Journey Mapping: A New Approach for Defining Automotive Drive Cycles

JOURNEY MAPPING: A NEW APPROACH FOR DEFINING AUTOMOTIVE DRIVE CYCLES

BY

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To my family and loved ones…

Abstract

Driving has become a very common activity for most of the people around the world today. People are becoming more and more dependent on vehicles, contributing to the growth of automotive industry. New vehicles are released regularly into the market in order to meet the high demand. With the increase in demand, the importance of vehicle testing has also increased by many folds. Besides testing new vehicles for their performance prediction, existing vehicles also need to be tested in order to check their compliance to safety standards.

Drive Cycles that have been traditionally defined as velocity over time profiles are used as vehicle testing beds. The need for re-defining drive cycles is demonstrated through the high deviations between the predicted and the actual performance values. As such, a new approach for defining automotive drive cycles, Journey Mapping, is proposed. Journey Mapping defines a drive cycle more realistically as the journey of a particular vehicle from an origin to the destination, which during its journey is influenced by various conditions such as weather, terrain, traffic, driver behavior, road , vehicle and aerodynamic.

This concept of Journey Mapping has been implemented using AMESim for a Ford Focus Electric 2012. Journey Mapping was seen to predict its energy consumption with about 5% error; whereas, the error was about 13% when it was tested against the US06 cycle, which provided the most accurate results out of the various traditional drive cycles used for testing for the selected scope.

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Notation and Abbreviations

CAN	Controller Area Network
DEM	Digital Elevation Model
ECE	Economic Commission for Europe
EPA	Environmental Protection Agency
EUDC	Extra Urban Driving Cycle
EUDCL	Extra Urban Driving Cycle for Low-powered Vehicles
EV	Electric vehicle
FUDS	Federal Urban Drive Cycle
FTP	Federal Test Procedure
GIS	Geographic Information System
GPS	Global Positioning System
HEV	Hybrid Electric Vehicle
HFEDS	Highway Fuel Economy Driving Schedule
HWFET	Highway Fuel Economy Test
HYZEM	Hybrid Technology Approaching Efficient Zero Emission Mobility
ICE	Internal Combustion Engine

IM Inspection and Maintenance

Lb-ft Pound-foot

LFP Lithium Iron Phosphate

MARC McMaster Automotive Resource Center

MPG Miles per Gallon

MPGe Miles per Gallon Equivalent

NEDC New European Driving Cycle

NYCC New York City Cycle

PHEV Plug-in Hybrid Electric Vehicle

PID Proportional Integral Derivative

RAV Recreational Activity Vehicle

RPM Revolutions per Minute

UDDS Urban Dynamometer Driving Schedule

Notations

α	Road slope in %
acc	Driver acceleration control
$advAnt$	Advance time for control anticipation in seconds
AR	Aspect ratio
$brak$	Driver braking control
C_x	Air penetration coefficient
dw	Rotary stick velocity threshold for longitudinal slip in rev/min
D_{rim}	Wheel rim diameter in meters in AMESim simulation model
err	Error on speed in m/s
f	Coulomb friction coefficient
$F_{L,front}$	Front axle longitudinal slip in %
$F_{L,rear}$	Rear axle longitudinal slip in %
$F_{N,front}$	Front normal force in Newtons
$F_{N,rear}$	Rear normal force in Newtons
F_{aero}	Aerodynamic drag in Newtons
F_{cl}	Climbing resistance in Newtons

F_{dr}	Driving Force in Newtons
F_{res}	Total resistive force in Newtons
g	Gravity of acceleration in m/s^2
GA_{acc}	Anticipative gain for acceleration control loop
GA_{br}	Anticipative gain for braking control loop
GI_{acc}	Integral gain for acceleration control loop
GI_{br}	Integral gain for braking control loop
GP_{acc}	Proportional Gain for acceleration control loop
GP_{br}	Proportional Gain for braking control loop
$height$	Tire height in % in AMESim simulation model
H_{ts}	Tire sidewall height in feet
J_w	Wheel inertia in kgm^2 in AMESim simulation model
k	Viscous friction coefficient in 1/ (m/s)
$mass$	Total vehicle mass in kg in AMESim simulation model
$m_{distrib}$	Mass distribution in %
M_t	Tire mass in slugs

m_{veh}	Total vehicle mass in kg accounting for wheel inertia effect in AMESim simulation model
M_w	Wheel mass in slugs
ρ_{air}	Air density in kg/m^3
RI_t	Rotational Inertia of the tire in kgm^2
RI_w	Rotational Inertia of the wheel in kgm^2
R_{dyn}	Dynamic wheel radius in meters
R_t	Tire radius in feet
R_w	Wheel radius in feet
R_{ws}	Wheel radius in meters in AMESim simulation model
S	Vehicle active area for aerodynamic drag in m^2
S_L	Longitudinal slip in %
S_w	Wheel size in inches
T_{wi}	Tire width in mm
μ	Tire to ground grip coefficient
v	Vehicle linear velocity in m/s
$v_{cont}Ant$	Control speed at time $t + advAnt$

V_{cont}	Vehicle control speed in m/s
V_{veh}	Vehicle speed in m/s
v_{wind}	Wind speed in m/s
$width$	Tire width in meters in AMESim simulation model
WI	Overall Wheel Inertia in kgm^2
$wind$	Windage coefficient in 1/ (m/s) ^2
w_{rel}	Relative wheel rotary velocity in rev/min
W_t	Tire weight in pounds
ω_W	Wheel rotary velocity in rev/min
W_w	Wheel weight in pounds

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1 Introduction

1.1 Motivation

Vehicle Drive Cycles have been originally defined as velocity over time profiles. There are two major parts associated with the traditional definition of a drive cycle – the vehicle profile as well as the driver information. Most of the known standard drive cycles can be divided into three major categories- European, Japanese and US. Most of these standard drive cycles such as the New European Driving Cycle (NEDC), Urban Dynamometer Driving Schedule (UDDS) and others have been defined with the use of a velocity versus time profile. These drive cycles, ideally, are unique for a particular route and a particular driver. However, generalizations are usually made based on the standard drive cycles. European (excluding Hybrid Technology Approaching Efficient Zero Emission Mobility or Hyzem cycles) and Japanese drive cycles, being modal, do not represent real-life scenarios. However, the US drive cycles, being transient, represent real life conditions [1].

Drive cycles such as NEDC assume flat roads and the absence of wind for their drive cycle definition. Road conditions, weather conditions and terrain influence the vehicle profiles for velocity over time, quite heavily. However, they are not directly represented in all of the drive cycle definitions (terrain is included in some definitions); although, selection of a specific region for the drive cycle development in- directly implies the above conditions. As such, the traditional definition of velocity over time profile is insufficient to accurately describe a particular vehicle's behavior on a particular road. Drive cycles have also been defined as "test procedures" [2], "standardized driving pattern"[3] and as "a journey of a vehicle in which the engine temperature has been raised from cold (below 49 deg C) to normal operating temperature (above 71 deg C)" [4] (not part of standard drive cycles). However, none of the drive cycle definitions provide accurate vehicle behavior information in its entirety as they do not represent the concept of a vehicle travelling from an origin to a destination, directly. In addition, most of these drive cycle definitions are applicable to common on-road driving. Un-common off-road driving such as on hills, mountains and other terrain for applications such as military is completely ignored. As such, there is a significant need to develop a new definition for drive cycles.

A Drive Cycle can be re-defined as a vehicle's journey from an origin to a destination that is influenced by weather conditions, road conditions, terrain, vehicle condition, traffic and driver behavior. This new definition will aim towards bridging the gap in understanding a vehicle's drive cycle.

1.2 Problem Statement

Predicting how a vehicle will behave on the road has become a major concern for the auto-makers, governments and the researchers. It is extremely important to test any new vehicle for its performance before it is released into the market. Along similar lines, it is also important to verify already existing vehicles' performance on the road in order to make sure that the vehicle's performance has not significantly degraded over time. For any such vehicle tests it will be practically impossible to test every single vehicle physically on the road in their particular driving conditions. As such, standard drive cycles are generally used to simulate general conditions of the drive. However, since most of the standards are simply generalized velocity versus time profiles, it does not provide a complete picture of what the vehicle might actually go through on the road. This is mainly because the velocity profile might be affected by many different conditions at different times such as weather, traffic, terrain, road, driver behavior and so on.

