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1. Introduction

This report has been constructed in order to demonstrate how with the use of readily available OBD-II data logging systems can provide adequate results to enable manipulation into more correlative and developed understandings of the vehicles operation within real-world driving procedures, not just the basic constructed homologation procedures. The validity of the data provided is to be discussed to outline the unfortunate inherent issues with this style of data acquisition, but it will be shown that there is plenty to be gained from the data when correctly correlated using simple mathematic relationships. Following on from the validation study, each of the vehicles characteristics will be compared in regards to the apparent driveability, efficiencies, load demands and operating limits in order to gain an understanding of how manufactures are trying to defeat the standard testing procedures, given their own manufacturing limitations.

The paper will then discuss the potential impact that changing to an alternative style of powertrain could most certainly be utilised. In order to reduce, if not eliminate, the emissions outputted by the vehicle, along with the decrease in running costs. Although the development will be based upon multiple assumptions, it will be shown that the chosen development vehicle could benefit from; changing fuel to a higher alcohol content, changing from a purely ICE style to work effectively in unison with electrification or with respect to enhancing the ICE to become more thermally and mechanically efficient through the use of new technologies. This vehicle will then have a full specification created to demonstrate the feasibility of the changes, along with the thought to be pros & cons of the change.

Objectives –

- Validate the provided data regarding miscalculation and raw measured inputs.
- Provide a correlation between each vehicle in terms of their driveability, load demand and overall apparent efficiency.
- Investigate the integration of new technologies and alternative powertrains.
- Discuss the feasibility of harnessing said changes to the vehicle for a mass production manufacturer.
- Provide evidence and reasoning to the proposed changes.

2. Data Validation

This study was done for three different types of vehicle, two of which were light passenger vehicles and the other being a motorcycle. The passenger vehicles used to collect data were a 2016 Volvo V40 Cross-Country D2 family hatchback and then a 2016 Toyota Aygo 1.0 VVT-i X-Pression 5dr Hatchback. The motorcycle was a 2011 Triumph Tiger 800 XC. Each of the fundamental vehicle characteristics are shown below.

	Test Vehicle Characteristics		
	Volvo V40 D2	Toyota Aygo X-Pression	Triumph Tiger 800 XC
Year of Manufacture	2016	2016	2011
Vehicle Type	Family Hatchback	Hatchback	Motorcycle
Engine Displacement	1969 cc	998 cc	799 cc
No. Cylinders	In-Line 4	In-Line 3	In-Line 3
Fuel Type	Diesel	Petroleum	Petroleum
Induction Type	Forced Induction - Turbo Charged	Naturally Aspirated	Naturally Aspirated
Fuel injection type	Common Rail Electronic Fuelling	Multipoint sequential electronic fuel injection	Multipoint sequential electronic fuel injection
Maximum Engine Speed [RPM]	4500	6300	10000
Maximum Power [Kw]	88 @ 3750RPM	51 @ 6000RPM	69.1 @ 9300RPM
Maximum Torque [Nm]	280 @ 1500 - 4500RPM	95 @ 4300RPM	79 @ 7850RPM
Front Wheel Size	16"	14"	21"
Front Tyre Size	205/55 R16	165/65 R14	90/90 ZR21
Rear Wheel Size	16"	14"	17"
Rear Tyre Size	205/55 R16	165/65 R14	150/70 ZR17
No. Forward Gears	6	5	6

Table 1 Test Vehicle characteristics (Volvo, 2019), (Toyota, 2016), (motorcyclespecs, 2011), (Wheel-Size, 2020).

Data provided was in the form of both an 'LGF' file and '.csv' formats. The 'LGF' was simple log file to be used within the software platform of ScanXL, designed by Palmer Performance Engineering. Palmer are also the creators of a mobile phone application titled "Dash-Command", to which is the basis to begin the data logging for the chosen vehicle.

The Dash-Command application has been designed to be simple and very user-friendly, giving the basic user or hobbyist the ability to return their highly sought-after power and torque figures. However, from initial investigation into the application there is clear immediate issues that would render a considerable amount of the recorded data invalid. This is thought because the application requires a lot of very basic characteristics of the vehicle. Such as vehicle type, year, fuel preference, engine size and so on, as can be seen in the figure below that represents the vehicle “setup” sheet given.

Vehicle		Vehicle Advanced Settings	
2016 Volvo V40 HATCHBACK		Fuel tank capacity	Fuel tank capacity
Identification		Brake specific fuel consumption	Brake specific fuel consumption
Owner		Volumetric efficiency	Volumetric efficiency
VIN (automatically filled if left blank)	VIN	MAF PID	MAF PID
specifications		MAP PID	MAP PID
Engine displacement	2.0 l	Lambda (actual) PID	Lambda (actual) PID
Fuel type	Diesel	Lambda (commanded) PID	Lambda (commanded) PID
OBD-II settings		Tire size specification	Tire size specification
Advanced settings		Final drive ratios	Final drive ratios
		Curb weight	Curb weight
		Additional weight	Additional weight
		Drag coefficients	Drag coefficients
DELETEVALIDATE PIDS			

Figure 1 Basic Vehicle Characteristics within the Dash-Command Application.

All of the values are to used within the application to fill in variables within it's configured 'math' channels, that will then attempt to calculate values for; fuel consumption, fuel flow, power, torque, boost pressure and countless other channels that all required these potentially poorly estimated, singular input values.

Because of these required singular values, calculations for channels such as the brake specific fuel consumption and the volumetric efficiency, are going to be null and completely invalid. Simply because they're both measurements of variables that are extremely sensitive and highly transient, with values constantly changing as the vehicle travels, the engine warms up and variations in percentage of load.

For example, BSFC is given the units of 'g/Kw·h' denoting that it's a measurement of fuel usage for a specific power output for a given period. It's used within industry as a unit of measurement for understanding engine efficiency, considered as a dimensionless parameter that relates the work done per cycle in the engine, to the given value of fuel inputted (Heywood, 1988). The BSFC is usually represented in a graphical form to demonstrate the values across the range on engine speed for the given torque output at those points, demonstrating the area that is most efficient as the lowest value.

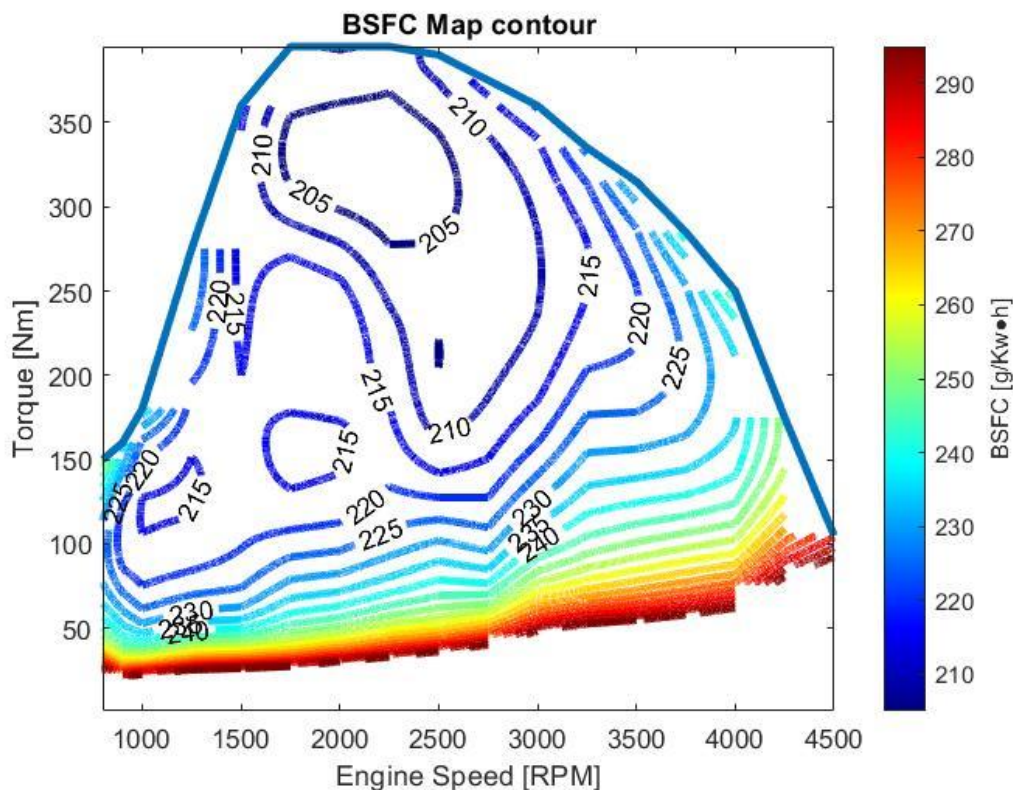


Figure 2 BSFC Contour Map of a Ford Panther 2.0L EcoBlue Diesel ICE.

Therefore, it can indefinitely be said that the application is going to produce some potentially incoherent and invalid data. As will now be proven, by looking at the supposedly measured application data for the fuel flow of each vehicle (see below), that is the fundamental driving force for multiple other channels, alike; miles per gallon achieved, predicted fuel use over the driving cycle, emissions production, power and then subsequently the torque values given by the software. Rendering them all obsolete with respect to actual values, but none the less, they do show a correctly expected trend throughout each vehicle in this drive cycle.

