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Research School of Engineering

ENGN 2226– Systems Engineering Analysis

Research Portfolio

A comparison of New European Driving Cycle to US Federal Test Procedure, with particular emphasis on the accuracy of cycles compared to real life driving data

Date: Monday 17th October

Student Number: u6124465

ENGN2226 Research Portfolio Coversheet

Submission and assessment is anonymous where appropriate and possible.
Please do not write your name on this coversheet.

Student ID: u6124465

Portfolio Topic or Research Question:

A comparison of New European Driving Cycle to US Federal Test Procedure, with particular emphasis on the accuracy of cycles compared to real life driving data

Analysis Tools

Place an 'x' next to each of the eight research methods and system perspectives you have engaged with:

	Research methods		System perspectives
X	R01: Research question	X	S01: Social & cultural
X	R02: Surveys and interviews	X	S02: Safety & risk
X	R03: Quantitative & qualitative		S03: Anthropometrics
X	R04: Data organisation	X	S04: Planning approaches
	R05: Research ethics		S05: Queue theory
	R06: Coding research data		S06: Process control
X	R07: Error types	X	S07: Control theory
X	R08: Descriptive statistics	X	S08: Material impact
X	R09: Hypothesis testing - populations	X	S09: Energy-mass balance
X	R10: Hypothesis testing - categories	X	S10: Energy efficiency
	R11: Simple linear regression	X	S11: Life-cycle cost
	R12: Confidence intervals		S12: Payback period

Any comments to the reviewee

Contents

Abstract

This portfolio documents the research methods and systems perspectives applied to compare the NEDC and FTP driving cycles, and comparing the accuracy of the results against real life data. The report describes, analyses and provides recommendations for the individual test cycles. Driving cycle are specific tests performed on vehicle to simulate driving conditions and predict carbon emissions and fuel consumption.

It was found that in fact both test results varied considerably from actual data of the fuel consumption and CO_2 emissions of the vehicles. A discussion of possible causes and recommendations for adjustments of the driving cycles is contained within the summary section of this portfolio.

There were numerous learning outcomes to this assignment. It developed students' skills of crafting a research question and a resulting research portfolio. The report also demonstrated the uses and importance of rules of thumb, research methods and systems perspectives. The link between theory taught in the classroom and real life applications are not always clear and this report helped strengthen the link. The portfolio also offered a view of what working as a systems engineer would be like.

Introduction

A driving cycle is a standardised test performed on vehicles to test fuel economy and exhaust emissions levels. Driving cycles aim to mimic typical usage of the vehicles. The tests are generally performed on rolling road (chassis) dynamometer. The test cycles typically attempt to simulate common driving situations e.g. urban driving, motorway driving.   However test cycles vary from country to country, the two most advanced being the US test cycle, comprising of the FTP – 75 (Federal Test Procedure), EPA City cycle and the EPA Highway Fuel Economy, and the European cycle, NEDC (New European Driving Cycle) comprising of the Urban Driving Cycle and Extra Urban Driving Cycle. Vehicle emissions are affected by driving patterns, traffic speed and congestion, altitude, temperature and other ambient conditions; by the type, size ,age and condition of the vehicles engine; and , most importantly, by the emission control equipment and its maintance (Faiz, Weaver, & Walsh, 1996).

The aim of this Research portfolio is to compare the FTP to the NEDC, for light-duty vehicles. The comparison will focus on the test cycles' accuracy compared to real life data for vehicles.

The issue of the discrepancy between test results from both cycles to real world data became the subject of public controversy when it was discovered that Volkswagen was installing "defeating devices". These devices were able to detect when the vehicles was being tested and to control the emissions switch, pumping out nitrogen oxide when the testing had be completed.

Motor vehicles emissions is a major contributor to urban pollution and the production of ozone. The emissions from the exhaust of a vehicles typically contains Nitrogen, water vapour, Carbon Dioxide, Carbon Monoxide, Nitrous Oxides and unburnt hydrocarbons. Carbon Dioxide is a greenhouse gas, contributing to global warming, and with global motor vehicles sales increasing yearly the levels of CO_2 are expected to increase to 500 ppm by 2020 the highest CO_2 concentration in 3 billion years (United States Environmental Protection Agency, 2016). Carbon monoxide, unburnt Hydrocarbons and Nitrous Oxides are all toxic emissions, and estimated to cause 53,000 early deaths in the United States each year. (Caiazzo, Ashok, Waitz, Yim, & Barrett, 2013). Motor vehicle emission also hugely impact air quality in cites and are the main component of smog. It is estimated that motor vehicles contribute to 72% of all carbon monoxide emissions, 70% of all nitrous oxide emissions and 6% of all sulfur dioxide emissions in Melbourne (EPA Victoria, 2016).

Fuel consumption and emissions are directly proportional, the higher the fuel consumption, the higher the fuel emissions. To get an accurate depiction of the driving cycles to real life data, both fuel consumption and emissions will have to be considered.

Approach

The NEDC and FTP cycles will be compared using a systems engineering approach, focusing particularly on research methods and systems perspectives. Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. Systems engineering integrates all the disciplines and specialties of engineering. (INCOSE - International Council on Systems Engineering, 2016) The comparison will focus on the test cycles' accuracy compared to real life data for vehicles. In order to compare the data for the two tests cycles, research will need to be obtained and analysed. After comparisons between NEDC performance and FTP of light weight vehicles, the cycles will be compared to real life driving data from Spritmonitor.de and ICCT (International Council of Clean Transport).

Every research assignment, regardless of the topic or discipline all starts with one essential step – crafting a research question. A research question is the fundamental core of a research project, study, or review of literature. It focuses the study, determines the methodology and guides all the stages of inquiry, analysis and reporting (Research Rundowns, 2016).

The research problem I chose was the problem of the real world data of fuel efficiency and emissions of light-duty vehicles, not matching the results from the NEDC and FTP driving cycles. This lead to the research questions of "*how much do the respective driving cycles results differ from each other?*" and *"how much do the results from the driving cycles differ from real world data?".* It also rose the question of *"what could be done to improve the driving cycles for more accurate results?".*

New European Driving Test Cycle

The NEDC was first implemented in 2000, replacing the MVEG-A test cycle. The biggest difference between the NEDC driving cycle and the MVEG-A cycle is that the NEDC has a cold-start i.e. the car cannot be left running before the test to heat the engine. The NEDC was designed to represent typical car usage in in Europe, seen in Figure 1 below. Originally the NEDC was designed for petrol cars but has since been used on diesel cars also. More recently the NEDC has been used on electric vehicles and Hybrid cars to estimate emissions and fuel consumption.

