

University of Wales Trinity Saint David-Swansea

A Theoretical Deployment of an Electric Drivetrain on an Existing Delivery Vehicle

Research Methods & Project M6X02206

Ashleigh Dylan Jones 1707089

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Supervisor: Mark Sandford

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Abstract

The project primarily investigates the adaption and conversion of an existing Tesco van with the standard diesel engine and converting said engine with an electric drivetrain. By investigating the van's existing power output by the means of drive cycle testing. The outcome of these tests are utilised to find suitable gearing, motor, controller and battery. Additionally, due to the business of the van, a suitable method of keeping the shopping cold is identified to ensure the van is fit for purpose and is able to be sustained throughout the duration of the run. The Carbon Dioxide of both systems is investigated and is found that the electric system pollutes 25%-57% Carbon Dioxide than the diesel engine. This difference is only a guideline due to the unknown testing style of the van manufacturer. Due to the limitations of the testing equipment, the actual Carbon Dioxide that was being exhausted from the van during the drive cycle wasn't monitored. To ensure an accurate test, the 'New European Drive Cycle' (NEDC) testing method should be utilised on the Tesco van and results compared accordingly.

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1.0 Introduction

Electric vehicles first appeared in the mid-19th century but due to the restriction of technology, the system was limited. One limitation of electric vehicles was the batteries. The lead acid batteries were very heavy however this was the only option for electric energy storage. Also, the DC brushed motors in electric vehicles were inefficient because they didn't last very long and were inefficient for the amount of time the vehicle was used for. However, electric vehicles have become a viable option as a result of advancements in motor, battery and control. Advancements in battery storage have enabled electric vehicles to store more energy and as a result travel further and longer on a single charge. This has led to advancements in motor and controller technology as a result.

Pollution is an ever-growing problem that affects the environment and the inhabitants in many different ways. One of the main global problems nowadays is air pollution also known as air emissions. The term 'air emissions' refers to the release into the atmosphere of air pollutants and greenhouse gases due to both anthropogenic activities (e.g. fuel combustion) and natural processes (e.g. volcanoes) (European Environment Agency, 2014). There is a vast amount of pollutants that are being released into the atmosphere affecting the environment in many different ways but the one of the main pollutants is Carbon Dioxide (CO₂). CO₂ is a greenhouse gas and according to Zielinski (2018) since 1850 human behaviour has caused an increase in the amount of CO₂ which is released into air causing the ozone layer to thicken. As a result of the ozone layer thickening the heat energy that's being reflected from earth is being reflected and retained within the atmosphere instead of being reflected out of the atmosphere. Therefore, the heat energy being retained in the earth's atmosphere is causing the planet to increase in temperature (Zielinski, 2018).

The government has put measures in place to reduce the amount of CO₂ produced. At the moment, the government are particularly targeting the motor industry due to the vast number of cars on the road in the UK. As a response, manufacturers are researching, developing and manufacturing electric vehicles (EV) to ensure that these vehicles do not exhaust any pollutants to ensure that the manufacturers future proof the brand. Delivery vehicles present a separate issue and is more complex than a passenger car. Due to the nature of the business, delivery vehicles are often used for either long journeys, multi drop, heavy loads or a combination of all three. These present a

challenge to ensure that the vehicle can withstand these requirements so that the vehicle can conduct the task sufficiently without causing further pollution.

Tesco delivery service presents an adequate test base due to the multidrop aspect, base to base operation and additional loads associated with the fridge and freezer. The vehicle will undergo a duty cycle analysis to gauge the power and energy associated with the vehicle and what conditions the vehicle undergoes. A suitable electric drive system will be identified theoretically to identify the advantages and disadvantage of choosing this system. Also evaluating electric and diesel systems based on the CO₂ pollutants.

2.0 Literature Review

To conduct the present study thorough research has been conducted on the impact of CO₂ and delivery vehicles on the environment which is present below.

The impact of CO₂ pollution on the environment

Akitt (2018) states in his research that an excess of CO₂ and water vapour in the atmosphere causes Infar-red (IR) radiation to be reflected back to the surface of the earth. The layer is close to 12cm thick but is enough to cause a considerable amount of IR reflection. Akitt (2018) states 52% of the radiation leaves the atmosphere in two principle window regions but isn't enough to for the earth equilibrium temperature. With the increased ozone layer, the earth surface temperature has risen by 0.9°C since 1880 (Akitt, 2018). This is supported by the journal of scientific research which identifies the importance of greenhouse gasses due to this ability of being transparent to visible light energy but opaque to energy radiated from the earth (Kweku, et al., 2017). The resistance of the greenhouse effect allows the earth to maintain a comfortable temperature for life to exist. Due to current human implications, an increased amount of pollutants causes an increase in the greenhouse effect which limits the IR ration to escape into outer space. This is due to the increased amount of the following gasses which include water vapor, CO₂, Methane, Nitrous Oxide (N₂O) and other gasses. The main culprit for the lack of IR radiation to leave the atmospheres is CO₂ (Kweku, et al., 2017). In the article supports Akitt (2018) in his clams of the effects of the increased amount of greenhouse gasses which causes an increase in the earth temperature.

The impact of delivery vehicles on the environment

Palmer (2007) reported that the emissions of delivery vehicles has an impact on the environment in terms of CO₂ production. Palmer (2007) aimed to employ a computer-based routing model that calculates the amount of CO₂ emitted from road journeys. By utilizing routing strategies, it is deemed that the CO₂ can be reduced by up to 5%. However, when considering other transport externalities, the benefits are dependent on the traffic volumes (Palmer, 2007). Furthermore,

research has looked into energy consumption and urban air pollution reduction in e-shopping adoption (Tehrani et al., 2009). This research conducted surveys to identify the number of people that use personal vehicles to travel to and from shops. This allows an understanding of the number of vehicles that are being used. Subsequently identifying the CO₂ output of the vehicles can be used to quantify the delivery vehicle CO₂ reduction. It has been revealed that if personal trips for supermarket goods are substituted with delivery services this can reduce the amount of pollution by 39% (Tehrani, et al., 2009).

Electric vehicles

According to (Ehsani, et al., 2004), states that electric vehicles, hybrid vehicles and fuel cell vehicles have typically been proposed to replace conventional vehicles to reduce the amount of pollution being exhausted around the transport industry. The bases of an electric vehicle (EV) drivetrain consists of three major components subsystems which are: electric motor propulsion, energy source and auxiliary. The whole electric propulsion subsystem composes of a controller, power converter, electric motor, mechanical transition and driving wheels. "Based on the control inputs from the accelerator and brake pedals, the vehicle controller provides proper control signals to the electronic power converter, which functions to regulate the power flow between the electric motor and energy source. The backward power flow is due to the regenerative braking of the EV and this regenerated energy can be restored to the energy source, provided the energy source is receptive." (Ehsani, et al., 2004).

Drive cycle to identify the output of a vehicle

According to Barlow et al. (2009) drive cycles are primarily used in the measurement of emissions by testing the vehicle under different conditions. The majority of the test performed are conducted in controlled conditions using a rolling road to imitate the type of driving the vehicle undergoes. In the European Union, an emissions test is required by law for all new vehicles. The tests are conducted on a chassis dynamometer where the vehicles wheels are positioned in contact with the rollers. The systems can imitate the friction losses and an aerodynamic resistance can inducing load on the rollers. Exhaust emission sampling is conducted while the vehicle is being tested through a predesigned driving cycle which is designed to simulate a real-world operation. This drive cycle parameters are based on speed and gear selection as a function of time. This testing style is NEDC which stand for New European Drive cycle. Alternative type of cycles are; TRAMAQ and EMPA (Barlow , et al., 2009).

As a result of this research is it clear to see the importance of carrying out further research on delivery vehicles in order to reduce pollution. The present study will identify the CO₂ impact of supermarket delivery vehicles and the implication of converting the original fossil fuel system by the means of testing the output of CO₂ emissions of the selected delivery vehicle and identify a suitable electric drive system theoretically for delivery vehicles which will help to further reduce pollution.

3.0 Abbreviations

DC	Direct Current
AC	Alternating Current
Wh	Watt Hour
KWh	Kilo Watt Hour
MPH	Miles Per Hour
CO ₂	Carbon Dioxide
Nm	Newton Meters
m/s	Meters Per Second
IR	Infar-red
MPG	Miles Per Gallon
EV	Electric Vehicle
GPS	Global Positioning System

4.0 Project Reasoning and Aims

As previously discussed in the introduction, the motor industry generates the majority of CO₂ pollution. This is evident in the graph below (figure 1) showing the CO₂ output of transport contributes an average of 23% of the total annual emissions (European Parliament, 2019; Andrew & Peters, 2013). Therefore, measures are employed to try and reduce the gas emissions in this sector.

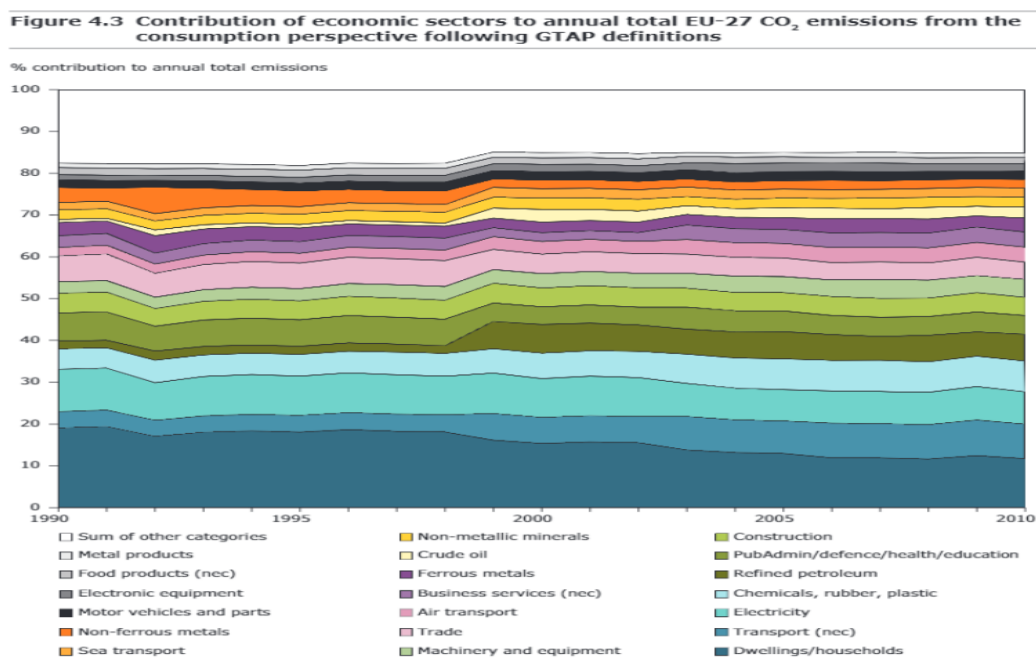


Figure 1 Percentage of CO₂ pollution per economic sector in the European Union (European Environment Agency, 2014)

A portion of the pollution produced can be attributed to the delivery sector due to the increasing amount of people ordering goods online, causing an increase in demand for delivery vehicles. The Tesco van which will be test during this study falls under the category of a light goods vehicle. The pollution percentage of light goods vehicles is 11.9% (figure 2) of the 23% annual total of transport emissions (figure 1). Therefore, reducing the amount of pollution from light goods vehicles can have a difference on the output CO₂ in the industry to further reduce the greenhouse effect.

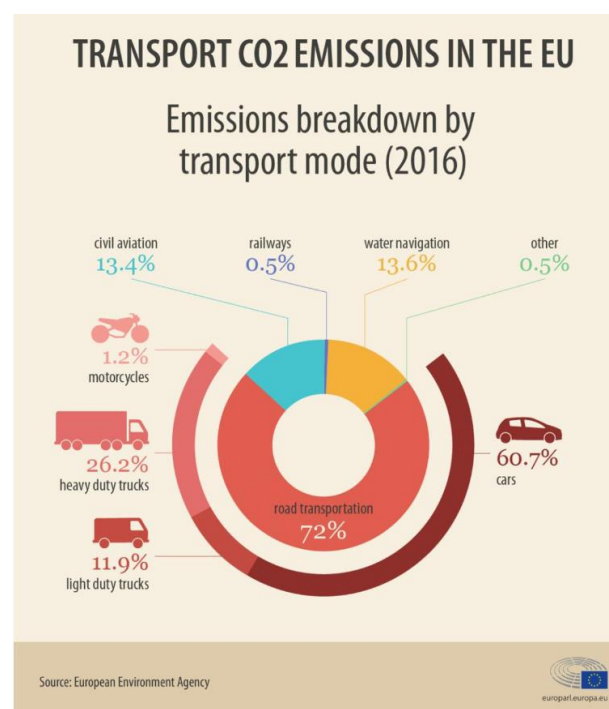


Figure 2 Transport CO₂ Emissions in the EU (European Parliament, 2019; Andrew & Peters, 2013)

5.0 Tesco Delivery Van

The Tesco delivery van is an Iveco daily 35s11, long wheelbase chassis cab. It's got a 2.3 litre diesel engine outputting 106bhp and 260Nm of torque which pumps out 218g/km of CO₂ (Figure 1) and incorporates an 8-speed automatic gearbox. The rear of the vehicle is a custom-made insulated body which incorporates layered racking for tray storage, 55mm wall and door insulated fridge and freezer powered by a Thermoking fridge and freezer. The Dot Com department has a fleet of 18 vans and is operated on a daily basis. The vans are used three times a day for 3.5-hour periods and return to store in between to reload the van. If the van is at the store, its plugged into the mains for the fridge and freezer to operate while standby. This is important for the identification of electric drivetrain to identify when the vehicle is available to be charged. The vehicle is also kept at store overnight so charging can take place overnight as well.

Found below is the Tesco van specifications:

Power (BHP)	106
Torque (Nm)	260
Height (m)	2.845
Width (m)	201
Mass (kg)	3045
Frontal area (m ²)	5.71845
Tire size	195/75/R16C
Tire Diameter (m)	0.6985
Tire Radius (m)	0.34925

Vehicle Details

Vehicle make	IVECO
Date of first registration	October 2015
Year of manufacture	2015
Cylinder capacity	2287 cc
CO ₂ emissions	218 g/km
Fuel type	DIESEL
Euro status	Not available
Real Driving Emissions (RDE)	Not available
Export marker	No
Vehicle status	Taxed
Vehicle colour	WHITE
Vehicle type approval	N1
Wheelplan	2 AXLE RIGID BODY
Revenue weight	3500 kg

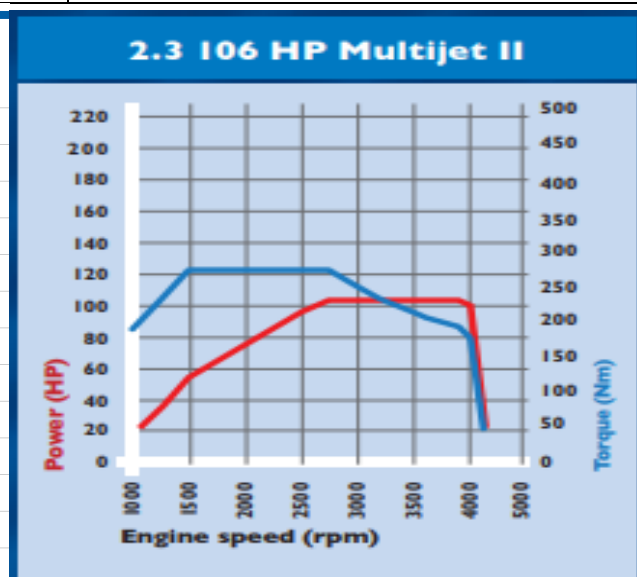


Figure 3.GOV Van Specs & Graph of the Power and Torque Output

5.1 Tesco Delivery Route

Tesco home delivery specialises in delivering shopping to the customers doorstep. As the demand increases so does the amount of deliveries made which causes an excess amount of CO₂ production. The premise of delivering shopping allows the CO₂ levels to drop overall due to the fact that it reduces the number of vehicles used to go to and from the shops. However, the weight and size of the vehicle causes it to be inefficient in comparison to an ordinary car. This is due extra weight of the shopping that causing an increase in rolling resistance as well as the larger van which has a larger frontal area causing more aerodynamic resistance.

The run selected for this experiment was chosen because it was representative of a typical delivery route. A typical route would consist of multidrop start stop in close proximity of each other as well as long distances as well as different gradients. The combination of these three factors allows the tests conducted to be as accurate as possible of the conditions faced by the vehicle on a daily basis. Listed in Appendix 1 is the run manifest with the personal data removed for data protection reasons. The manifest shows the area of the delivery, distance between drop, weight of shopping and timing. This data is utilised in the experiment to vary the conditions within the test, for example the weight is factored into the rolling resistance calculation to ensure accuracy in rolling resistance.

6.0 Methodology

6.1 Drive Cycle

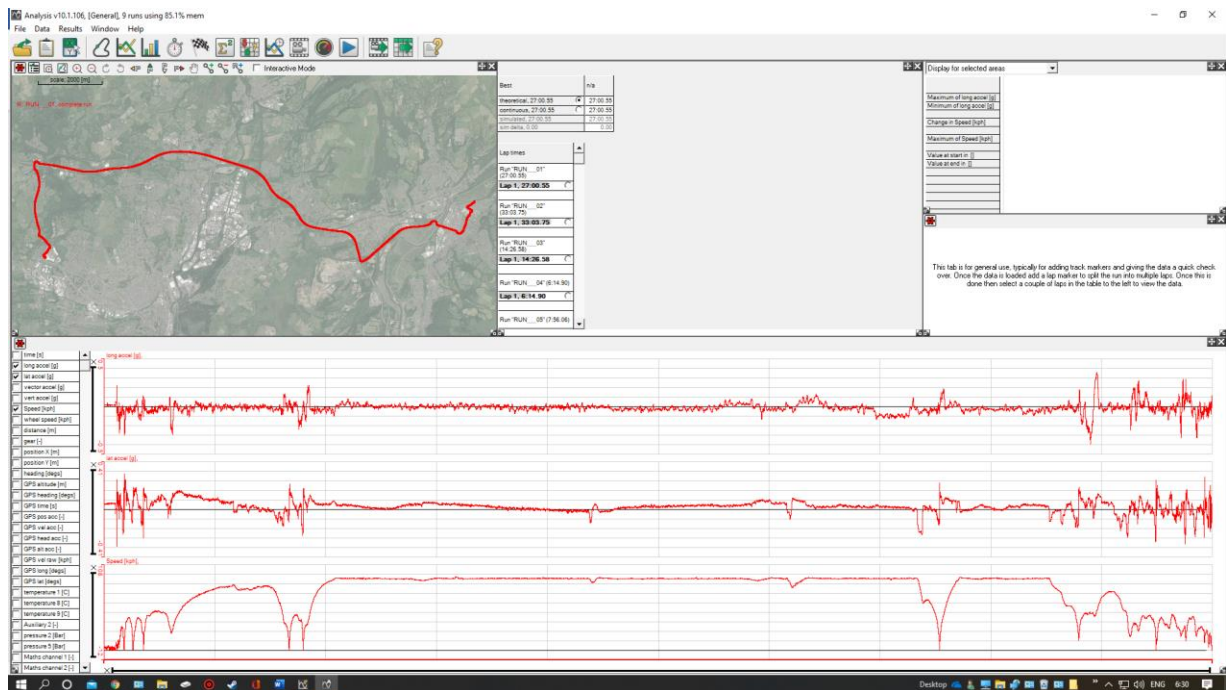
The drive cycle is carried out by using a data logging device to track key aspects of the vehicle. A Race technology DL1 Club data logger was used which incorporates accelerometers and GPS tracking which is utilised to understand the forces the vehicle undergoes as well as the speed, location and altitude the vehicle undergoes. The GPS antenna was fitted to the roof of the Tesco van to ensure accurate and clear line of sight to the GPS satellites. This is vital without a clear line of site to the GPS satellites can cause inaccuracy's in the data and possible spikes in data due to lost signal. The data tracker is set up inside the cab of the vehicle in a stable location to ensure accurate GeForces are read and to ensure the data logger doesn't get damaged if it gets dislodged. The data logger is connected to the GPS antenna and connected to the vehicle via the cigarette port to supply power. Once power is provided, the logger is setup by connecting the unit to a laptop and the DL1 software is utilised to adjust the logger to specific preferences relevant to the test. The orientation of the logger is specified, to ensure that that the correct G-Forces is recorded in the correct designated axis. If this isn't specified, then the longitudinal and lateral G-Forces could be reading in the wrong axis.