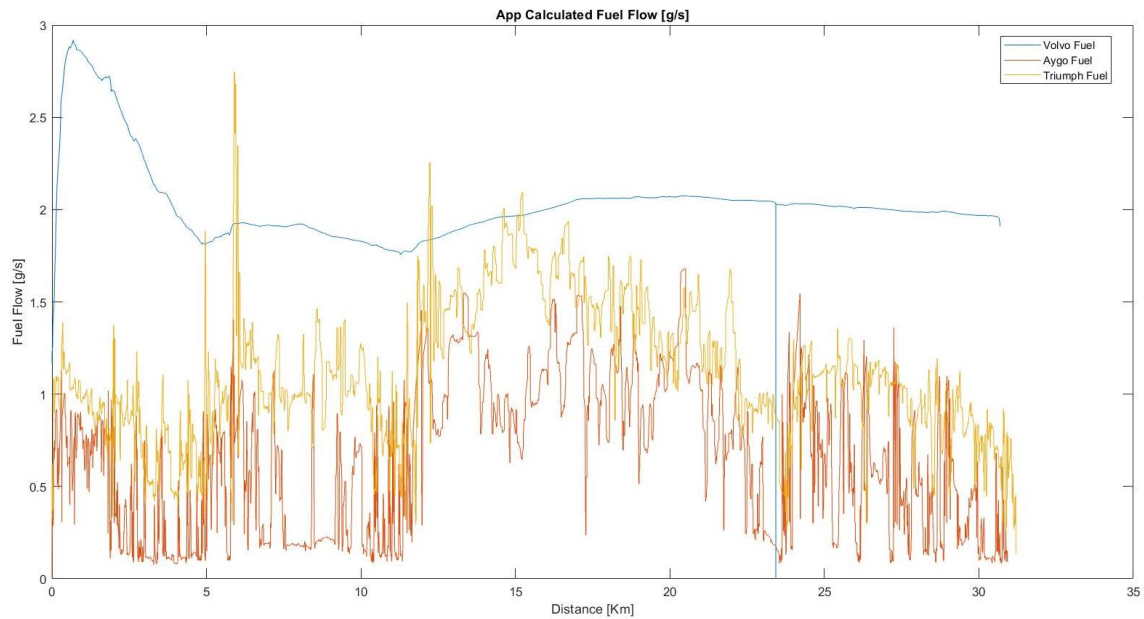


Figure 3 Fuel Flow calculated for each vehicle within the application.

The measurement of the fuel flow for the Aygo is far more representable than that of the Volvo and the Triumph. But it itself is under predicting in terms of fuel use and caused a predicted MPG value of 62, when the stated value across this specific cycle is 50 ± 1 MPG.

As for the Triumph Tiger, it was predicting a total fuel use of 1.902Kg giving an MPG of 34.76, then the Volvo grossly overpredicting and calculating a total fuel usage of 3.9Kg of fuel giving an MPG of 18.47. Both vehicles are also said to have achieved the same MPG of 50 ± 1 , showing that this application calculated data is currently completely void.

However, because the application wasn't given the data is specifically ask's for, or it was incorrectly inputted, nor were the multitude of other SAE vehicle onboard sensors calibrated within the OBD-II read, there was always going to be an issue with correlation.

Hence why, it wouldn't be wrong to assume that the application could certainly begin to more accurately calculate and log, various important channels that could pose useful for gaining a better understanding of the vehicle, if the full vehicle specification had been inputted.

[Fuel densities for the fuel usage calculations were taken as; Petroleum $750 \frac{Kg}{m^3}$ & Diesel as $830 \frac{Kg}{m^3}$]

Moving away from the calculated or vehicle sensor SAE channels, the application can provide GPS tracking data also. Because it's being used on a mobile phone, it can then consider these auxiliary inputs within its calculations. Along with being able to provide a form of validation for the vehicle speed sensors, both wheel and engine, because they will most likely use the same hall effect type sensors.

These auxiliary inputs were easily identified within the .csv files in excel because of the correctly titled 'AUX...'. The values recorded from the external input are the GPS tracking, used for developing world positioning in the form of longitude and latitude. Along with logging the altitude of the vehicle, which then using Microsoft Excel allows the replication of a 3D - map configuration, as seen in the following.

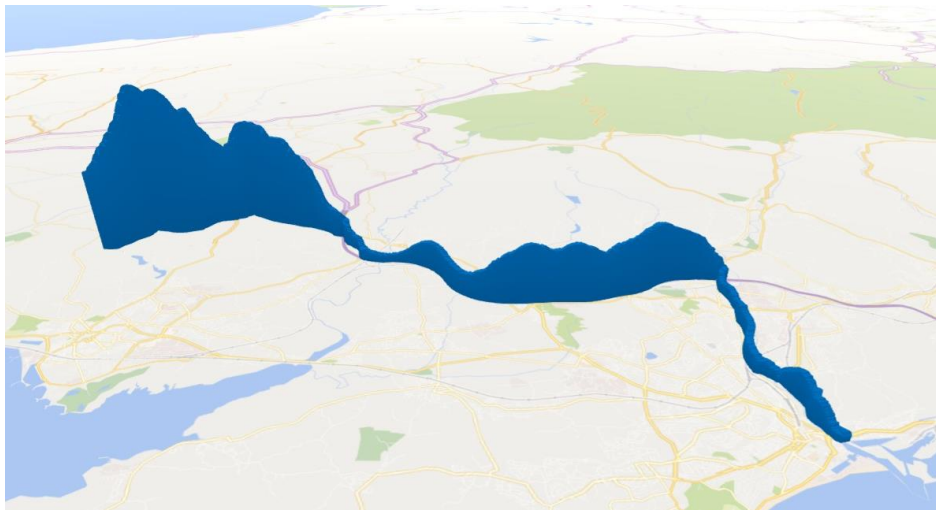


Figure 4 3D Map representation of the recorded; Longitude, Latitude & Altitude.

All three of the vehicles can then be shown to have followed the same path and correctly done the same route, demonstrating the power demand due to the course and altitude is consistent. The only real discrepancy between the vehicles was a small section upon the motorway part of the drive cycle, where the Aygo remained at a slightly higher speed and altitude. This suggests that the vehicle may have been in a different lane for this section, or perhaps there was simply a lack of traffic on this day in comparison to the other two, allowing the vehicle to travel at a slightly higher speed for longer. Or perhaps there was a disruption with the Bluetooth signal that caused a delay of sorts. This latency is thought to be the reason for the clear discrepancies in GPS speed and vehicle measured speeds.

[Refer to Appendix A]

3. Comparison of Vehicle Characteristics

Given each of the vehicles used for the study, are in some respect completely different from each other, there is clearly going to be a difference in; driving styles, load demand, fuel use and otherwise general driveability. To characterise this, the author has chosen to develop a wheel force model for each vehicle to gain an understanding of the demand the vehicles powertrain is being required to produce. Along with recreating the gear shifting log across the cycle to understand how capable the vehicles are, in terms of the length of time spent in gear because the vehicle is incapable of easily accelerating through it, therefore requiring a higher engine speed to generate enough torque to overcome the required force. These characteristics can also be seen when studying each vehicles acceleration during the cycles, highlighting the vehicles capabilities to cope with the demanded torque to overcome all resistive forces.

Starting with the wheel force and torque demand for each vehicle, it's clear to see how much of an impact the extra mass of the Volvo has caused, therefore demanding it's much larger ICE in comparison to the two other vehicles, in order to maintain the perception of comfortable driving.

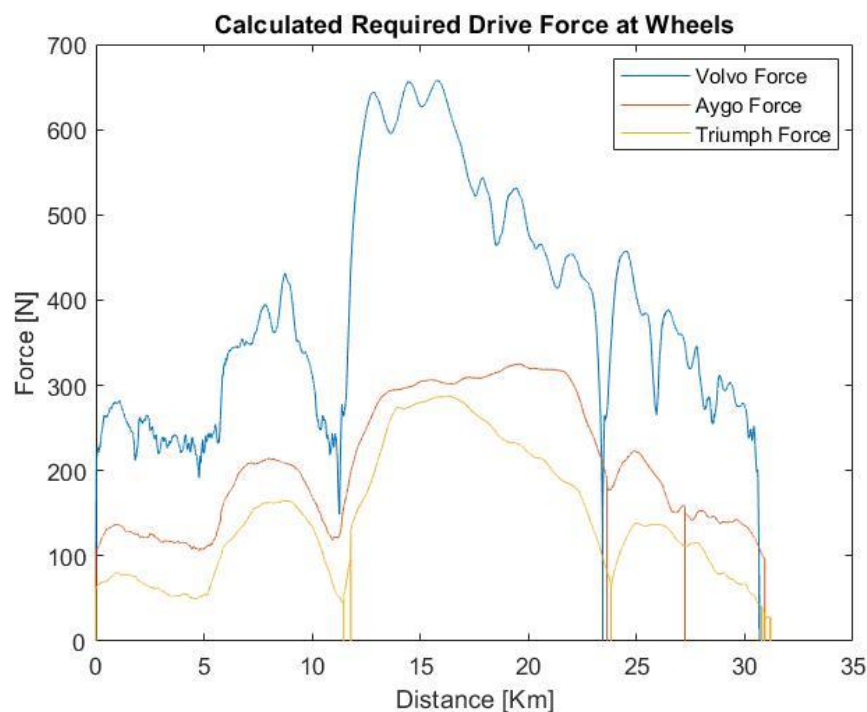


Figure 5 Vehicle calculated resistive wheel forces.

This wheel force model was done so using the three main collective force equations that represent the rolling resistant force, aerodynamic drag force and an inertial force required to accelerate the masses of the vehicle.

The rolling resistance is governed by the tyres and their inflation pressure, temperature and the speed the vehicle is travelling, because these factors will change the coefficient used in the equation:

$$F = m \cdot g \cdot \mu_r$$

[Rolling resistance equation]

Where m is the vehicle mass, g is the acceleration due to gravity [9.81 m/s²] and μ_r is the coefficient that represents tyre resistance.

This coefficient can be seen to change consistently with speed alone, in an exponential fashion.

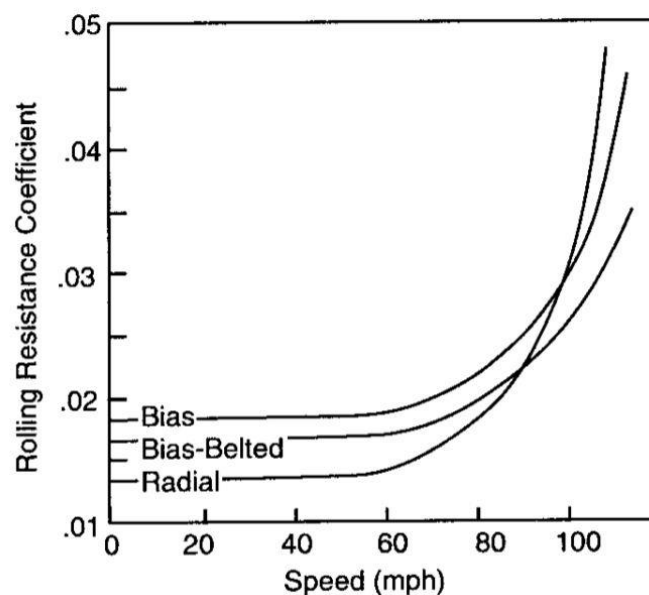


Figure 6 Rolling Resistance coefficient changing with vehicle speed (Gillespie, 1992).