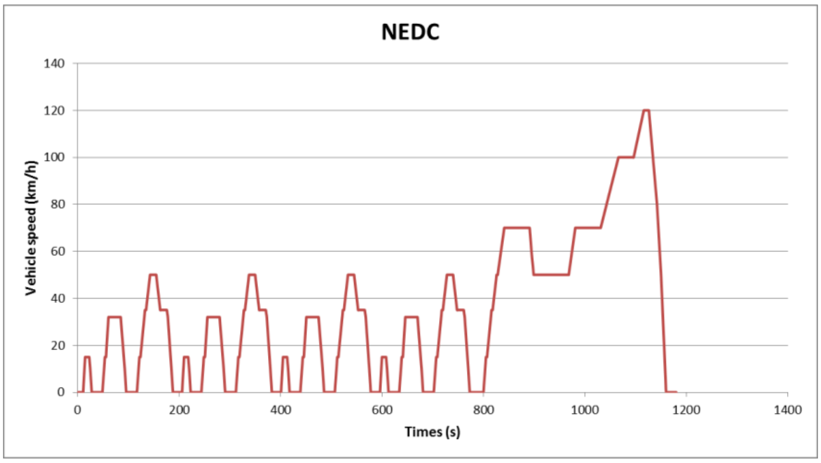

Figure 1 NEDC Test cycle

The NEDC measures:

- Urban Fuel Economy (fuel economy in parts of cycle that simulate Urban Driving)
- Total Fuel Economy (fuel economy over the entirety of the test cycle)
- CO_2 emissions levels
- Carbon Monoxide Levels
- Nitrogen Oxides

Test procedure

The test is carried out on a vehicle between 20-30 °C on a rolling road dynamometer. This insures repeatability and that the results are not affected by wind. The resistance of the dynamometer can be adjusted for several different classes of vehicles to simulate aerodynamic drag and the inflow of air into the engine is provided by fans. All ancillary loads (radio, air-conditioning etc.) are turned off for the testing. As seen from Figure 1, the test begins with the 4 repeats of the ECE cycle (Figure 2). The ECE cycle represents urban driving. There is a low vehicle speed and load to simulate driving in high congestion traffic and at low urban speeds. The exhaust temperature during this part of the driving cycle is low as a result. The maximum speed during this section of the cycle is 50 km/h.

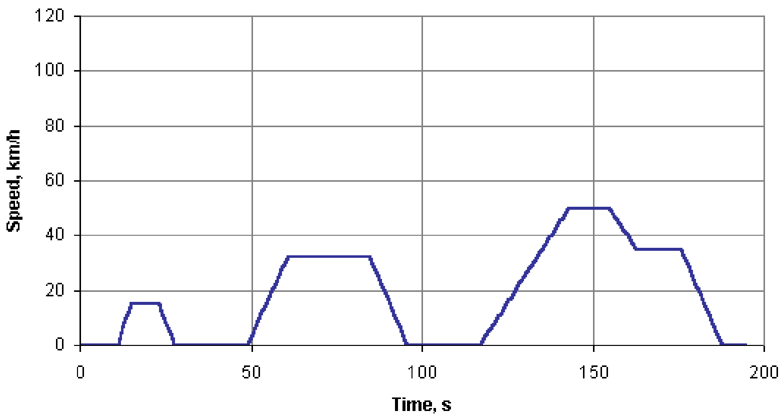

Figure 2 ECE Cycle

Next the EUDC (Extra Urban Driving Cycle) is performed. This segment has higher speeds than the ECE, with a maximum speed of 120 km/h. It was introduced to represent much aggressive driving with higher loads.

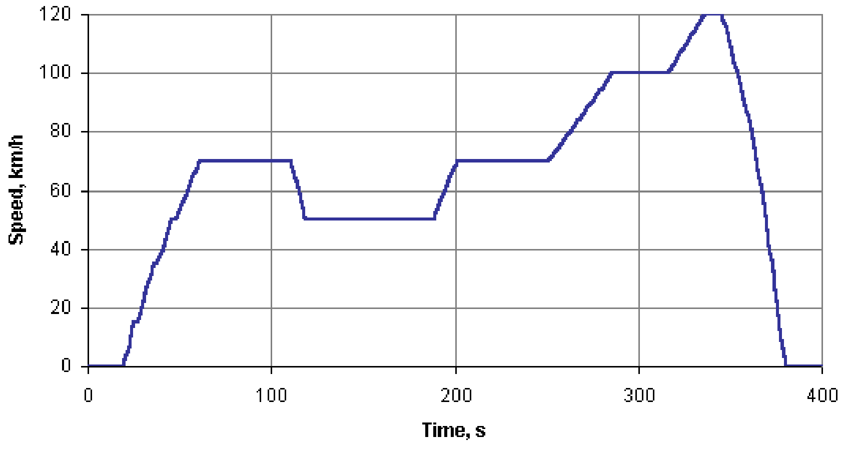

Figure 3 EUDC Cycle

Characteristics	Unit	ECE 15	EUDC	NEDC†
Distance	km	0.9941	6.9549	10.9314
Total time	s	195	400	1180
Idle (standing) time	s	57	39	267
Average speed (incl. stops)	km/h	18.35	62.59	33.35
Average driving speed (excl. stops)	km/h	25.93	69.36	43.10
Maximum speed	km/h	50	120	120
Average acceleration[1]	m/s^2	0.599	0.354	0.506
Maximum acceleration[1]	m/s^2	1.042	0.833	1.042

† Four repetitions of ECE 15 followed by one EUDC
[1] Calculated using central difference method

Table 1 Parameters tested during NEDC

Federal Test Procedure

Unlike the NEDC, which is a synthetic cycle, the FTP cycle was derived from real world driving data. The FTP starts with a cold start, but later in the test the start is repeated with a hot start. Initially it was designed for vehicles powered by fossil fuels but has recently been used on electric vehicle as an estimation of the range on a single charge. The test attempts to simulate the driving typical driving usage in the United States. The FTP cycle is also implemented in Australia under the name ADR 37 (Australian Design Rules 37).

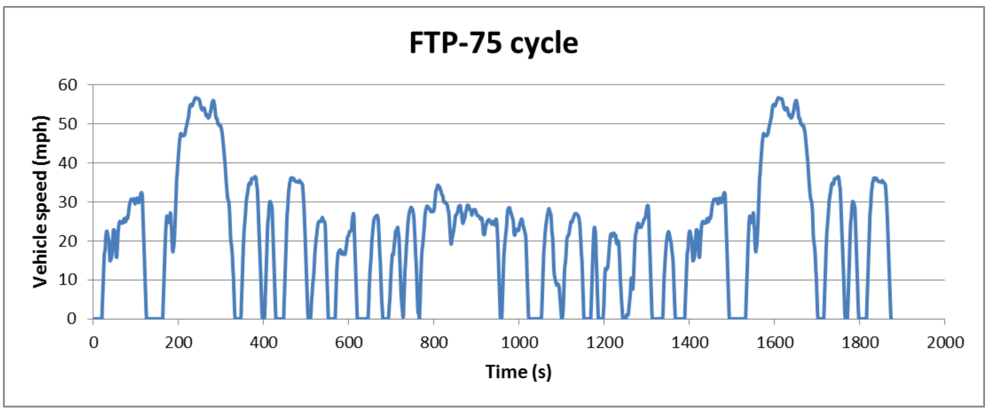

Figure 4 FTP- 75 Cycle

The FTP cycle simulates urban driving, cars travel 17.77 km for 1876 seconds, with an average speed of 34.1 km/h. the maximum speed is 91.3 km/h. From Figure 4 it is clear the test consists of 4 parts:

- Cold start phase (0-505 sec)
- Stabilised phase (506-1372 secs)
- Hot soak phase (min of 540 secs and a max of 660 secs, during this phase the engine is stopped)
- Hot start phase (0-505 sec, identical to cold start phase except the engine has been heated up)

The FTP is also performed on a rolling road dynamometer, with all ancillary loads turned off.