Inadequate test standards might eventually result in deviated or inaccurate vehicle performance results. In other words, in order to have accurate vehicle performance results, it is very important to have accurate drive cycles which serve as test beds for these simulations. Accurate vehicle behavior prediction can be very helpful in preventing many accidents that have been occurring on the road due to the unknown driving conditions. In essence, there is an immense need of proposing a new or revised definition of drive cycles that can provide a more complete picture of the vehicle's behavior on the road. Even though it might be very difficult to create an entirely accurate system, there is a necessity of improving the definition as much as possible in order to predict vehicle performance more accurately.

1.2.1 Solution

A solution that has been proposed in this thesis is geared towards re-defining the existing concept of drive cycles as "Journey Mapping". Journey Mapping proposes to define a drive cycle as the journey of vehicle from a particular origin to a destination which during the journey is influenced by several conditions such as road, traffic, terrain, weather, driver behavior and vehicle's aerodynamic conditions. This Journey Mapping concept has been incorporated in the form of a simulation model in this thesis. This definition is able to better predict the actual vehicle performance on the road by calculating parameters that are much closer to the true values. This concept will not only be helpful in anticipating if the existing vehicles are in good condition for continued usage, but will also be very helpful in analyzing if any of the new designs can be released into the market or not. In essence, any type of simulation-based vehicle testing can be carried out more accurately with the use of the proposed Journey Mapping concept.

1.3 Thesis Contributions

This thesis proposes a new approach for defining automotive drive cycles – Journey Mapping. The drive cycles were traditionally defined as velocity over time profiles. Journey Mapping acts as a more realistic as well as an accurate driving simulation technique for vehicle testing and performance prediction. Journey Mapping defines drive cycle as the journey of a particular vehicle from an origin to a destination which during its journey is influenced by several conditions such as weather, traffic, road, terrain, driver behavior, vehicle, aerodynamic and so on.

There was a significant deviation noticed between the EPA labels for fuel economy and energy consumption and the true values measured. Also, the deviation was significant for the values predicted by standard drive cycles, namely UDDS, NEDC, JC08, Federal Test Procedure (FTP) 75 and US06 when compared to the true values. This demonstrates a need for re-defining drive cycles. Journey Mapping fills this gap. Journey Mapping is able to predict vehicle performance with about five percent error when compared to the true data.

1.4 Scope of Research

In order to implement the proposed Journey Mapping concept, it was very important to select a certain route and vehicle as varying all the constraints at the same time would give misleading results. As such, for the purposes of this thesis, the Ford Focus Electric 2012 and Toyota Prius 2004 were selected. The origin of the journey was selected to be the McMaster Automotive Resource Center (MARC) located at 200 Longwood Rd. S, Hamilton, Ontario and the destination was selected as Mohawk College situated at 135 Fennel Avenue West, Hamilton, Ontario. Thus, the scope of this research was restricted only to one hybrid and one all electric vehicle implementation. Also, the vehicles were only tested in city driving conditions. Although the Journey Mapping concept comprises a lot of conditions such as road, terrain, weather, traffic, driver behavior and vehicle's aerodynamic conditions, only the road, terrain, weather and the vehicle's aerodynamic conditions have been considered in this thesis. Traffic, driver behavior and any other drive conditions that might impact a vehicle's performance have not been included in this thesis' scope. Although, the traffic and driver behavior were not used in the modeling, their impact has been briefly studied in the results section.

1.5 Thesis Organization

This thesis is divided into six different chapters. The first chapter provided an introduction to the problem as well as the proposed solution. The scope of this study was also identified. The second chapter highlights fundamental concepts about hybrid and electric vehicles. Their classifications, electric machines used for them, their benefits and limitations, in addition to currently existing models in the market have been discussed. The third chapter describes about the conventional drive cycles, their types, benefits and limitations. The fourth chapter highlights the concept of Journey Mapping, conditions governing it, its data collection, its benefits and limitations. The fifth chapter consists of AMESim and Autonomie simulation modelsand their results for the Ford Focus Electric 2012 and Toyota Prius. The corresponding true results collected using the Controller Area Network (CAN) data logger have also been described as applicable. A sensitivity analysis of various parameters as well as a general discussion is also included. The sixth chapter is the final chapter concluding the work described in this thesis and suggesting future work.

2 Fundamentals of Hybrid and All-Electric Vehicles

2.1 Introduction to Hybrid and All-Electric Vehicles

The concept of electric vehicles is not a new idea. Instead, the original idea was from more than a hundred years ago [5]. However, due to the concern arising from poor battery capacity and short driving range, conventional internal combustion engine vehicles seemed to be a more feasible option at the time. In addition, the 1973 Middle East crisis dropped the oil prices immensely. This increased the importance of the fossil fuel vehicles [6].

However, due to the increased risk of greenhouse gas emissions, long term supply concerns and vastly increasing oil prices, auto-makers have been under pressure to come up with better alternatives [5]. Due to these driving forces, electric vehicles have been coming back into the market again. A lot of research has been ongoing to improve the battery capacity, driving range and other challenging aspects of an electric vehicle which have always been considered as a hindrance to their growth.

This compromise between increased pollutants resulting from internal combustion engine vehicles versus the short driving range and limited battery capacities has always left the auto market in a confusion as to which would be a better option. This gave rise to the idea of hybrid electric vehicles which carry the advantages of the electric vehicle as well as the internal combustion engine vehicles.

2.2 Types and Degrees of Hybridization [6]

The term "Hybridization" is usually generalized to drive-train hybridization. In other words, whenever a hybrid vehicle is referred to, it is assumed to be a combination of electric and the internal combustion engine vehicles. However, this is not completely representative of what it actually means. Hybridization means a combination of any two entities or features. When applied to vehicles, this hybridization could take two different forms, namely – fuel hybridization or drive train hybridization. Drive train hybridization will be described in further details in the next section titled Classification of Hybrid Electric Vehicles based on varying powertrain configurations. As far as fuel hybridization is concerned, as it can be understood from the name, it refers to the usage of more than one type of fuel within an internal combustion engine vehicle. Some flexible fuel vehicles can function with gasoline as well as natural gas. Also, some vehicles that consist of a certain type of fuel such as gasoline can be modified to work with an alternate type of fuel such as ethanol, methanol, bio gas, natural gas, gasol, hydrogen gas et cetera. Please note that almost all gasoline powered vehicles can be filled with ten to fifteen percent ethanol without making any major technical modifications.

Hybridization in vehicles also comes in various degrees. This classification of hybrid electric vehicles based on the degree of hybridization is in general relevant to drive-train hybridization type. There are three different degrees of hybridization – full, assist and mild hybrid electric vehicles. A full hybrid vehicle is the one that can run completely on the engine, on the battery or on a combination of both. Toyota Prius and Ford Escape are examples of such vehicles. When such vehicles are working only on a battery, it needs to be made sure that the battery being used is of a very high capacity. An assist hybrid vehicle uses the engine mainly for the majority of the power. The electric motor is only needed when extra torque boost is required such as when turning the engine on or during hard acceleration. Since, the vehicle mostly runs on the engine, the electric power needed is not as much as a full hybrid vehicle. Thus, the batteries in assist hybrid vehicles are usually of less capacity compared to full hybrid vehicles. Mild hybrid vehicles have the least fuel economy of all. Their motors help the vehicle to reach its operating speed first and then add the fuel as required.

2.3 Classification of Hybrid Electric Vehicles based on varying powertrain configurations

This classification of hybrid electric vehicles is completely based on the different ways various components within a hybrid electric vehicle connect with each other. There are three major types – series, parallel and power split.

Series hybrid electric vehicles have the batteries majorly powering the car. The engine does not power the car directly at all. It is only used for powering up an electric generator.