Unfortunately, these pressures weren't known so the functionality of developing the model to include a changing coefficient as the vehicle speed increased was neglected and the value was left fixed throughout. To then enable the recreation of a simple road load model as shown in the following.

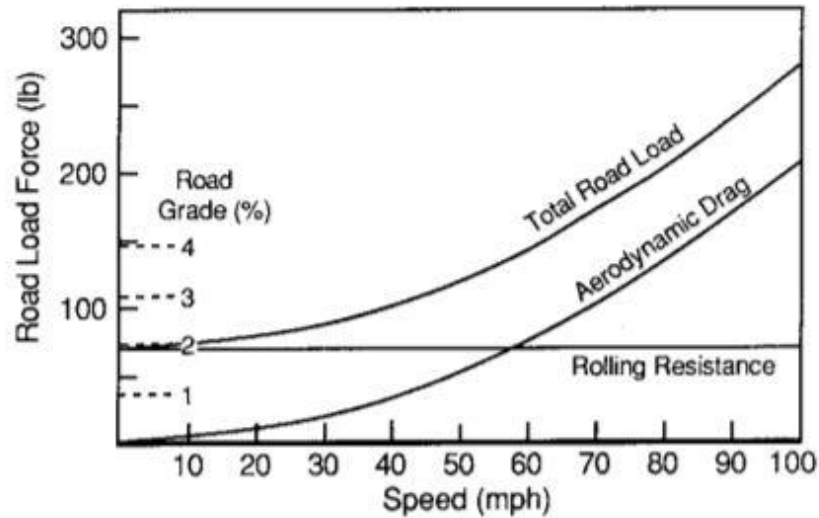


Figure 7 Representation of Aerodynamic drag, Rolling Resistance and the total Road Load Force (Gillespie, 1992).

Regarding the aerodynamics of the vehicles, the drag force is a major component to factor in when the vehicle is experiencing high speeds and become the most important factor if the vehicle were to see speeds above 200 Km/h (Katz, 1995).

The aerodynamic drag force is calculated using the well known 'Bernoulli's' equation in the form of:

$$\text{Drag Force} = \frac{1}{2} \cdot \rho \cdot C_d \cdot A \cdot V^2$$

[Drag Force Equation]

Where ρ is representing the density of air, to which the temperatures on the day of testing were taken to be at an average of $1.24 \frac{\text{Kg}}{\text{m}^3}$. This is because the test data was collected early in the morning with low air temperatures, but then being evened out with the drive cycle continuing back on the same route after an eight-hour period of rest. The drive cycle also covers a vast change in level in with respect to the standard measuring height of 'sea level'. This change in altitude can also have an effect on air density, in that the air will get "thinner" or less dense, the higher the vehicle travels because of the reduction in pressure (Benson, 2014).

C_d is the coefficient of drag and for the two automobiles the values were: Aygo C_d of 0.28 and the Volvo is 0.33, both stated within the specification sheets published by the OEMs.

The motorcycle didn't have a specified coefficient because little is currently known about the aerodynamics of motorbikes, therefore it was taken that, because of the poor shape of a bike and it's accompanying rider the drag coefficient will be around 0.7 (Foale, 2002).

A is the frontal area of the vehicle in m^2 , with automobiles it's thought that to attain the reference area, it can be found by taking 85% of the complete front area (Width · Height) in m^2 (A2 Wind Tunnel, 2013) and for the bike it was assumed that the full frontal area should be used because of the inclusion of the rider in this case. And finally, with the dimensionless addition of the coefficient of drag included, the vehicle speed becomes squared and therefore creates the parabolic shape that greatly increases with vehicle speed.

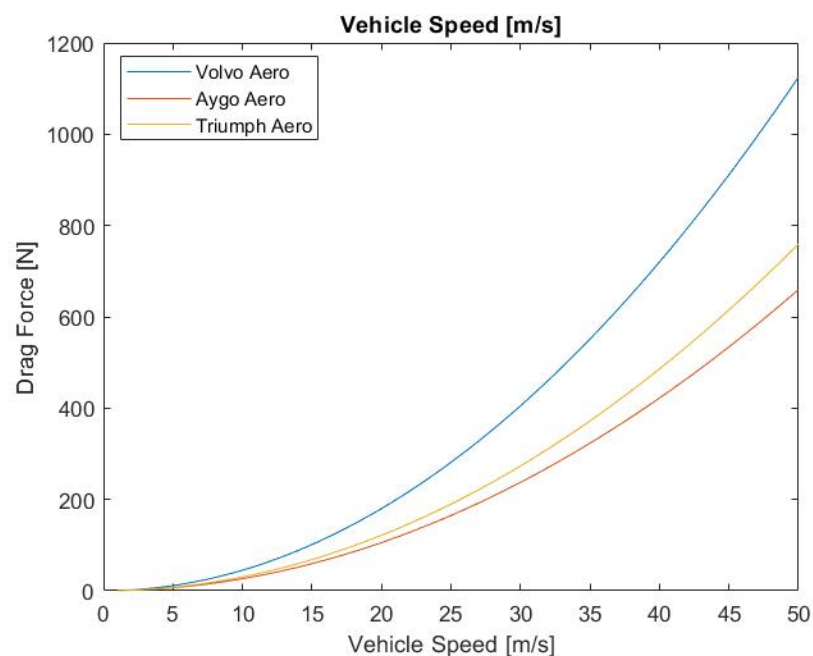


Figure 8 Drag Forces as speed increases.

	Test Vehicle Characteristics		
	Volvo V40 D2	Toyota Aygo X-Pression	Triumph Tiger 800 XC
Coefficient of Drag	0.33	0.28	0.7
Frontal Area [m^2]	2.2	1.52	0.7
Maximum speed [m/s]	32.78	31.11	33.06
Air Density [Kg/m^3]	1.24	1.24	1.24
Maximum Drag Force [N]	483.6	255.4	331.95

Table 2 Aerodynamic drag characteristics.

The last force used in the model was the equivalent inertial mass that requires acceleration from the ICE. This term should include all parts throughout the driveline for realistic modelling, including the; gears within the transmission and the attached shafts, the flywheel & clutch assembly and in the case of the motorcycle the additional connections for a primary drive system, driveshafts & joints all along the drivetrain, then finally the wheel hubs and brake discs/drums. These extra inertial resistances don't make a massive difference to the overall model, but they would be important for accuracy. The real important factors are the wheels and the internal inertia of the ICE itself, simply because they have a much higher moment of inertia and therefore require more torque to accelerate, therefore assumed values for this collective additional inertia force were added.

	Test Vehicle Characteristics		
	Volvo V40 D2	Toyota Aygo X-Pression	Triumph Tiger 800 XC
Wheel Moment of inertia	1.15	0.95	1.1
Engine Moment of inertia	0.2	0.14	0.12
Total inertia [$\text{Kg} \cdot \text{m}^2$]	4.8	3.94	2.32

Table 3 Additional inertias for each vehicle.

With these terms collected they are to be added to the force required to accelerate the mass of the entire vehicle, arguably the biggest contributing factor of them all, the total resistive force acting on the vehicles can be found. Which then further enables the calculation of their required power and torque figures during.

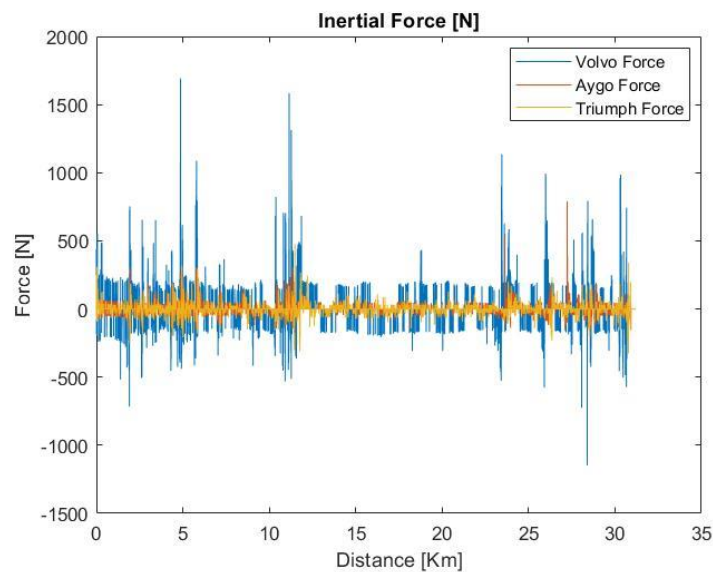


Figure 9 Inertial force for each vehicle.

With the collective forces required to move the vehicle at the wheels, the forward linear velocity, rolling radii and selected gears, it allows the correct calculation of the torque demand back through the drivetrain. These torque figures can be used to calculate a graph of the brake mean effective pressure within each of the engines, which can help give an understanding of the load demand on the engine and how efficient the engine is with respect to its capacity.

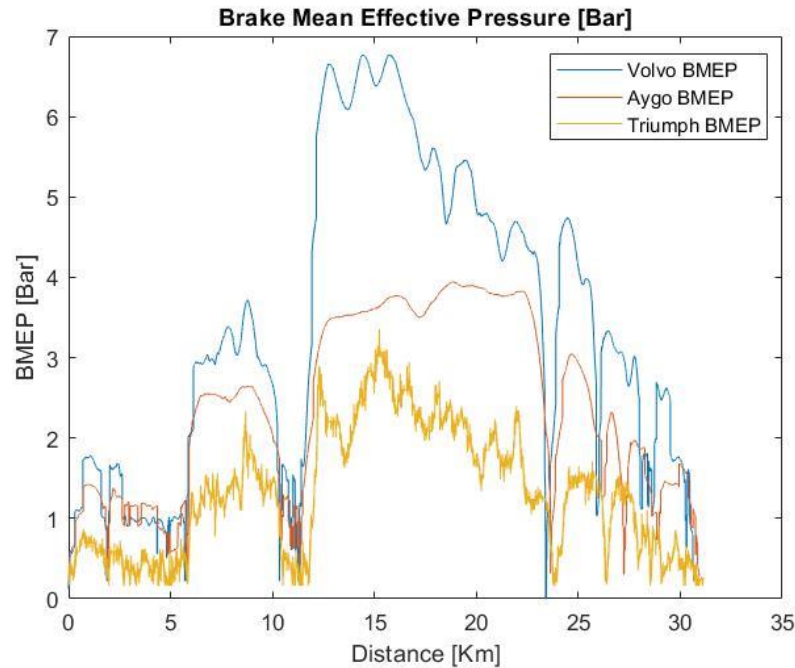


Figure 10 Brake Mean Effective Pressure for each vehicle.