NEDC vs FTP

	NEDC	**FTP**
Duration	1180	1876
Stop duration	293	367
Distance	11013 m	17780 m
% stopped	24.8%	19.6%
Maximum velocity	120 km/h	91.3 km/h
Average velocity without stops	44.7 km/h	34.1 km/h
Average velocity with stops	33.35 km/h	33.6 km/h
Maximum acceleration	1.04 m/s^2	1.48 m/s^2

Table 2 Comparison between NEDC and FTP

Qualitative Analysis

Because of the data intensive nature of this research assignment it is important to understand the two main types of data – quantitative and qualitative. Quantitative is data which can be recorded in numbers e.g. fuel consumption in litres/100 km. Qualitative data is information about qualities, which cannot be recorded in numbers e.g. the colour of a car. Quantitative and qualitative data provide very different outcomes, but are often used together during research of a population to best represent it, e.g. occupation of car owner (qualitative) and annual income of car owner (quantitative). It is very important to be aware of the difference between qualitative and quantitative data, as descriptive (summary) statistics can be applied to both, though it is more difficult to use for qualitative. To apply to qualitative data, numeric values need to be applied to categories of data and results are limited. However inferential statistics, (by making inferences projections for total population can be made) cannot be applied to qualitative data.

It is important to be aware of the type and limitations of data. The majority of the data that will be used in this research assignment will be quantitative, focusing on fuel consumption and CO_2 emission data. The research looks predominately at numerical engine data and graphs however it does include some qualitative data such as description of car, fuel type manual or automatic etc.

Data organisation is the logical ordering of data to increase the efficiency of working with the data. When dealing with a large amount of data it is easy for it to become disorganised and difficult to work with. It makes it easy for valuable information to be lost or mixed with another set of data. To prevent this from happening it is very important at the start of any research assignment to organise a filing system before you start collecting data, or very early in the data collection. At the start of this research assignment, separate folders were made to hold the results for the FTP and NEDC cycles and any other information about the cycles. The information was separated at the start to prevent mix-up as many of the results could be mistaken for the other test cycle. Tables and graphs are an essential part of this report, making it easy to compare values and display important information.

To compare the two driving cycles, ADVISOR Software from NLEC. Using the software the results of NEDC and FTP could be plotted. The car I chose was the Ford Focus Hatch, manual, 1.8L Diesel, representative of the light duty vehicles and a popular choice in this class of car.