A series midsized fixed gear two wheel drive hybrid electric vehicle's vehicle propulsion architecture was generated in Autonomie using the library files as follows:

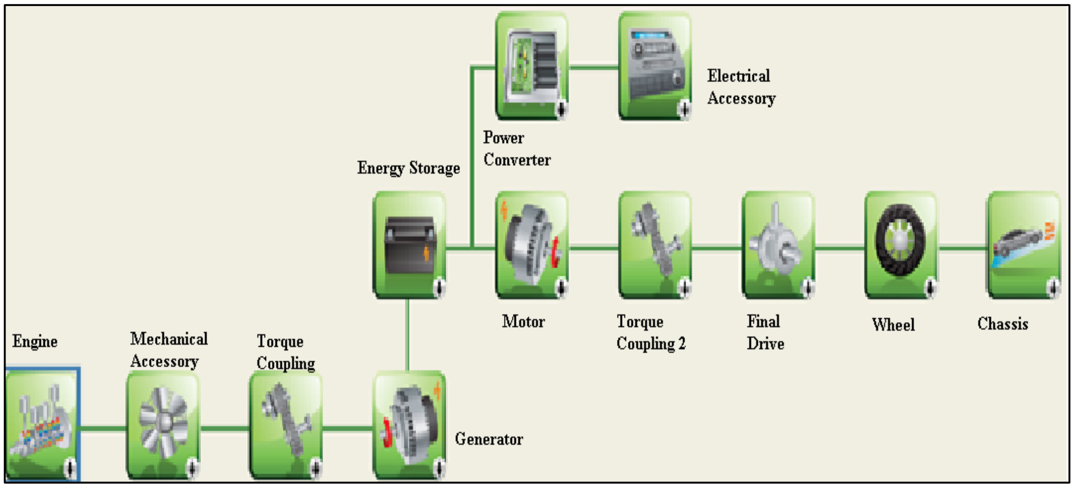

Figure 2.1: Vehicle Propulsion Architecture for a Series HEV generated in Autonomie

Parallel hybrid vehicles consist of a configuration where both the internal combustion engine and the electric motor powered by the battery can be connected to the transmission to drive the vehicle.

A parallel integrator starter alternator midsized automatic hybrid electric vehicle's vehicle propulsion architecture was generated in Autonomie using the library files as follows:

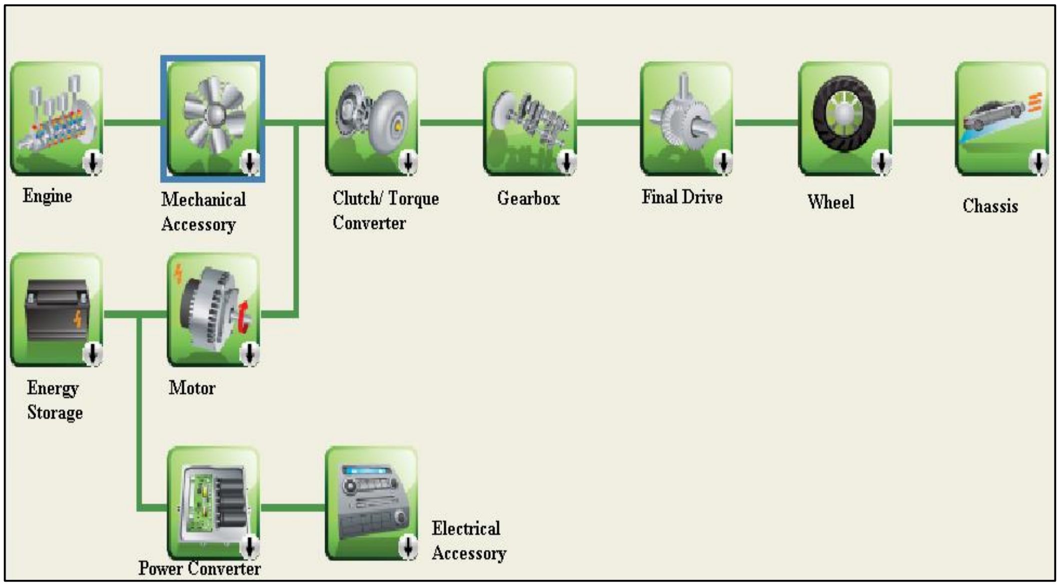

Figure 2.2: Vehicle Propulsion Architecture for a Parallel HEV generated in Autonomie

A power split hybrid vehicle is a combination of the series and parallel configurations. It is also known as a series-parallel configuration.

A series-parallel midsized Automatic Manual Transmission two wheel drive hybrid electric vehicle's vehicle propulsion architecture was generated in Autonomie using the library files as follows:

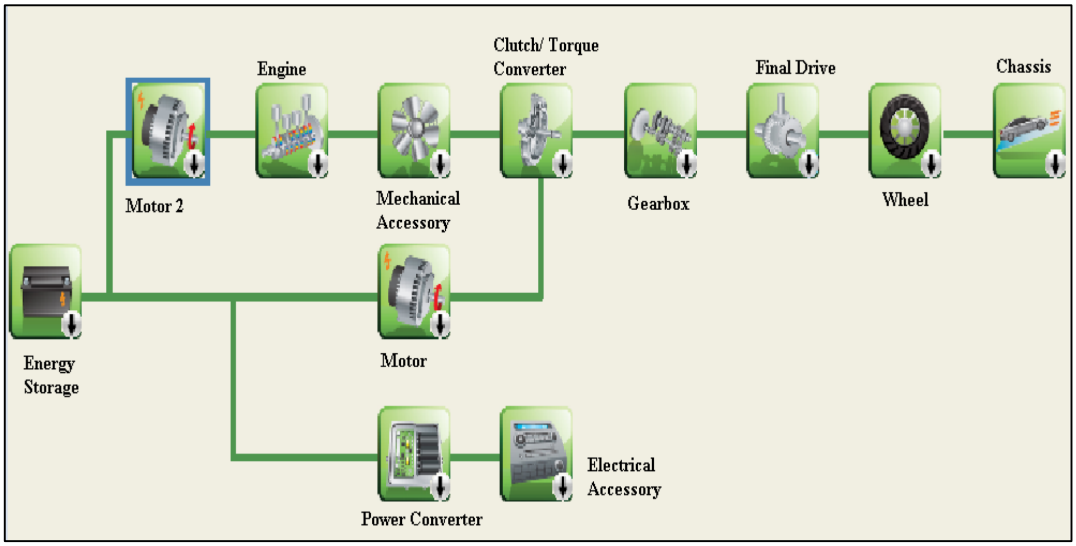

Figure 2.3: Vehicle Propulsion Architecture for a Series-Parallel HEV generated in Autonomie

2.4 Electric Machines for Hybrid and All-Electric Vehicles

Hybrid and electric vehicles come with varying powertrain configurations. There is a heavy amount of power electronics involved in building these vehicles. Also, there are a lot of different electric machines used within the vehicle ensuring their normal operation as well as for increasing their efficiency. This section summarizes some of these major concepts.

Some types of motors that are used in these vehicles include brushed direct current motor, brushless direct current motor, switched reluctance motor, synchronous permanent magnet outer rotor motor and axial flux ironless permanent magnet motor.

The brushed direct current motor consists of windings in the rotor. The stator can either have permanent magnets or windings. Its advantage over internal combustion engine cars is that it provides its maximum torque over lower speeds. However, one of its disadvantages is the excessive amounts of heat generated in the center of the motor, due to the losses in the rotor, making it difficult for the heat to be removed; which in turn results in limiting the power that can be delivered by the motor [6].

Power Electronic converters or drives are also vital to describing electric machines used for such vehicles. Mainly, inverters, rectifiers and two-quadrant converters are used. Inverters are used to convert direct current into alternating current. Rectifier offer an opposite application of converting alternating current into direct current. Two quadrant converters can behave both as rectifiers and inverters. Since, regenerative braking is a very advantageous phenomena in Hybrid Electric Vehicles (HEVs), these converters can become very applicable [6].

2.5 Benefits and Limitations

One of the major advantages of hybrid and all-electric vehicles arises from the major disadvantage of the internal combustion engine cars – greenhouse gas emissions. HEVs and EVs are very environmentally friendly. They can also be major contributors for renewable energy initiatives by using renewable modes of power generation such as solar, wind, hydro, et cetera for generating electricity that is needed for their charging. Due to increasing oil prices, they are also being viewed as a feasible alternate option.

When the hybrid vehicles, specifically, are compared to Internal Combustion Engine (ICE) vehicles it can be noted that the efficiency is much higher for the hybrid vehicles as they provide much higher fuel economy. Also, the engine in hybrid vehicles is able to work in their highest efficiency range. The presence of an electric motor helps in generating high torques at lower speeds. In addition, the concept of regenerative braking where part of the vehicle's kinetic energy can be captured and used for recharging the batteries saves a lot of energy from being wasted as heated which is usually what happens in ICE cars due to the mechanical braking. The reduced noise pollution and maintenance required is another attribute of hybrid vehicles that makes them a more attractive option when compared to ICE vehicles [6].