The route was selected on the type of delivery methods used to complete the deliveries. The route had a combination of longer steady state continuous driving (Motorway driving), maximum gradients (Steep hill) and multi drops. The varied delivery types are used in the test because this is represented of the type of deliveries that's being made allow ensure all the possible scenarios are covered. This is to gain an understanding of the drive cycle of the vehicle to gain an understanding of the forces acting upon it throughout the deliveries. Also, conducting a real-world test ensures accuracies for the forces applied with the combination of stop-starts. Without this cycle, a suitable drivetrain can't be selected.

In addition, the vehicle is driven to each drop according to the time specified on the manifest (Delivery sheet). When driving the vehicle, a constant acceleration, braking and cornering control was employed when conducting the test. This ensures that there isn't any variation in data that could cause the test to become invalid. Also, by keeping to the time frame ensures an accurate and reasonable speed between drops. Dash cam video was also recorded due to the possibility of unexpected events which could cause a variation in data for example; the need to brake suddenly due to an obstacle on the road would cause the results to be varied and this variable in the data could be unexplained if it wasn't for the video data explaining the certain event.

Once the data is collected and saved in the data logger, the data can be read by the Race Technology (Figure 4) software which can interpret and display the data graphically. This data can then be exported to excel to enable further calculations.

Below is a screenshot of race technology software of Run 1 from the data collected:



6.2 Excel

Excel is used to calculate and identify many different aspects of the run that is vital for the identification of the electric drivetrain and to find the vehicles CO₂ output. The data that is collected is vast and not all of the data collected is used as seen on figure 5 where irrelevant data is discarded. Vital data sets are extrapolated and selected which include; time, longitudinal accel, speed, distance and altitude. This data is then separated for each section of the run (9 in total) and calculations applied for each second of each run to gain an understanding of the what the vehicle undergoes at each section. The main aspects of the runs that is calculated is the total forces, power at the wheels and the torque at the wheels.

Figure 5 shows an Excel spreadsheet titled 'Data Output From Race Technology Data Logging System'. The spreadsheet contains 44 rows of data, with columns labeled A through AI. The data includes various metrics such as time, speed, position, and heading. A yellow warning bar at the top indicates 'POSSIBLE DATA LOSS'.

Figure 5 Excel Document of the Exported Run 1 Data Without the irrelevant data Removed

6.3 Calculations

The data recorded by the data logger does not have all of the required data to sufficiently identify the vehicle output. To ensure a suitable electric system is selected, calculations are conducted to gain an understand of the vehicle output. Calculations are listed below;

Velocity

The speed was recorded in MPH, so the speed had to be converted to the SI unit of m/s. This is done by multiplying the recorded speed in MPH by 0.44704. This gives the speed or the velocity in m/s. Equation is below:

Equation 1 Velocity

$$\text{Velocity (m/s)} = \text{Recorded speed (MPH)} \times 0.44704$$

Distance

The distance was recorded in Kilometres per hour, so this is converted to SI unit of meters by multiplying the Velocity (m/s) by 1 second and adding the previous distance to get the distance travelled. Equation is below:

Equation 2 Distance

$$\text{Distance (m)} = (\text{Velocity (m/s)} \times \text{Time}) + \text{Previous distance (m)}$$

Acceleration

Acceleration is calculated by dividing the change in velocity (m/s) by Time. is below:

Equation 3 Acceleration

$$\text{Acceleration (m/s)} = \frac{(\text{Current velocity (m/s)} - \text{Next velocity(m/s)})}{\text{Time}}$$

Acceleration Resistance

Acceleration resistance is calculated by multiplying the mass of the vehicle by the acceleration.

Equation Is below:

Equation 4 Acceleration Resistance

$$\text{Acceleration Resistance (N)} = \text{Vehicle mass (kg)} \times \text{Acceration(m/s)}$$

Aerodynamic Drag

The aerodynamic drag is the amount air resistance a vehicle encounters when the speed increases. Aero drag is calculated using the following formula:

Equation 5 Aero Drag

$$\begin{aligned} \text{Aero Drag (N)} &= \frac{1}{2} \times \text{Cross sectinol area (m}^2\text{)} \times \text{Coefficient Of Friction} \\ &\times \text{Density of air } \left(1.2 \frac{\text{km}}{\text{m}^2}\right) \times \text{Velocity}^2(\text{m/s}^2) \end{aligned}$$

Rolling Resistance

The rolling resistance is calculated by multiplying the vehicles mass by the coefficient of friction of the tires which is all divided by the tire radius. This is then multiplied by the account tires on the vehicle, in this case, four. Equation is below:

Equation 6 Rolling Resistance

$$\begin{aligned} \text{Rolling Resistance (N)} \\ &= \frac{\text{Vehicle Mass (km)} \times \text{Coefficient of Friction}}{\text{Tire Radius (m)}} \\ &\times \text{Amount of tires on the vehicle} \end{aligned}$$

The coefficient of friction of the tires is a constant and can be identified experimentally. This study has already been conducted and the coefficient is identified. The coefficient is listed on the table below (Table 1) which identifies the coefficient of friction between 0.006 – 0.01. This coefficient isn't definite and in real world testing would show that under normal conditions

there are different road surfaces which alters the coefficient of static friction. Another factor that is not considered is the tire compound. This table only accounts for a standard rubber compound which is probably a close representation of the rubber used on the vehicle but for an accurate test, the coefficient of friction of the tire used needs to be identified. Although to maintain accuracy in the duty cycle data, the vehicle load will change as the deliveries are being made. To account for this, the vehicle weight is adjusted each drop. This means that when a delivery is made, the vehicle gets lighter which causes the rolling resistance to decrease.

Table 1 Table of Rolling Resistance Coefficients (Ehsanj, et al., 2018)

Rolling Resistance Coefficients	
Conditions	Rolling Resistance Coefficient
Car tires on a concrete or asphalt road	0.013
Car tires on a rolled gravel road	0.02
Tar macadam road	0.025
Unpaved road	0.05
Field	0.1–0.35
Truck tire on a concrete or asphalt road	0.006–0.01
Wheel on iron rail	0.001–0.002

Total Forces

The total force is the acceleration force, aero force, front rolling resistance and rear rolling resistance added together. This assumes that the aerodynamic load doesn't change due to the lack of data of the aerodynamics of the vehicle. Gradient resistance is not included in the total forces due to the altitude recorded is incomplete and vague which causes the gradient angle to be inaccurate. This is evident in the altitude change, where it appears that the altitude moves several meters a second which is unrealistic.

Total forces equation is as follows:

Equation 7 Total Forces

Total Forces (N)

$$= \text{Acceleratiuon Force (N)} + \text{Aero Force (N)} + \text{Front Rolling Resistance (N)} \\ + \text{Rear Rolling Resistance (N)}$$

Power

Power is calculated by multiplying the total force (N) by the velocity (m/s²). Equation is below:

Equation 8 Power

$$\text{Power (W)} = \text{Total Forces (N)} \times \text{Velocity (m/s}^2\text{)}$$

Torque at the wheel

Torque at the wheel is calculated by multiplying the forces (N) by the arm length. In this case that would be the wheel radius (m). Equation is below:

Equation 9 Torque at the Wheel

$$\text{Torque at the wheel (Nm)} = \text{Total Forces (N)} \times \text{Tire Radius (m)}$$

Maximum Gradient Force

Below is the formula used to calculate gradient. The Gradient forces and power are calculated based on the maximum hill gradient measured out over the whole delivery radius. This is due to the inaccuracy in altitude previously discussed which caused inaccurate gradient angles causing inaccurate gradient results.

Equation 10 Gradient Force

$$\begin{aligned} \text{Gradient force (N)} \\ = & ((\text{Vehicle Mass (kg)} \times \text{Gravity (9.81m/s}^2)) \times \text{SIN (Max Gradient } (^{\circ})) \\ & + (\text{Coeficidne of friction} \times \text{Vehicle Mass (kg)}) \times \text{Gravity (9.81m/s}^2) \\ & \times \text{COS (Max Gradient } (^{\circ})) + \text{Rolling resistance (N)} \end{aligned}$$

Gradient Power

Gradient force is calculated by multiplying the Gradient force (N) by the velocity of the particular hill. Equation is below:

Equation 11 Gradient Power

$$\text{Gradient Power (w)} = \text{Gradient Force (N)} \times \text{Velocity of the hill (m/s}^2)$$

Fuel Mass Flow Rate

The fuel mass flow rate is calculated by using the following formula

Equation 12 Fuel Mass Flow Rate

$$\text{Fuel mass flow rate} = \frac{2 \times \pi \times \text{No. of crank rotations} \times \text{Engine Torque}}{\text{Engine speed} \times \text{Engine Displacement}}$$

Brake Specific Fuel Consumption (BSFC)

The BSFC is calculated by dividing the fuel mass flow rate by the engine effective power Equation is below:

Equation 13 Brake Specific Fuel Consumption

$$\text{BSFC} = \frac{\text{Fuel mass flow rate}}{\text{Effective engine power}}$$

7.0 Results and Analysis

7.1 Drive Cycle Lap Data

Table 2 below shows the outcome of the drive cycle analysis. The data that has been calculated and identified are:

- Maximum power
- Maximum tractive effort
- Maximum torque at the wheels
- Maximum gradient force
- Maximum tractive effort including maximum gradient force
- Maximum power including maximum gradient power
- Maximum engine torque

This data is then utilised in the investigation of the electric system, efficiencies, gear ratios and CO₂ outputs.

Table 2 Drive Cycle Results

Maximum Power, Tractive effort and Wheel Torque of each run										
	Run 1	Run2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Maximum of The whole cycle
power (w)	81410.33		79482.15	57829.12	67594.23	45557.07	46891.49	80518.00	46252.58	79156.00
Tractive effort (N)	7700.64		7726.79	7277.31	7010.34	6614.38	8137.17	6993.99	6229.25	1711.74
Torque at the wheels(Nm)	2689.45		2698.58	2541.60	2689.45	2310.07	2841.91	2442.65	2175.56	597.82
Maximum gradient of the Whole of delivery radius (Constitution Hill)										Total Maximum Forces including Gradient(N)
Gradient (°)	Speed (mph)	Velocity (m/s)	Gradient force (N)		Gradient Power (w)		Tractive effort Max			
	12.4	10	4.4704	4622.787912		20665.71108		Gradient force		
										9573.45
										4622.79
										14196.23
Duration (S)	Duration (h.m)	Distance Travelled (km)	top speed (mph)	Average speed (mph)		Total Maximum Power including Gradient (w)				
	8645.00	2.40	91.98	58		23.75		Power Max		
										80651.74
										Gradient power
										20665.71108
										101317.45
Maximum Torque at the engine (Nm)										Total max forces (N)
										13804.1863
										max torque @ Wheels (Nm)
										4821.11
										1st gear ratio
										4.696
										Final drive ratio
										3.615
										283.9950933

A velocity-time graph is used to illustrate the vehicle speed as time progressed through the run (figure 6). By graphically plotting the data, an understanding of any abnormal spikes in the data can be identified. In the case of the data tracker, the majority of errors was due to the data that was recorded off GPS. If the connection disconnected, then the data points jump dramatically for a single second causing the data to be inaccurate. By identifying these inaccuracies, these data point can be singled out to be invalid and removed from the data so that the data is no longer invalid. This graph was created for each run (Appendix 2)

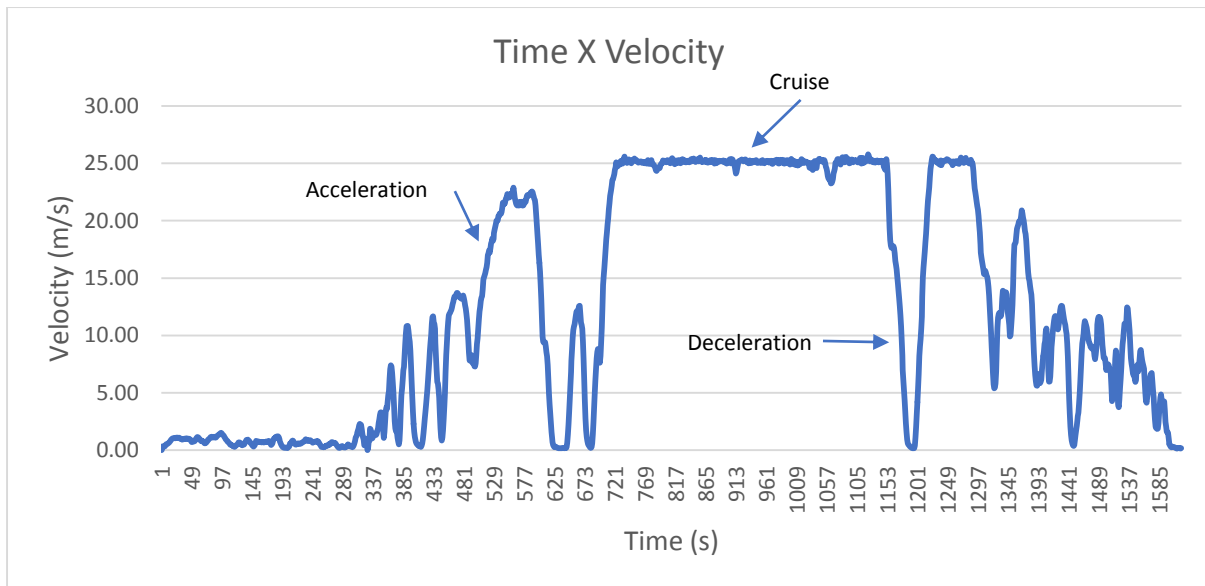


Figure 6 Time Over Velocity Graph of Run 1

A power-time graph is used to illustrate the power being drawn at different times (Figure 7). This data is handy to identify the amount of power being consumed at a given time. By using this data, a correlation is made between the velocity of the vehicle and the power consumed. This correlation is illustrated by the two graphs (Figures 6 & 7) which shows when the vehicle speed increases. The power needed increases due to the linear forces that were being applied due to calculated aerodynamic forces. This means that the both of the graphical lines should virtually have the same shape. The labels presented on the graphs show the power being applied virtually match the velocity time graph due to the discussed linear aerodynamic forces. This correlation would be easier if the two graphs were directly overlaid, but due to the units, the lines won't meet. In the real world, the forces applied to the vehicle vary due to different factors like aerodynamic loading due to head wind, aerodynamic downforce, rolling resistance changed due to surface changes and changes in gradient. This graph was created for each run (Appendix 4).

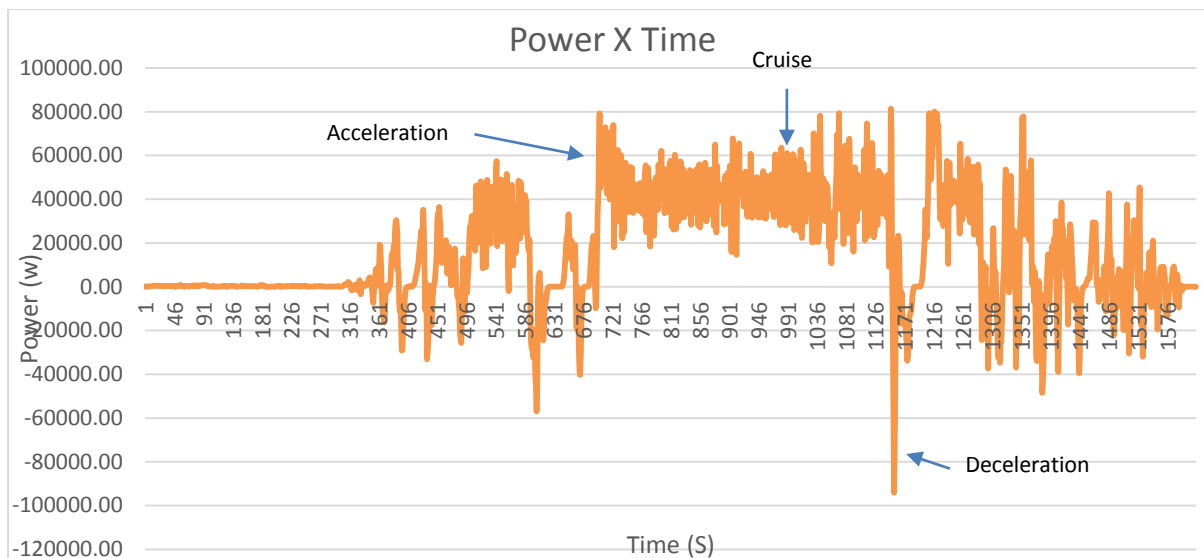


Figure 7 Power Over Time Graph of Run 1

As seen on the graph (figure 8) shows cumulative energy. This identifies the amount of energy used throughout the drive cycle. This graph can identify the rate of energy, which is being consumed, for example the steeper the gradient the quicker the energy is being used. A shallower gradient means less energy is being consumed. If the demand decreases energy is being put back into the system meaning that the vehicle is braking. This can be utilised when it comes to energy recovery. To further investigate into energy recovery, a graph was created for each run (Appendix 5). This study has identified the amount of energy that was being put back into the system for the whole run. For example, in figure 8 shows the areas that the energy that can be recovered. This provides justification for the investigation into different energy recovery options and the amount of energy that can be recovered.

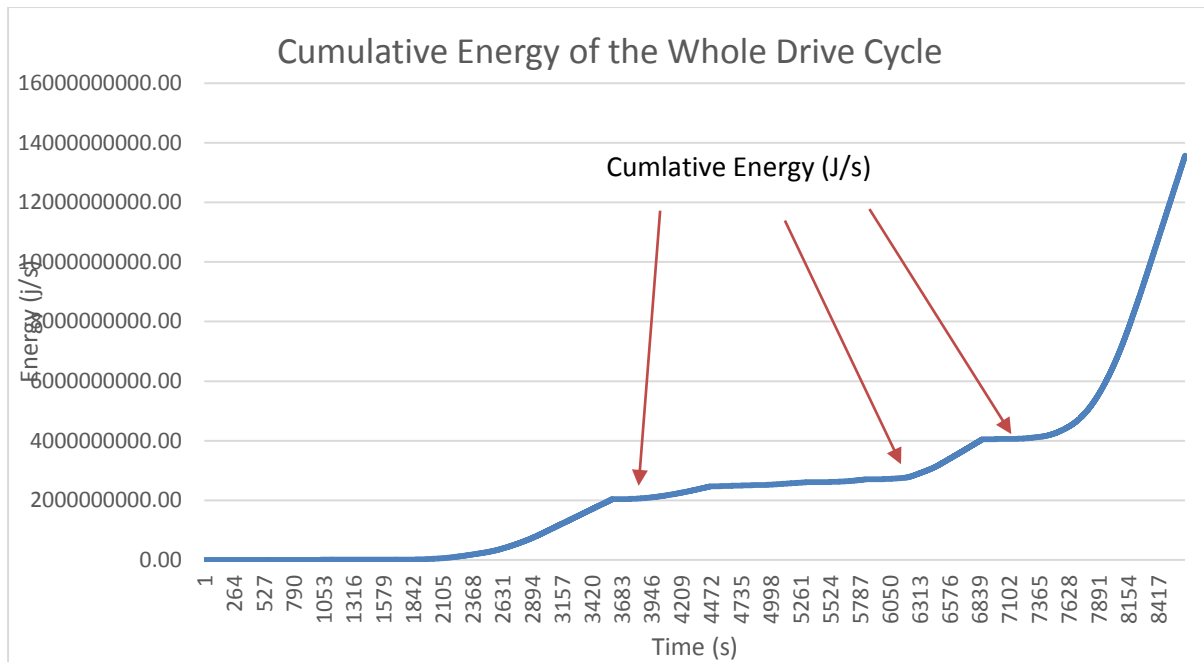


Figure 8 Cumulative Energy Graph of the whole run

7.2 Efficiency

Efficiency is vital to gain an understanding of the true power needed for the battery. Each component is not 100% efficient due to different factors like heat, friction, resistance for example. Therefore, efficiency is researched and identified to allow an understanding of the power loss at the particular component. This process is repeated at each component to give an understanding of the battery required to run the vehicle.