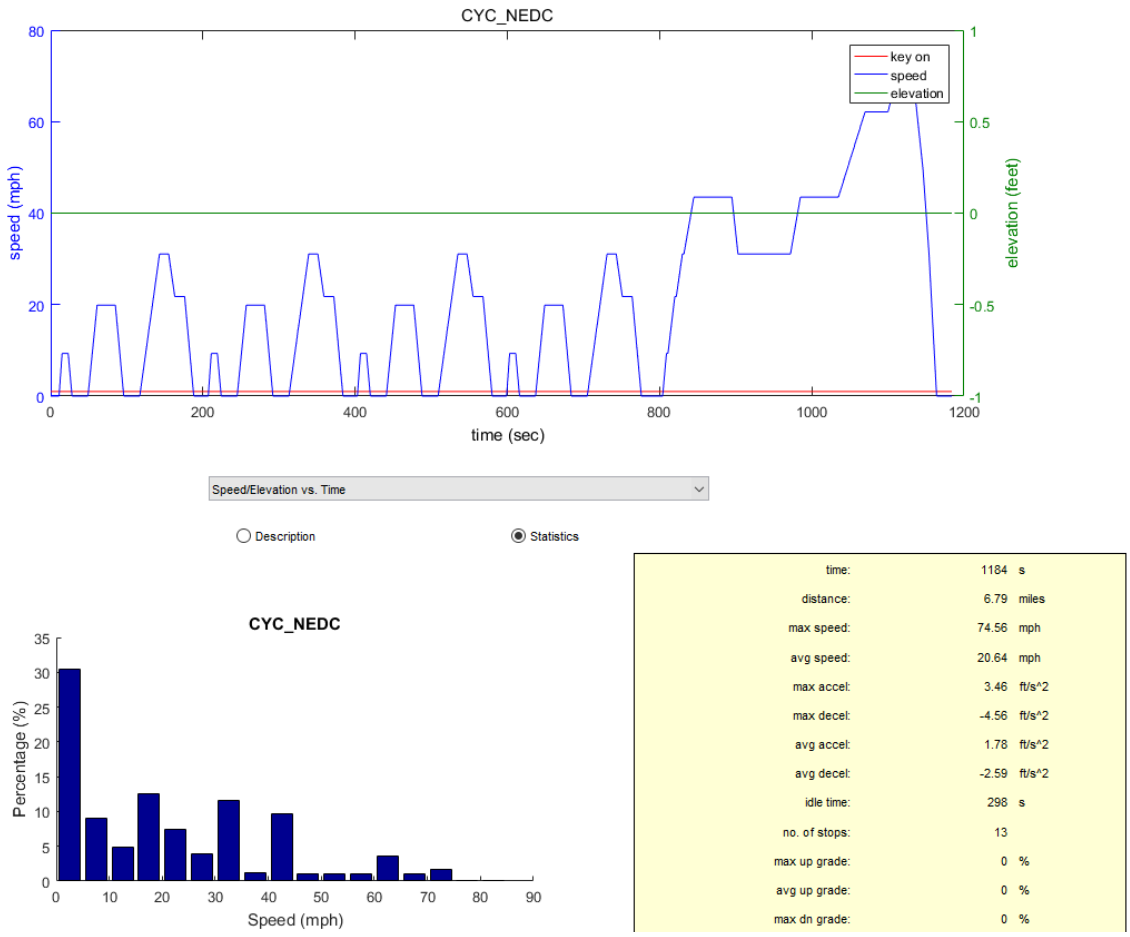

Figure 5 NEDC results for Ford Focus

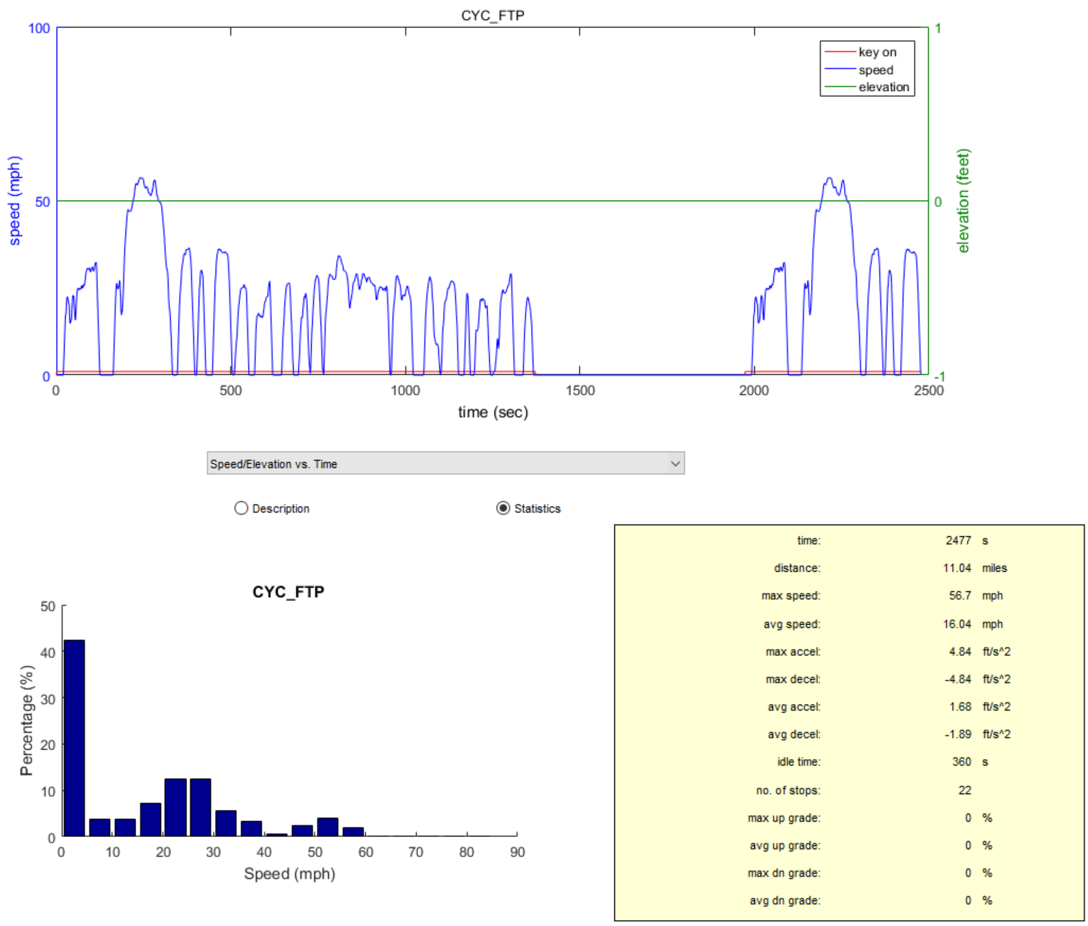

Figure 6 FTP results for Ford Focus

Descriptive statistics is the term given to the analysis of data that helps describe, show or summarize data in a meaningful way such that, for example, patterns might emerge from the data. Descriptive statistics do not, however, allow us to make conclusions beyond the data we have analysed or reach conclusions regarding any hypotheses we might have made. They are simply a way to describe our data (Laerd Statistics, 2013). The use of descriptive statistics has essential in the determining of the average speed and fuel consumption of each stage in the cycle and the overall driving cycle.

It was extremely difficult to find the actual results from individual ECE and EUDC and FTP 75 to use in the following equations. As it wasn't possible to perform the experiments myself I had to rely on results from reputable sources. The results of the fuel consumption and CO_2 were found using the Ford buyers' brochure (both European and US) for Ford Focus Hatch, manual, 1.8L Diesel engine car. The buyers' brochure quotes the values of the NEDC and FTP.

To calculate the predicted fuel consumptions the following equations would be used:

$$NEDC\left[\frac{km}{l}\right] = 4 \times ECE\left[\frac{km}{l}\right] + 1 \times EUDC\left[\frac{km}{l}\right]$$

$$FTP\left[\frac{km}{l}\right] = \frac{1}{\left(0.003259 + \frac{1.3466}{FTP\ 75\ \left[\frac{km}{l}\right]}\right)}$$

To calculate the predicted CO_2 emissions the following equations would be used:

$$NEDC\left[\frac{g}{km}\right] = \frac{4059\ \times\ ECE\left[\frac{g}{km}\right] + 6955\ \times\ EUDC\left[\frac{g}{km}\right]}{4059 + 6955}$$

$$FTP\left[\frac{g}{km}\right] = \frac{0.43\ \times FTP1\left[\frac{g}{km}\right] \times FTP2\left[\frac{g}{km}\right] \times 0.57\ \times\ FTP3\left[\frac{g}{km}\right]}{0.43 + 1 + 0.57}$$

The Hypothesis tested in this research assignment was that the FTP and NEDC results for a Ford Focus (representing the light- duty vehicles class), would differ substantially. The alternate hypothesis was that the results from the NEDC, FTP and real world data would not differ significantly.

	NEDC	**FTP**	**Real World Data**
Fuel consumption [L/100km]	4	5.8	6.39
CO_2 Emissions [g/km]	115	134	169

Table 3 Ford Focus NEDC, FTP and Real World Results

From Table 3, above there is a clear discrepancy in the results from each test. Although further more thorough experiments and analysis would be required, it would suggest that there isn't enough evidence to reject the null hypothesis. The real life data was found by taking the results of an average of 10 user's data for Ford Focus Hatch, manual, 1.8L Diesel engine cars. The results were taken from users who had been a member of the site for a long time and the cars data was based on 80+ refuellings. This was to obtain more realistic results. The data used can be found in the appendix of the report.

When carrying out research it is important to realise error in results is unavoidable. Error is the deviation from the true value of a parameter. Error may be minimised by taking careful measurements etc. can never be removed from an analysis, only reduced. When designing a methodology for research steps should be taken to minimise the effects of error. Because the results in this research portfolio were based on physical measurements there are many types of errors which affect the results such as:

- Sampling error – sample tested is not large enough and does not represent the population, faulty cars may have been tested
- Coding error – a mistake made in the code for analysing alters results
- Errors in recording data

Planning Approach

As with any research assignment, deadlines determined the scope of the assignment and as this was is a semester long project, it needed planning. Gantt charts are an excellent way to illustrate the necessary steps needed and to create a plan. The timing of each step was be important to ensure the project remained on time and took into account other time restraints such as assignments from other courses. The chart had to be revised on more than one occasion as parts of the assignment took longer than expected, particularly finding the data needed for the analysis.

Planning of a project and awareness of timing and sequencing is essential of an efficient system. Gantt charts are used to visualise this. A Gantt chart is series of horizontal lines which show a project schedule. It breaks a project into smaller steps, showing the time scale for each step, and illustrating steps which can be performed in parallel and which steps are dependent on each other.