On the other hand, some aspects of electric vehicles which inhibit their growth include range problems, extra weight and vehicle space added due to the battery packs, high cost and safety factors of the batteries, charging problems due to lack of infrastructure and so on [7]. Thus, the hybrid vehicles seemed to be a more feasible option as they combined the advantages of both electric and ICE vehicles. Some of the disadvantages of hybrid vehicles could be their increased cost compared to similar ICE vehicles. In addition, the infrastructure for plug-in hybrid vehicle charging is still quite limited. Also, the increased weight of the car in addition to the safety concerns arising from the presence of a large battery pack adds to its disadvantages. Due to the addition of sophisticated components within the car, their replacement or maintenance can sometimes become a challenge. These negative aspects of hybrid vehicles can most probably be eradicated in the near future with the growth of research in this field [8].

2.6 Currently existing Hybrid and All-Electric Vehicles

There are a lot of different models of HEVs and EVs existing in the market. Ford, Honda, Toyota and so on are some of the biggest makers of such vehicles. According to the U.S. News and World Report, the Toyota Camry Hybrid, Ford Fusion Hybrid, Honda Accord Hybrid, Toyota Prius V and Toyota Avalon Hybrid have been ranked as the top five hybrid cars (ranked from top one to top five) for 2014 [9]. These cars have been ranked on the basis of performance, interiors, safety, reliability and critics' rating.

The 2014 Toyota Camry Hybrid, which has been ranked as the best hybrid car of 2014 has a Miles per Gallon or MPG of 43 for city and 39 for highway driving. The engine's net horsepower at 5700 RPM is 200 and the net torque at 4500 RPM is 156 lb-ft [10]. The 2014 Ford Fusion Hybrid, which is ranked as the second best, has a MPG of 44 for city and 41 for highway driving. The net engine horsepower is 188 at 6000 RPM and the net torque is 129 lb-ft at 4000 RPM [11]. The 2014 Honda Accord Hybrid, which is ranked the third best has a MPG of 50 for City and 45 for highway driving. The engine's net horsepower is 195 at 6200 RPM and the net torque is 122 lb-ft at 3500 RPM [12]. Toyota Prius V which has been ranked as the fourth best hybrid car has a MPG of 44 for city and 40 for highway driving. Its engine has a net horsepower of 134 at 5200 RPM and 105 lb-ft torque at 4000 RPM [13]. Lastly, the Toyota Avalon Hybrid, which was ranked fifth best hybrid car has a MPG of 40 for city and 39 for highway driving. The net engine horsepower is 200 at 5700 RPM and the torque is 156 lb-ft at 4500 RPM [14].

Similarly, electric cars have also been rated by CNET in terms of range on a charge, Miles per Gallon Equivalent or MPGe as well as the cost. According to CNET, the Tesla Model S, Nissan Leaf, Ford Focus Electric, Fiat 500e and Toyota RAV4 electric have been ranked as the top five electric cars for 2013-2014 (ranked from top one to five) [15].

The Tesla Model S is one of the most powerful electric cars around. There are two different variations for the 2014 Tesla Model S. The first type has 270 kW motor and 85 kWh battery pack. This type has a combined (highway and city) MPGe of 89 and a range of 265 miles on a single charge. The second type of 2014 Tesla

Model S has a 225kW motor and 60 kWh battery pack. This has a combined MPGe of 95 and a range of 208 miles [16].

Similar to the Tesla, most of these other electric vehicles have several models and types. Each model has its own specifications. For simplicity purposes, only one common model will be discussed for each of the following vehicles. The Nissan Leaf, which has been ranked as the second best, has a 80 kW motor giving a combined MPGe of 114 [17]. In addition, the range on a single charge is 73 miles [15]. The Ford Focus Electric which has been ranked as the third best electric car has a 107 kW electric motor giving a range of 81 miles and a combined MPGe of 105 [16]. The Fiat 500 e, which has been ranked as the fourth best electric car has a range of 87 miles and MPGe of 116 [15]. It has a 83 kW electric motor [18]. Finally, the fifth best electric car, Toyota RAV4 electric has a 115 kW electric motor giving a combined MPGe of 76 and range of 103 miles on a single charge [16].

3 Conventional Drive Cycles

3.1 Standard Drive Cycle Definitions and Examples

Drive Cycles have been traditionally defined as vehicle speed and gear selection over time profiles [1]. There have been many different drive cycle standard definitions created keeping in mind the driving scenarios such as city or highway driving. Also, different standard drive cycles have been created for different type of vehicles. These standards were originally created so that the conventional internal combustion engine cars could be tested for vehicle emissions and pollutants. Since it would be very difficult for every vehicle to be tested on the actual road, the standard drive cycles were to be used as test-beds for testing the quality of the car. As the research in the automotive sector progressed, the standard drive cycles were used as a testing standard for almost any kind of vehicle simulation. In essence, all the way from real vehicles to simulated vehicles are all tested using certain standard driving cycles. This ensures a practical, economic and timely method for testing vehicles.

There are over two hundred different drive cycle standards. Some examples of standard drive cycles have been generated using the Autonomie libraries as follows. Please note that only one cycle of each drive cycle has been shown here. Also, the x axis or time is in seconds and the y axis or the vehicle speed is in m/s :