	Test Vehicle Characteristics		
	Volvo V40 D2	Toyota Aygo X- Pression	Triumph Tiger 800 XC
Max BMEP Across Cycle	6.77	3.94	3.36
Max BMEP of Engine	17.87	11.96	12.43
Load Difference	37.89	32.97	27.01

Table 4 Comparison on load demand for each vehicle across the cycle.

So, with respect to the load demand on the vehicles is clear to see that none of the three vehicles are being put under much stress, which is perhaps why there is such inefficiency from the vehicles. But given the realism of the testing cycle it could be said that this is an area in which the engines should be made most efficient by the OEM's. Simply because the load is low but is operating within a range that will be seen most for the average driving period and because the engine speed is also on

the lower end of their maximum power outputs, the pumping losses due to specifically friction will also be low.

Therefore, given the definite correlation between the vehicles in terms of fuel use (MPG), load on the engine being around 30% and the vehicle speeds, it could be said the Volvo is clearly the most efficient operating vehicle within this cycle. It's thought the primary reason for this would be the larger capacity, turbocharged diesel engine being able to achieve a constant state of over 100% volumetric efficiency, whilst simultaneously harnessing otherwise waste heat energy from the exhaust gases. The other advantage of diesels is the lack of closed throttle pumping losses and its ability to simply run the engine in a much leaner condition than those of gasoline. The motorcycle was certainly the worst operating vehicle in the cycle because of the dramatic difference in weight to be accelerated from both the Aygo and Volvo, a 325% & 565% difference in mass respectively, but yet requiring essentially the same amount of fuel energy to do so.

Another point to take from the driveability prospective, is that the Volvo is most likely the most comfortable vehicle simply because of the diesels low speed, high torque nature not requiring large sweeps through the "rev range", unlike the Aygo. Where there are periods in which the vehicle has seemingly has to remain in a lower gear to maintain the higher engine speeds, that in turn give more power to overcome the road load conditions.

[Refer to Appendix B & C]

4. Alternative Powertrain Implementation

Given the unnerving reality of the global emissions epidemic, the rapid increase in vehicles sales and production in the past years and the eventual decline in resources, it's now become the most important factor of an automobile to be propelled by various sources that aren't simply internal combustion engines fuelled by petroleum or diesel. There is now also the concern for actual homologation testing cycles and the demand it now has, to pass the test. Coupled with the current prediction of fines induced by fleet vehicle carbon dioxide production being around £30 Billion spread across the major OEM's, namely VW and the PSA group thought to be facing around £10 Billion between themselves alone (King, 2020).

Therefore, from the prospective of fleet sales and vehicles used by many, it's an understandable approach that current manufactures are looking at purely electric vehicles, because of their perceived "Carbon Neutral" nature. Along with "Hard Hybrids" they rely primarily on electric driving force and an ICE of sorts as a generator to charge the batteries, not run the vehicle. Because the reduction across actual homologation procedures could pose massive for them. But given the rest of the vehicles, the large passion for ICE's from many and their every growing efficiencies, they could be begun to run on more sustainable fuels. Such as liquid hydrogen, alcohols or higher percentage blends and biofuels that are created from otherwise waste products (Shaw, 2013).

Based on the idea of alternate fuels and blending fuels small study was conducted using the principle of fuel energy required to accomplish the cycle based on the 50MPG statement. The study was done on the Toyota Aygo, simply because it's a good representation of many vehicles on the roads today; light, low capacity engine and relatively "cheap" with respect to accessories.

The expected fuel use, assuming the demand is the same for the journey back, is a collective mass of 2.62Kg of fuel, 1.31Kg each way. (Assuming a density of 750 Kg/m³)

Using this mass of fuel and the idea that combustion remains at a state of stoichiometry throughout, the expected carbon dioxide mass produced is 4.04Kg which throughout equates to 130.6g/Km produced. These calculations are based off using the fuel Iso-Octane because it's thought to be the most representable of petroleum.

A study into alternative fuels was conducted, based on the amount of energy required to do one half (30Km) of the drive cycle. Using the 1.31Kg of fuel and an expected LHV of 44.341 MJ/Kg, the total energy would be 58.11 MJ.

Looking at the availability of energy from various blends of Methanol - Iso-octane, Ethanol - Iso-octane and Ethylene - Iso-octane. Rearranging the mass of fuel required to match the original for each of the blends, shows that the Ethylene blend requires less mass to produce the same energy and in turn could prove to produce less CO₂ across this cycle.

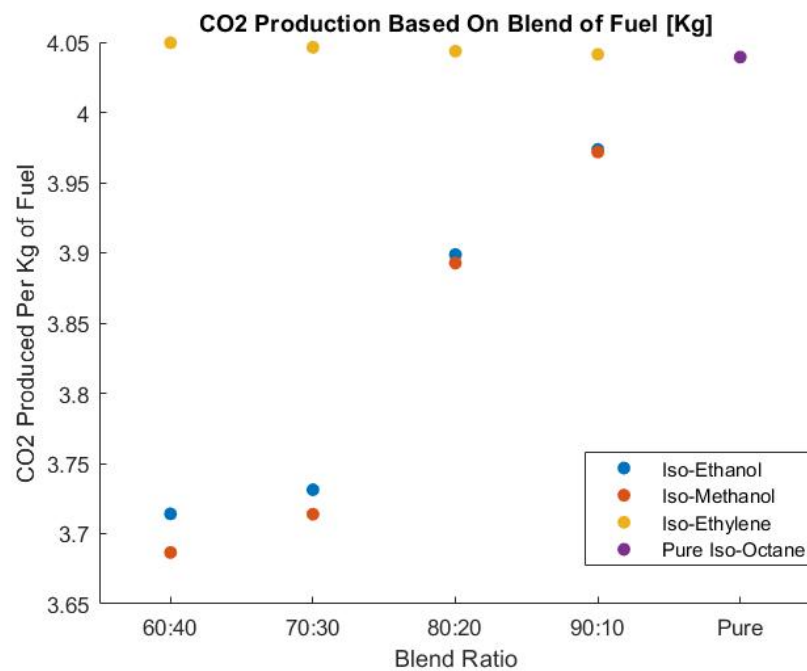


Figure 11 CO2 Production from combustion of an Kg of each fuel blend.

The fuel blends are done using Iso-Octane as the major component, blended as; 60%, 70%, 80%, 90% and then the original fuel usage as it's singular fuel.

With considering the difference in lower heating values, it's then the next step to correlate the difference in required mass of fuel to obtain the same amount of energy during combustion.

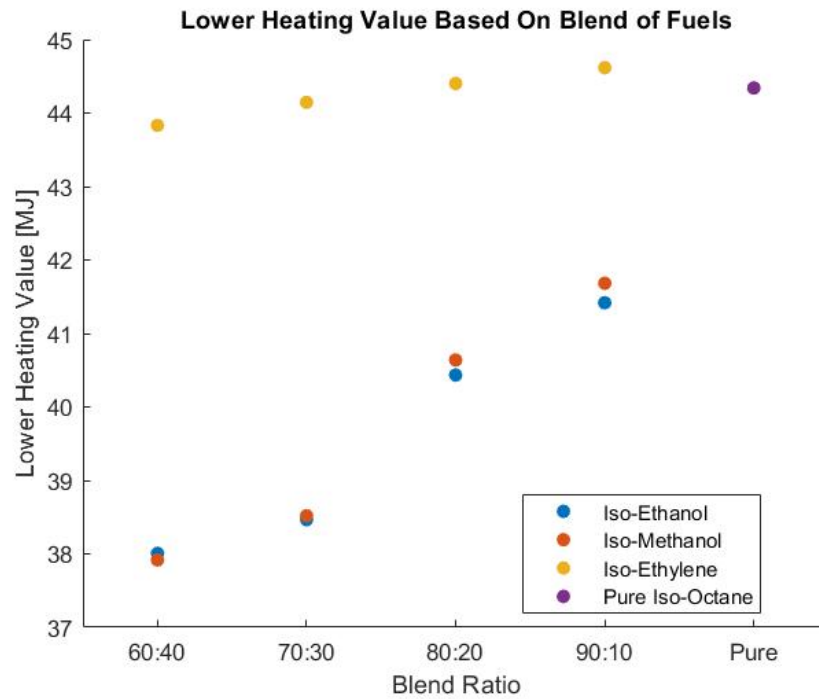


Figure 12 LHV of each fuel blend for 1Kg.

So, based from the required energy, the amount of carbon dioxide produced across 30Km trip would be:

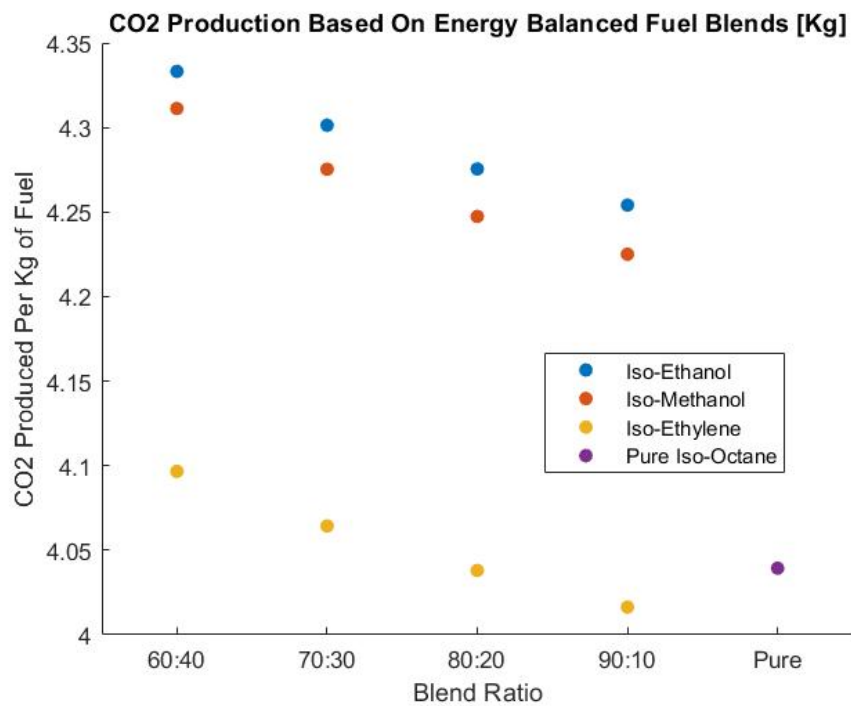


Figure 13 Potential CO2 produced across one half of the test cycle assuming stoichiometry.