To create a Gantt chart all the steps required in a process must be listed and the dependencies of the steps identified. The time to complete each step must be estimated. Identify the steps that can be run in parallel.

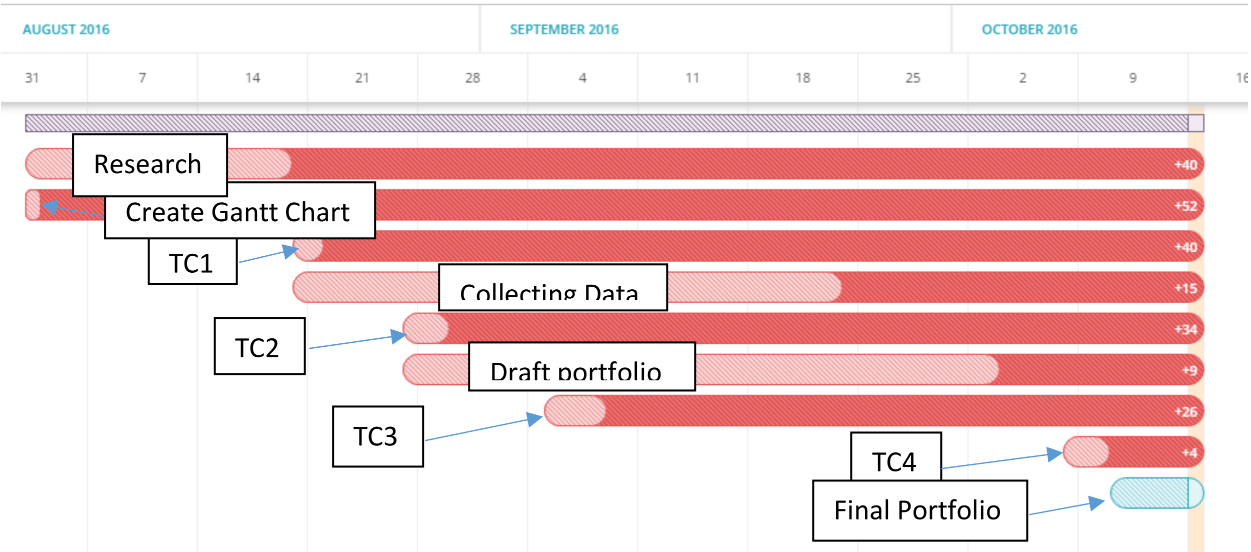

Figure 7 Gantt Chart

Another important factor to be aware of when planning a research assignment is Parkinson's Law. Parkinson's Law is an observation "that work expands to fill the time available for its Completion", famously proposed by historian and political analyst Cyril Parkinson, while working in the UK civil service. Essentially the law says if you are assigned to do a 1 hour task in a week, the task will expand so that it takes a week to complete, however if you are only given 1 hour, you would complete the assignment in 1 hour. Parkinson's Law is a statistical model now used in large companies to prevent the growth of bureaucracy, as it was observed more people were being employed in the civil service enough though the work load was not increasing. Awareness of this statement proved critical for this research project as time management was key in the success of the portfolio.

Human Factors

Since the Volkswagen scandal there has been a great interest in the area of Fuel Economy and emissions. This change in Social perspective has meant more research and development in these areas in the last several years. This awareness of the harm of the emissions from engines for public health, air quality and the ozone layer, has led to the public putting pressure on companies like Volkswagen to right there wrongs and demands on governments to enforce harsh penalties. It has also called for a review of current testing procedures.

To fully understand the public opinion I researched surveys conducted on perception of quality of Volkswagen after the discovery of the test beaters and the confidence of the consumer in the brand. The perception of quality fell over 20% 3 days after the discovery, and reputation dropped almost 40% in the 10 days after the discovery (Connelly, 2015). Consumer confidence has a huge impact on the economy and will drive Volkswagen and other motor vehicles manufacturers to improve fuel economy and reduce emissions.

Risk is the likelihood that that a person may be harmed or suffer adverse health effects if exposed to a hazard (Health and Saftey Authority, 2016). A hazard is something that has the potential to cause harm. Volkswagen's Violation of the Clean Air Act, with their vehicles producing 40 times the allowable NO_x emissions in the United States. This was a hazard to the general public. It is estimated that 59 people in the United States will die prematurely due to the excess air pollution caused by Volkswagen cheating emission tests, and if all the affected vehicles are removed by the end of 2016, it could prevent a further 130 premature deaths (Vaughan, 2015). These premature deaths are estimated to be caused by particulate pollution and ozone exposure. There is also predicted increase in respiratory problems. To reduce these risks, serious research and funding will be needed to reduce the NO_x emissions from combustion engines. Imposing large fines for companies such as Volkswagen for failing to produce cars under the NO_x emissions standards should result in large fines to raise the funding for such research.

Material Factors

Fossil fuels are the main input into combustion engines and are responsible for the harmful emissions such as NO_x and CO_2. This research portfolio focused on diesel engines. However many types of diesel exist, creating an impact on the emissions produced. The main types of diesel are:

- Standard diesel fuel
- Biodiesel fuel

Standard diesel has two types, 1 and 2, which are classed according to their octane number. The diesel used in light-duty motor vehicles is within the range of 40-45. Diesel engines typically have a higher fuel efficiency than petrol engines and lower CO_2 emissions. This makes diesel engines more environmentally friendly, however the recent Volkswagen scandal suggests that diesel engines are not as green as once suspected. Biodiesel is fuel obtained from vegetable or animal fats, e.g. rapeseed oil. Biodiesel has the potential to be a green fuel, however currently it is mixed with standard diesel of blends of up to 30%. Biodiesel has much lower fuel emissions, but is made from valuable food crops. Biodiesel also has high NO_x emissions.

The material used on a system has a large impact on the efficiency and the environmental impact of the system. The fuel used during driving cycle tests has an impact on the results. Even when standard diesel is used, depending on the origin of the diesel the chemical composition is different. This introduces unavoidable error in the results.

Energy Factors

Sankey diagrams are used to visualise the size of transfers within a system. They can be used to illustrate energy, cost, and material transfer in a system. There are extremely useful in identifying the main contributors of energy consumption etc. in a system. The diagram consists of a number of arrows, each arrow a different aspect of the system, e.g. a Sankey diagram of energy transfer of an electric light would have two arrows – heat and light. The thickness of the arrow, the greater amount of energy, cost etc. used .In order to create a Sankey diagram the inputs and outputs of a system need to be identified, the flows must be measured and the losses recorded. Sankey diagrams are essential in identifying areas where improvements in efficiency can be made and losses reduced.