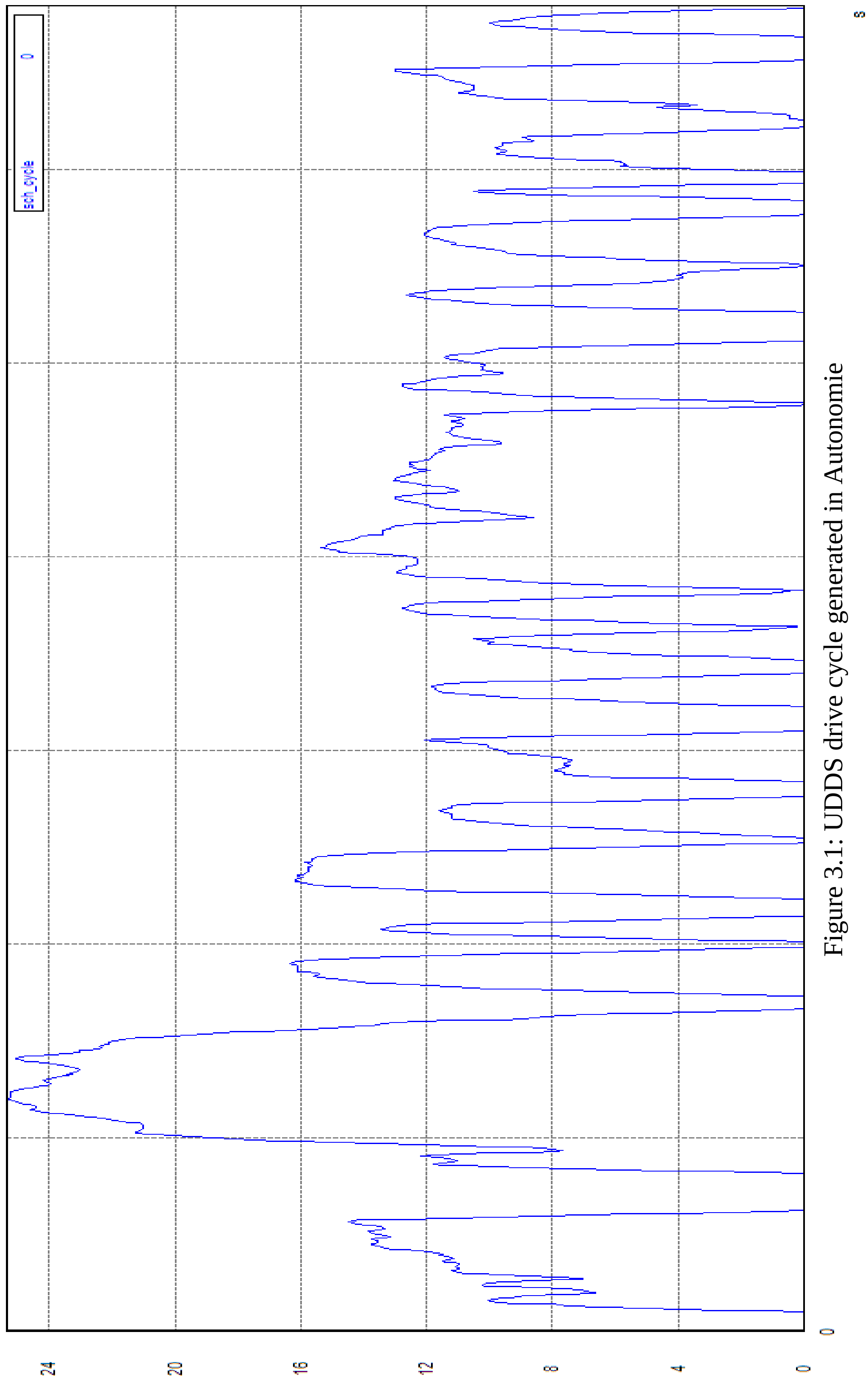

Figure 3.1: UDDS drive cycle generated in Autonomie

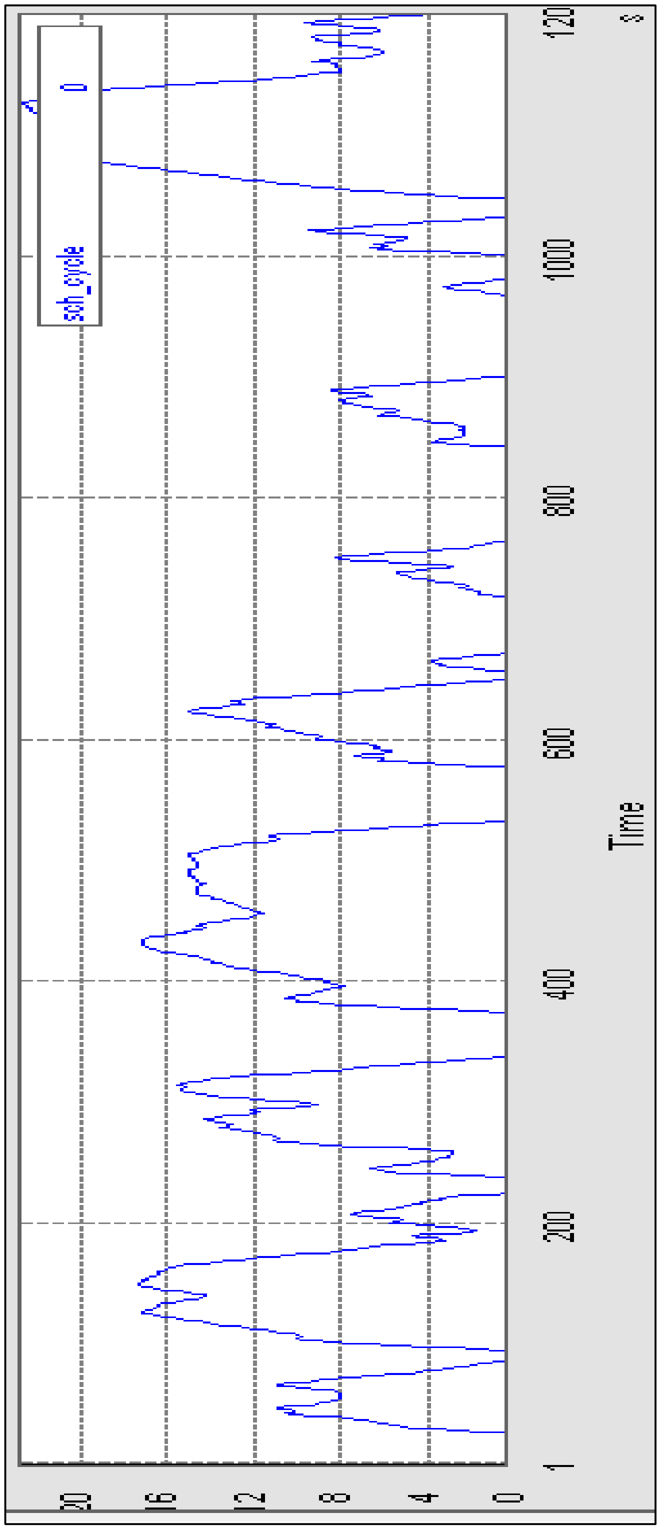

Figure 3.2: JC08 drive cycle generated in Autonomie

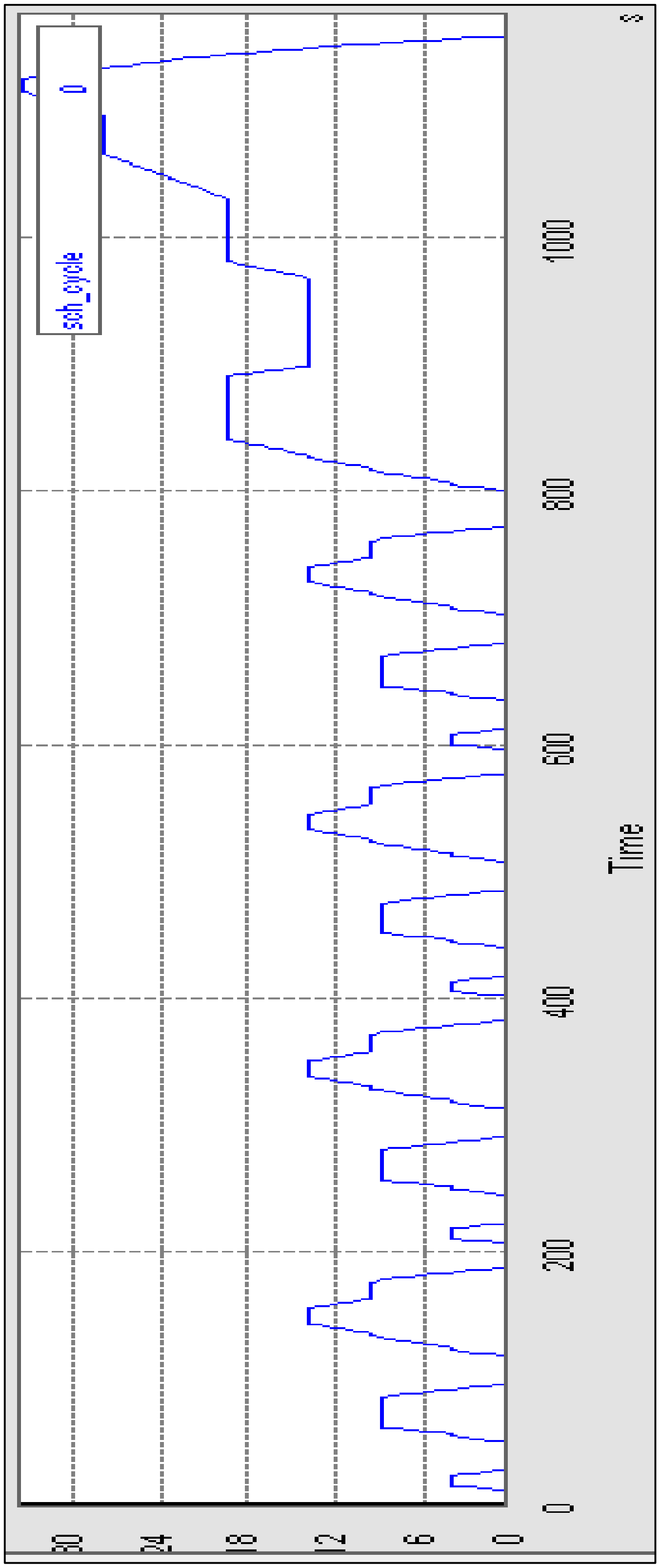

Figure 3.3: NEDC drive cycle generated in Autonomie

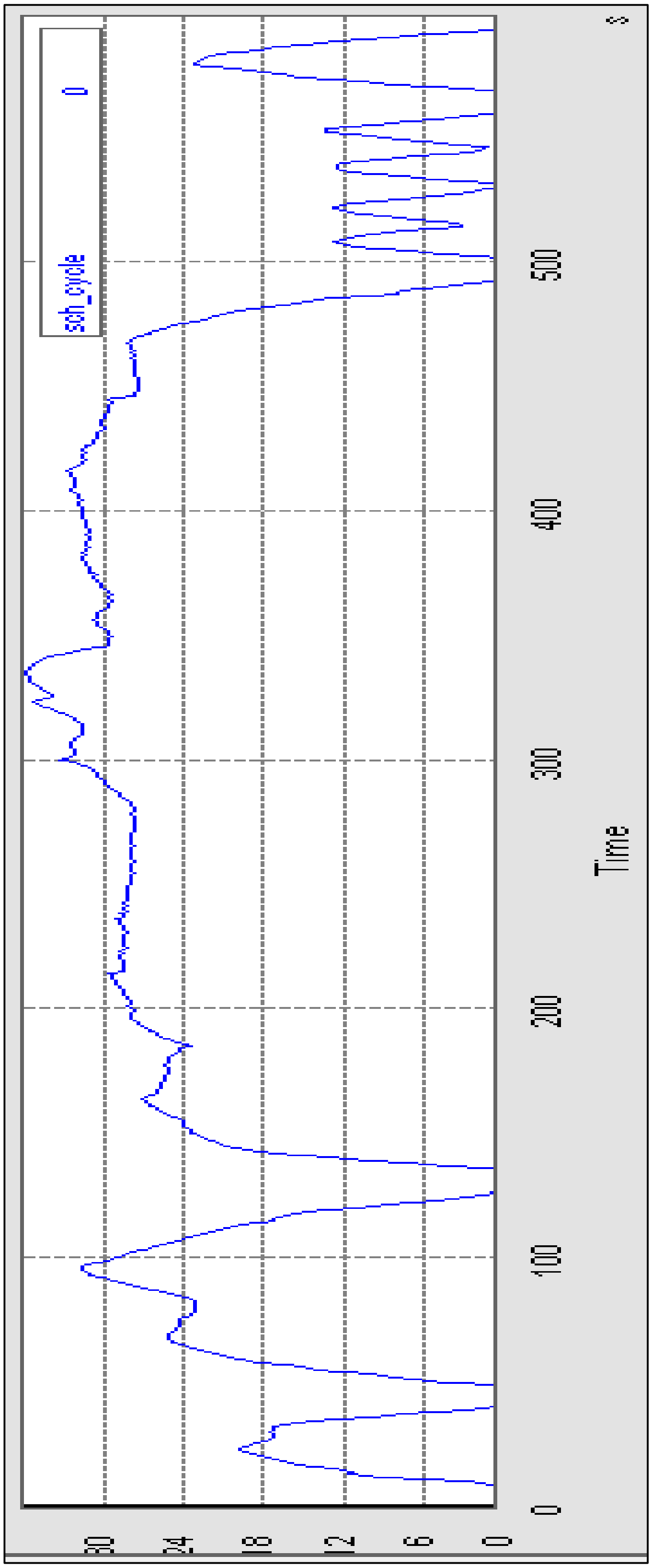

Figure 3.4: US06 drive cycle generated in Autonomie

Please refer to figures 7.1 to 7.20 in Appendix A for some other examples of traditional drive cycles.

3.2 Currently existing drive cycle models

As stated above, most of the standards define drive cycles as a velocity over time profiles. The only difference is in terms of conditions under which these standardized driving patterns are created. Also, the location, application, type of driver and vehicle varies for each standard. However, the underlying idea of representing driving patterns in terms of velocity over time profiles is the same across all these standards.

An effort, however, has already been made by many in order to develop particular drive cycle models for their specific applications. This section will provide a summary of some such work.

A company known as FleetCarma developed a web portal based on a unique concept of duty cycles. According to them, duty cycles were vehicle plots or models developed based on a specific vehicle's daily utilization. They developed this concept mainly as a part of their Plug-in BC program. By installing portable data loggers in many vehicles, they collected a lot of data for vehicle utilization. Based on this data, they created a web portal where any vehicle could be matched to a correct duty cycle. The idea was to make sure that their EV was capable of running for the entire distance that the user needs in a day without losing the charge in addition to making sure that the cost of the vehicle is efficiently utilized. For Plug-in Hybrid Electric Vehicle (PHEVs), the goal was to use the electrical mode for as long as possible. The web portal that was developed would provide an accurate EV solution according to drivers' specific needs based on their daily utilization [20]. Although, the duty cycle models include the average daily utilization as one of the constraints, many external factors such as weather, traffic or driver's behavior patterns were not included. These conditions could alter the duty cycles significantly on a day to day basis.

There is another novel Drive Cycle Generation Tool model implemented in [21]. Their model uses a combination of different ideologies such as standard drive cycles governed by velocity over time profiles for vehicles, duty cycles in terms of the power demand versus time, driving patterns which include environment as well as driver behavior, driving profiles including all the different drive cycle in the life time of a vehicle, driving scenarios identified by the topography such as highway versus city driving and finally, driving pulses which are basically the data collected between two idle events [21]. Although, their model is very comprehensive, it is not location specific. As such, a vehicle being tested under similar conditions but at a different location with varied terrain, traffic and so on can produce different vehicle performance results.

Another drive cycle generator model that generates velocity over time profiles based on the standard UDDS is discussed in [22]. Although, they have included a lot of different external parameters such as the vehicle's aerodynamic coefficients and the gradient coefficient, they are a part of the vehicle's dynamics or simulation model; they haven't been explicitly included in the drive cycle definition [22]. Also, once again their model is not location, traffic or drive behavior specific.

Another concept was developed in [23] which included a linear car following model and a lane changing model in order to represent a unique driver-vehicle pair. This information was then used to generate a driving cycle represented in the form a velocity over time profile [23]. Once again, the varying parameters have been implemented in the vehicle simulation; however, the definition of drive cycles has not been altered. Also, changes in the driver behavior according to the varying weather or traffic conditions were not considered.