7.2.1 Gear Box, Differential and Prop-Shaft

The gearbox, differential and prop shaft all have losses affiliated with it. In the case of the gearbox, the main contributor of power loss is the gear meshes which often have a loss of 2% per gear mesh. The bearings also have efficiency losses which is usually 1% per ball bearing (Fernandes , et al., 2015). The gearbox has the input shaft and an output shaft which has bearing on both ends of the shafts, so a basic gearbox has 4 bearing. In the case of the gear mesh, it only applies to the gear engaged. So, for each gear there is only one mesh at a time except for reverse. Overall, the gearbox has an assumed loss of 95%. The differential main task is to ensure that the torque is split between the two wheels. Also, the diff has a final drive ratio due to the mesh between the pinion gear and ring gear. For the majority of the journey, the diff will be going in a straight line so the slider gear

isn't turning so all of the efficiency is based on the pinion gear and the ring gear (Nice, 2000). The differential has three bearings and one gear mesh. Based on the same theory of the gear and bearing efficiency, the differential has an assumed efficiency of 93%. The prop shaft is used to transmit the power of the gearbox to the differential. Prop shaft also have efficiency losses as well due to the friction in the universal joints. This efficiency of a universal joint is around 1%. The Tesco van has two joints meaning that the efficiency is 98%. All of these efficiencies can be added together to get a total efficiency of 86%. This is evident in table 3 where the efficiency is calculated on excel.

Table 3 Table Calculating efficiency on Excel

Gearbox Efficiency	95%
Prop shaft Efficiency	98%
Differential Efficiency	93%
Total Efficiency Identified	86%
Maximum Power at the wheels (w)	101,317.45
Power after losses (w)	14,184.44
Power after Drivetrain losses (w)	115,501.89

7.2.2 Motor

The motor has three main type of losses that occur. These losses are resistance in the windings which causes heat energy losses. Additionally, a small amount of losses occurs in the bearing either end of the motor stator. As a result of the construction of the AC brushless motor, there isn't any frictional losses due to the lack of brushes which allows for a high efficiency.

The motor is simpler identifying the efficiency due to the provided efficiency graph. The company (Emrax) has conducted an investigation to identify the efficiency of the motor at certain motor speeds and torque. This allows the user to identify the efficiency of the motor at certain points to identify the energy usage at certain points. In this case the torque at the flywheel and the motor speed is identified at the top speed of 56 mph. This is to gain an understanding of the efficiency when the vehicle is on the motorway. This is to gain an understanding of the maximum range of the vehicle and the fact that the varying speeds cause the efficiency to fluctuate. In the table below (Figure 9) shows that the rpm is identified by conducting a test to identify the engine rpm at 56mph. The rpm would be the same for the engine and the motor due to the original gearbox and differential is being utilised. This means that the gear ratios do not differ so in theory, the input rotation should output the same wheel speed. Once the engine rpm and torque are identified, the efficiency map can be used from the manufacturer which is listed below (Figure 9). With the engine speed being 1600rpm and the torque of 236Nm shows the efficiency of 95% illustrated by the red

dot on figure 9. Using this efficiency, the loss can be identified from the drivetrain losses. The loss of the motor is then added onto the drivetrain losses which is the energy provided before the motor.

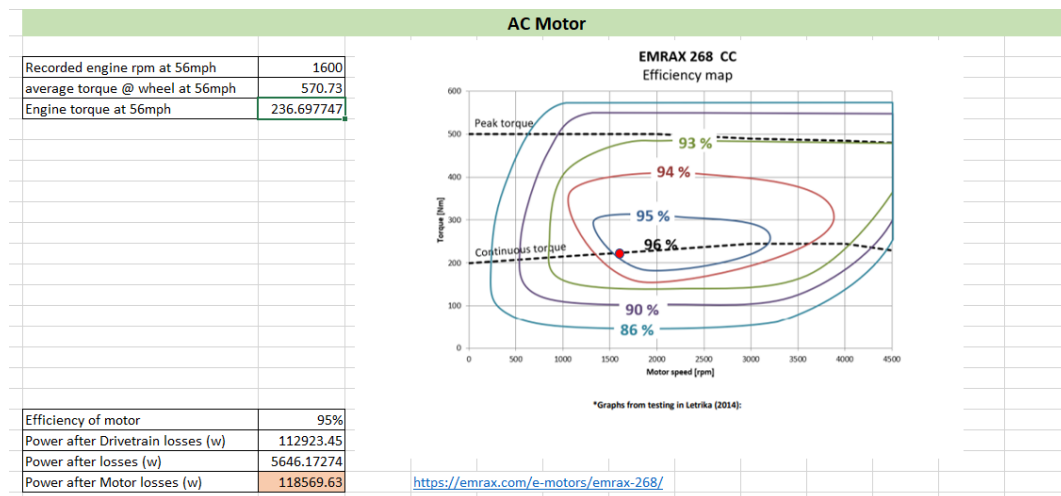


Figure 9 AC motor Efficiency Investigation

7.2.3 Motor Controller

The Motor controller has the efficiency defined by the manufacturer where controlled experiments are conducted to identify the efficiency losses. The efficiency is provided in the manufacturer technical data sheet (Figure 11) and so this efficiency is used. In a system like a controller, resistance in the electronic components causes additional heat energy to be produced causing hindering the efficiency. As previously stated, the manufacturer Yasa has identified the efficiency of the controller to be 96% efficient. This is evident in the supplied manufacture technical sheet (Figure 11). Using this efficiency, controller power losses is identified and is added onto the power after motor losses. This is shown on the table below (Table 4):

Table 4 Table Calculating the Efficiency of the Motor Controller

Efficiency Identified	96%
Power after Motor losses (w)	118,569.63
Power Loss (w)	4,742.78
Power After Controller Loss (w)	123,312.41

7.2.4 Refrigeration Unit

The refrigeration unit used is basically a large moving fridge and the principle is the same as a normal domestic fridge. The inefficacy of the refrigeration unit in the fridge is mainly the compressor and the cooling unit of the system. The inefficacies are tested by the manufacturer and factored on the manufacture energy consumption specs.

7.2.5 Energy Storage

Batteries have an efficiency which is calculated by the ratio of the current inputted into the battery and the current outputted by the battery. This is called the Coulombic or Faradaic efficiency. There are losses within the battery due to internal resistance during a cycle. This efficiency is called the Ohmic efficiency (Rahn & Wang, 2013). In the case of the Tesla lithium ion battery, it has an efficiency rating of 80-90%. In this case, the energy output of the battery has the efficiency factored in place.

7.3 Component Sizing

7.3.1 Gear Ratios and Final Drive

Gear ratios vary in different manner due to the requirement of the vehicle. The majority of electric vehicles have no gearbox and just rely on the final drive. This is because the motor is capable enough to move the vehicle without the need to increase the ratio. In the case of the adaption of the delivery van, the torque required out of the wheels is relatively high, so a gearbox is needed to increase the ratio and increase the mechanical advantage to increase the amount of torque being supplied. For this vehicle there are two main options in terms of gear selection. One method is keeping to the original gearbox, prop shaft and differential making the conversion simpler and cheaper to produce. This is due to the fact that the components are already designed and manufactured by Iveco, so no alteration needs to be carried out. This enables the conversion of the system just to be isolated to the motor. The second option is to remove the standard drivetrain and convert the system to have the motor on the rear axle itself removing the need of a prop shaft. This limits the ratios of the system to be a single final drive ratio limiting the amount of torque or speed that's outputted.

7.3.1.1 Specifications

Due to the high maximum torque requirement at the wheels of 3343.53Nm, the drive ratios need to multiply by the torque from the motor to accommodate this demand. Adequate gear ratios need to be selected in the gearbox and the final drive differential to ensure that the torque requirement is met.

7.3.1.2 Solution

Different gear ratio scenarios were introduced to identify if any gear ratios will accommodate for the required wheel torque. It was identified that the gear ratios that were originally on the vehicle were sufficient for the application required. The gear ratio on the differential final drive also matched the requirement. To validate if the wheel torque is sufficient, initial investigation of the motor is conducted to identify if the motor torque that being supplied is enough for the wheel torque wheel torque wheel torque.

Table 5 below is the theoretical wheel torque of the standard engine based on the drive cycle and the calculated wheel torque of the electric motor based on the motor specs. The existing wheel torque of the standard engine is 71% lower than the calculated wheel torque of the electric motor. This is due to the peak motor torque of 500Nm which is listed on the motor specification sheet (figure 10). A smaller motor would have been chosen but due to the minimum power requirement, a larger motor was selected.

Table 5 Gear Torque Calculations

Theoretical Wheel Torque of the Electric Motor											
Gears	1st	2nd	3rd	4th	5th	6th	7th	8th	Final	Rev	
Gear Ratios	4.696	3.13	2.104	1.667	1.285	1	0.839	0.667	3.615	3.297	
Existing Wheel torque (Tw) (Nm)	4018.19	2678.22	1800.31	1426.39	1099.53	855.66	717.90	570.73		2821.12	
Calculated Wheel torque based on motor specs (Tw) (Nm)	8488.02	5657.475	3802.98	3013.103	2322.6375	1807.5	1516.493	1205.603		5959.328	

7.3.2 Motor

The selection of a motor is vital to ensure that the vehicle can be driven with sufficient power and torque. If the motor is undersized, then the motor can become damaged due to the high loads demanded from the small motor. If a large motor is used, an excess amount of energy is consumed when running the motor causing the system to become inefficient. There are two main motor power types on the market which are a direct current (DC) and Alternating current (AC). DC motors have a high torque output and can be controlled by varying the input voltage which means that DC motors do not need a complicated speed controller. These motors tend to be inefficient and have a lot of friction due to the brushed construction. AC motors can produce reliable power for an extended period of time making the system relatively efficient. The disadvantage of the AC motor is that it needs a complicated controller due to the alternating phases when the motor poles rotate increasing cost and complexity. Regardless, the AC motor is used since it maintains efficiency for a prolong period allowing for maximum vehicle range.

A DC brushed motor has a permanent magnet on the casing of the unit with the winding on the shaft of the motor. The brushes make contact to the commutator and is used to direct the current into the windings inducing a magnetic field. This motor type used DC voltage and is generally used for

portable and small applications with low voltages. This type of motor is usually 75%-80% efficient and usually gets pretty hot under high loads.

AC induction three phase motor operates by having the winding on the stator and the permanent magnets on the rotor. The winding is then alternated in a circle which opposes on the permanent magnets attached on the rotor turning the system. This type of motor has an efficiency of around 78%. (Khan & Goyal, 2015)

An axial flux motor composes of stator winding around a ring and the rotor plate houses the magnets. The stator winding has poles that run outward in the direction of the central shaft. The polarities alternate in the ring formation which push against that permanent magnets on the outer rotating plate which causes rotational torque. This system works off an inverted AC current which fluctuates the current between the three poles. This system has an efficiency of 90% and higher (Clemens, 2018) which is a contender to reduce the amount of losses on system.

7.3.2.1 Specifications

The motor needs to output sufficient amount of power and torque to move the vehicle adequately. The standard vehicle has a power of 79.04Kw (106hp) and a torque output of 260Nm from the engine. The drive cycle shows a maximum power of 81.41kw (109hp) and a torque output of 241.77Nm.

7.3.2.2 Solution

The motor selection is based on the power output of the standard vehicle, drive cycle and the requirements from the gear ratio investigation. The motor needs to fulfil these requirements so multiple variants are researched and identified.

The axial flux AC motor is used due to its ability to house several inductions in a small package making it the most efficient platform. An Emrax 268 motor is used for the task due to the specs presented on the technical specification (Figure 10). This particular motor has a maximum torque of 500Nm and average power output of 86kw (115hp) (86kw if the motor is water and air cooled). This motor has a voltage of 800-250 volts allowing the option of batteries and controller to be relatively broad.

EMRAX 268 Technical Data Table

Type	EMRAX 268 High Voltage			EMRAX 268 Medium Voltage			EMRAX 268 Low Voltage*		
Technical data	AC	LC	CC	AC	LC	CC	AC	LC	CC
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC									
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air Flow = AF; Inlet Water/glycol Flow = WF; Ambient Air = AA) If inlet WF temperature and/or AA temperature are lower, then continuous power is higher.	AF=20m /s; AA=25° C	WF=8l/mi n at 50°C; AA=25°C	WF=8l/mi n at 50°C; AA=25°C	AF=20m/s ; AA=25°C	WF=8l/mi n at 50°C; AA=25°C	WF=8l/mi n at 50°C; AA=25°C	AF=20m/s ; AA=25°C	WF=8l/mi n at 50°C; AA=25°C	WF=8l/mi n at 50°C; AA=25°C
Weight [kg]	20,0	20,5	20,3	20,0	20,5	20,3	20,0	20,5	20,3
Diameter ø / width [mm]	268 / 91								
Maximal battery voltage [Vdc] and max load RPM	800 Vdc (3600 RPM)			650 Vdc (4500 RPM)			250 Vdc (4500 RPM)		
Peak motor power at max load RPM (few min at cold start / few seconds at hot start) [kW]	160			200			200		
Continuous motor power (at 2000-4000 RPM) depends on the motor RPM [kW]	67	73	86	86	91	107	86	91	107
Maximal rotation speed [RPM]	4500 (5500 for a few seconds with magnetic field weakening)								
Maximal motor current (for 2 min if it is cooled as described in Manual) [Arms]	250			400			1000		
Continuous motor current [Arms]	125			190			500		
Maximal motor torque (for a few seconds) [Nm]	500								
Continuous motor torque [Nm]	200	213	250	200	213	250	200	213	250
Torque / motor current [Nm/1Aph rms]	1,90			1,30			0,46		
Maximal temperature of the copper windings in the stator and max. temperature of the magnets [°C]	120								
Motor efficiency [%]	92–98 %								
Internal phase resistance at 25 °C [mΩ]	22,9			10,5			1,8		
Input phase wire cross-section [mm²]	11,4			17			42,5		
Wire connection	star								
Induction in Ld/Lq [μH] of 1 phase	292/273			126/118			17/15,9		
Controller / motor signal	sine wave								
AC voltage between two phases [Vrms/1RPM]	0,126			0,0825			0,0304		
Specific idle speed (no load) [RPM/1Vdc]	5,4			8,2			22,0		
Specific load speed (max load) [RPM/1Vdc]	4,5			7			18		
Magnetic field weakening (for higher RPM at the same power and lower torque) [%]	up to 100								
Magnetic flux – axial [Vs]	0,1014			0,0664			0,0245		
Temperature sensor on the stator windings	kty 81/210								
Number of pole pairs	10								
Rotor inertia LC motor [kg*m²]	0,0922								
Bearings (front:back) – FAG	7206:3207 (for axial-radial forces; for pull-push mode, α=25°)								

*EMRAX 268 low voltage version always has 2 sequences of phase connectors (2xUVW).

Figure 10 Motor Specification (Emrax Innovative E-Motors, 2020)

7.3.3 Motor Controller

Motor controller is used to vary the speed of the motor based on an input or demand. An AC controller worked by varying the frequency of the current for example, larger amplitude, the slower the motor, larger amplitude faster the motor. For this system, a three phase AC controller is needed which functions by the same principle but for each independent phase.

7.3.3.1 Specifications

The motor controller needs to have the ability to controller the motor adequately between the voltages of 800-250 volts DC and minimum current of 500 Arms.

7.3.3.2 Solution

The motor controller is limited in options due to the requirements of the motor. Conducting research, a YASA Si400 motor controller was specification identified (Figure 11) which conformed to the voltage requirements stated in the specification. This system has a maximum voltage output of 400Volts DC which is within range. As for the amps, 500Arms is within the top end of the specification.

Si400 Motor Controller



Key Specifications

Peak Current (5 sec)	500 ARMS	Dimensions ²	84 x 251 x 277 mm
Continuous Current ¹	210 ARMS	Mass ³	5.75 kg
Input Voltage Range	50 – 400 V _{DC}	Volume ⁴	4.8 litres
Efficiency (peak)	96%		

Figure 11 YASA Si400 motor controller specifications (Yasa, 2019)

7.3.4 Refrigeration Unit

A refrigeration unit is used to ensure that the fresh and frozen produce remains at its respected temperatures. A system is chosen due to its substantial draw on the system when operating.

Chiller

For choosing the chiller, there are many different systems on the market that are specially for delivery vehicles. It's a case of choosing a suitable system of the application. There are two main companies that manufacture these the chillers. These companies are Thermoking and Carrier which both do the same job but are competitors in the market. The Thermoking specification of products are not supplied by the manufacturer on the website but the charrier system has all of the specification of the units listed on the which includes the power usage of the unit. In this case the Carrier Pulsor 350 is a main contender due to the lower power usage and the capability of chilling a large chiller compartment of the van.

Freezer

A freezer unit is used to reduce the temperature of an insulated compartment. Like the chiller, Thermoking and Carrier are the main companies that provide freezer units. The same Carrier Pulsar 350 can also be used to cool down the freezer areas but used slightly more energy. To save the energy consumption, an alternative system is utilised. An icepack and a cooler box that's made to fit inside the trays can be utilised to keep frozen condense at the required temperature for an extended period of time. As shown in the image (figure 12), illustrates the Sainsburys system of an icepack. This whole package is then put in the chiller to further extend the -18°C temperature.



Figure 12 Image of Sainsburys tray with insulated box and freezer pack

7.3.4.1 Specifications

Due to the business the vehicle is targeted for, the vehicle needs to have the ability to keep a section of the cargo area refrigerated and frozen to maintain the freshness of produce. The temperature ranges are as follows:

Fridge: +4°Celsius

Freezer: -18°Celsius (Food Standards Agency, 2018)

In this case, refrigeration and a freezing method needs to be identified with the ability to run the system electrically and without causing excess amount of energy draw.

7.3.4.2 Solution

The refrigeration system can be run by any vehicle compatible refrigeration system due to the majority of systems running off the 12-volt supply. The system chosen is a Carrier Pulsor 350 Refrigeration unit has a power output of 2,610Wh which is capable of reaching temperatures of +4°Celsius. This system is primarily used for vehicles with 12 volts supply so ideal for this situation. For the freezer, an alternative procedure is employed where a pre frozen icepack and a insulated box is used. This package is then placed inside the chiller to remain cool. This system is the best in terms of energy saving due to the lack of a freezer system increasing the energy usage on the battery.

7.3.5 Storage System

For an electric car to function, a storage device is needed to ensure the energy can be stored. In this case, a substantial amount of energy needs to be stored to ensure that the vehicle can travel the delivery route with the increased weight of the shopping and the load of the climate-controlled zones. Below is the different storage options and the respected attributes.

Lead Acid

The lead acid battery is constructed in individual cells in the battery combining layers of lead plates, a separator and a lead dioxide submerged in a solution of water and sulfuric acid. Lead acid batteries is the cheapest option of battery due to its simplistic construction. In the case of the electric vehicle, the battery is very heavy and it's the least energy dense meaning that for the weight and size of battery, the energy output is poor. The battery suffers with fast charging so the

capability of using fast chargers or energy recovery systems would be redundant due to the possibility of damaging the lead acid batteries. The efficiency of a lead acid battery is 85% but as the charge decreases, so does the efficiency. (Ehsani, et al., 2004)

Capacitors

Capacitors or for the Tesco van super capacitors, which are another method of energy storage. The super capacitor operates by having two plates which is separated by a thin insulator. When the super capacitor is fully charged, a double layer is formed. This only stores a voltage of 1-2 volts but once connected in series can amplify the total voltage output. The disadvantage to this system is that the capacitor can be instantly charged and discharged which means that the charge life is limited. (Woodford, 2015)

Nickel metal hydride

Nickel metal hydride (NiMH) batteries are a relatively inefficient batteries which specified the efficiency at 66%. This type of battery is also heavy which is a limiting factor when trying to ensure that the vehicle is as light as possible. These types of batteries are mainly used on smaller rechargeable batteries for small electronics. (Sun, 2010)

Lithium Ion

Lithium ion is the most popular battery, being used on most portable devices. This is due to the high energy output for the size of the battery. As a result of this, its popular on many different vehicles for example those produced by Tesla, Nissan, jaguar. The efficiency of a lithium battery is between 80-90% which allows for efficient energy storage (Sun, 2010).

Flywheel

A flywheel energy storage system works by having a rotating flywheel which is a rotating mass which acts as an energy storage. As the brakes are applied, the rotational inertia of the braking force is transmitted to the flywheel causing it to rotate which is known as a rotation exchange. When the vehicle is accelerating, then the system will deploy transferring the power to the drive wheels. This is a mechanical form energy storage device which means that the discharge of the system is 100%.

The disadvantage to this system is the is the limited storage capacity due to the rotational mass and rotational speed. (Kapoor & Parveen, 2013)

7.3.5.1 Specifications

The batteries need to last the duration of the run which is four hours and equivalent of 36kwh of energy. Based on the controller, the system can't exceed a voltage of 400 volts. The system can be too heavy otherwise the payload will be reduced.