Because of the requirements to obtain Ethylene from cracking of either naphtha or ethane being highly energy intensive, joint with its production via fermentation being reliant on the ethanol enrichment, it's hard to justify using it in comparison to methanol and ethanol blends (Madhav Ghanta, 2013). Therefore, another investigation into multi-blend fuel containing a minimum of 80% Iso-octane with either; 15% Methanol – 5% Ethanol, 10% Methanol – 10% Ethanol and then 5% Methanol and 15% Ethanol was conducted because of the multitude of sources for creation of both the alcohol fuels. Such as fermentation of sugars and starches, biomass waste and then if required, synthetic production from crude oils products (greener Industry , n.d.).

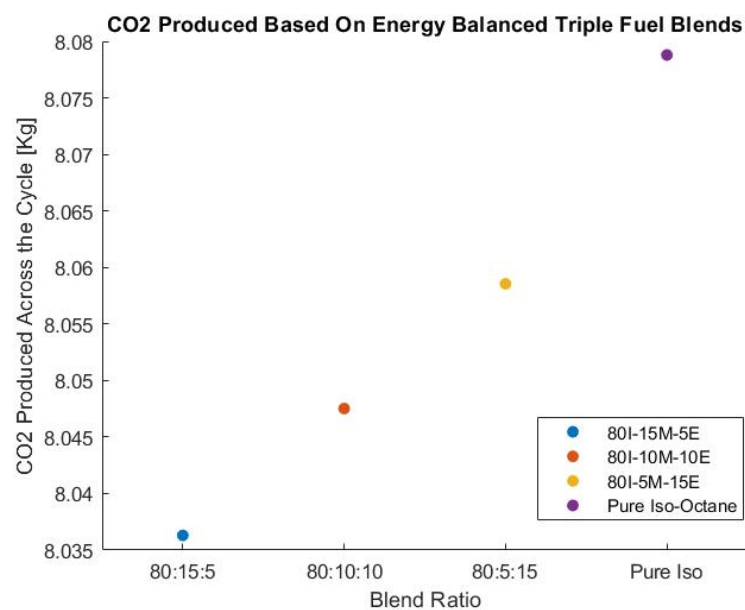


Figure 14 Triple Blended fuels and the stoichiometric production CO2 across the cycle.

From the graph it's clear that a blend consisting of 80% Iso-Octane – 15% Methanol – 5% Ethanol could potentially reduce the production of carbon dioxide across this testing cycle, albeit by a small amount. But given the potential for a reduction in external pollutants during production of said fuels, it could pose a more viable option for at least the near future fuelling of petrol ICE's. It's already been shown that the blend of Methanol – Petroleum can reduce the production of CO₂ by a potential of around 10% (Brinkman, Gallopoulos, & Jackson, 1975), Ethanol – Petroleum in the form of 'E85' fuel can reduce or remain equivalent; carbon monoxide, hydrocarbon and significantly reduce production of nitric oxides. Then with blends of all three fuels demonstrate less deviation in profile of gasoline combustion in comparison to E85 (Turner, Pearson, Bell, Goede, & Woolard, 2012).

A small investigation into implementation of a flywheel based kinetic energy recovery system was conducted using the assumptions that the vehicle was experiencing braking when acceleration was below -0.5 m/s^2 and that the system operated on a minimum efficiency of 70% (Boretti, 2010).

The integration construction of the KER system can be thought to follow the same as the following figure:

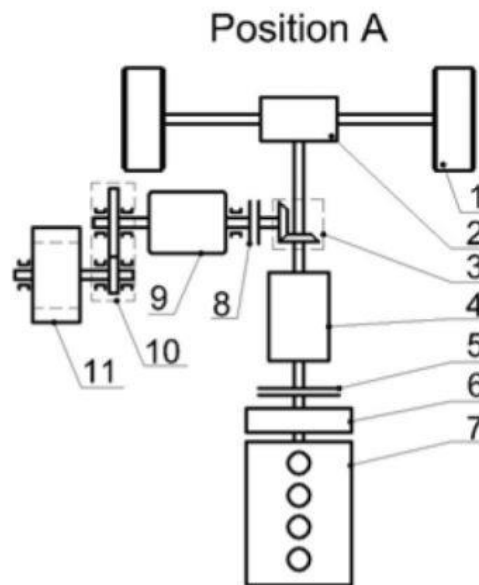


Figure 1. Mechanical KERS configuration 1-Vehicle wheel 2-Differential 3-KERS connection gearbox 4-Gearbox 5-Engine frictional clutch 6-Engine flywheel 7-IC engine 8-KERS clutch 9-CVT 10-KERS auxiliary transmission 11-KERS Flywheel

Figure 15 Construction of KERS into the drivetrain (Moro, Cavina, Trivić, & Ravaglioli, 2010).

Looking at the periods in which the vehicle appeared to be braking with a deceleration at a rate larger than -0.5 m/s^2 , the time spent doing so was found to be 20.753 seconds.

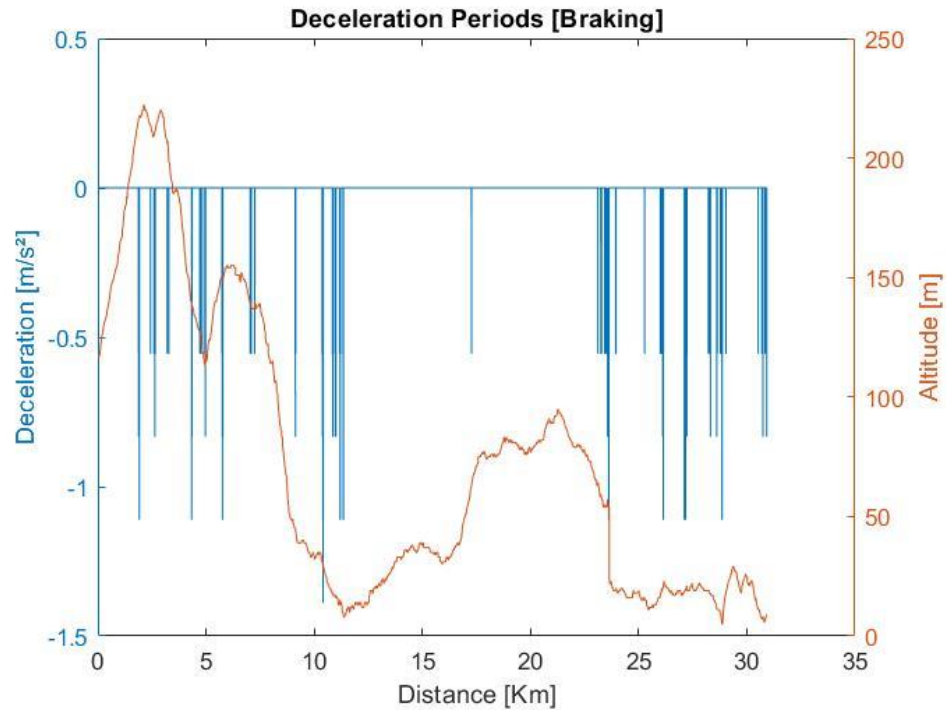


Figure 16 Braking periods of the Aygo with position of vehicle altitude.

Using a flywheel that has the capability to charge and discharge within a time period of 0.05 (s), a maximum energy storage of 400 KJ and maximum power storage of 30 Kw and a moment of inertia of $0.024 \text{ Kg}\cdot\text{m}^2$ and a mass of 13.4Kg. There is a potential to obtain 12.115 MJ of kinetic energy on the journey to university (assumption that it can do the same on the return), with 70% of that returned into the system, there is potential to charge and discharge the system 13 times each way with full power capacity reached.

Upon using this type of system integration, the proposed savings of:

	Original Equipment	KERS System	% Difference Original ICE & With KERS
1 Fuel Energy [MJ]	58.112	49.631	17.087
2 Fuel Mass [Kg]	4.0394	3.4499	17.087
3 CO2 Mass [Kg]	1.3106	1.1193	17.087
4 CO2 Production [g/Km]	130.62	111.56	17.087

Table 5 Difference between original vehicle and one fitted with KERS.

	Triple Blend Fuel	KERS & Triple Blended Fuel	% Difference Triple Blend Fuel & With KERS plus Fuel Blend
1 Fuel Energy [MJ]	58.112	49.631	17.087
2 Fuel Mass [Kg]	4.0182	3.4318	17.087
3 CO2 Mass [Kg]	1.452	1.2401	17.087
4 CO2 Production [g/Km]	129.94	110.98	17.087

Table 6 Additional change from triple blend fuel and fitment of KERS.

As can be seen, there is a definite advantage to including KERS within the powertrain because of the ability to harness what would otherwise be wasted energy produced by the fuel, for what has become a reasonable and affordable addition.

The final small study into a fully electric conversion was carried out using the following assumptions; a removal of power demand where the vehicle could be utilising “Stop Start” technology, full system efficiency of 75% because of the given operating equivalent ‘Engine Speed’ and torque demand, an energy density for a Lithium Ion battery being 0.72 MJ/Kg, the final that the energy to get back from University would be the same.