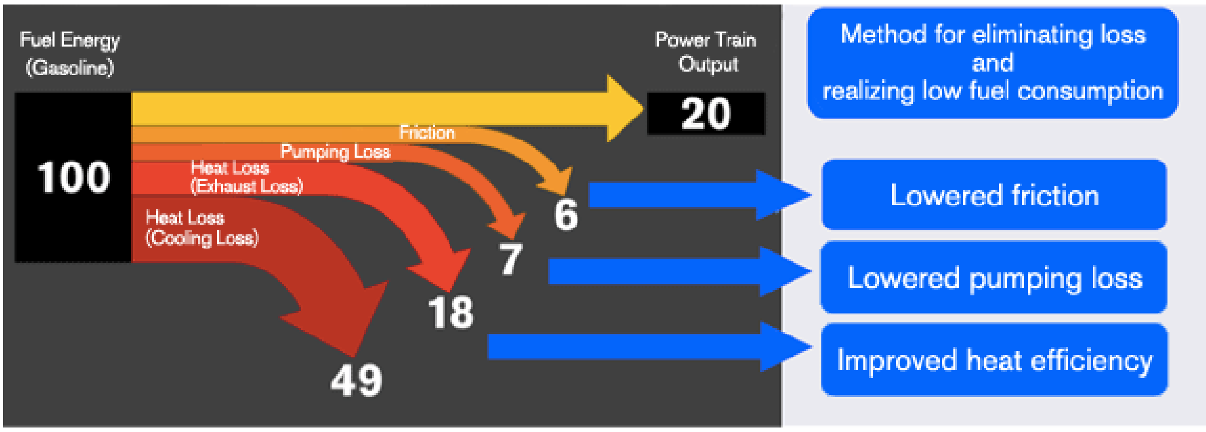

Figure 8 Typical Sankey Diagram of Fuel Efficiency (Sankey Diagrams, 2014)

The above diagram illustrates a typical Sankey Diagram of Fuel Efficiency of a vehicle. Unfortunately with the publically available information, it was not possible to construct a Sankey Diagram for the Ford Focus. Ford Motors have not released Sankey diagrams for any of their vehicles. Identifying losses in a system help identify areas that can be improved. Sankey diagrams of vehicles would be useful when designing a new driving cycle.

Mass balances (also known as material balances) and energy balances are calculation techniques to allow you to calculate the amount of mass (or energy) in process and waste streams. It is typically used where it is difficult to measure directly (Manufacturing Skills Australia, 2012).Mass balances are based on the First Law of Thermodynamics, energy and mass can neither be created or destroyed but converted from one form to another.

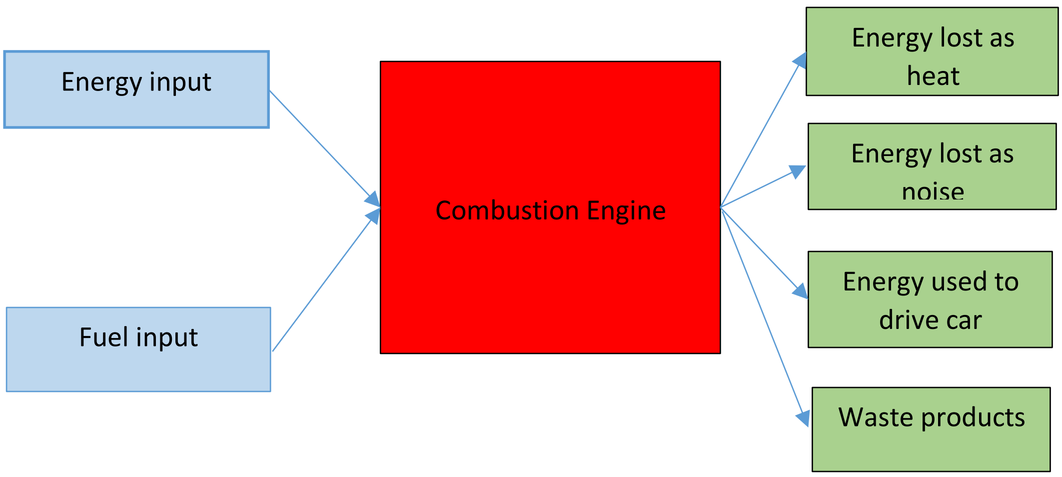

Figure 9 Energy - mass balance of Combustion Engine

Impact of inaccuracies of Driving cycles

Because the driving cycles do not accurately predict the fuel consumption or carbon emissions this will have a considerable impact on the predicted and actual emissions of a car over its life time. When scientists make predictions about greenhouse gases levels and consumption of crude oil, they often use figures based on NEDC and FTP test results. Taking the average life expectancy of a light weight vehicle as 15 years and the average kilometers driven over the lifetime of the car as~300,000 km.

	NEDC	**FTP**	**Actual**
CO_2 emissions [g/300000km]	34.5 x10^6	40.2 x10^6	50.7 x10^6
Fuel Consumption [L/300,000km]	16.2x10^3	1.74x10^3	1.917x10^3

Table 4 Difference between predicted and actual emissions and fuel consumption over lifetime of a car

These higher than expected emissions will have a sufficient impact on health and greenhouse gas levels. It is difficult to make legislation and strategies to combat these problems without accurate information. These large discrepancies over time suggest a more accurate driving cycle is needed to replace the current cycles.

Summary

This research portfolio investigated the difference in the results from the New European Driving Cycle, US Federal Test Procedure and real world data. Although the report doesn't have enough examples to make a definite recommendation, the data would suggest that neither of the test cycles are particularly accurate when compared to real world data. There is also a clear discrepancy in the results of the NEDC and the FTP, suggesting a universal driving test cycle may be required. It proved difficult to find the NEDC, FTP and Real world data, which affected the proposed time schedule of the report. The lack of publically available data affected the scope of the assignment, and after the Volkswagen Emission Scandal it has been suggested that there should be more transparency in the test cycle results. To analysis the system, research methods and systems perspectives were used to break the system into smaller parts and using numerous techniques analysis these sections to gain a better understanding of the entire system.

Recommendations of possible changes to driving cycle

It is impossible for any driving to cycle to exactly predict the CO_2 emissions and fuel usage of a car, as individual drivers and the routes they take affect the results. However a test which better predicts the test could be achieved. Although the results of the analysis in this portfolio are not varied enough and do not have sufficient numbers of vehicle to make a recommendation for a new cycle, following observations of the shortcomings of both driving cycles were observed:

Acceleration rates

The tests do not take heavy acceleration into account, which typically loads the engine more, increasing fuel consumption and increase pollutants. Changing the acceleration rate during parts of the test would increase the accuracy of the results.

Not testing full range of the engine

The driving cycles only test a fixed range of the engines possible speed and acceleration abilities. This results in manufacturers focusing on improving the fuel consumption and emissions of parts that are tested by the tests and manufacturers take advantage of this to increase the power and performance of their vehicles under off-cycle conditions, as a result vehicle emissions may increase dramatically under these conditions (Faiz, Weaver, & Walsh, 1996).