Table 6 Table of the energy used in the run after efficiency losses

Battery Requirements	
Van Usage time (Hours)	3.5
Power after all losses (w)	125,922.41
Energy after losses (wh)	35,977.83
Energy after losses (kwh)	35.97
energy used for whole run (kwh)	125.92

7.3.5.2 Solution

Tesla's battery module was selected due to the Tesla battery having a vast amount of development and technology allowing for increased battery storage for the size of the battery. The Tesla module has a voltage of 22.8 volts and a capacity of 5.8kWh (Figure 12). Utilizing multiple of these modules in series can multiply the voltage and capacity of the battery. Calculations were conducted in excel (Table 7) to identify the minimum number of modules needed to complete the run. As stated in the specification, the battery needs to supply a minimum of 128.73 kwh, so the energy of each module is divided by the energy needed and the number of modules is revealed to be 24.29. The number of modules was overestimated to 26 battery modules compensate for the possibility of the van being out longer or longer journeys so the van does not break down. Due to the limitation of the speed controller input voltage of a maximum of 500 volts, the modules in series would cause the battery bank to be 592.8 volts which is over the limit. A solution was devised of creating 2 banks of 12 modules. Each bank having the modules in a series configuration equalling a voltage of 296.4 as shown in table 7. These 2 banks are then combined in parallel to have an output voltage of 296.4 and a capacity of 137.8Kwh.

Capacity: 232Ah, 5.3kWh
Height: 3.1 Inches
Width: 11.9 Inches
Length: 26.2 Inches
Weight: 55 Pounds
Bolt Size: M8
Voltage nominal: 3.8V/Cell, 22.8V/Module
Charge voltage cut-off: 4.2V/Cell, 25.2V/Module
Discharging cut-off: 3.3V/Cell, 19.8V/Module
Maximum Discharging Current (10 sec.):750 Amps
Warranty Period: One year

Figure 13 Specs of the Tesla battery from supplier (EV West, 2017)

Table 7 Battery Selection investigation

Selected Battery	
Battery type	Lithium ion
Battery cell voltage (volts)	22.8
Battery capacity (kwh)	5.3
Battery capacity (Ah)	232
Minimum No. of Batteries to cover one run	24.29
Amount of battery going to be used	26
Voltage of battery in series	592.8
No. of batteries in Bank 1	13
Bank 1 Battery Voltage (Series)	296.4
No. of batteries in Bank 2	13
Bank 2 Battery Voltage (Series)	296.4
Banks 1 & 2 Voltage (Parallel)	296.4
Battery bank capacity (kwh)	137.8

7.3.6 Energy recovery

Due to the business nature of the delivery van, the vehicle undergoes multiple stop-start conditions. The braking energy can be utilised and stored to then be later used for accelerating the vehicle. This very system is called KERS (Kinetic Energy Recovery) and comes in many different formats. These formats are:

- Mechanical
- Electrical
- Hydraulic
- Chemical

On the system selected, the motor used can be utilised as a generator to generate energy when the vehicle is braking. When the driver removes their foot off the throttle or starts braking, the motor will switch to generation mode which converts rotational energy into electrical energy which is stored in the battery. Due to the work-done, the motor has resistance due to the generation which causes the vehicle to slow down. Once the vehicle has reached a low speed, the motor can generate sufficient amount of energy and the system is switched off (Kapoor & Parveen, 2013).

8.0 CO₂ Investigation

The CO₂ identification of the vehicle is primarily focusing on the output of the vehicle which includes the production of the electricity and fuel but not focusing on the manufacture of the vehicle. Due to the inaccuracies of the CO₂ testing methods, the CO₂ that is being exhausted is only an assumption and is used as a reference to gain a basic understanding of the differences of the two system types.

8.1 Standard Tesco Diesel van.

As the vehicle is running its exhausting CO₂ which is inherently bad for the environment as previously discussed. Therefore, the CO₂ output of the vehicle has been researched which revealed the CO₂ output released by the manufacture (figure 3). Knowing the CO₂ output of the vehicle means that the total CO₂ output of the run can be identified. By multiplying the manufactures CO₂ data of 218g/km by the total run distance of 91.99 km (figure 14) shows that the CO₂ output of the Tesco van is 20,052.98 grams. This data is only an estimated result and isn't accurate due to the varying real-world factors the vehicle undergoes. As the load on the engine increases so does the CO₂ output due to the engine working harder. The factors that increase load and subsequently increases the CO₂ output are;

- Acceleration: Under hard acceleration, the engine would work harder to accommodate for the demand increasing the load.
- Gradient: Force required increases the steeper the gradient due to the amount of gravitational forces acting on the vehicle the steeper the gradient becomes increasing the load.
- Aero drag: Increases as the speed increases causing more force required to move the vehicle.
- Weight: As the weight of the vehicle increases, so does the rolling resistance which increases the amount for force to move the vehicle and subsequently increasing load on the engine.

To get an accurate test, a gas analyser would be used for the whole run to identify the exact CO₂ output of the vehicle.

8.2 Proposed Electric System

The electric system proposed can travel the whole run without generating harmful gasses. This allows the for the vehicle to have an advantage over the fossil fuelled vehicles in terms of decreasing the carbon footprint of the lifecycle of the vehicle. The generation of the electricity on the other hand can cause an issue in the production of CO₂. Different countries utilise different electricity generating methods. However, focusing on the UK the main source of electricity generation is natural gas (Figure 14). The main issue of using fuels is it pollutes CO₂ while generating the energy. This means that even though the electric vehicle is not exhausting any CO₂ out of the exhaust, the carbon footprint that charges the batteries has an associated CO₂ output which is a limitation. The goal to ensure that electric cars become less polluting is to reduce the amount of fuels being burned and replacing them with renewable sources like solar, wind or hydroelectric.

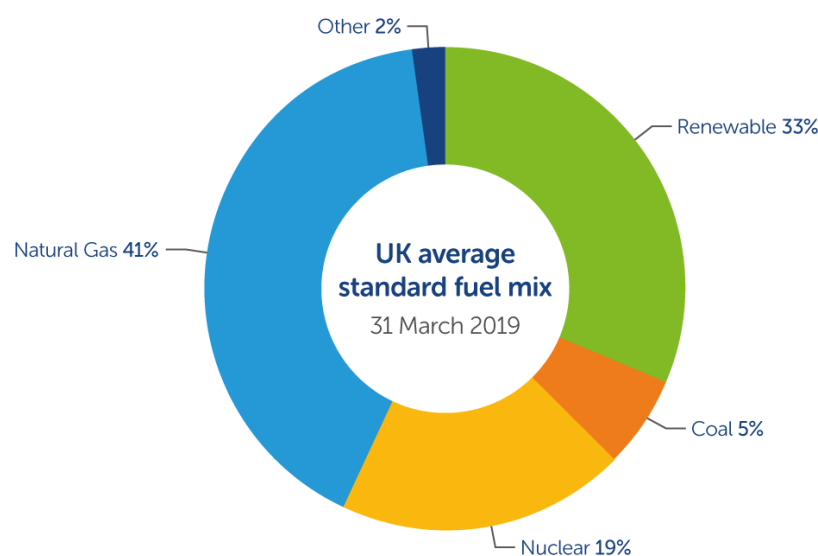


Figure 14 Fuel UK uses to generate energy (SSE Energy , 2019)

Table 8 below shows the UK fuel production and the related CO₂ pollutants. It reveals that the CO₂ that is being polluted per kWh is 0.281kg which this is relatively high in comparison with other countries on the list.

Table 8 CO₂ Production in the UK (European Environment Agency, 2014)

Country	kg CO ₂ per kWh
Sweden	0.013
Lithuania	0.018
France	0.059
Austria	0.085
Latvia	0.105
Finland	0.113
Slovakia	0.132
Denmark	0.166
Belgium	0.17
Croatia	0.21
Luxembourg	0.219
Slovenia	0.254
Italy	0.256
Hungary	0.26
Spain	0.265
United Kingdom	0.281

European Union (current composition)	0.296
Romania	0.306
Portugal	0.325
Ireland	0.425
Germany	0.441
Bulgaria	0.47
Netherlands	0.505
Czechia	0.513
Greece	0.623
Malta	0.648
Cyprus	0.677
Poland	0.773
Estonia	0.819

The

energy calculated from the duty cycle is multiplied by the researched CO₂ output of the energy generated in the UK (figure 8) which gives the theoretical CO₂ output of the electric system. Looking at table 9 shows a total of 36,175.40 grams of CO₂ produced from the electric vehicle. This can be compared with the CO₂ produced from the standard van which is 20,052.98g of CO₂ which means that the electric drivetrain produced 57% more CO₂ than the standard diesel engine. Using the data, the CO₂ per km was calculated to be 393.27g/km. This number is very high in comparison to the standard vehicle which has an output of 218g/km. However, the validity of the manufacture stated diesel CO₂ output is questionable because the drive cycle to conduct the test was NEDC. To conduct a real-world test, NEDC is questionable research method due to the fact that the test is conducted on a rolling road and the vehicle is operated under a fixed schedule to ensure that the test results are reproducible (Barlow, et al., 2009). The drive cycle conducted in this experiment was a real-world scenario and was driven on real run to ensure accuracy that the results match the real-world circumstances of the particular van. To further gain accuracies in the results, a gas analyser should have been used to record the amount of CO₂ being exhausted on the test. This is to ensure that CO₂ matches the loads being exhibited on the road. If a NEDC test is conducted, the van would have

induced loads by the rolling road and set throttle responses to mimic road conditions. This isn't accurate to the fact that the testing conditions don't take in account many real-world factors that affect the emission output. These factors are:

- Gradient variations
- Altitude air density
- Rolling resistance due to different surfaces
- Weight variation (Delivery loads)
- Rolling resistance due to weight variation
- Aerodynamic loads
- Wind direction
- Scrub resistance (resistance when turning)
- Rear wake negative pressure
- Weather conditions

The CO₂ output that's calculated from the manufactures NEDC data can be compared and validated to gain an understanding of the accuracies of the test. Using the brake specific fuel consumption (BSFC) formula, the CO₂ output can be calculated. BSFC mainly specifies the internal combustion engine efficiency. The main method of obtaining the BSFC is the use of a dynamometer to identify key engine parameters like; fuel mass flow rate, torque, etc (X-Engineer, 2020). To maintain maximum amount of accuracy in this test, the parameters are calculated using the drive cycle data. One aspect of that is assumed is the fuel mass flow rate and is inserted into a table to enable to be used in the BSFC investigation. Fuel mass flow rate is usually gathered by engine dyno testing at certain rpm and torque. The BSFC is used to compare and validate the manufacturers claims of the CO₂ output to ensure accuracy in the comparison between the internal combustion engine (ICE) and the electric drivetrain. Using the BSFC table (Table 9), shows the fuel consumption at different rpm and torque that's being outputted by the engine. Using this table, the BSFC is identified at the maximum speed of the van which revealed to be 56MPH. The rpm and torque is identified for the speed specified and the BSFC is revealed to be 161.63 g/KWh. The BSFC is then multiplied with the energy used in the vans drive cycle to identify the amount of fuel used for the whole run. The weight of CO₂ per one litre of diesel is identified to be 2,392 grams which is multiplied by the distance travelled in kilometres (Table 10). This gives the vans CO₂ per km which can be used to compare against the NEDC data from the factory.

Comparing the NEDC CO₂ data from the factory and the calculated BSFC CO₂ data shows a clear difference in CO₂ data output. As stated previously, table 11 shows the NEDC CO₂ output to be 218g/Km but the calculated BSFC has a CO₂ output of 307g/km. This is a difference of 89g/km. This difference is due to the factors that are not considered in controlled dyno NEDC test. Real world testing would give a live representation of the CO₂ output so is more accurate, but the drive system is difficult to repeat. Using the CO₂ data from the BSFC calculations still shows that the electric vehicle is 25% more polluting than the standard diesel van.

Table 9 Table of the Fuel Mass Flow Rate and BSFC of the Tesco van

Fuel Mass Flow Rate												
g/s	Engine Torque (Nm)	23.7	47.33	70.96	94.59	118.22	141.85	165.48	189.11	212.74	236.37	260
	500	0.139	0.201	0.252	0.301	0.347	0.426	0.480	0.588	0.588	0.654	0.719
	1000	0.278	0.366	0.458	0.559	0.645	0.779	0.898	1.033	1.176	1.307	1.438
	1500	0.417	0.554	0.706	0.833	0.956	1.073	1.213	1.343	1.544	1.960	2.156
Engine Speed (RPM)	2000	0.539	0.719	0.912	1.091	1.250	1.412	1.555	1.777	2.029	2.385	2.875
	2500	0.633	0.866	1.090	1.291	1.511	1.679	1.944	2.222	2.500	2.900	3.594
	3000	0.711	0.995	1.272	1.519	1.789	2.088	2.367	2.666	2.999	3.529	4.313
	3500	0.743	1.081	1.372	1.784	2.201	2.549	2.882	3.156	3.551	4.174	5.032
	4000	0.948	1.294	1.729	2.209	2.565	2.999	3.339	3.686	4.293	4.836	5.750
	4500	1.103	1.603	2.153	2.588	2.996	3.418	3.885	4.411	5.015	5.624	6.469
	5000	1.552	2.091	2.573	3.022	3.472	3.872	4.500	5.064	5.778	6.453	7.188
Brake Specific Fuel Consumption												
BSFC g/kwh	Engine Torque (Nm)	23.7	47.33	70.96	94.59	118.22	141.85	165.48	189.11	212.74	236.37	260
	500	403.19	291.99	244.68	218.61	201.97	206.78	199.66	213.92	190.16	190.19	190.18
	1000	403.02	265.90	222.09	203.16	187.74	188.94	186.59	187.79	190.16	190.17	190.18
	1500	403.06	268.30	228.04	201.98	185.37	173.50	168.04	162.82	166.40	190.18	190.18
Engine Speed (RPM)	2000	391.19	261.18	220.93	198.41	181.79	171.13	161.62	161.63	164.02	173.53	190.18
	2500	367.46	251.67	211.41	187.72	175.86	162.81	161.62	161.63	161.64	168.78	190.18
	3000	343.76	241.00	205.48	184.15	173.48	168.75	164.00	161.63	161.64	171.15	190.18
	3500	308.21	224.36	190.03	185.33	182.98	176.59	171.13	164.01	164.02	173.53	190.18
	4000	343.77	235.05	209.52	200.78	186.55	181.81	173.51	167.58	173.53	175.91	190.18
	4500	355.62	258.80	231.85	209.10	193.68	184.19	179.45	178.27	180.18	181.85	190.18
	5000	450.44	303.91	249.43	219.79	202.00	187.76	187.06	184.21	186.84	187.79	190.18

Table 10 Carbon Dioxide per kilometre using BSFC chart

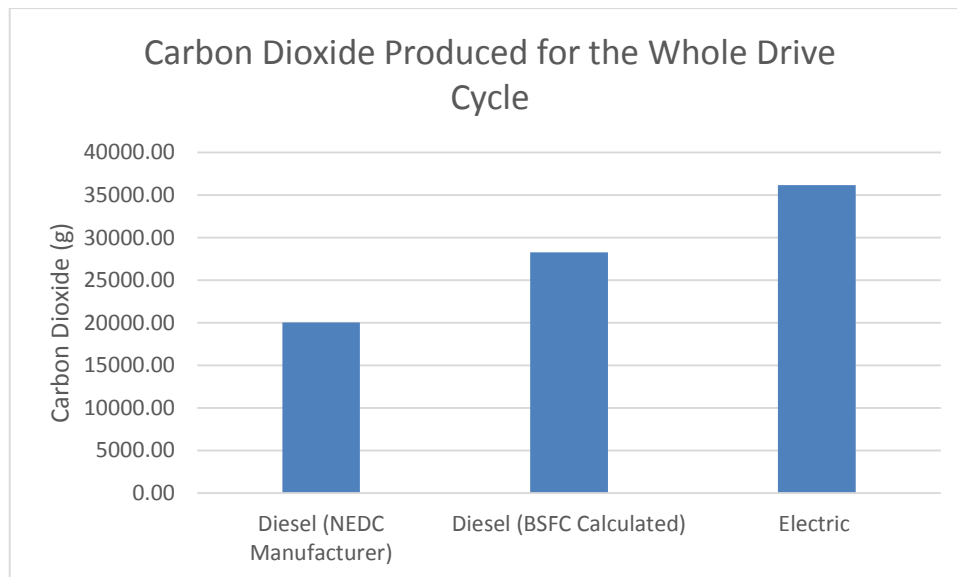
Carbon Dioxide per kilometre using BSFC chart	
Engine RPM	1600
Ground speed (MPH)	56
Toque (Nm)	236.70
BSFC (g/KWh)	161.63
Energy used in van drive cycle (kwh)	128.74
Amount of diesel used (g)	20808.5475
Amount of diesel used (Litres)	24.92041617
Amount of diesel used (Gallons)	5.479999515
miles travelled	120.5599893
Miles to kilometres	194.0447277
Vehicle CO ₂ per Km output (g/km)	307.1953367

Estimated CO ₂ Outputs			
System Type	Distance Travelled (km)	Vehicle CO ₂ per Km output (g/km)	Total Co2 Produced (g)
Diesel (NEDC)	91.99	218.00	20052.98
Diesel (Calculated)	91.99	307.20	28257.71
System Type	Energy used for whole run (KWh)	Energy CO ₂ per KWh (g/kwh)	Total Co2 Produced (g)
Electric	128.74	281	36175.40
		Co2 Production Difference (%) (NEDC)	57.35
		Co2 Production Difference (%) (Calculated)	24.58
		Electric CO ₂ per Km output (g/km)	393.27

Table 11 Calculated CO₂ output of electric and diesel powertrain

All of the data can be plotted graphically (Figure 15) which shows that the electric vehicle is the produces more CO₂ compared with the CO₂ of the standard diesel engine.

Figure 15 BSFC of entire run



As the NEDC does not take in account certain factors, the figure the manufacturer tested and released is only a guideline of the amount of CO₂ produced. Ideally the tests would utilise a mobile gas analyser to properly gain an understanding of the CO₂ produced so that the comparison between the Diesel engine and the electric drivetrain can be adequately compared. To validate the CO₂ produced, the test should be conducted again under the NEDC controlled testing conditions but using the real-world test drive cycle data. The data produced can be compared and contrasted to reveal any errors between the two testing methods.

In terms of the high CO₂ output of the electric vehicle, this number is high due to the amount of fuel being used to generate the grids electricity. If more renewable solutions were employed to generate

electricity like solar or wind, then the CO₂ per kWh would be reduced dramatically. Another reason why the CO₂ output is high is the amount of energy being used due to the extra weight of the vehicle as well as the increased frontal area causing a high amount of drag as well as the fridge causing a parasitic draw on the system. Additionally, the CO₂ per km is high due to the limited range the vehicle covers. This increases the amount of CO₂ per km, giving the illusion that the vehicle is inefficient. Theoretically on paper the electric system seems to not be worth it due to the high CO₂ output compared to the diesel drivetrain. If this system is applied practically and the same drive cycle is conducted, the system could outperform what stated on paper due to fact that the gearbox is not taken into consideration in the final output of the vehicle. Due to the reduction in ratio would put less strain on the electric motor allowing the system to not work as hard which would cause the energy usage to decrease. Once the vehicle is tested again for energy usage and distance travelled, the two systems can be compared to give a true representation of the results.

9.0 Conclusion

The drive cycle performed is mainly used to identify vans power output throughout a delivery route. This is to enable a suitable drivetrain is selected based on the data identified. For the purpose of identifying the CO₂, this system only identified a basic understanding due the fact that the emissions output is calculated based on specified CO₂ that is calculated and supplied from the manufacturer. To gain an understanding of the actual CO₂ output of the vehicle, a NEDC controlled test is advised to be conducted to eliminate any variables. The drive cycle that has been recorded of the actual run can then be implemented into the schedule as well as the loads calculated to gain a further understanding of the power output and CO₂ output of the vehicle. Another benefit of conducting the NEDC test is to measure the actual power, torque and energy that being outputted to validate the data gathered and calculated within the results with the actual measured values.

The drivetrain chosen for this vehicle that is based on the drive cycle of one run. This data could be expanded for multiple runs for example a week or month of journeys a Tesco van undertakes. This data could then be averaged out to allow for the deviation in conditions through the days. By getting an average ensures that the data recorded is valid and accurate, so an adequate drivetrain is selected. If further tests are conducted, then gas monitors should be used to gain an understanding of the live CO₂ output of the vehicle. To validate the results, the NEDC test previously discussed can be carried out and compared to identify if the results valid.