The required energy at the wheels across the cycle can be shown to be:

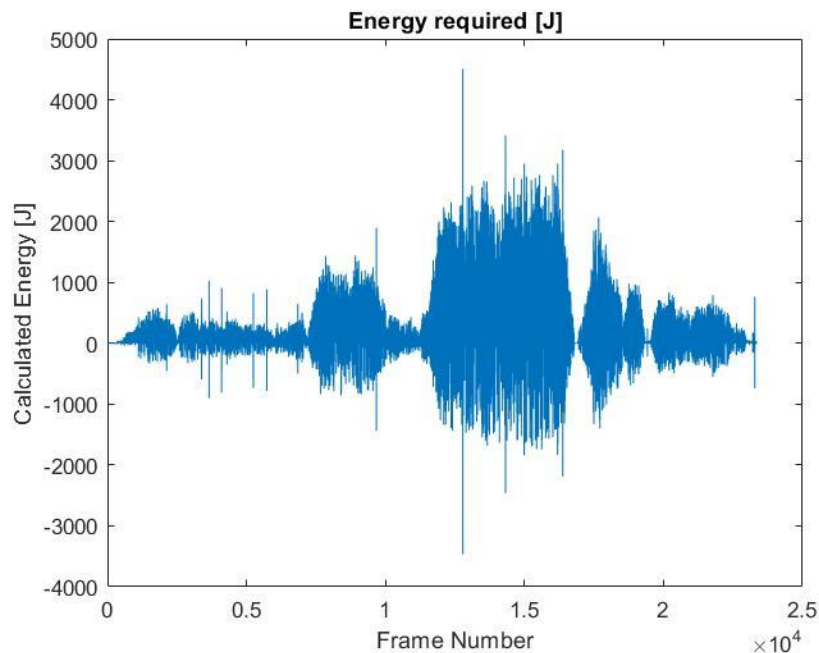


Figure 17 Required energy across half the cycle.

Considering this requirement and a 75% system efficiency and that the depletion of the battery would decline rapidly once it drops below 20% charge. The actual energy

in storage would be required to give a minimum of 21.9 MJ, making the minimum battery weight be 30.5 Kg in order to complete the full cycle.

The using the idea that the original three-cylinder engine and its accompanying five speed manual transmission would collectively weight around 160 Kg. Using a motor (P400RS) and system controller (Si400) provided by YASA, including its fluids and connectors, contributing to a collective mass of 44 Kg. There is 116 Kg left to replace with battery's in order to maintain a "like for like" situation, meaning no change in forces required at the wheels, allowing the vehicle to repeat the 30Km distance of the cycle 7.65 times before depletion, meaning it could cover 146.95 miles on one charge.

5. Vehicle Specifications

Given this testing cycle, it could be shown that using a fully electric vehicle specification would pose to prove the best emissions values. Because of its ability to complete at the very least, a possible 147 miles. This is without taking into the consideration there would be prolonged periods at the start and middle, where the vehicle could be charged to well above 80%, if not fully across a minimum time period of eight hours.

If the testing cycle were to be considered a representation of a homologation cycle, alike the 'New European Driving Cycle', where the CO₂ usage of the original could be considered as an equivalent of the stated 95 g/Km across the NEDC. It would also pose a viable option, given the fleet usage fines motivation, to investigate the development of alternative fuel types, from further investigation into production and development of the alcohol-based fuels. Or to develop more sophisticated synthetic fuels from otherwise wasted materials already in the atmosphere, from recycling otherwise waste biomass or development of more organic based fuels.

But the argument could be made that, with the smaller capacity engines, there is an indefinite requirement to use forced induction methods with the engine to not only harness waste energy but increase efficiency of the engine. This could be used in conjunction with a kinetic energy recovery system to develop a highly efficient vehicle capable of defeating the drive cycle, about emissions. Along with giving a more reliable, sustainable and comfortable driving car, that is the economically friendly, powerful and could be developed at a competitive price in comparison to equivalents in the market.

Given the perspective of impending time and economic pressures, the most viable option for this vehicle would be to swap the original low efficiency, low power internal combustion engine and replace it with a much more capable fully electric system.

	Toyota Aygo X-Pression	
	ICE	YASA Electric Motor & Controller
Type	Three Cylinder ICE	Single Motor
Max Power [Kw]	51	160 [60 continuous]
Max Torque [Nm]	95	370 [200 continuous]
Powertrain Cost	£3,900	£10,000
Battery Cost	-	£3,645
Original Cost	£12,840	-
Additional Costs	-	£9,745
Total	£12,840	£22,225

Table 7 Comparison of electric and original ICE.

The motor and electronic controller would be supplied from YASA for a price of £10000 (Appendix D), and by using a Lithium ion battery pack with a suspected price of £157/Kw·h (Goldie-Scot, 2019), the vehicle would require an expected sales price of around £22,225, an increase of 73% in cost.

Although this cost difference could be seen as excessive, the price is a fair match with many of the “hot hatches” of the competing market. This vehicle would have the competitive capability, comfort, driveability and style to compete, while maintaining an essentially zero emissions prospective regarding travel of the vehicle. Which could in turn bring down the fleet production of CO₂ for the manufacture and dramatically reduce the potential fines incurred, all the while being able to invest into research and future technologies to ever forward the industry in time for the major change of no more petrol, diesel or hybrids.

6. Conclusion

To summarise this report, the ability to collect raw valid data has most definite become more readily available for the many and may no longer be said to require 'professional' equipment. But because of the sheer magnitude of differences between vehicles in todays age, their individual operating efficiencies and the magnitude of contributing effecting factors, it's thought that the data provided within the open applications and their accompanying "processing" software's, they most definitely lack validation and can provide data that is of no use for anything. So, from an engineering prospective, the more developed and subsequently expensive the software and hardware, the more adequate and valid the data.

From the multiple small studies into each vehicle, its apparent that the differences between the supposedly 'dirty' diesel vehicles and gasoline vehicles is somewhat negligible in this day in age. Given the multiple emissions 'aftercare' devices now integrated as standard on most diesel vehicles, three-way catalytic converters, ad-blue systems and exhaust gas recirculation, the current diesel vehicles and far exceeding the ability of gasoline engines for the same if not better costs.

With respect to future technologies, it is still difficult to currently justify the difference in cost of a fully electric vehicle when there is a large chain of major polluting factors in harnessing the materials, production of the motors and batteries, along with the lack of recyclability and the cost of researching in the first place. Especially given that diesel vehicles can do around 2 – 3 times the mileage, for half the price in terms of vehicle cost and gasoline is getting more and more efficient in the recent years due to the aggressively changing regulations. Given the current state of global warming and pollution concerns, it's certainly a step in the right direction, but it's thought it shouldn't be depended upon as the future of powertrains, given the lack of facilities and infrastructure alone.

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8. Appendices

Appendix A

The following graphs are the auxiliary channel inputs from each of the vehicles given data, that has then been normalised against distance travelled by the vehicles, instead of the frame number that is representing the time steps in recorded data.

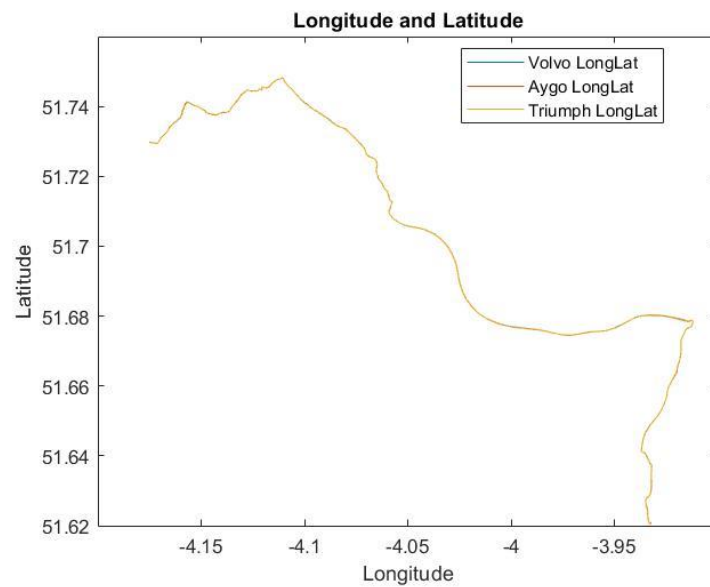


Figure 18 Overlay of the three vehicles recorded longitude and latitude path.

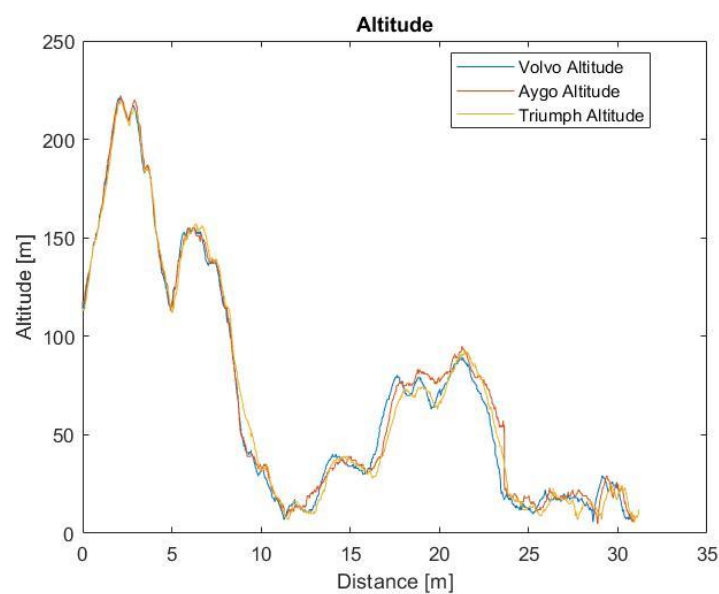


Figure 19 Overlay of each vehicles recorded altitude.

Both graphs are showing that the three vehicles tested, maintained the same course and therefore making the data a fair comparison of only the vehicles efficiency and driveability, not the individual manufacturers personal technologies implemented to pass the NEDC homologation test.

It's also shown that each vehicle was able to achieve the same sort of speeds during each section of this real world driving cycle, so the transferred engine speeds can then be used to get a good understanding of their own efficiencies, as a result of vehicle load and transmission design.