Ancillary loads

During the NEDC and FTP, all ancillary loads (radio, air-conditioning etc.) are turned off. This leads to a less accurate results as in cars the radios are normally on and depending on the country and time of year there is normally air conditioning or heating also being used. Instead the dynamometer load is increased to simulate the additional loads on the engine (Faiz, Weaver, & Walsh, 1996), as a result manufacturers don't optimise the fuel efficiency of the ancillary loads as they know they will not be tested. To simulate a more realistic driving cycle the ancillary loads should be incorporated into testing.

More rigorous testing of driving cycles

Applying control theory to the testing of the cars could help improve the testing method. Making small changes to the testing cycle and observe the results for sufficiently large number of cars, and compare to the test results after a year would help improve the driving cycles.

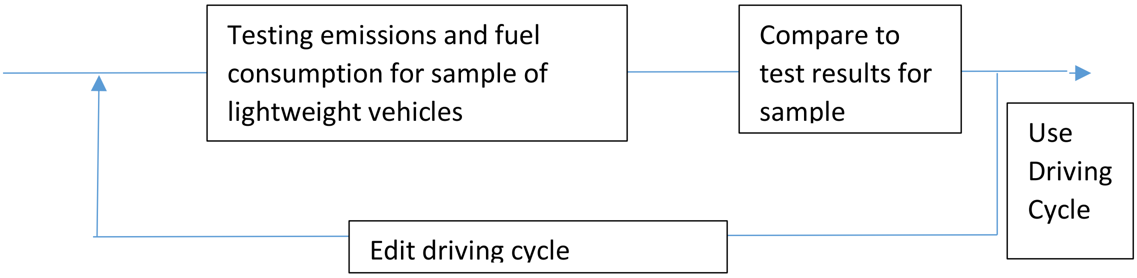

Figure 10 Feedback loop for testing of new driving cycle

Limitations of Results

Due to the difficulty of obtaining results of the NEDC and FTP for cars, this impacted the number of samples used in the report. Because of the small number of samples, it is not possible to draw conclusive results for all light duty vehicles. Also as I did not carry out the testing of the vehicles, it is difficult to identify errors and their propagation. I have presumed that the tests were carried out as outlined in the NEDC and FTP. The real world data was obtained from users on spritmonitor.de. To reduce the error of results, I took the CO_2 emissions and fuel consumption results for 10 Ford Focus Hatch, manual, 1.8L Diesel engine and average results. It would have been favourable to use more samples of the real life data, however I decided to only take results from users who had been a member of the site for a long time and had more than one car results on the website. I also only took results with 80+ refuellings to obtain more realistic results.

Bibliography

ADVISOR Advanced Vehicle Simulator. (2013). *ADVANCED VEHICLE SIMULATOR*. Retrieved from ADVISOR Advanced Vehicle Simulator: http://adv-vehicle-sim.sourceforge.net/

Australian National University. (2016). *Data Organisation Guidlines*. Retrieved from Australian National University: https://services.anu.edu.au/research-support/tools-resources/data-organisation-guidelines

Caiazzo, F., Ashok, A., Waitz, I., Yim, S., & Barrett, S. (2013). Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005. *Atmospheric Environment Volume 79*, 198-208.

Car Engineer. (2016). *FTP*. Retrieved from CarEngineer: http://www.car-engineer.com/wp-content/uploads/2012/12/FTP-75.png?46ac1a

Car Engineer. (2016). *NEDC*. Retrieved from CarEngineer: http://www.car-engineer.com/wp-content/uploads/2012/12/NEDC.png

Connelly, T. (2015). *Study reveals how public perception of Volkswagen changed throughout scandal*. Retrieved from The Drum: http://www.thedrum.com/news/2015/09/28/study-reveals-how-public-perception-volkswagen-changed-throughout-scandal

Dieselnet. (2016). *ECE 15 + EUDC/NEDC*. Retrieved from Dieselnet: https://www.dieselnet.com/standards/cycles/ece_eudc.php

Dieselnet. (2016). *ECE 15 + EUDC/NEDC*. Retrieved from Dieselnet: https://www.dieselnet.com/standards/cycles/ece_eudc.php

Dieselnet. (2016). *Emission Test Cycles*. Retrieved from Dieselnet: https://www.dieselnet.com/standards/cycles/

Dieselnet. (2016). *EPA Highway Fuel Economy Test Cycle*. Retrieved from Dieselnet: https://www.dieselnet.com/standards/cycles/hwfet.php

EPA Victoria. (2016). *Vehicle Emissions and Air Quality*. Retrieved from EPA Victoria: http://www.epa.vic.gov.au/your-environment/air/vehicle-emissions-and-air-quality

Esposito, E. (2013). *Step-by Step instructsions for creating a Gantt chart in Excel*. Retrieved from Smartsheet.com: https://www.smartsheet.com/blog/gantt-chart-excel01

European Automobile Manufacturers Association. (2016). *Key Figures*. Retrieved from European Automobile Manufacturers Association: http://www.acea.be/statistics/tag/category/key-figures

European AutomobileManufacturers' Association. (2016). *REDUCING CO2 EMISSIONS FROM PASSENGER CARS AND LIGHT COMMERCIAL VEHICLES POST-2020.* Brussels: ACEA.

Faiz, A., Weaver, C., & Walsh, M. (1996). *Air pollution from motor vehicles: standars and technologies for Controlling Emissions.* World Bank Publications.

Falconer, J. (2016). *How to use Parkinson's Law to your Advantage*. Retrieved from Lifehack: http://www.lifehack.org/articles/featured/how-to-use-parkinsons-law-to-your-advantage.html

FORD EU. (2016). *http://www.ford.ie/SBE/DownloadeBrochure_Car.* Retrieved from FORD.ie: http://www.ford.ie/SBE/DownloadeBrochure_Car

FORD USA. (2016). *http://www.ford.com/services/assets/Brochure?make=Ford&model=Focus&year=2016.* Retrieved from FORD.com: http://www.ford.com/services/assets/Brochure?make=Ford&model=Focus&year=2016

GFEI. (2016). *Cleaner More Efficent Vehicles*. Retrieved from UNEP: http://www.unep.org/transport/gfei/autotool/approaches/information/test_cycles.asp#US

Government of South Australia Department of Planning, Transport and Infrastructure. (2016). *Test Drive Cycles*. Retrieved from Low Emission Vehicles: http://www.lowemissionvehicles.sa.gov.au/knowledge_bank/reference/test_drive_cycles

Health and Saftey Authority. (2016). *Hazard and Risk*. Retrieved from HSA: http://www.hsa.ie/eng/Topics/Hazards/

INCOSE - International Council on Systems Engineering. (2016). *What is Systems Engineering*. Retrieved from INCOSE: http://www.incose.org/AboutSE/WhatIsSE

Laerd Statistics. (2013). *Descriptive and Inferential Statistics*. Retrieved from Laerd Statistics: https://statistics.laerd.com/statistical-guides/descriptive-inferential-statistics.php

Lukeprog. (2013). *Fermi Estimates*. Retrieved from lesswrong.com: http://lesswrong.com/lw/h5e/fermi_estimates/