In conclusion, the drive cycle performed has revealed the requirements need to complete a Tesco delivery route which is represented of the majority of the runs. This data has revealed a suitable

electric system which would theoretically replace the existing diesel drivetrain. The purpose of switching a delivery vehicle drivetrain is to possibly reduce the amount of CO₂ produced in the industry. Research was conducted on the diesel and electric power train to identify if the system would be beneficial to the environment. It was revealed that the electric system would theoretically pollute 25%-57% more CO₂ into the atmosphere. The validity of the CO₂ emissions that claimed by the manufacturer is questionable due to the lack of testing methods specified. As a result of this, further testing needs to be conducted to further identify if the electric system is suitable for Tesco delivery vans. However, deliveries in comparison to individual vehicles are better for the environment due to less CO₂ emissions which this should be reviewed by shops to increase availability of deliveries to positively impact the environment. Additionally, the financial impact needs to be investigated and identified and to gain a understanding if the expense of running a electric fleet is financially justified.

Viva

Due to the recent pandemic, there are many factors that has affected this final dissertation. On April 6th, the country has gone into lock down which has caused the research conducted to be limited. Additional drive cycles would have been conducted to furthered conclude and validate the results gathered. In addition, the research into the subjects are limited due to the limited library resources available which has caused the research to be mainly internet based, taking advantage of some virtual libraries. The Viva presentation is also affected due to the social distancing and the university closed so the viva conclusions are based on this report. A factor that has also affected the project is my work commitments. Due to the pandemic, I'm duty bound to increase my working hours as a Tesco delivery driver. This has caused a reduced amount of time research into my project. Due to the increased hours delivering to isolating residence, I suspect that I have also contracted the virus and I'm dealing with my personal recovery.

Talk about the presentation that can be done

10.0 References

- Akitt, J., 2018. Some observations on the greenhouse effect at the Earth's surface. *Spectrochimica Acta Part A: Molecular and Biomolecular*, 230(A), pp. 127-134.
- Andrew, R. & Peters, P., 2013. A Multi-region Input-output Table Based on the Global Trade Analysis Project Database. *Economic Systems Research*, 25(1), pp. 99-121.
- Barlow, T. J., Latham, S., McCrae, I. S. & Boulter, P. G., 2009. *A Reference Book of Driving Cycles for use in the Measurement of road Vehicle Emissions*. 3 ed. Wokingham: TRL Limited.
- Clemens, K., 2018. *A New Generation of Axial Flux EV Motors*. [Online]
Available at: <https://www.magnax.com/magnax-blog/a-new-generation-of-axial-flux-ev-motors>
[Accessed 10 March 2020].
- Ehsani, M., Gao, Y., Gay, S. E. & Emadi, A., 2004. Energy Storages. In: M.H.Rashid, ed. *Modern Electric, Hybrid Electric and Fuel Cell Vehicles*. Florida: CRC Press, pp. 310-314.
- Ehsani, M., Gao, Y., Gay, S. E. & Emadi, A., 2004. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*. 1 ed. Cleveland: CRC Press.
- Ehsanj, M., Gao, Y., Longo, S. & Ebrahimi, K., 2018. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*. 3 ed. Boca Raton: CRC Press.
- Emrax Innovative E-Motors, 2020. *Emrax 268*. [Online]
Available at: <https://emrax.com/e-motors/emrax-268/>
[Accessed 2020 April 19].
- European Environment Agency, 2014. *European Union CO2 emissions*, Luxembourg: Publication Office of the European Union.
- European Parliament, 2019. *CO2 emissions from cars: facts and figures*. [Online]
Available at: <https://www.europarl.europa.eu/news/en/headlines/society/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics>
[Accessed 13 April 2020].
- EV West, 2017. *Tesla Model S Lithium Ion Battery 18650 EV Module - 22.8 Volt, 5.3 kWh*. [Online]
Available at:
https://www.evwest.com/catalog/product_info.php?cPath=4&products_id=463&osCsid=2i3jo51ftj5i

7h7s1gg58ub5a1

[Accessed 10 04 2020].

Fernandes , C., Marques, P., Martins, R. C. & Seabra, J., 2015. Gearbox Power Loss. *Part II: Friction Losses in gears*, Volume 88, pp. 309-316.

Food Standards Agency, 2018. *Chilling food correctly in your business*. [Online]

Available at: <https://www.food.gov.uk/safety-hygiene/chilling>

[Accessed 31 March 2020].

Kapoor, R. & Parveen, C. M., 2013. *Comparative Study on Various KERS*. London, WCE.

Kapoor, R. & Parveen, C. M., 2013. *Proceedings of the World Congress on Engineering*. s.l.:s.n.

Khan, B. & Goyal, A., 2015. Efficiency Improvement of Three Phase Induction. *International Journal for Research in Applied Science & Engineering*, 3(1), p. 191.

Kweku, D. W. et al., 2017. Greenhouse Effect: Greenhouse Gases and Their Impact on Global Warming. *Journal of Scientific Research & Reports*, Volume 17, pp. 1-9.

Nice, K., 2000. *How Differential Work*. [Online]

Available at: <https://auto.howstuffworks.com/differential1.htm>

[Accessed 2020 4 10].

Palmer, A., 2007. *The Development of an Integrated Routing and Carbon*, Cranfield: Cranfield University.

Rahn, C. D. & Wang, Z., 2013. *Battery Systems Engineering*. 1 ed. Hoboken: John Wiley & Sons.

Shrink That Footprint , 2016. *Shades of Green: Electric Cars' Carbon Emissions Around the Globe*.

[Online]

Available at: <http://shrinkthatfootprint.com/electric-car-emissions>

[Accessed 13 April 2020].

SSE Energy , 2019. *Standard fuel mix*. [Online]

Available at: <https://www.ssebusinessenergy.co.uk/help-and-advice/standard-fuel-mix/>

[Accessed 13 April 2020].

Sun, J., 2010. *Car Battery Efficiencies*, Stanford: Stanford University.

Tehrani, S. M. et al., 2009. Prediction of energy consumption and urban air pollution reduction in e-shopping. *Journal of Food, Agriculture & Environment*, 7(3), pp. 898-903.

Woodford, C., 2015. *Supercapacitors*. [Online]

Available at: <http://www.explainthatstuff.com/how-supercapacitors-work.html>

[Accessed 16 2 2020].

X-Engineer, 2020. *Brake Specific Fuel Consumption (BSFC)*. [Online]

Available at: <https://x-engineer.org/automotive-engineering/internal-combustion-engines/performance/brake-specific-fuel-consumption-bsfc/>

[Accessed 29 April 2020].

Yasa, 2019. *Yasa Si400 Motor Controler*. [Online]

Available at: <https://www.yasa.com/controllers/>

Zielinski, S., 2018. *Science News for Students*. [Online]

Available at: <https://www.sciencenewsforstudents.org/article/explainer-co2-and-other-greenhouse-gases>

[Accessed 5 January 2020].

11.0 Appendix

Appendix 1

www.tesco.com		DELIVERY DETAILS		Page 1 of 4
Van: 10T	Distance: 55 miles Weight: 405kg	FZ : 3 Tray(s) AM : 28 Tray(s)	CH : 10 Tray(s)	Departure Time: 31/10/2019 19:15:00 Return Time: 31/10/2019 22:49:00
Order No. 19:45 19:00 - 20:00 4829	SA11 3HG	Distance: 12 miles	Contact Numbers: Day: Evening: Mobile: Grid Reference: 0275701978 Weight: 50 Kg	Total Items: 46 This customer has 3 Ambient trays 1 Chilled trays 1 Frozen trays
Customer Signature:		Delivery Time:		
Delivery Instructions: (none)		CDA Notes: (none)		
Customer:				
Order No. 20:18 17:00 - 21:00 4836	SA13 3LK	Distance: 9 miles	Contact Numbers: Day: Evening: Mobile: Grid Reference: 0286101963 Weight: 53 Kg	Total Items: 41 This customer has 3 Ambient trays 2 Chilled trays
Customer Signature:		Delivery Time:		
Delivery Instructions: (none)		CDA Notes: (none)		
Customer:				

Original copy
Page 1 of 4

Van: 10T	Distance: 55 miles	FZ : 3 Tray(s)	CH : 10 Tray(s)	Departure Time: 31/10/2019 19:15
	Weight: 405kg	AM : 28 Tray(s)		Return Time: 31/10/2019 22:49:00

Order No.	Distance: 5 miles	Total Items: 44
20:44 20:00 - 21:00 4842	CF34 9HP	Contact Numbers: Day: Evening: Mobile: Grid Reference: 0285901890 Weight: 52 Kg
This customer has 4 Ambient trays 1 Chilled trays		
Customer Signature:		Delivery Time:
Delivery Instructions: Top of the street nearly opposite the		CDA Notes: (none)
Customer:		

Order No.	Distance: 1 miles	Total Items: 42
20:55 17:00 - 21:00 4847	CF34 9SN	Contact Numbers: Day: Evening: Mobile: Grid Reference: 0286701890 Weight: 34 Kg
This customer has 2 Ambient trays 1 Chilled trays		
Customer Signature:		Delivery Time:
Delivery Instructions: (none)		CDA Notes: (none)
Customer:		

DELIVERY DETAILS

Order No. 10T	Distance: 55 miles	FZ : 3 Tray(s)	CH : 10 Tray(s)	Departure Time: 31/10/2019 19:15:00
	Weight: 405kg	AM : 28 Tray(s)		Return Time: 31/10/2019 22:49:00

Order No. 21:07 21:00 - 22:00 4852	Distance: 1 miles CF34 9DQ	Contact Numbers: Day: Evening: Mobile: Grid Reference: 0285701906 Weight: 38 Kg	Total Items: 13 This customer has 4 Ambient trays
Customer Signature:		Delivery Time:	
Delivery Instructions: (none)		CDA Notes: (none)	
Customer:			

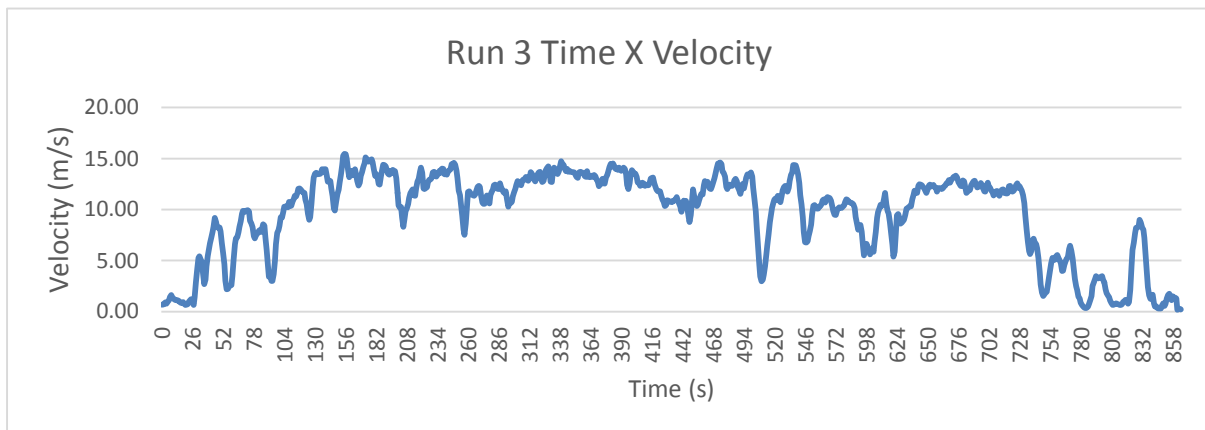
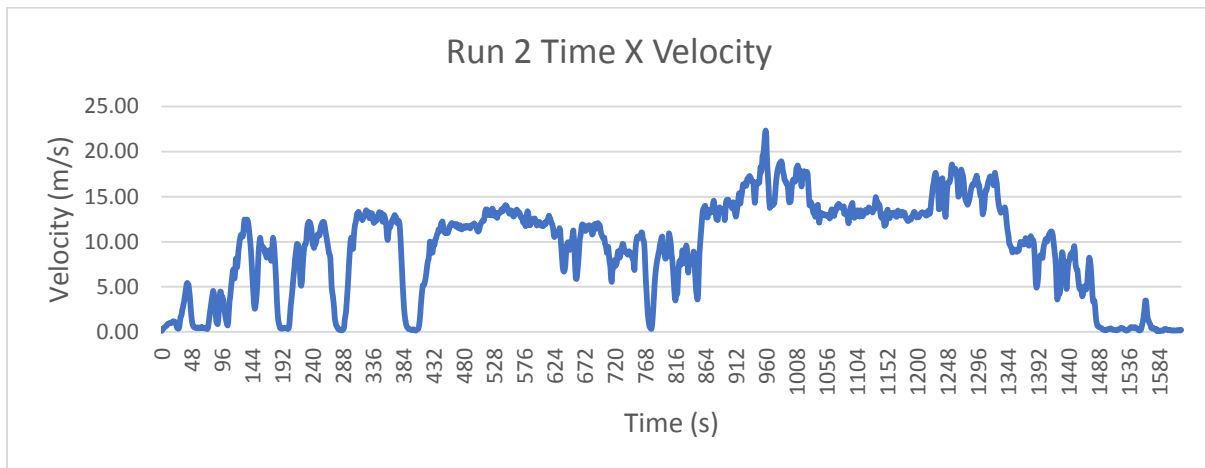
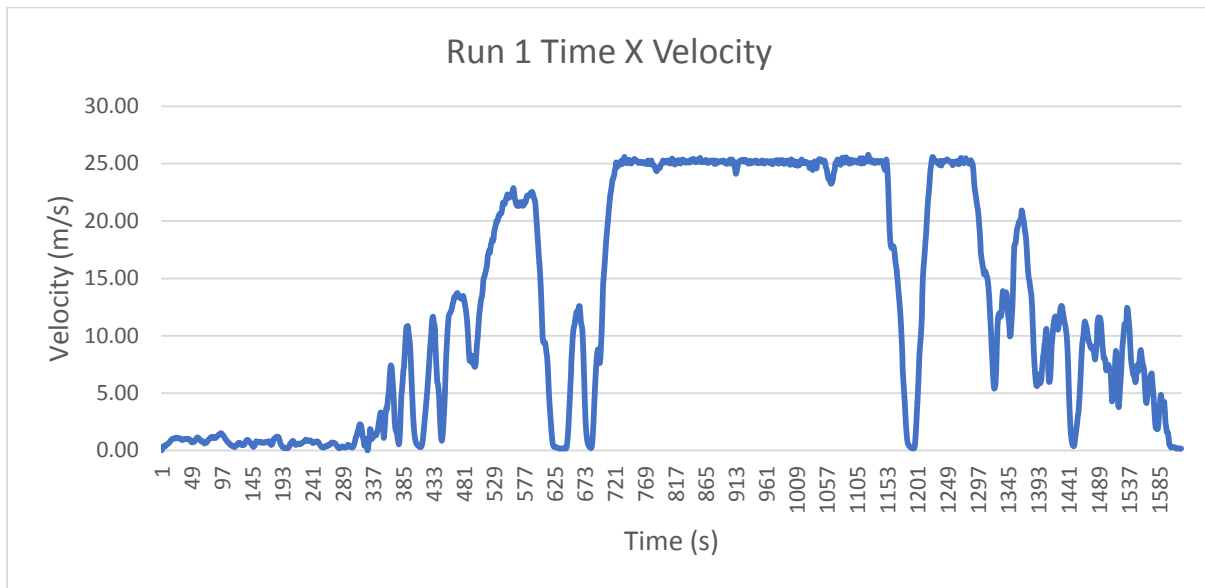
Order No. 21:26 21:00 - 22:00 4857	Distance: 3 miles CF34 0RW	Contact Numbers: Day: Evening: Mobile: Grid Reference: 0285401940 Weight: 67 Kg	Total Items: 90 This customer has 4 Ambient trays 1 Chilled trays 1 Frozen trays
Customer Signature:		Delivery Time:	
Delivery Instructions: (none)		CDA Notes: (none)	
Customer:			