Another model proposed in [24] includes the driving style and driving conditions in the simulations. However, once again, the basic definition of the drive cycle is still represented in terms of a velocity over time profile.

Many such concepts and models including [25] try to propose a more efficient manner for carrying out vehicle simulations by adding some external parameters.

However, these models do not alter the basic idea of defining drive cycles as velocity over time. Also, these models are not location specific, in addition the concept of varying all the parameters simultaneously in real time is not considered as a part of the drive cycle definition.

3.3 Types of Drive Cycles

There are mainly two different types of drive cycles – transient and modal. The transient cycles represent real driving patterns and on-road conditions. These cycles may cover many speed changes throughout the cycle. However, modal cycles are not representative of real-life conditions. In other words, they do not represent the changes in the driver behavior. These cycles may contain straight acceleration and constant speed periods [26].

Based on these definitions, the standard drive cycles are divided into three main groups – European driving cycles, US driving cycles and Japanese driving cycles. The European driving cycles can in turn be categorized into four main cycles – Economic Commission for Europe (ECE 15), Extra Urban Driving Cycle (EUDC), Extra Urban Driving Cycle for Low-powered Vehicles (EUDCL) and New European Driving Cycle or NEDC [3].

ECE 15 mainly represents urban driving where the speeds are relatively low in addition to an exhaust temperature and engine load that are also low. EUDC has higher speeds and acceleration compared to ECE 15 as it is based on a suburban driving scenario where highway driving is introduced towards the end of the cycle. EUDCL is similar to EUDC but mainly for low powered vehicles. Lastly, the NEDC or the ECE cycle is one of the most famous driving cycles used for vehicle testing. It consists of four ECE 15 cycles followed by either an EUDC or an EUDCL cycle [3]. Since, these European cycles are mostly modal; they are not completely representative of real driving patterns. As such, another category of cycles called Hyzem cycles were created. These Hyzem cycles; although are unofficial; they are mainly used since being transient, they represent real driving patterns in Europe. They are comprehensive in the sense that they contain urban, extra urban as well as highway driving scenarios [3].

The US driving cycles are mainly transient; as such, they provide a better understanding of the real driving patterns. Some common cycles belonging to this category include FTP 72 or UDDS, SFUDS, FTP 75, Highway Fuel Economy Driving Schedule (HFEDS), Inspection and Maintenance (IM) 240, LA-92, New York City Cycle (NYCC) and US 06 [3].

FTP 72 is one of the most common US driving cycles used for vehicle testing. It has many other names including UDDS, Federal Urban Drive Cycle (FUDS) or LA-4. This cycle starts with a cold start phase. After the cold start, a transient phase is included with many speed peaks. This cycle is mostly used for urban driving. The SFUDS cycle was mainly developed to graph the phenomenon of charging and discharging of an Electric Vehicle (EV) during a trip. Most of these cycles are nearly identical to each other; there are usually just one or two features modified for each one. FTP 75 is very similar to FTP 72. The only addition is of an extra phase at the end of the cycle in order to model hot engine. The HFEDS cycle represents highway as well as extra urban driving. The IM 240 cycle is mainly used for periodic emissions or more generally, maintenance tests. The LA-92 cycle is similar to the FTP 72 cycles just with higher speeds, on average. The NYCC represents urban roads in New York, generally characterized by low speeds, on average. Finally, the US 06 cycle is an aggressive cycle developed for modeling high engine loads [3].