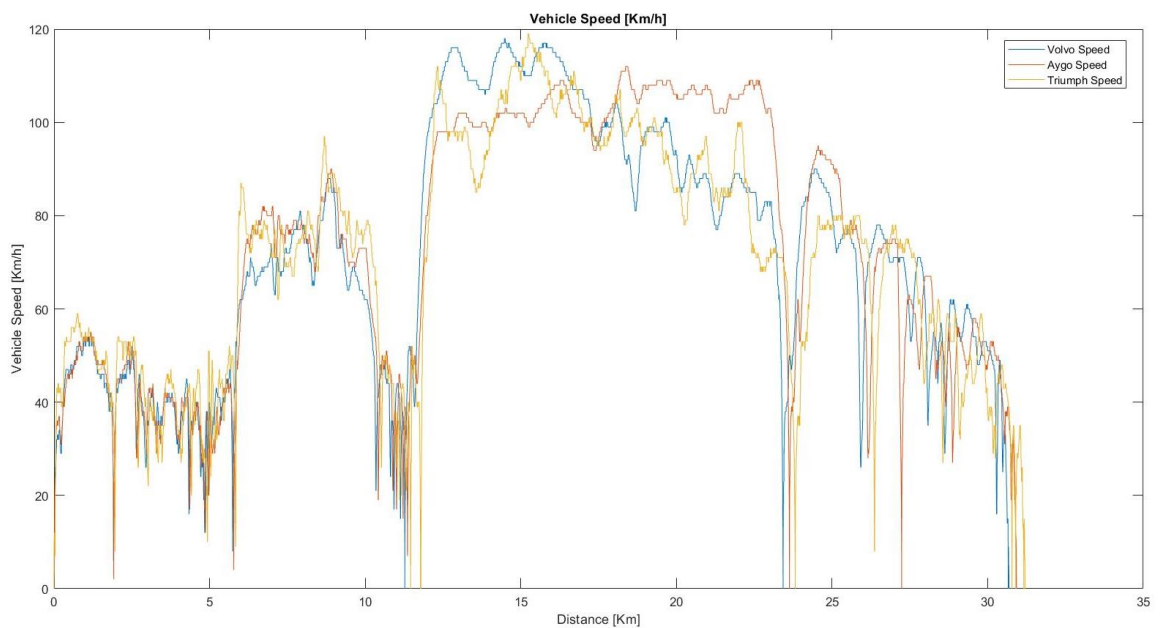


Figure 20 Individual vehicles speed during the course of the cycle.

Appendix B

In order to gain a better understanding of load placed upon the actual engine within the vehicle and not just the demand at the wheel, the gear the vehicle was in at each point was required. This is because of the multiplication nature of the transmission and the vast differences that could come from potential losses within. Because a transmission is only able to transmit a certain percentage of its inputted torque, due to losses in the form of heat from frictional contact and then sound because of the mechanical contact operation. The clutch could also produce losses if there were to be slippage occurring between the frictional contact faces and the clutch plate/s.

An average efficiency of the transmissions were taken to be 95% efficient. There are many factors to consider, from temperature of the transmission that will affect oil viscosity, to mechanical wear within the components and frequency of use with the provided torque. So, because of the low speed high torque attribute of first gear, it will not be as efficient as perhaps fifth gear because it has much less torque to transfer because the vehicle will already be travelling at high speeds and will most likely not require hard acceleration.

In order to correctly assign which gear was being used for each period of the test, the specified ratios for the vehicles were required. Each of which were given either in the data sheet provided or a workshop sheet available from the manufacturer. Below are the ratios of each gear for each vehicle used.

	Test Vehicle Characteristics		
	Volvo V40 D2	Toyota Aygo X-Pression	Triumph Tiger 800 XC
First Gear Ratio	3.583	3.545	2.313
Second Gear Ratio	2.050	1.913	1.857
Third Gear Ratio	1.267	1.310	1.500
Fourth Gear Ratio	0.838	1.027	1.285
Fifth Gear Ratio	0.617	0.850	1.136
Sixth Gear Ratio	0.510	-	1.043
Final Drive Ratio	4	3.550	3.125
Primary Drive Ratio	-	-	1.667
Reverse Gear Ratio	2.833	3.214	-

Table 8 Individual Vehicle Gear Ratios.

With these it led to the gear positions being calculated by matching the engine speed to the SAE measured engine speed channel. This was done using the simple relationships that relates the forward linear velocity to engine speed;

$$V = r\omega$$

$$\omega = \frac{V}{r}$$

With V as linear speed in m/s and r as the rolling radius of the wheel in meters.

Then using;

$$\omega_{at\ wheel} \cdot FD_{ratio} \cdot Gear_{ratio} = \omega_{of\ engine}$$

With the FD_{ratio} being the fixed final drive ratio and Gear ratio being the correct ratio of the chosen gear, the engine speed can be found and correctly matched against the measured engine speed provided in the data.

Also to be noted the motorcycle also includes the primary drive ratio that is simply used in the multiplication occurring on the left hand side of the above equation.

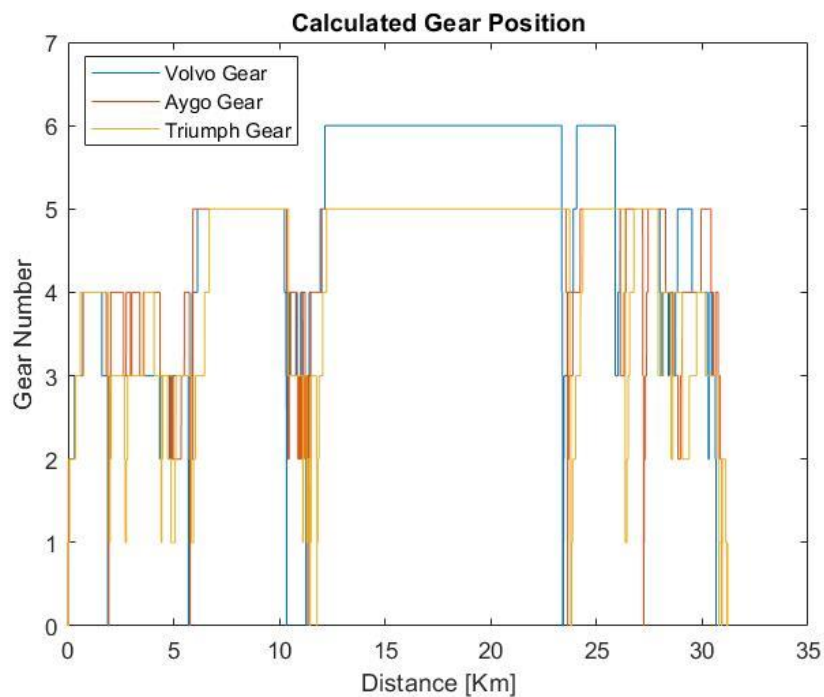


Figure 21 Found gear selections for each vehicle used during the cycle.

Then as can be seen underneath, the predicted engines speeds match the real measured with an average accuracy of; 98.95%, 98.9% and 99.82% for the Volvo, Aygo and Triumph respectively. There are some major discrepancies within the prediction modelling that occur at the points in which the clutch is depressed because of the unpredictability and inconsistency from vehicle to vehicle, due to the drivability of the vehicle. Then also amount the braking points, these occasionally caused discrepancies.

The smaller differences in prediction to real speed also comes from the rolling radius of the wheel because of it's use within transferring the linear vehicle speed, into angular speed at the wheel. This radius will change consistently as the vehicle travels due to road surface changes, road pitch changes and then cornering because of the weight transfer the will occur on the car will change the contact patch loading condition. And although the change may be small it's enough to cause modelling issues.

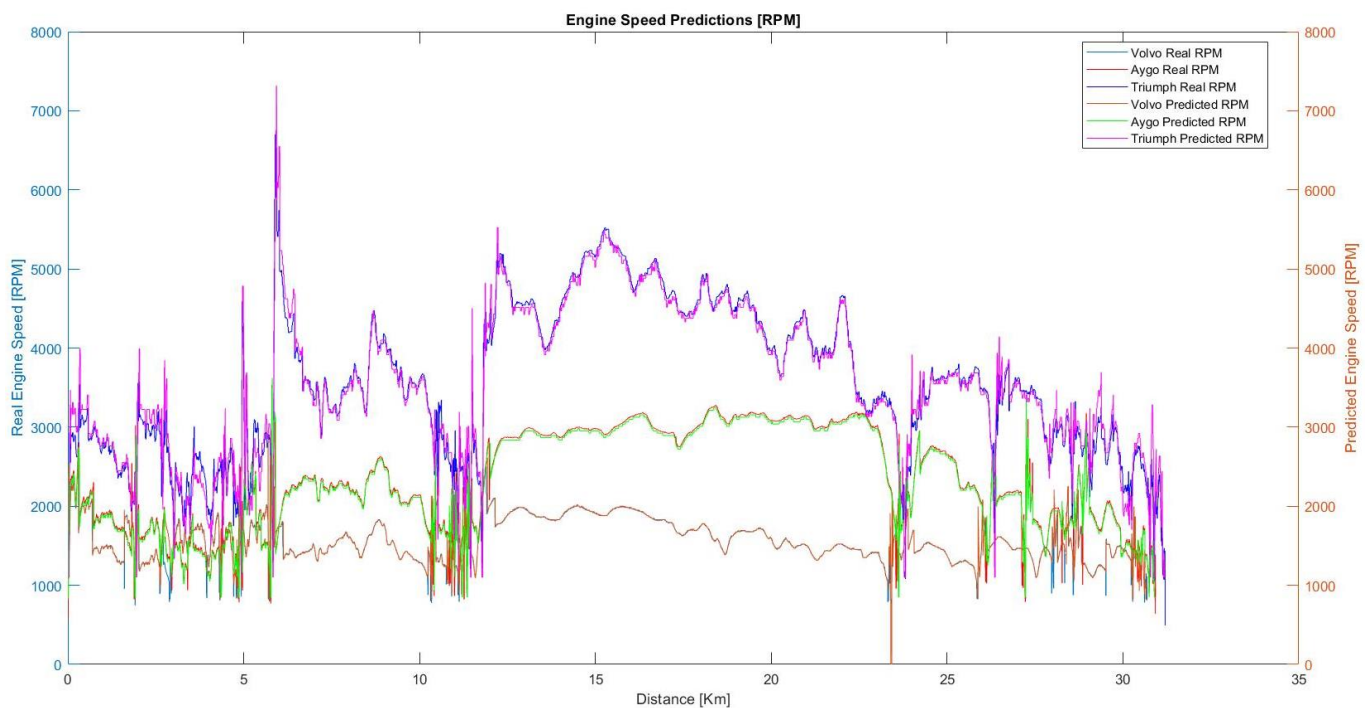


Figure 22 Engine speed predictions based off matching selected gears.