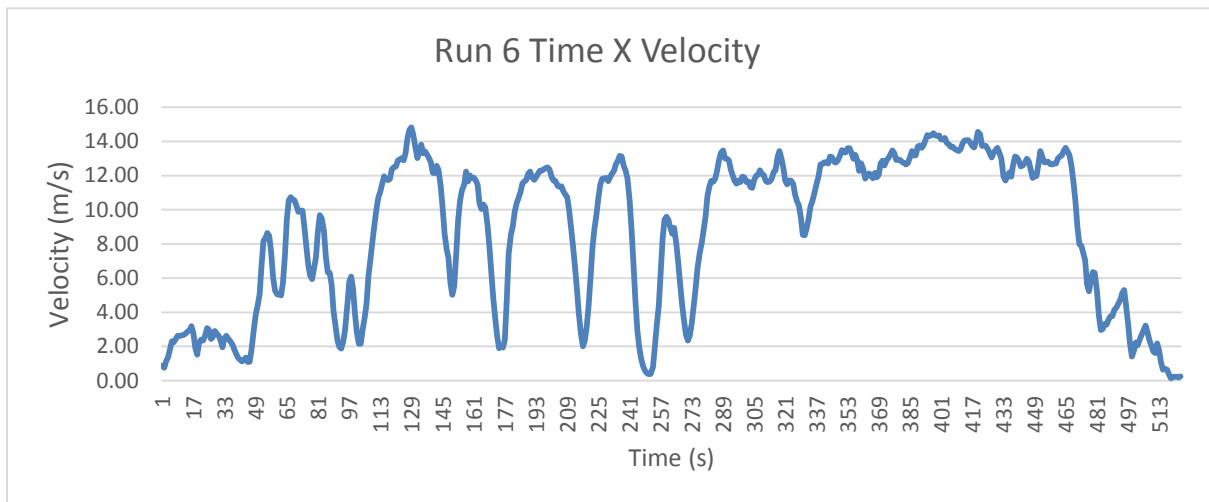
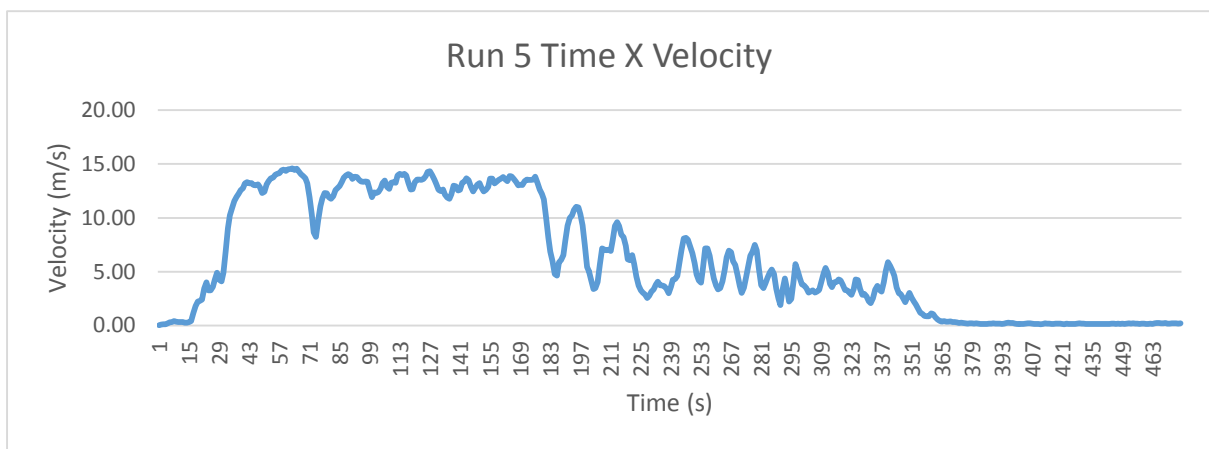
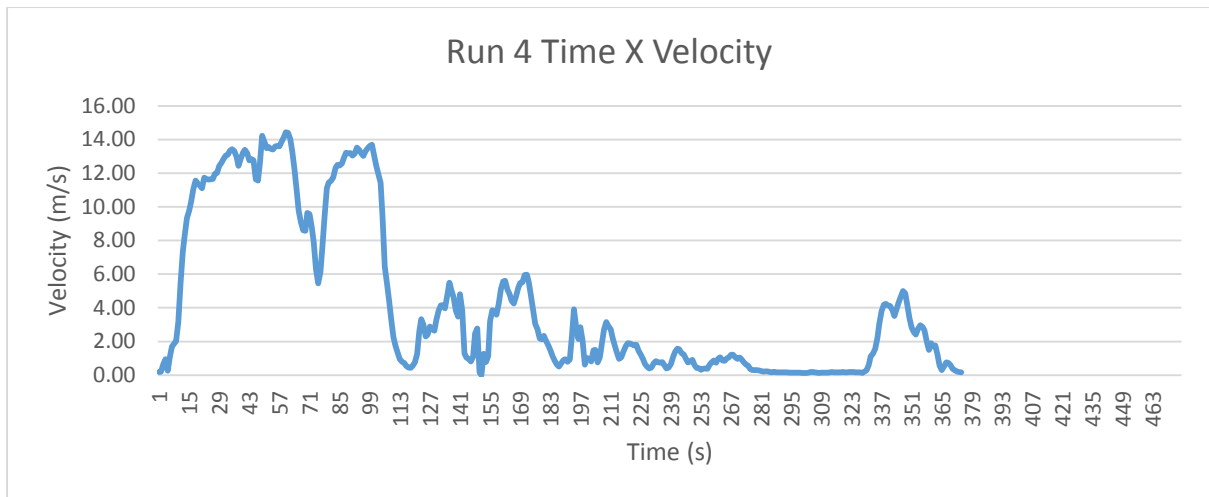
Van: 10T	Distance: 55 miles Weight: 405kg	FZ : 3 Tray(s) AM : 28 Tray(s)	CH : 10 Tray(s)	Departure Time: 31/10/2019 19:15:00 Return Time: 31/10/2019 22:49:00
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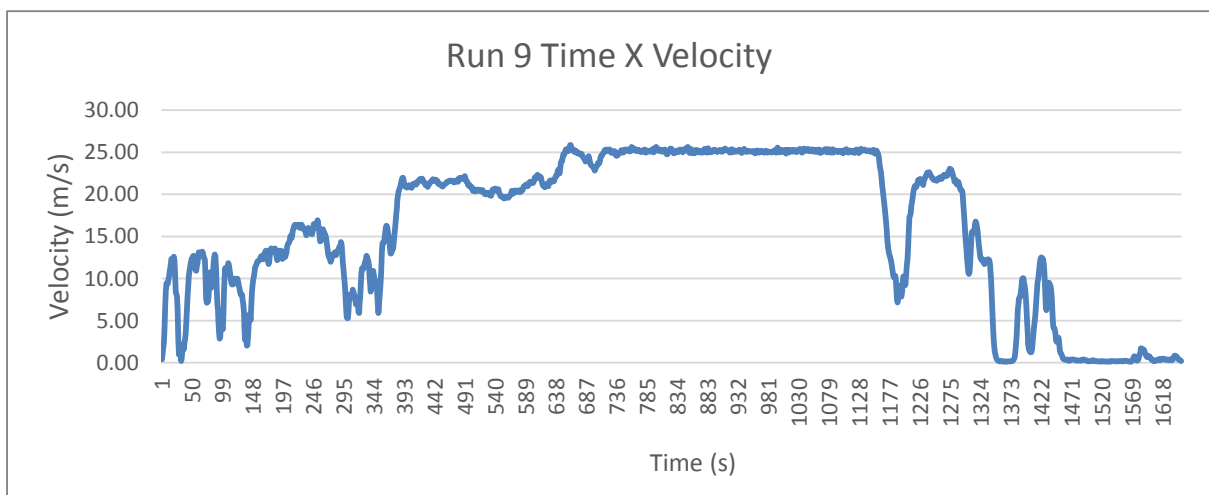
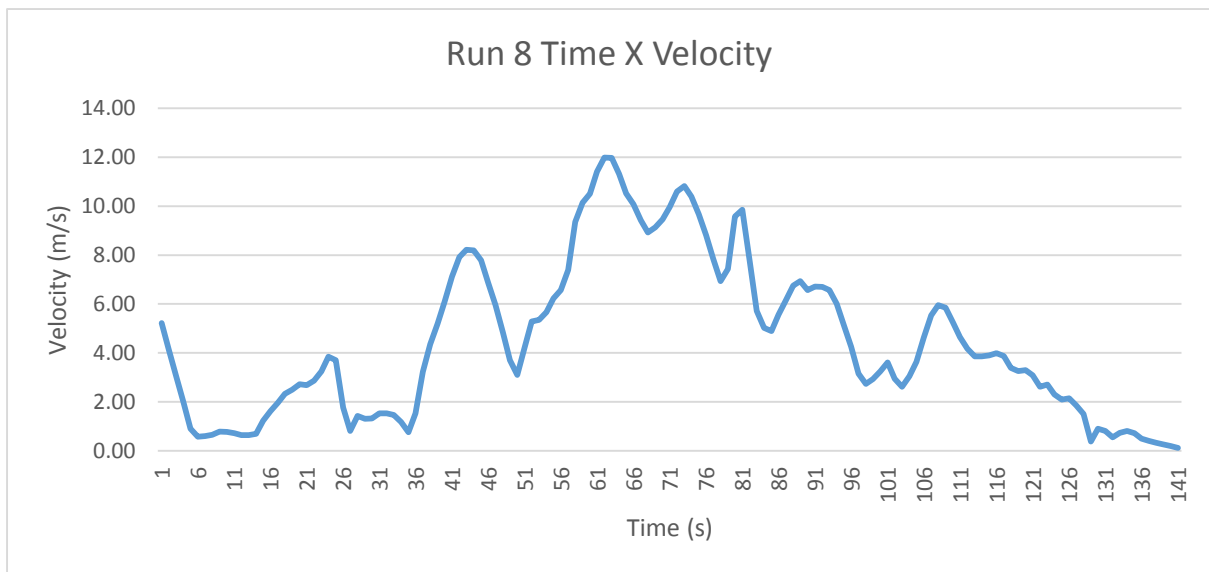
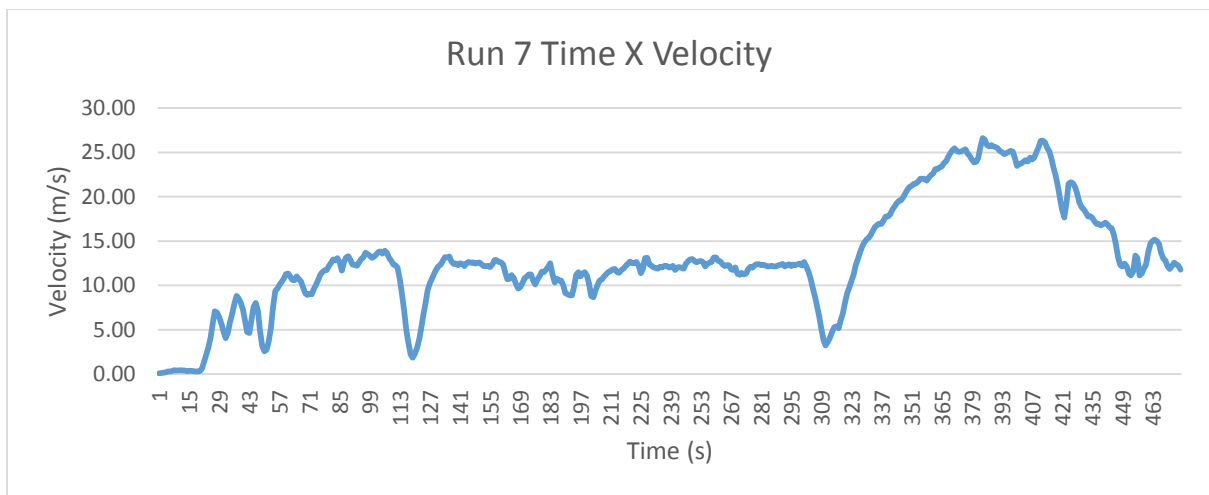
Order No. 21:53 21:00 - 22:00 4863	SA12 9LD	Distance: 7 miles Contact Numbers: Day: Evening: Mobile: Grid Reference: 0277701924 Weight: 70 Kg	Total Items: 93 This customer has 5 Ambient trays 3 Chilled trays 1 Frozen trays
Customer Signature:		Delivery Time:	
Delivery Instructions: (none)		CDA Notes: (none)	
Customer:			

Order No. 22:06 22:00 - 23:00 4868	SA12 9PT	Distance: 0 miles Contact Numbers: Day: Evening: Mobile: Grid Reference: 0278201926 Weight: 39 Kg	Total Items: 43 This customer has 3 Ambient trays 1 Chilled trays
Customer Signature:		Delivery Time:	
Delivery Instructions: (none)		CDA Notes: (none)	
Customer:			

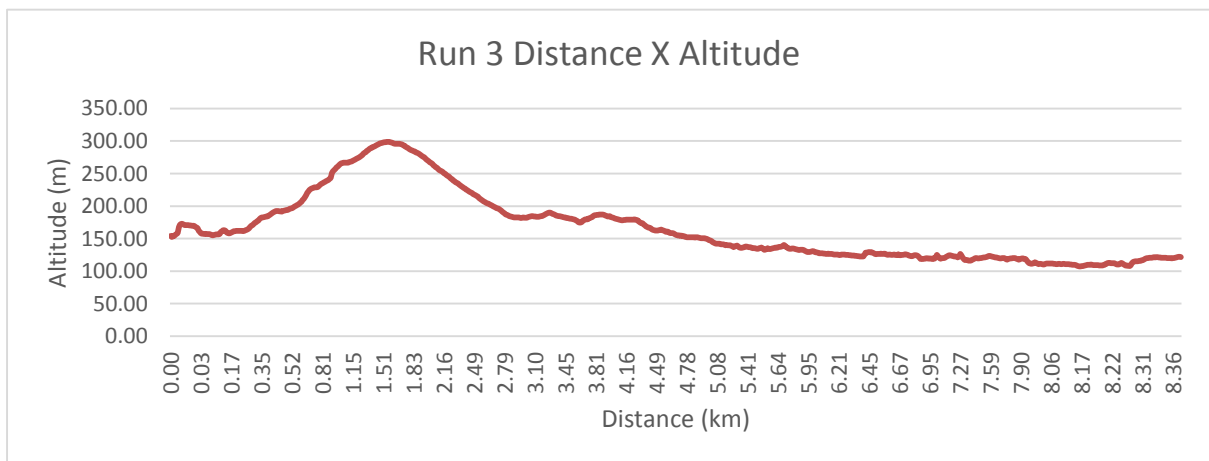
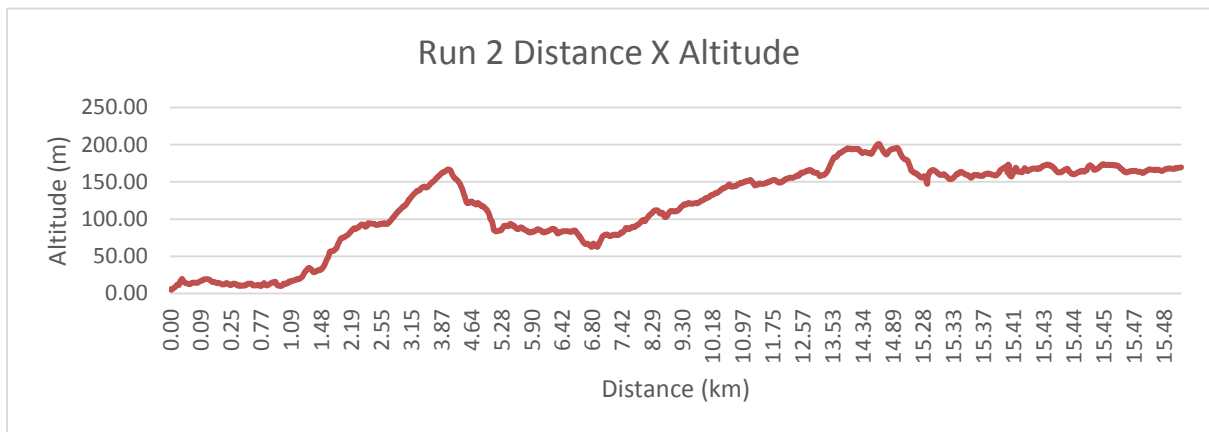
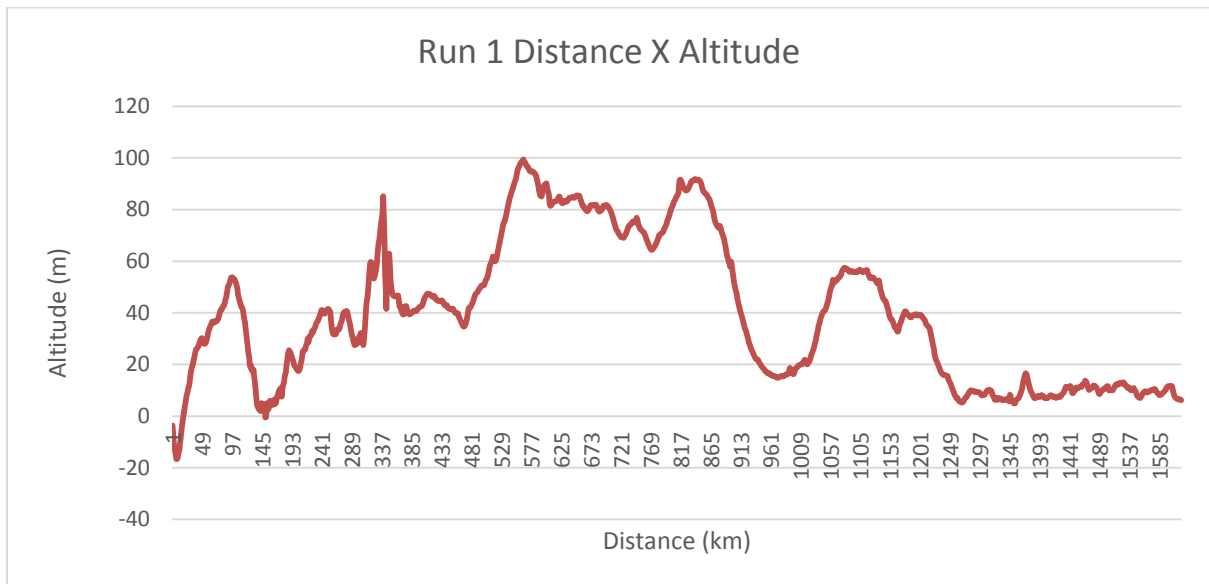
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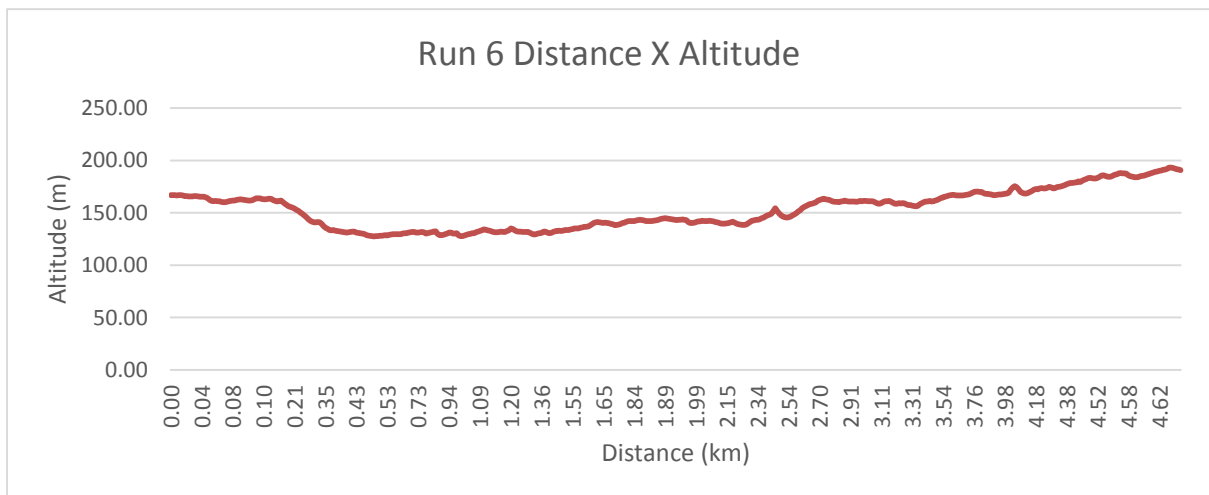
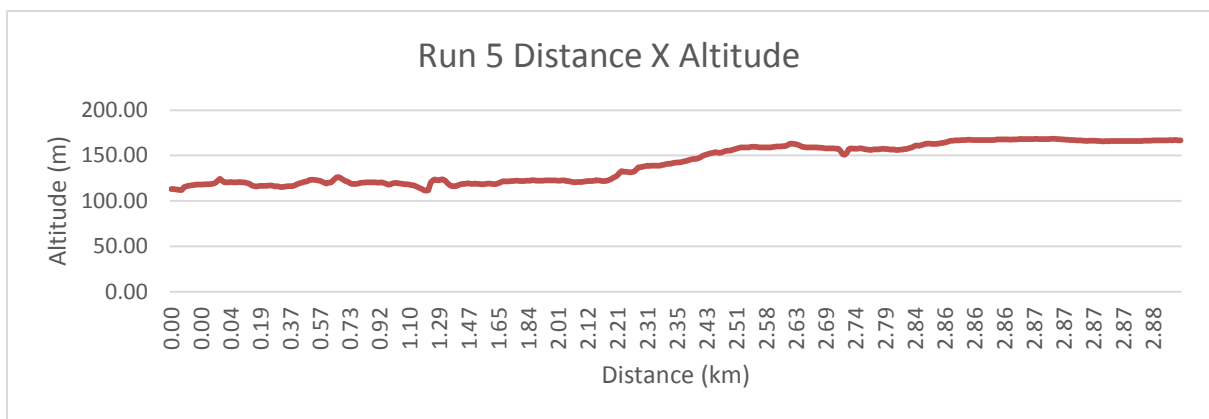
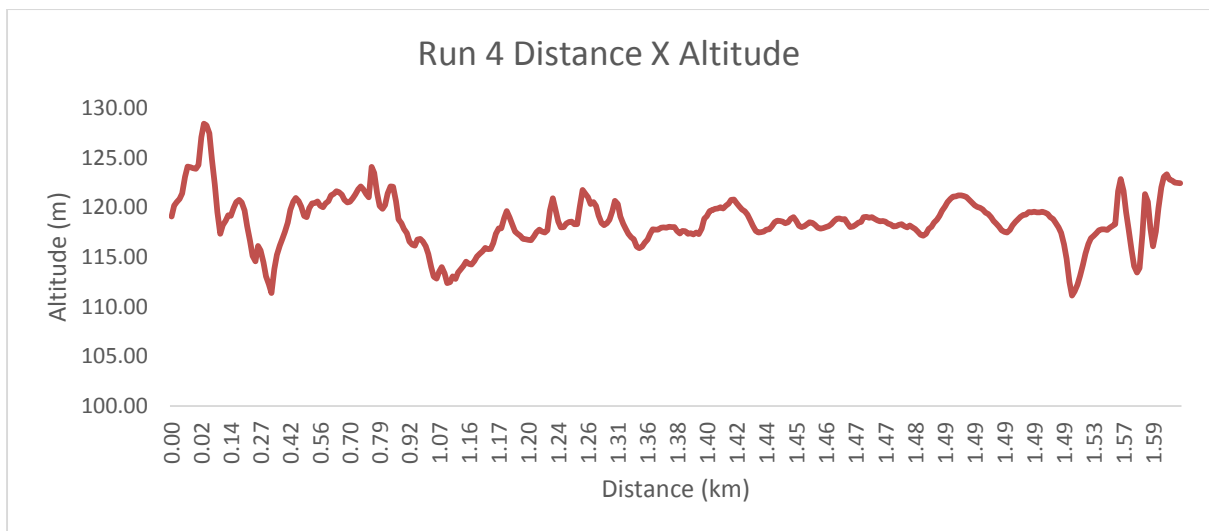