Finally, the last category of driving cycles is Japanese cycles. These cycles are also modal, similar to the European cycles. The Japanese cycles can be further categorized into 10 Mode, 15 Mode and 10-15 Mode [3].

The 10 Mode cycle mainly represents urban road; whereas, the 15 Mode cycle represents both an urban and an extra-urban road. Lastly, the 10-15 Mode cycle, as the name suggests, is a combination of both the 10 Mode and the 15 Mode. There is 10 Mode cycle repeated three times. It has a 15 Mode cycle both at the beginning and the end of the 10 Mode cycle occurrences [3].

3.4 Applications

Some of these standard drive cycles are more applicable than the others. However, the usage, or selection, of a particular drive cycle depends on their application. These drive cycles are in general used as test beds or testing standards for almost any kind of vehicle testing – real or simulated designs. The concept of driving cycles was mainly introduced because it seemed as a more feasible, timely and a cost-effective option to test vehicles on a standardized driving pattern rather than testing them physically.

One of the major applications is for maintenance or emissions tests. The Fuel consumption of a particular vehicle can be evaluated when the drive cycle is run on a dynamometer. For EVs, energy consumption can be evaluated instead of the fuel consumption. In addition to emissions and energy or fuel consumption, many other vehicle parameters such as the mechanical power, electrical energy and so on can be evaluated [3].

Also, most of the vehicle simulations use a specific drive cycle to test their individual vehicle's specific designs. Since these drive cycles serve as a major testing tool in order to evaluate a vehicle's performance, it becomes very important for the cycles to be as accurate and precise as possible. It is also important for the specific drive cycles to represent the actual utilization of the vehicle as well as the specific driving conditions that the vehicle might encounter in its specific trips. In essence, the main usage of drive cycles is to evaluate or test vehicles in order to predict their performance on the road before-hand. This in turn can be very helpful in understanding how the real-life vehicles or the simulation designs can be modified in order to meet market, business as well as the government requirements.

3.5 Limitations

Drive cycles are one of the major testing standards used for vehicle testing and evaluation in order to predict their performance on the road. The vehicle performance prediction can only be accurate if the test-beds, drive cycles that they are tested upon, are representative of the respective driving conditions. It is extremely important to also notice that no matter how accurate and precise the drive cycles are in themselves, they will not contribute much to accurate vehicle testing and performance prediction unless they represent drive conditions that very similar, if not exactly the same, to what the vehicle will experience on a specific road at a specific time and when driven by a specific driver. Since, external conditions such as weather, traffic, driver behavior, road conditions, terrain and vehicle conditions can actually impact the vehicle performance it is essential to include those conditions' effect in the drive cycle definition; not just the simulation parameters, in order to calculate accurate vehicle performance results.

In addition, not all the standard drive cycles are representative of real driving conditions. For example, the modal cycles – namely, European and Japanese cycles are stylistic drive cycles [3]. The vehicle performance is highly location dependent. As such, it will be very difficult to expect accurate performance prediction based on standardized patterns as the real-life scenario for a particular trip might be quite different.

Although, it is extremely important for the auto industry as well as the government to have accurate drive cycles for vehicle evaluation, it will be a very challenging task to come up with a scenario that might be applicable for every single trip of any particular vehicle. However, by using guided change management techniques, simulation options could be created where the drive cycles could be defined more accurately than the currently pre-existing ones, if not exactly representing the driving scenarios.

4 Journey Mapping Concept

4.1 Proposed Journey Mapping Definition

The idea of Journey Mapping was born from the limitations of the existing standard drive cycles as well as generic drive cycle models. Since drive cycles are primarily used for vehicle testing and vehicle performance prediction; unless they are very accurate, similar results cannot be expected. In order to predict how a vehicle will behave during a particular trip, it is essential to model exact or very similar drive conditions that the vehicle will encounter during the trip. As such, a new approach for defining drive cycles- Journey Mapping was proposed as follows:

Journey Mapping defines a vehicle's drive cycle as the journey of that particular vehicle from its origin to destination on that particular road which is affected by various conditions; some of which are terrain, weather, road conditions, traffic, driver behavior, vehicle condition et cetera. This definition is pictorially represented as follows:

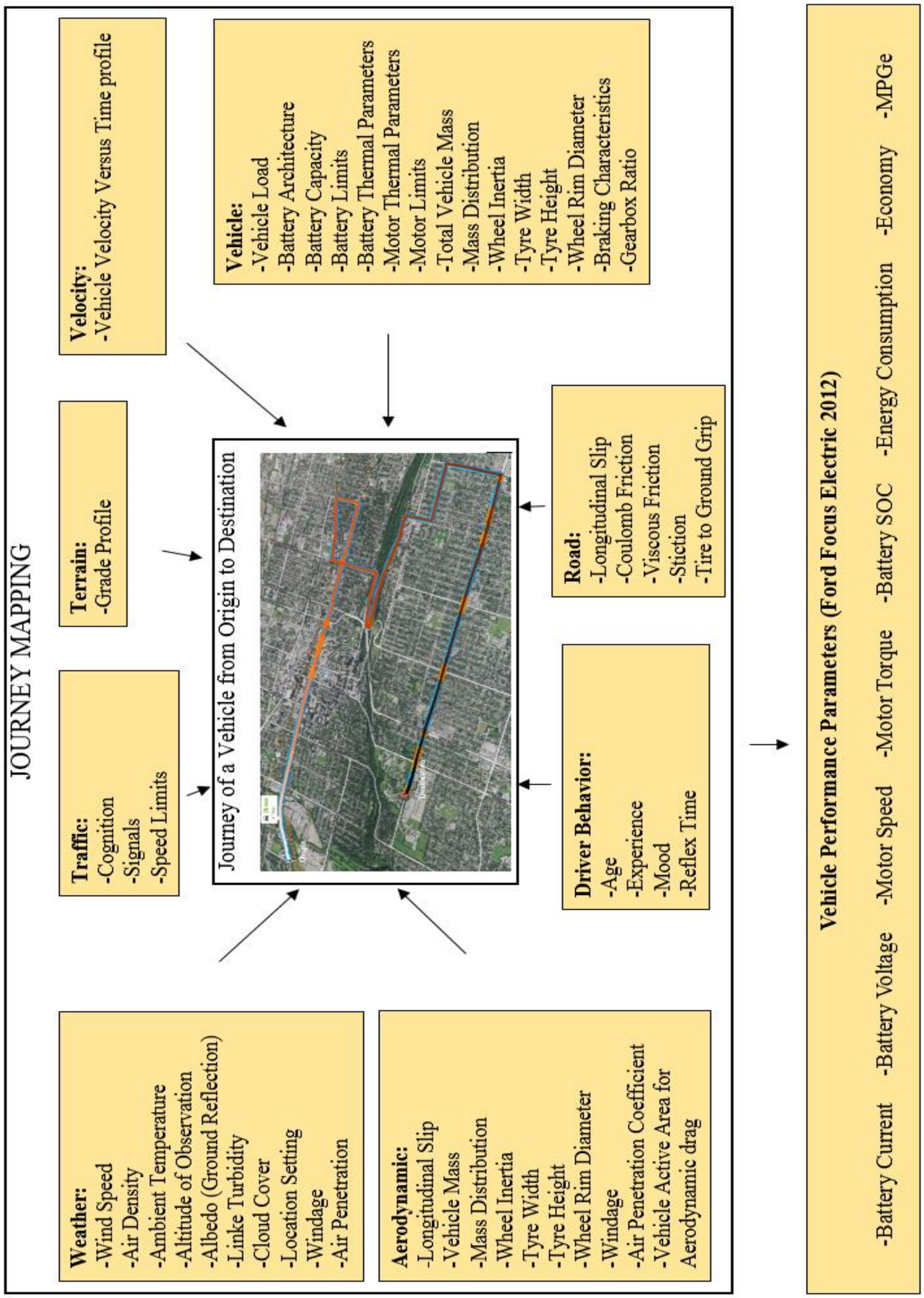

Figure 4.1: Journey Mapping Model

4.2 Conditions governing the Journey Mapping Concept

In theory, a vehicle is affected by various conditions during its drive such as terrain, weather, traffic, driver behavior, road conditions and vehicle conditions in addition to the changes in its velocity profile which in some cases might be a result of the above conditions as well as any changes in the auxiliary power load and so on. As such, implementation of these conditions in the drive cycle definition in order to test that particular vehicle will definitely result in accurate performance prediction by enabling modeling scenarios closer to the real-life situations.