Appendix C

Load differences with respect to the maximum pressure capability for each the vehicles in order to represent the lack load required during this testing cycle. Because of the similarity in uphill to downhill sections is can be presumed that the load demand would be similar for the return section of this testing cycle.

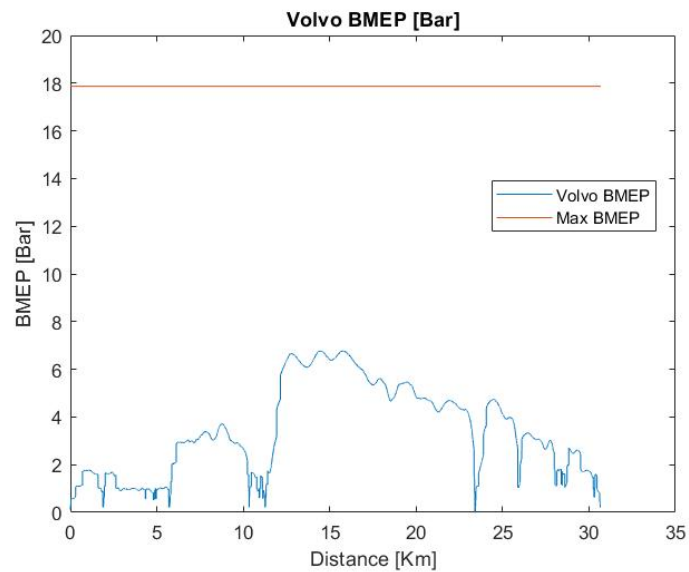


Figure 23 Volvo BMEP Across cycle in comparison to maximum capable pressure.

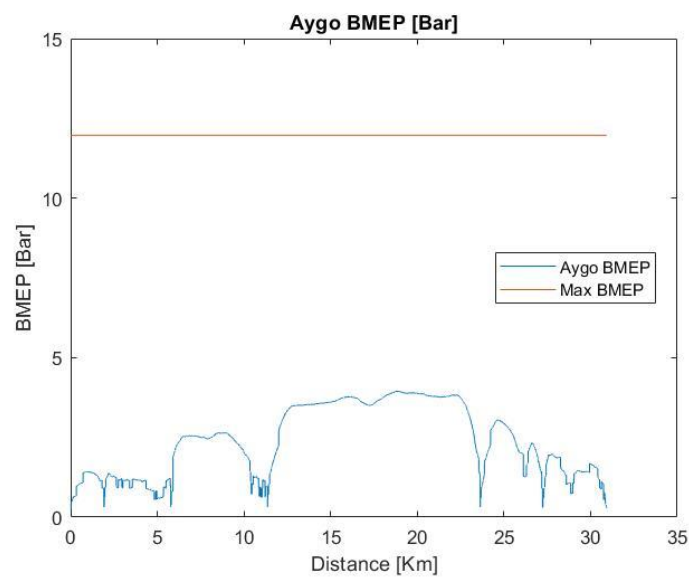


Figure 24 Aygo BMEP Across cycle in comparison to maximum capable pressure.

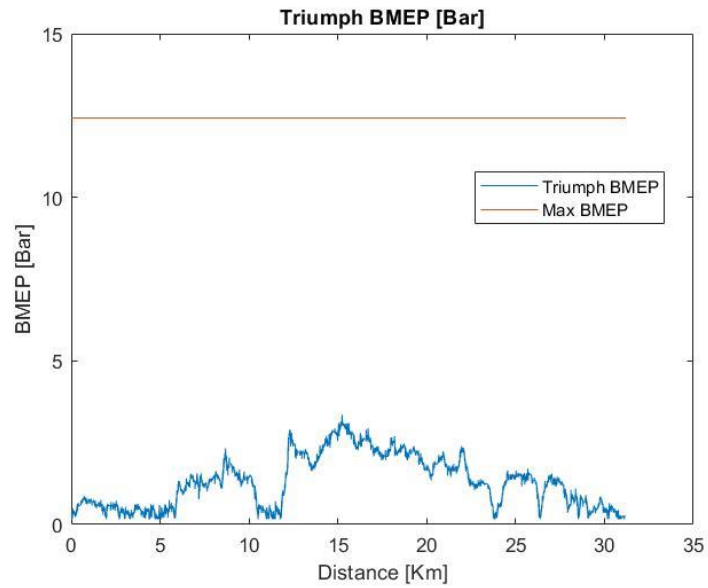


Figure 25 Triumph BMEP Across cycle in comparison to maximum capable pressure.

Appendix D

Mechanical

Casing Diameter	305 mm
Mounting 8x Ø8.3	294 mm PCD
Axial length	106.7 mm
Dry Mass	28.2 kg
Stator Cooling	Oil

Electrical

Peak Torque @450 A	up to 370 Nm
Continuous Torque	up to 200 Nm
Peak Power @700V	160 kW
Continuous Power	up to 60 kW
Maximum Speed	8000 rpm

Table 9 Motor Specifications (YASA, 2020).

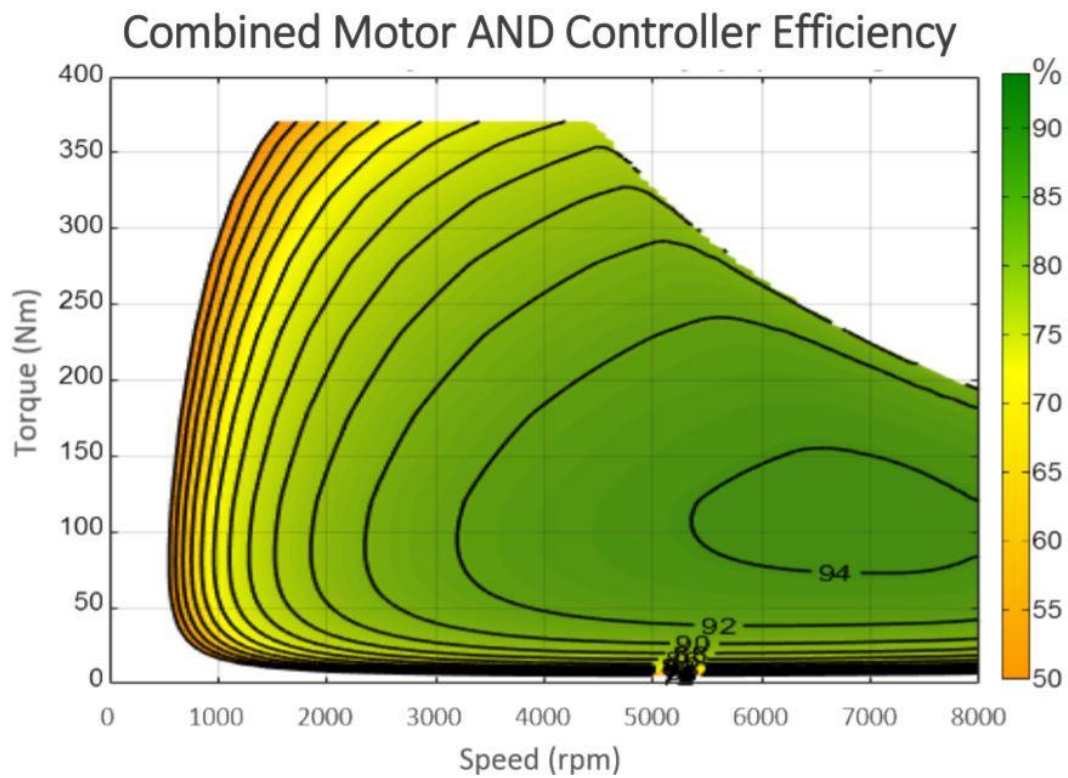


Figure 26 Motor & Controller Efficiencies (YASA, 2020).

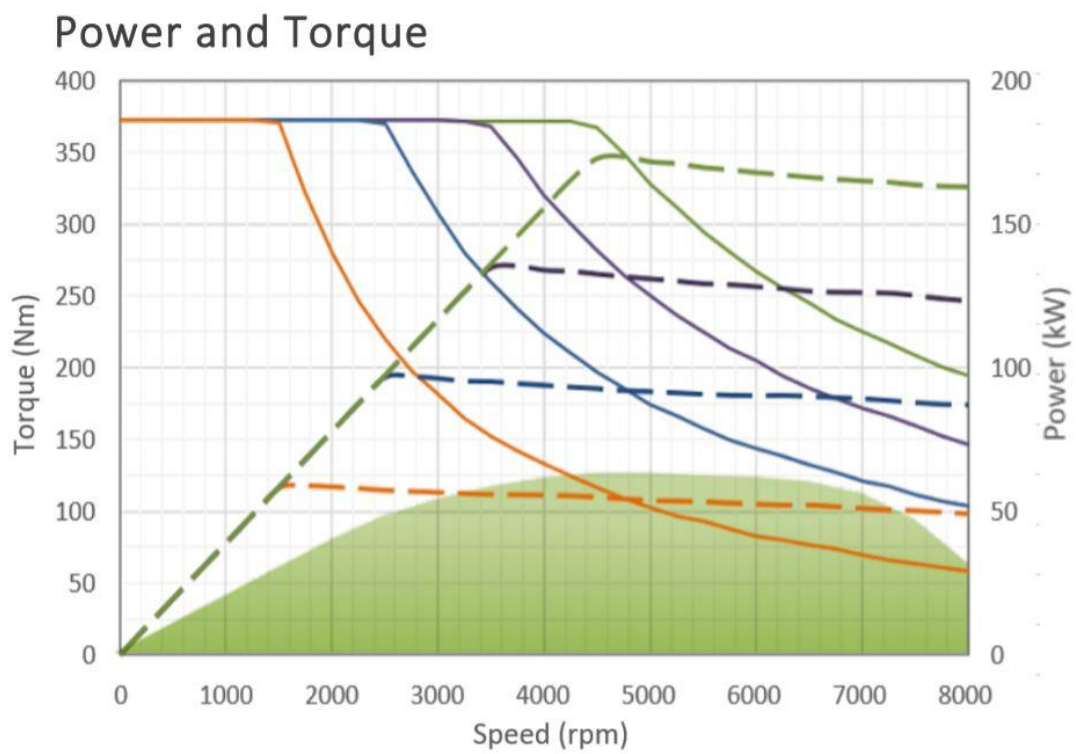


Figure 27 Motor Power and Torque Figures (YASA, 2020).