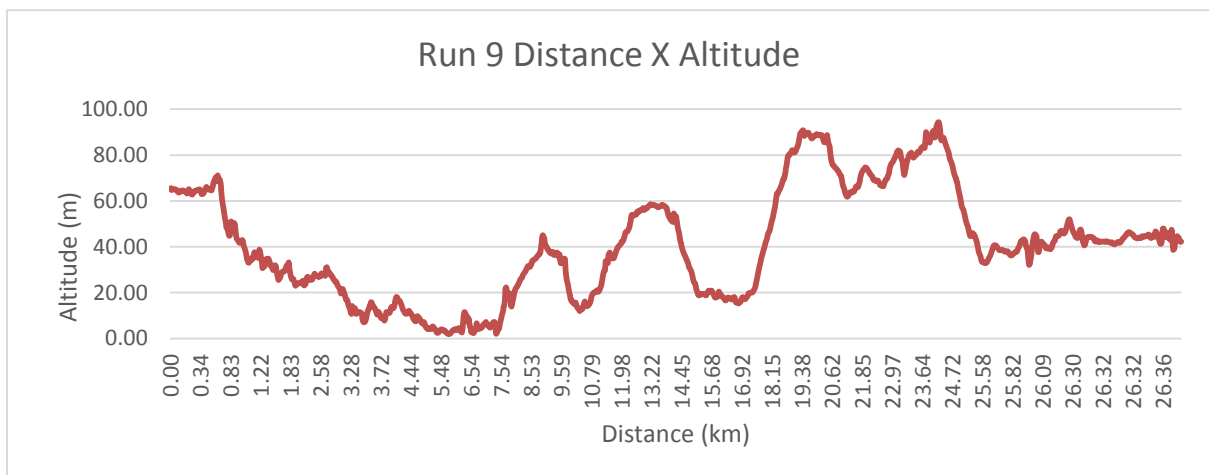
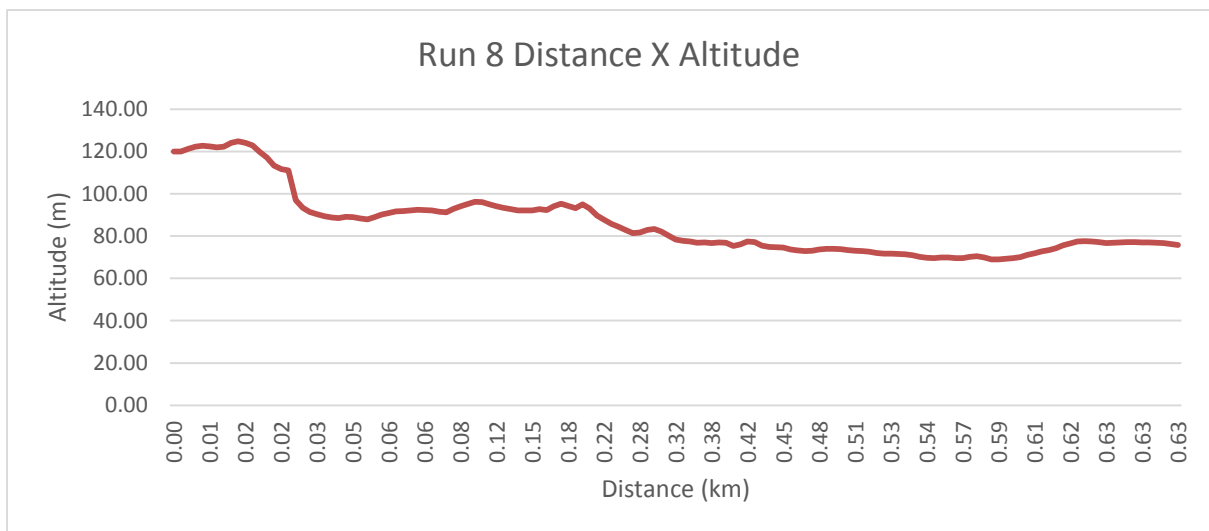




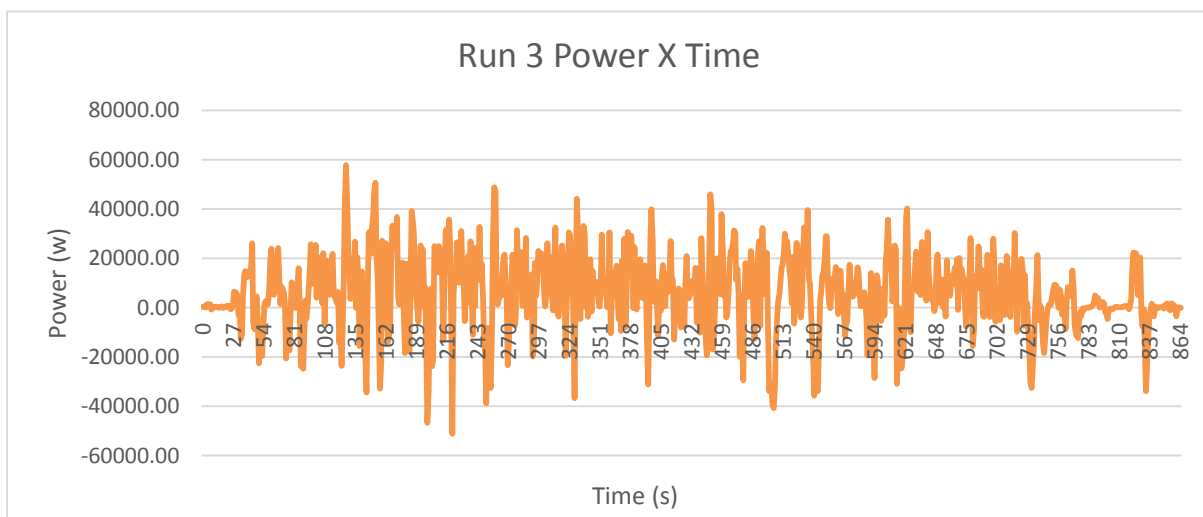
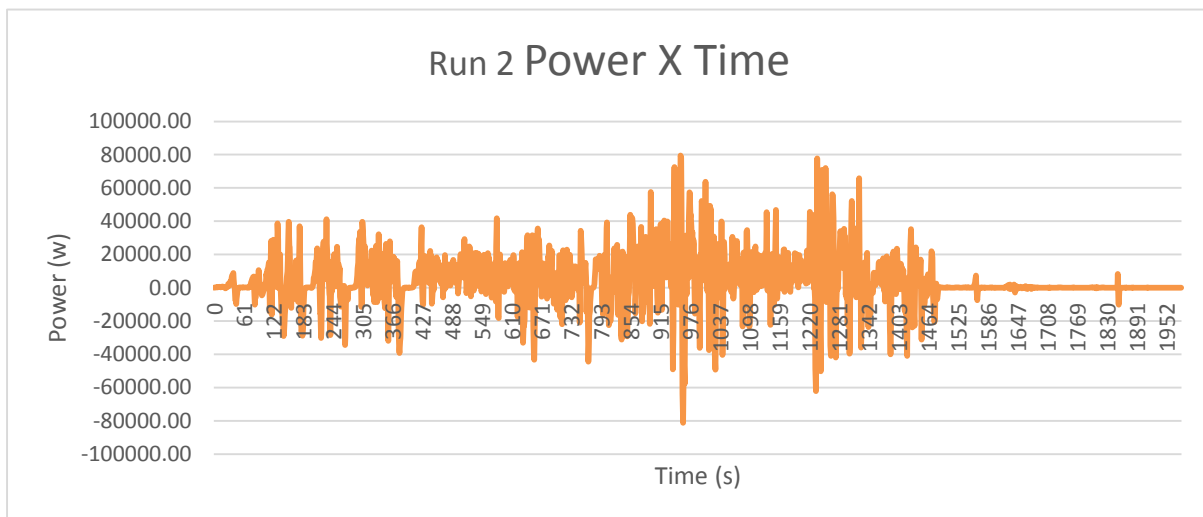
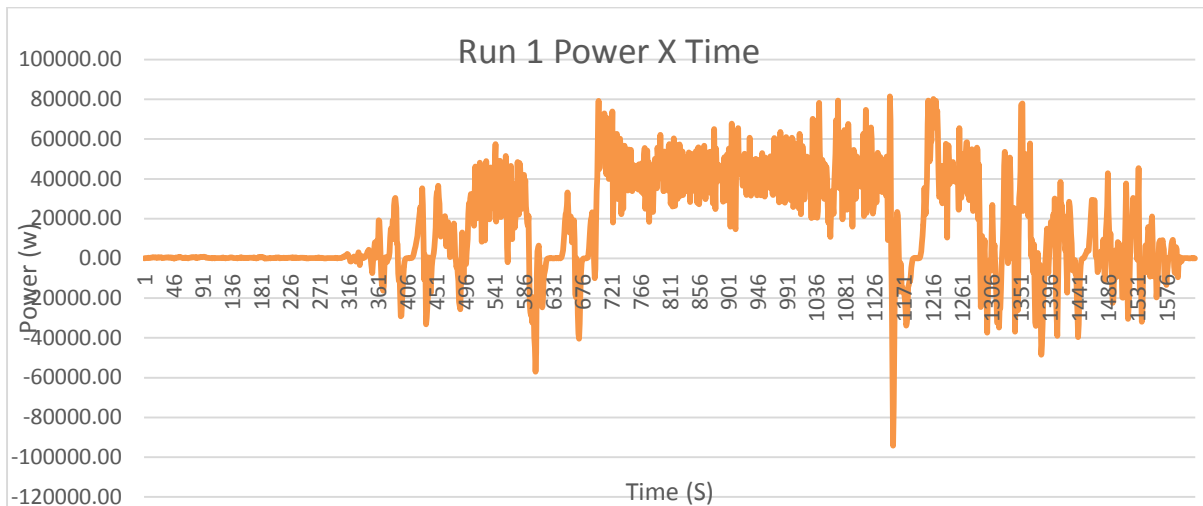
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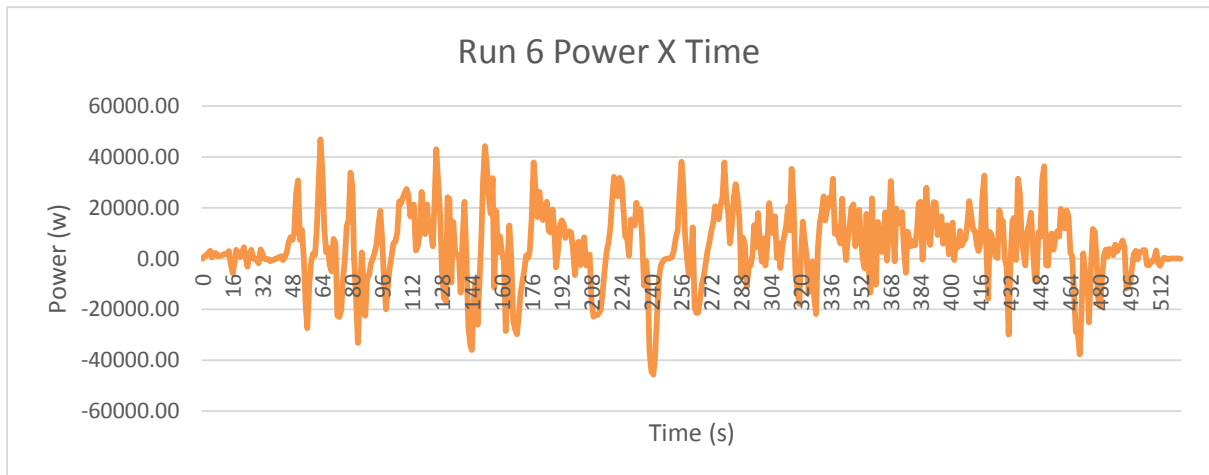
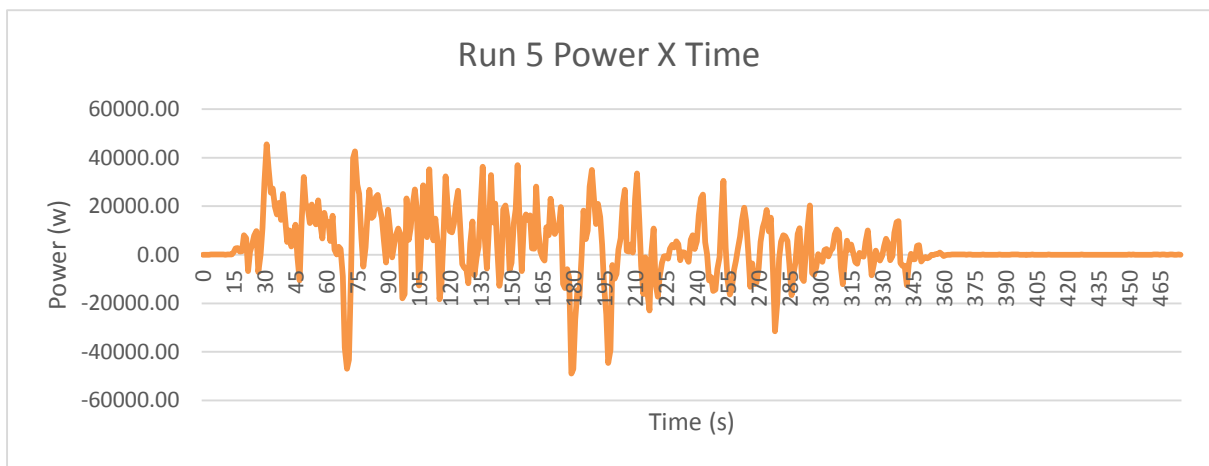
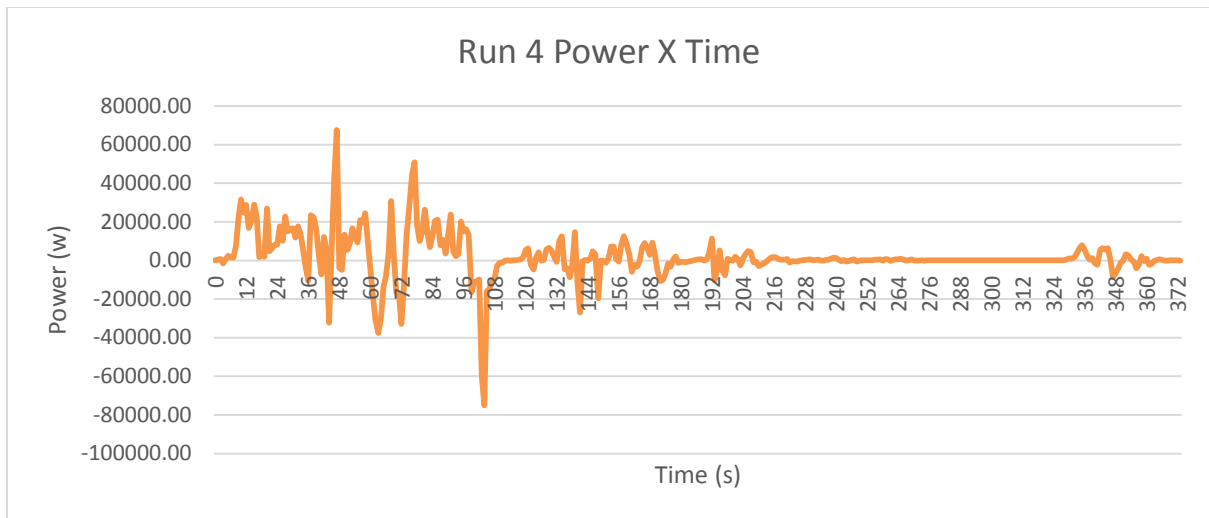


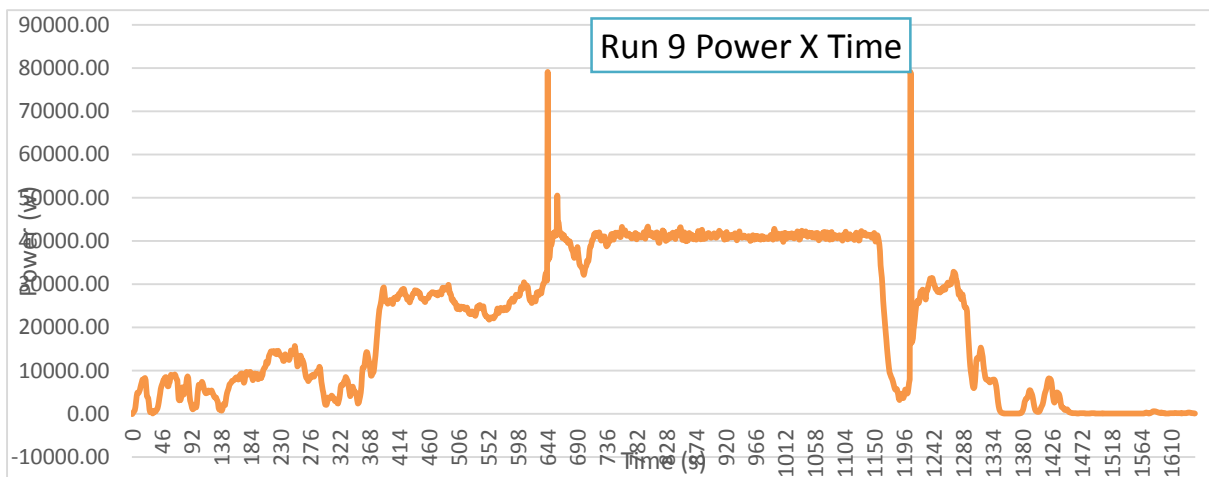
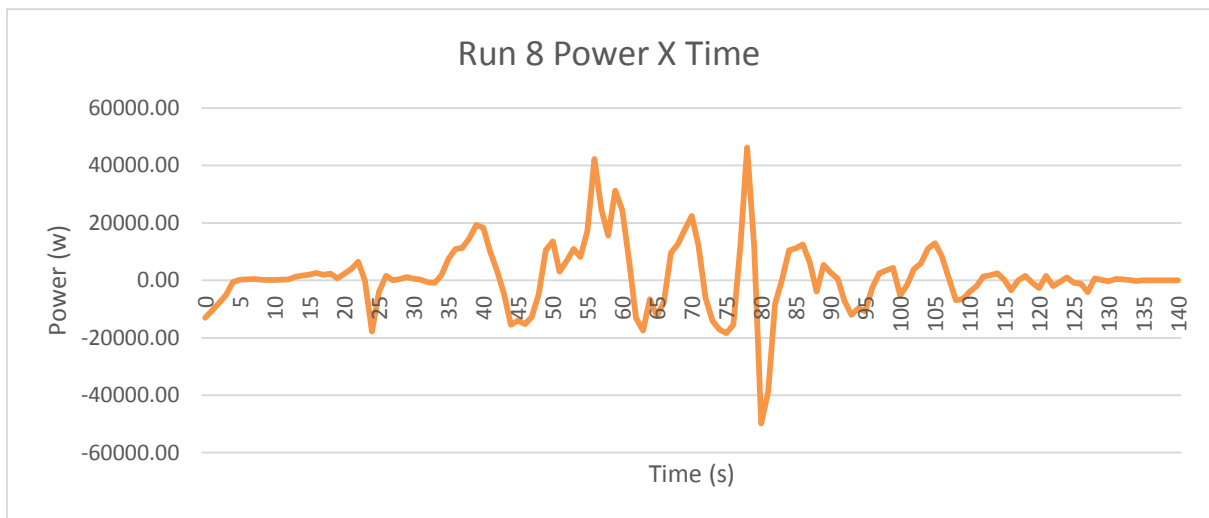
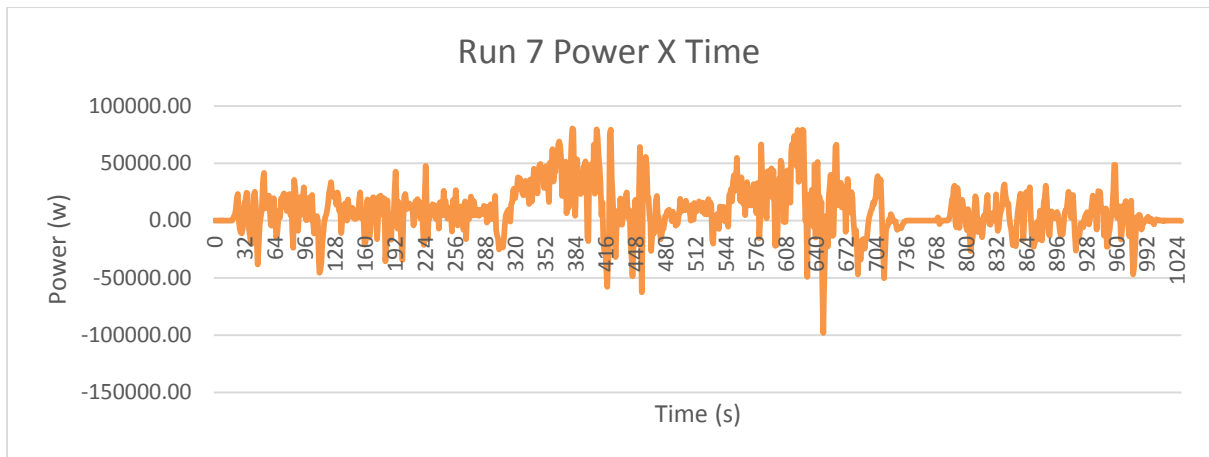




