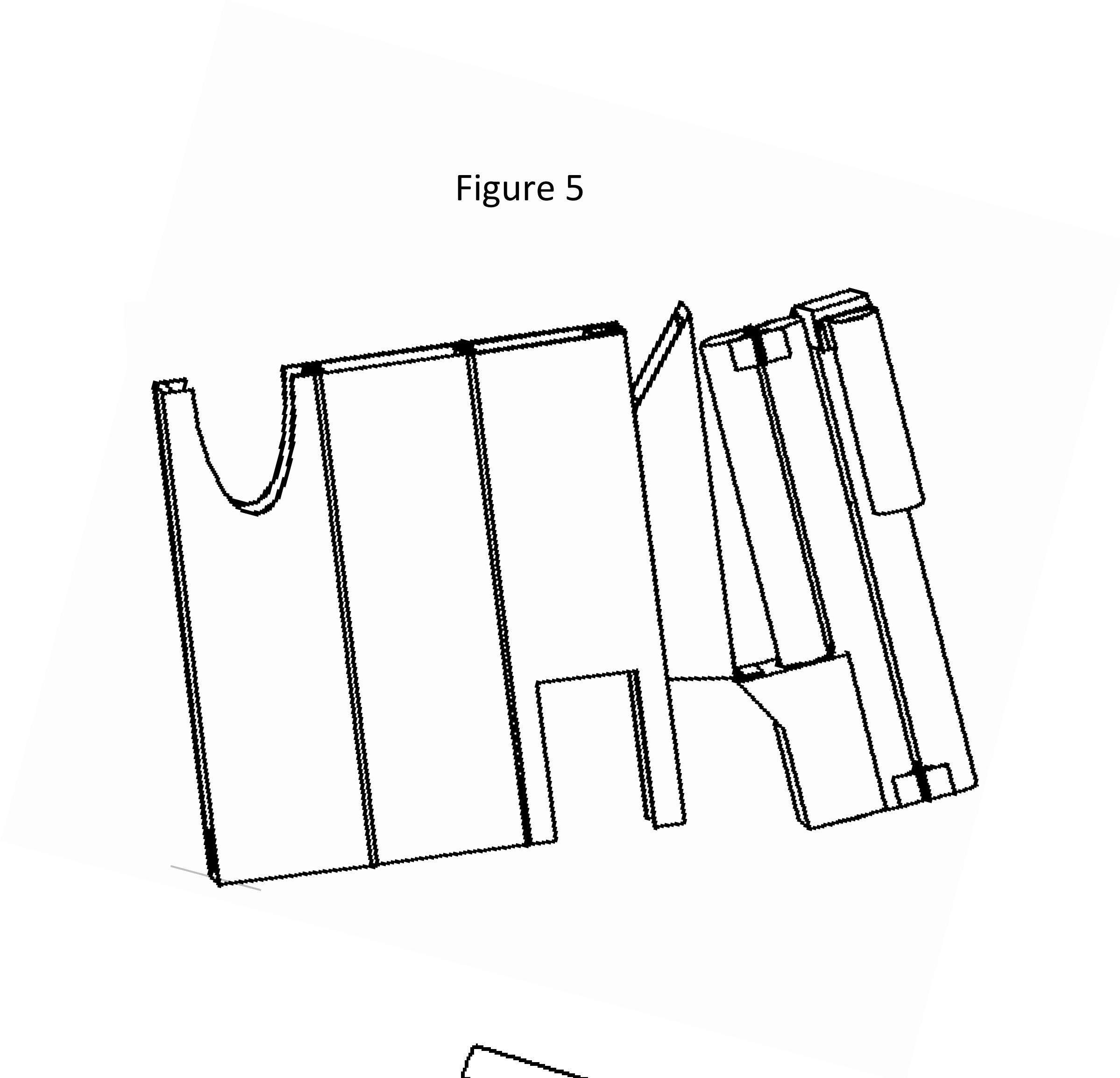


Figure 5



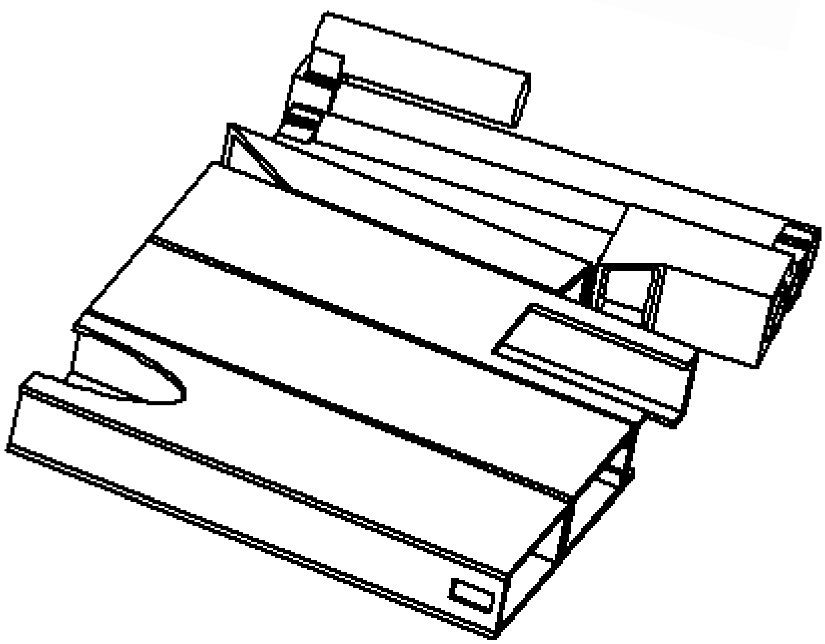
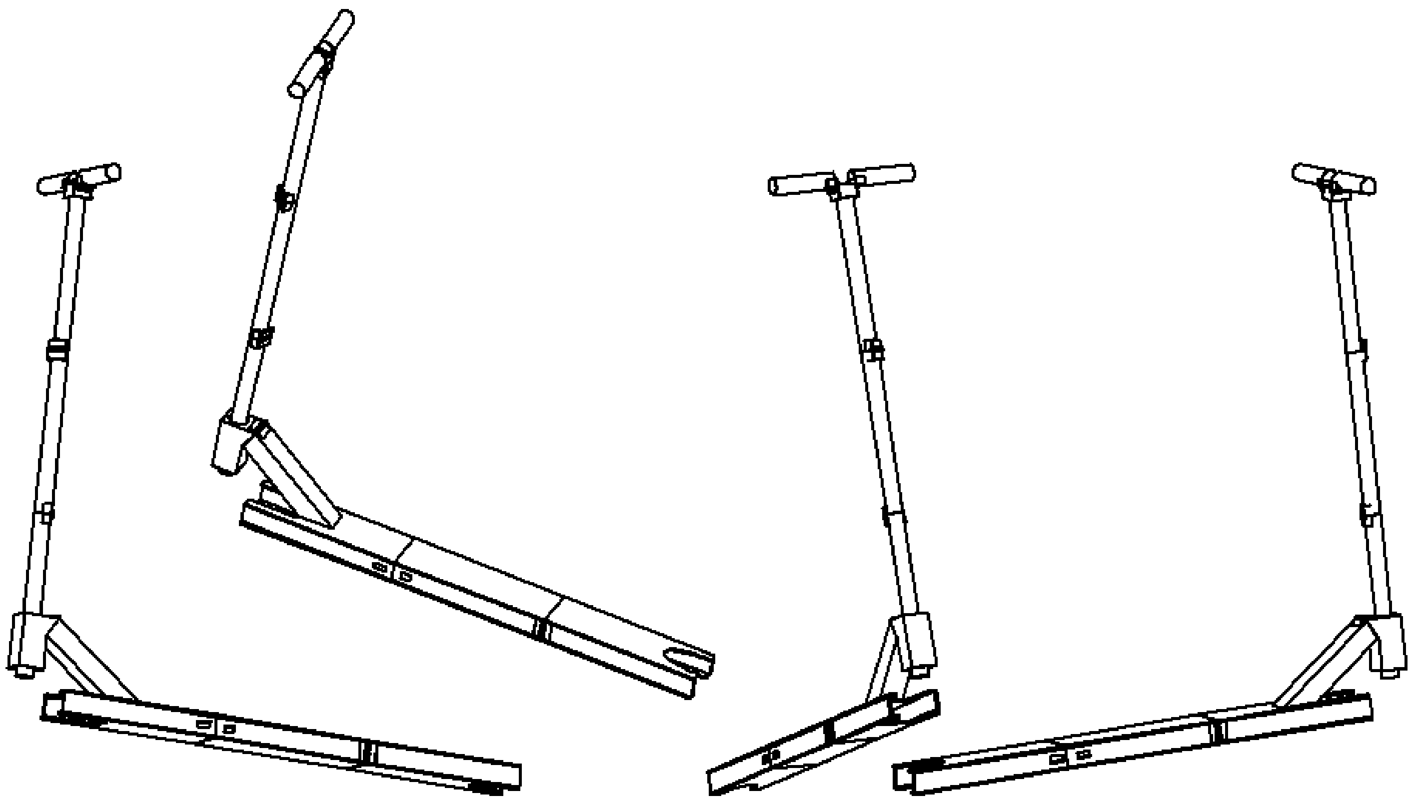


Figure 6



ABSTRACT

The disclosed scooter is composed of two main parts, the deck and steering column. Both of those parts are designed such that they are able to be folded into a more practical shape for carrying and storage, the deck is uniquely designed such that it achieves this goal, while preserving the hollow space within itself, to be used for the placement of batteries and electronics for the purpose of the electric propulsion of the scooter. The deck is divided into three sections as shown in the diagrams, with hinges and locks on alternating, opposite sides. This allows the deck to fold into a rectangular prism. The steering column detaches from the deck and has its own hinge-lock system arranged such that it folds in a form complementary to the deck, the two having a final collapsed shape of that shown in figure 5. A handle will be attached to the rear end of the front deck section, as this allows the scooter to be carried like a briefcase very easily, as well as being near the centre of mass of the collapsed scooter, reducing wrist strain and increasing ease of carrying.