Manufacturing Skills Australia. (2012). *Abour mass and energy balance*. Retrieved from Skills for Sustanibility: http://sustainabilityskills.net.au/wp-content/uploads/2012/07/About-mass-and-energy-balancing_June12.pdf

Nicolas, R. (2013). *The Different Driving Cycles*. Retrieved from Car Engineer: http://www.car-engineer.com/the-different-driving-cycles/

Owencb. (2014). *Make your own cost effectiveness Fermi estimates for one-off problems*. Retrieved from lesswrong.com: http://lesswrong.com/lw/ldo/make_your_own_costeffectiveness_fermi_estimates/#

Research Rundowns. (2016). *Writing Research Questions*. Retrieved from Research Rundowns: http://researchrundowns.com/intro/writing-research-questions/

Sankey Diagrams. (2014). *Car Engine Efficiency*. Retrieved from Sankey Diagrams: http://www.sankey-diagrams.com/tag/engine/

SankeyDiagrams. (2016). *Energy Flows*. Retrieved from Sankey Diagrams: http://www.sankey-diagrams.com/

Spirtmonitor. (2016). *Volkswagon - Golf*. Retrieved from Spritmonitor: http://www.spritmonitor.de/en/detail/678422.html

Steven, H. (2013). *Homologation Test cycles worldwide.*

The Economist. (1955). *Parkinson's Law*. Retrieved from The Economist: http://www.economist.com/node/14116121

The International Council on Clean Transportation. (2016). *Real World Fuel Consumption Transportation*. Retrieved from The International Council on Clean: http://www.theicct.org/faceted-search?search_api_views_fulltext=real%20world%20fuel%20comsumption&f[0]=type%3Aarticle

Truedelta. (2016). *Volkswagon Golf Fuel Economy*. Retrieved from Truedelta: http://www.truedelta.com/Volkswagen-Golf/mpg-279/2015

Truedelta. (2016). *Volkswagon Golf Fuel Economy*. Retrieved from Truedelta: http://www.truedelta.com/Volkswagen-Golf/mpg-279/2015

Tutuianu, M., Bonnel, P., Ciuffo, B., Haniu, T., Ichikawa, N., Marotta, A., . . . Steven, H. (2015). *Development of the World-wide harmonized Light duty Test Cycle (WLTC) and a possible pathway for its introduction in the.* Elsevier.

United States Envionmental Protection Agency. (2016). *Federal Test Procedure Revisions*. Retrieved from EPA: https://www3.epa.gov/otaq/sftp.html

United States Environmental Protection Agency. (2016). *Future of CLiamte Change*. Retrieved from EPA: https://www.epa.gov/climate-change-science/future-climate-change

University of Cambridge. (2016). *Organising your Data*. Retrieved from University of Cambridge: http://www.data.cam.uk/data-management-guide/organising-your-data

Vaughan, A. (2015). *VW emissions cheat estimated to cause 59 premature US deaths*. Retrieved from The Guardian: https://www.theguardian.com/environment/2015/oct/29/vw-emissions-estimated-to-cause-59-premature-us-deaths

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Appendix

MATLAB inputs into ADVISOR

Ford Focus NEDC

Last Saved Vehicle Name: Small_car_in

drivetrain: conventional
fuel_converter: FC_SI95
transmission: TX_5SPD
wheel_axle: WH_SMCAR
vehicle: VEH_FOCUS
exhaust_aftertreat: EX_SI
powertrain_control: PTC_CONV
accessory: ACC_CONV

Initial Conditions

amb_tmp= 20
air_cp= 1009
ex_cat_mon_init_tmp= 20
ex_cat_int_init_tmp= 20
ex_cat_pipe_init_tmp= 20
ex_cat_ext_init_tmp= 20
ex_manif_init_tmp= 20
fc_c_init_tmp= 20
fc_i_init_tmp= 20
fc_x_init_tmp= 20
fc_h_init_tmp= 20
ess_mod_init_tmp= 20
mc_init_tmp= 20
ess_init_soc= 0.7
ess2_init_soc= 0.7

Ford Focus ECE

drivetrain: conventional
fuel_converter: FC_SI95
transmission: TX_5SPD
wheel_axle: WH_SMCAR
vehicle: VEH_FOCUS
exhaust_aftertreat: EX_SI
powertrain_control: PTC_CONV
accessory: ACC_CONV

Initial Conditions

amb_tmp= 20
air_cp= 1009
ex_cat_mon_init_tmp= 20
ex_cat_int_init_tmp= 20
ex_cat_pipe_init_tmp= 20
ex_cat_ext_init_tmp= 20
ex_manif_init_tmp= 20
fc_c_init_tmp= 20
fc_i_init_tmp= 20
fc_x_init_tmp= 20
fc_h_init_tmp= 20
ess_mod_init_tmp= 20
mc_init_tmp= 20
ess_init_soc= 0.7
ess2_init_soc= 0.7

Ford Focus EUDC

drivetrain: conventional
fuel_converter: FC_SI95
transmission: TX_5SPD
wheel_axle: WH_SMCAR
vehicle: VEH_FOCUS
exhaust_aftertreat: EX_SI
powertrain_control: PTC_CONV
accessory: ACC_CONV

Initial Conditions

amb_tmp= 20
air_cp= 1009
ex_cat_mon_init_tmp= 20
ex_cat_int_init_tmp= 20
ex_cat_pipe_init_tmp= 20
ex_cat_ext_init_tmp= 20

ex_manif_init_tmp= 20
fc_i_init_tmp= 20
fc_x_init_tmp= 20
fc_h_init_tmp= 20
ess_mod_init_tmp= 20
mc_init_tmp= 20
ess_init_soc= 0.7
ess2_init_soc= 0.7

Ford Focus FTP

drivetrain: conventional
fuel_converter: FC_SI95
transmission: TX_5SPD
wheel_axle: WH_SMCAR
vehicle: VEH_FOCUS
exhaust_aftertreat: EX_SI
powertrain_control: PTC_CONV
accessory: ACC_CONV

Initial Conditions

amb_tmp= 20
air_cp= 1009
ex_cat_mon_init_tmp= 20
ex_cat_int_init_tmp= 20
ex_cat_pipe_init_tmp= 20
ex_cat_ext_init_tmp= 20
ex_manif_init_tmp= 20
fc_c_init_tmp= 20
fc_i_init_tmp= 20
fc_x_init_tmp= 20
fc_h_init_tmp= 20
ess_mod_init_tmp= 20
mc_init_tmp= 20
ess_init_soc= 0.7
ess2_init_soc= 0.7

Results for Ford Focus real life data

Car number	**CO_2 Emissions [g/km]**	**Fuel Consumption [L/100km]**
1	178	6.8
2	182	7.9
3	156	4.8
4	159	6.7
5	162	5.8
6	173	7.4
7	169	4.9
8	171	6.4
9	173	6.7

10	167	6.5
Total	1690	63.9
Average	**169**	**6.39**