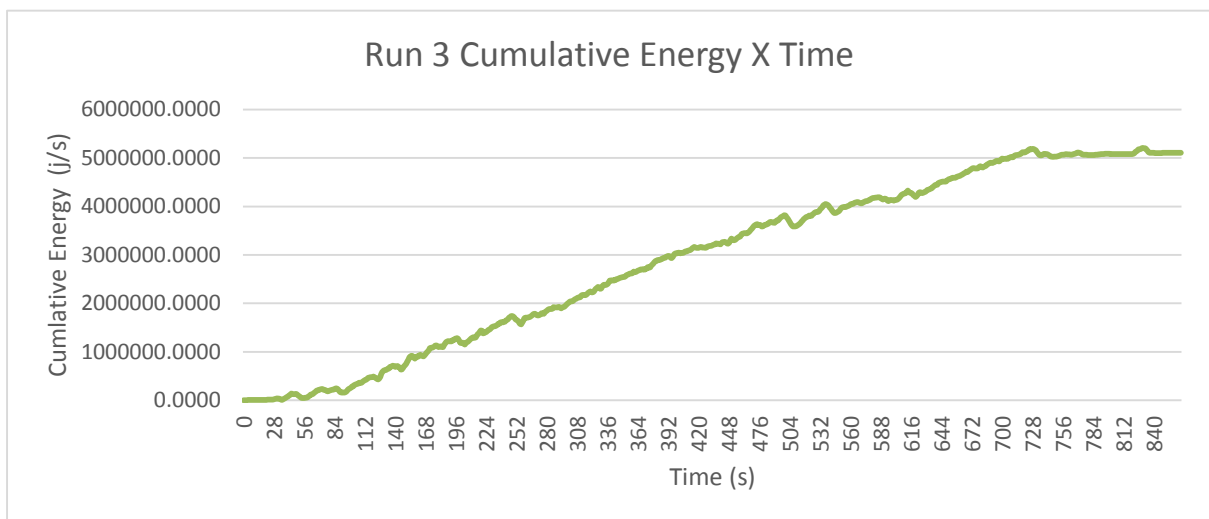
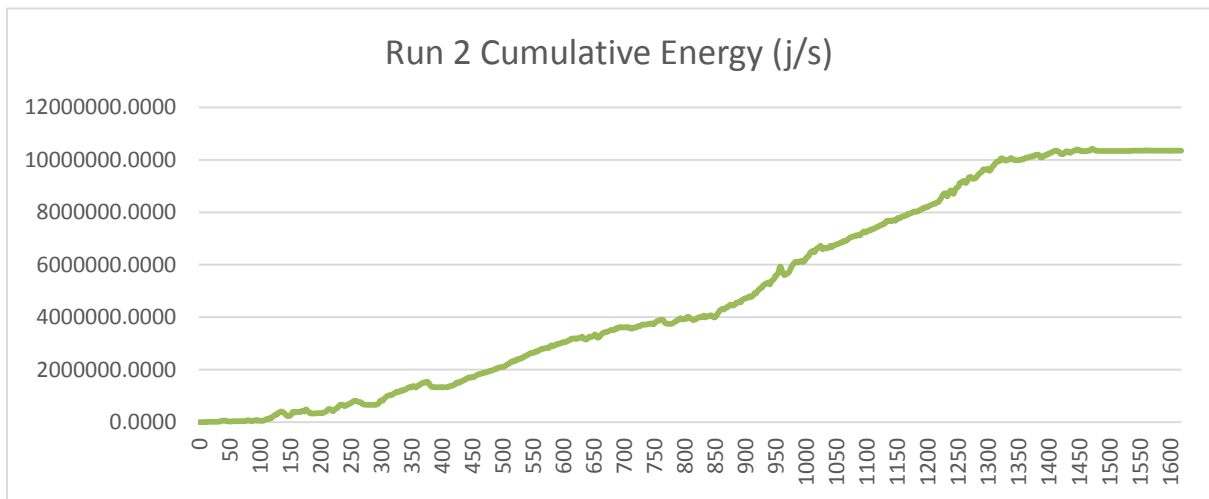
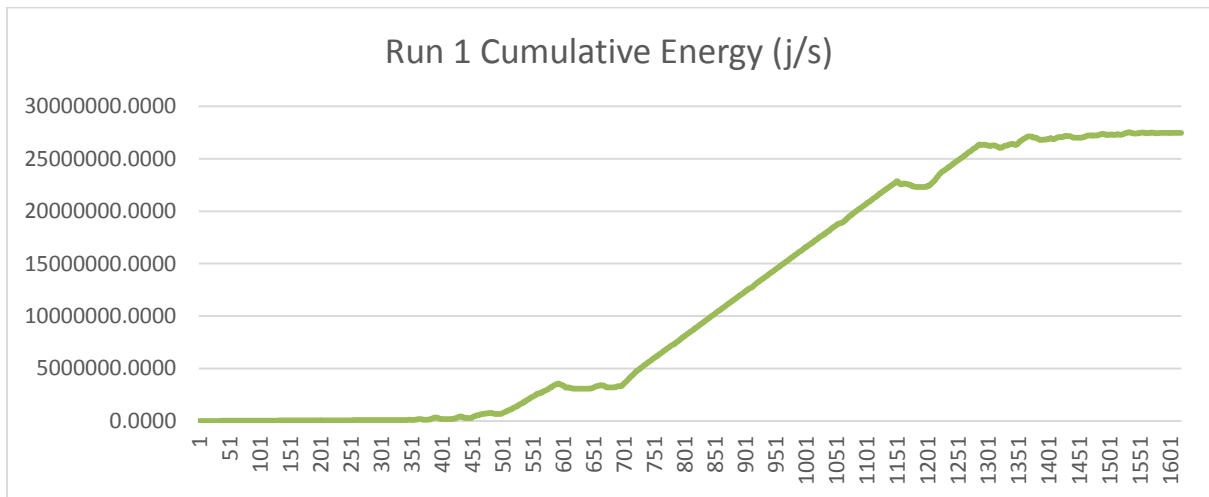
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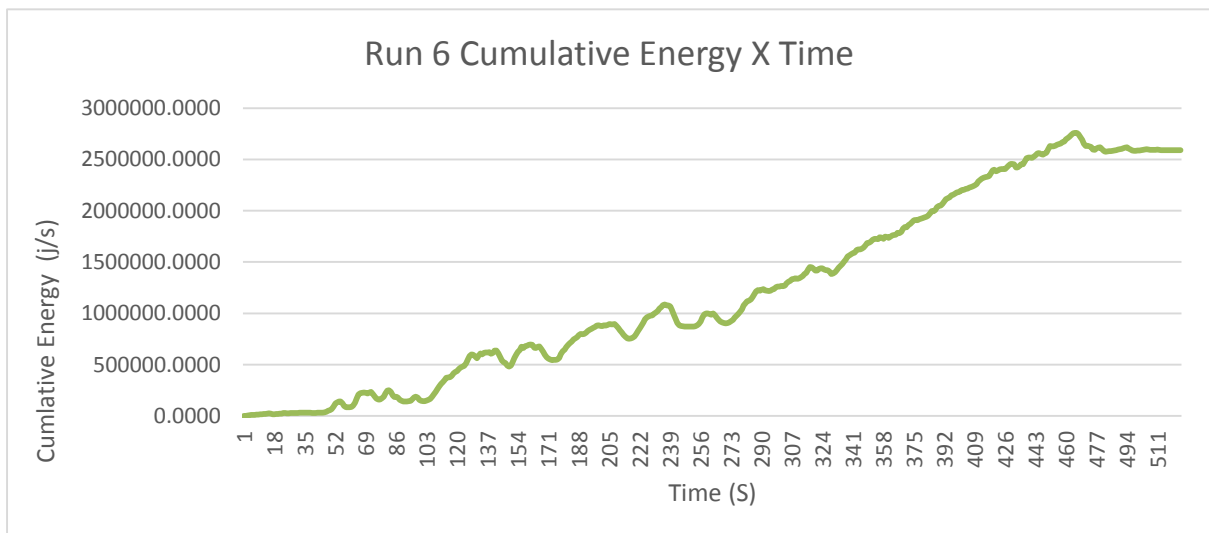
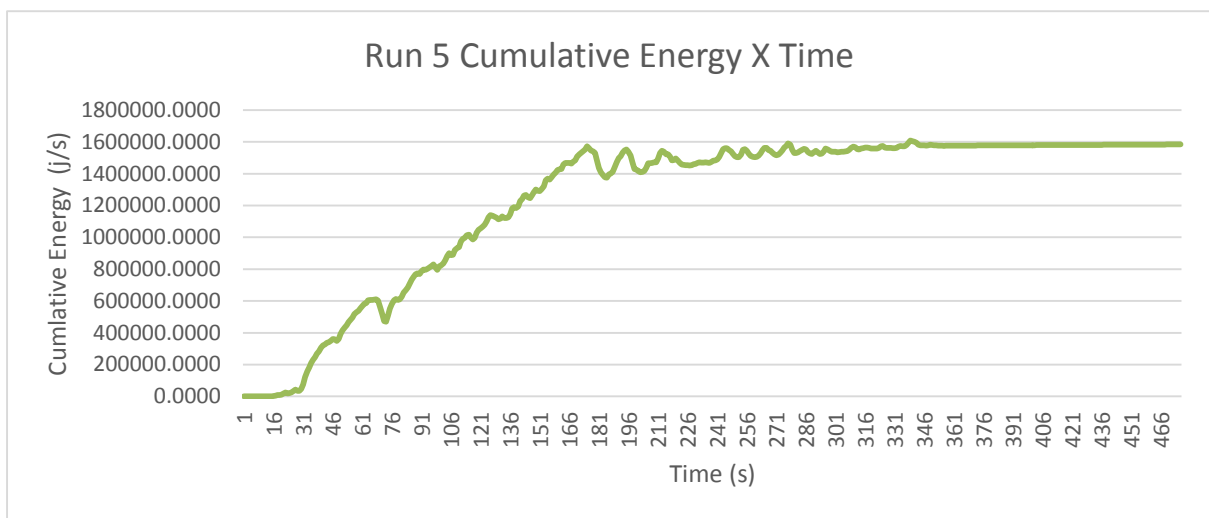
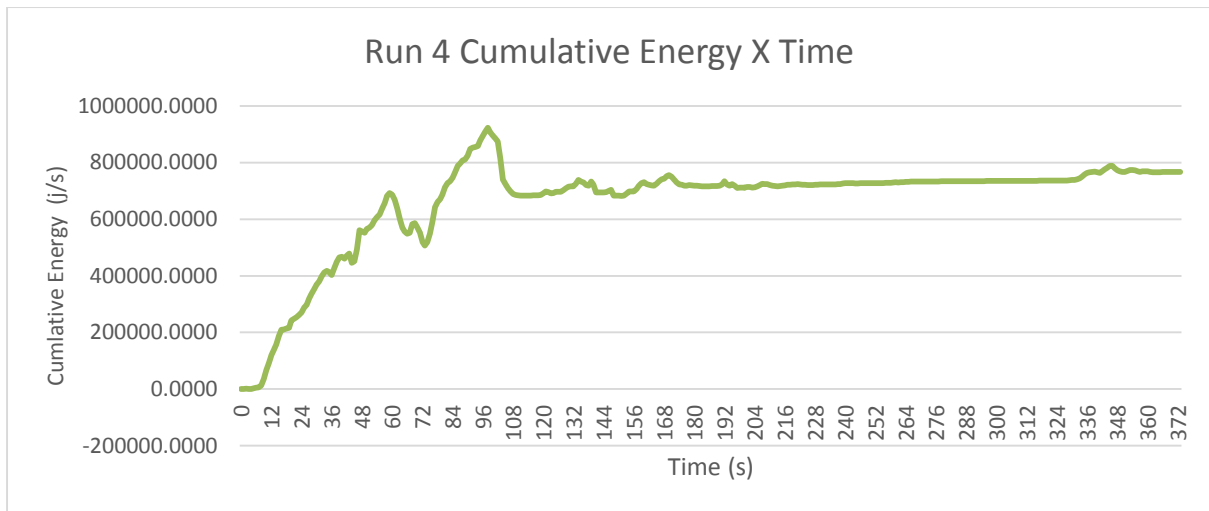


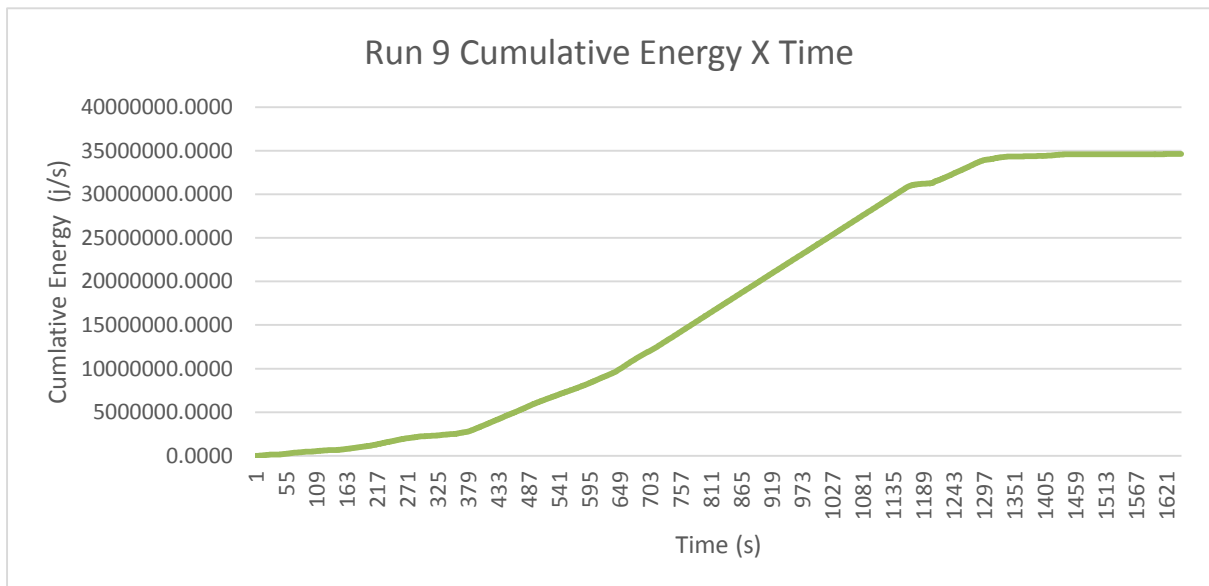
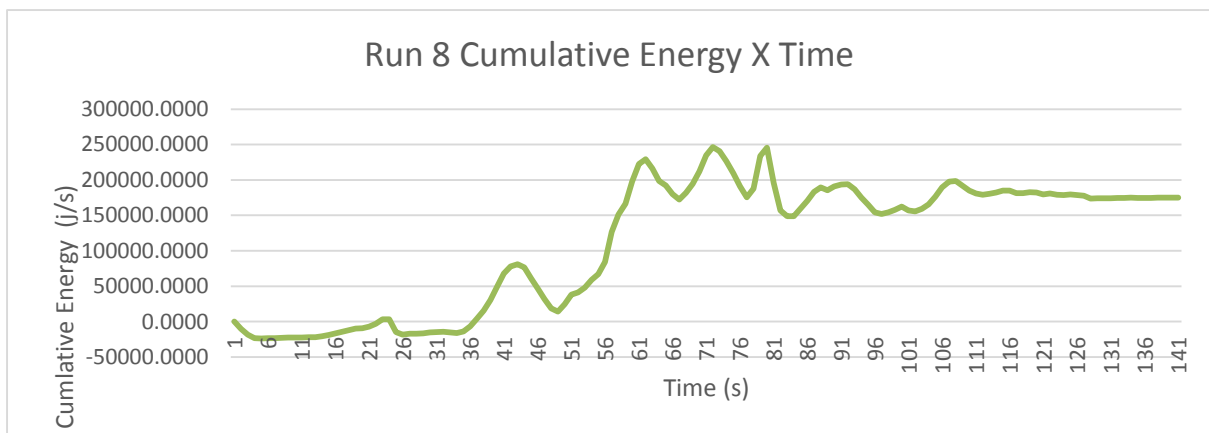
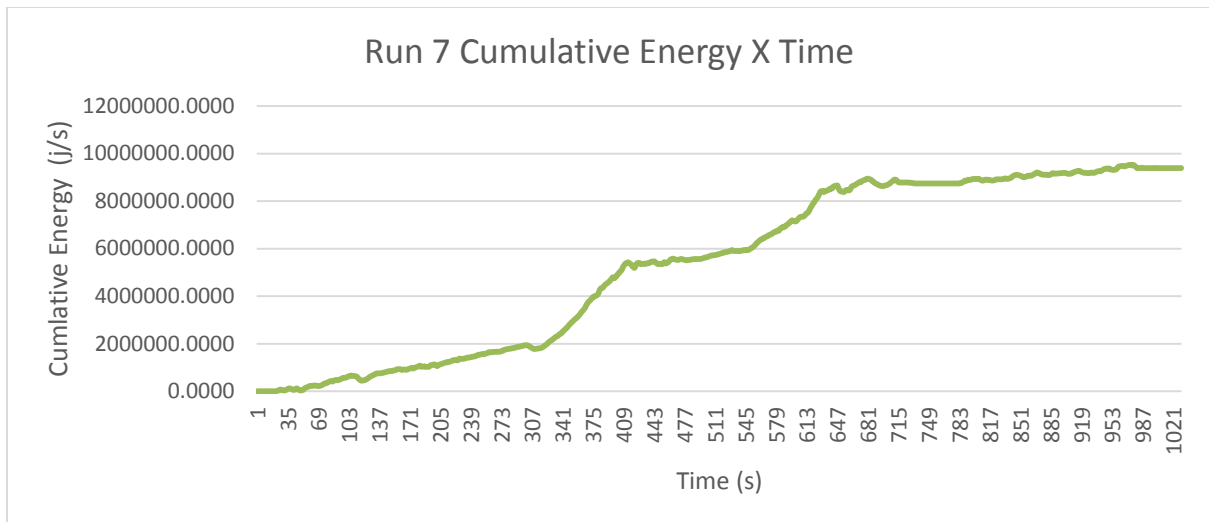




Appendix 5

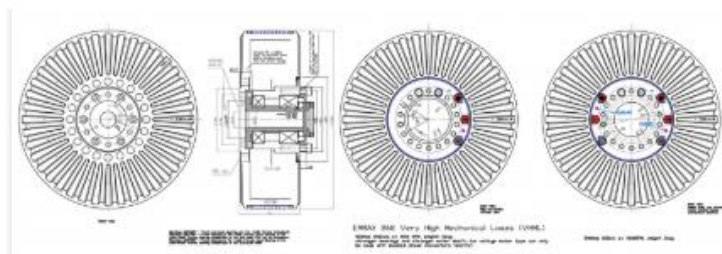
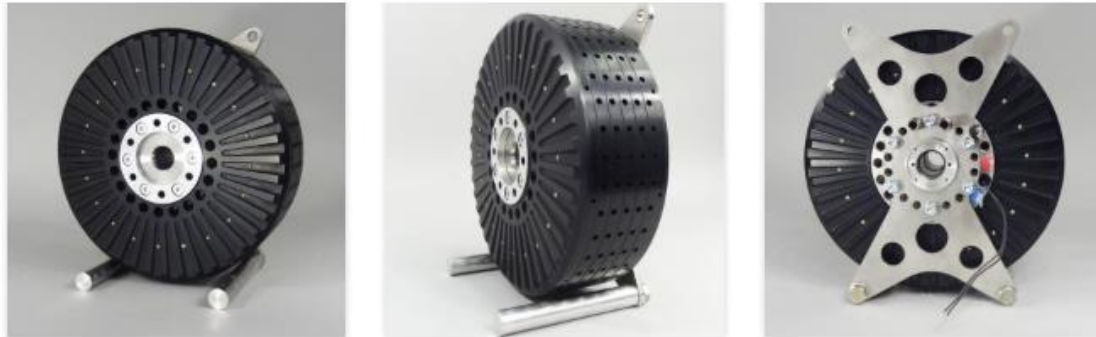






Appendix 6

EMRAX 268



Mechanical	
Type:	Axial flux motor / generator
Casing diameter:	268 mm
Axial length:	91 mm
Dry mass:	20,0 kg (AC) / 20,3 kg (CC) / 20,5 kg (LC)
Stator cooling:	air (IP21) / combined (IP21) / liquid (IP65)
Mounting:	Front: 6x M6 threaded holes Back: 8x M6 threaded holes
Stacking:	Two motors can be stacked together to achieve doubled power / torque. For more info click here .

Electrical	
Maximal battery voltage:	800 (HV) / 650 (MV) / 250 Vdc (LV)
Peak power (at 4500 RPM):	200 kW
Continuous power*:	up to 107 kW
Peak torque:	500 Nm
Continuous torque*:	up to 250 Nm
Efficiency:	92-98%

*Subject to drive cycle, thermal conditions and controller capability.