However, it would be practically impossible to include all the conditions that a vehicle might encounter during its trip in the simulation model. In addition, AMESim, the vehicle simulation software used for implementing journey mapping, has some limitations in terms of the conditions that it can model. As such, only the conditions for which data could be collected as well as modeled have been included.

In the simulation model, many different parameters have been included that represent various conditions. Some parameters provide a representation for more than one condition. For example, the modeling of friction or tire to ground coefficients can represent road conditions as well as the vehicle's condition. A detailed list of parametric values used and their description for various iterations will be described in the Modeling and Simulations chapter. A summarized list of the major parameters is described below.

Mission profile parameters such as wind speed, air density and ambient temperature, which model weather conditions, are constant values for one trip. However, they vary for every iteration or trip. Also, varying terrain is modeled using road grade or slope. This parameter varies with distance traveled by the vehicle throughout a trip. In addition, varying vehicle parameters such as its velocity profile as well as the gearbox ratio are also modeled as part of the mission profile. These parameters change with respect to time throughout a trip.

Ambient conditions parameters model weather conditions. Parameters such as the altitude of observation, albedo or ground reflection coefficient, linke turbidity factor and cloud cover factor in addition to the localization parameters such as the latitude, longitude, time zone, exact date and time at the start of the trip are modeled in this section. These parameters change for every trip or iteration, but are constant throughout a single trip. The ambient conditions parameters result in the calculation of the solar azimuth angles and solar altitude which varies with time throughout a trip.

Driver parameters enable in modeling driver behavior. Although, the simulation model does not include the exact behavior of the actual drivers that drove the test vehicles in order to collect the true data, a generic driver behavior and its impact on the vehicle performance can be seen. The driver model is conditioned using a Proportional Integral Derivative (PID) controller. Derivative, proportional and integral gains for the acceleration as well as the braking control are specified here. Also, the advance time for control anticipation as well as the duration between the beginning of pull away and the braking pedal lift is also specified here. These parameters are constant throughout a trip, but change for every trip. These help in the calculation of the driver acceleration and braking control throughout the trip, which vary with respect to time throughout a trip.

Vehicle parameters have been used to model aerodynamic, road as well as vehicle conditions. Aerodynamic and rolling parameters such as coulomb friction coefficient, air penetration coefficient, aerodynamic drag area, stiction coefficient and tire to ground grip coefficients have been modeled. These parameters are constant for one trip, but change for every trip. The vehicle parameters help in the calculation of braking and driving force, climbing resistance, aerodynamic drag, front and rear axle slip as well as rolling resistance. These vary with time throughout a trip.

Besides, the simulation parameters described above, CAN data logger parameters also model certain conditions. In the Ford Focus Electric 2012, the vehicle velocity data and auxiliary power is collected in order to model vehicle conditions. The outside temperature information models weather conditions. In addition, driver behavior is also monitored using a driver eco score which is calculated based on average velocity, % hard acceleration (how hard a driver accelerates), % hard braking (how hard a driver brakes) and number of idle events. The driver eco score is calculated within a range of 0 to 100 where 0 represents highly aggressive driving and 100 represents very efficient driving. Similarly, for the Toyota Prius 2006, the velocity as well as absolute load value have been collected for vehicle conditions. Outside temperature information is also collected to model weather conditions. Similar to the Ford Focus Electric, the driver behavior information is collected in terms of a driver eco score. Traffic information has also been collected using typical traffic data posted by Google Maps for the respective day and time of the trip. A traffic score of 1 to 4 was assigned where 1 corresponded to a very slow traffic, 2 corresponded to a slow traffic, 3 corresponded to a moderate traffic and 4 corresponded a fast traffic.

4.3 Data Collection

The data has been collected through various techniques which will be described below. It was not possible to have all the data collected through the same means because of a lack of equipment.

The terrain information, which was modeled using road grade, was mainly acquired through high accuracy Geographic Information System (GIS) software known as ArcGIS. Accurate Digital Elevation Model (DEM) data was received from McMaster University's Scholar's Geoportal. This data was then modeled using ArcGIS in order to acquire accurate terrain information. Terrain information was also collected using a Garmin Nuvi Global Positioning System (GPS) as well as a GateTel CAN data logger, GT-GE910-GNS.

The CAN data logger was plugged into the vehicle's CAN bus. There was also an attachment to measure GPS data. The CAN data logger setup was done as shown below for Toyota Prius 2006.

Figure 4.2: CAN Data logger setup

The traffic data was approximated using Google Maps. A typical traffic data depending on the day and time was acquired. The vehicle velocity data was acquired using the Garmin Nuvi GPS as well as the CAN data logger. The weather information was acquired using the CAN data logger as well as the hourly data files from Environment Canada. Lastly, the driver behavior information was collected using the CAN data logger.

4.4 Benefits and Applications

Journey Mapping provides a means for accurate vehicle testing and performance prediction by enabling the modeling of real-life conditions. It could serve as an accurate testing bed for various new and existing vehicles. This in turn could be helpful in revising the Environmental Protection Agency (EPA) energy consumption and fuel economy labels to reflect information that is closer to what drivers might actually see on the roads.

In addition, it could also be applied to conventional, off-road, military or emergency vehicles. Journey Mapping would be able to predict the vehicle performance before-hand, which could be very helpful for emergency vehicles which undergo trips with completely unknown conditions. Similarly, the Journey Mapping concept could be applied to bikes, aircrafts or even under-water vehicles in order to predict their performance before-hand.

It could also serve as a vehicle prediction tool and a means for intelligent decision making for autonomous-capable vehicles, when integrated with vehicle-to-vehicle, vehicle-to-infrastructure and advanced sensor information.

If commercialized through a simple web portal, any car driver would be able to predict their vehicle's performance for a particular trip before- hand just by entering the trip information. This could also help in making route-specific decisions.

4.5 Limitations

The Journey Mapping concept can very accurately predict vehicle performance because it aims to include most of the real-life conditions that a vehicle might experience during its trip from origin to destination. However, it is practically impossible to collect data for all the conditions to be able to simulate those simultaneously. The present Journey Mapping model does not include traffic conditions and true driver behavior. In addition, some of the road and weather parameters are modeled as constants for a single trip, but as variables for different iterations due to the limitation of the simulation software being used. Thus, when the bigger picture is considered, Journey Mapping needs to be associated with accurate weather and traffic prediction models as Journey Mapping's basis is constituted by the various conditions it is governed by.

5 Modeling and Simulations

5.1 Ford Focus Electric Model

A 2012 Ford Focus Electric was used for the purposes of this research. A model was constructed both in AMESim as well as Autonomie. The Autonomie model was used for testing the Ford Focus Electric against five different standard drive cycles. The AMESim model was used to test against the standard as well as the journey mapping drive cycles. Two different software packages had to be used as Autonomie was found incapable of considering all the different conditions such as road, terrain, driver behavior, weather and aerodynamic simulatenously for calculating the resulting vehicle behavior. As such, the Autonomie simulation model has been included here only to offer a comparison between the two software packages for standard vehicle testing.

AMESim Simulation for 2012 Ford Focus Electric:

This model was developed based on an existing model for an electric vehicle with battery safety control unit in AMESim's vehicle integration library. This model was mainly chosen as it consisted of components that are similar to Ford Focus Electric. Also, this was one of the models that allowed to incorporate a lithium-ion battery pack. Modifications were made to this model according to the specifications provided by Ford [27] in order to reflect Ford Focus Electric 2012. The main specifications that were incorporated into the simulation model include for the tires, motor, battery and the vehicle itself. An attempt was made to model the parameters as closely as possible to the Ford Focus Electric 2012 model; however, some approximations had to be made for the battery and the electric motor in order to incorporate some limitations of the simulation software. The exact parameters used for different components in the model will be described in detail below. The overall AMESim model for the implementation of Journey Mapping on the Ford Focus Electric 2012 is as follows:

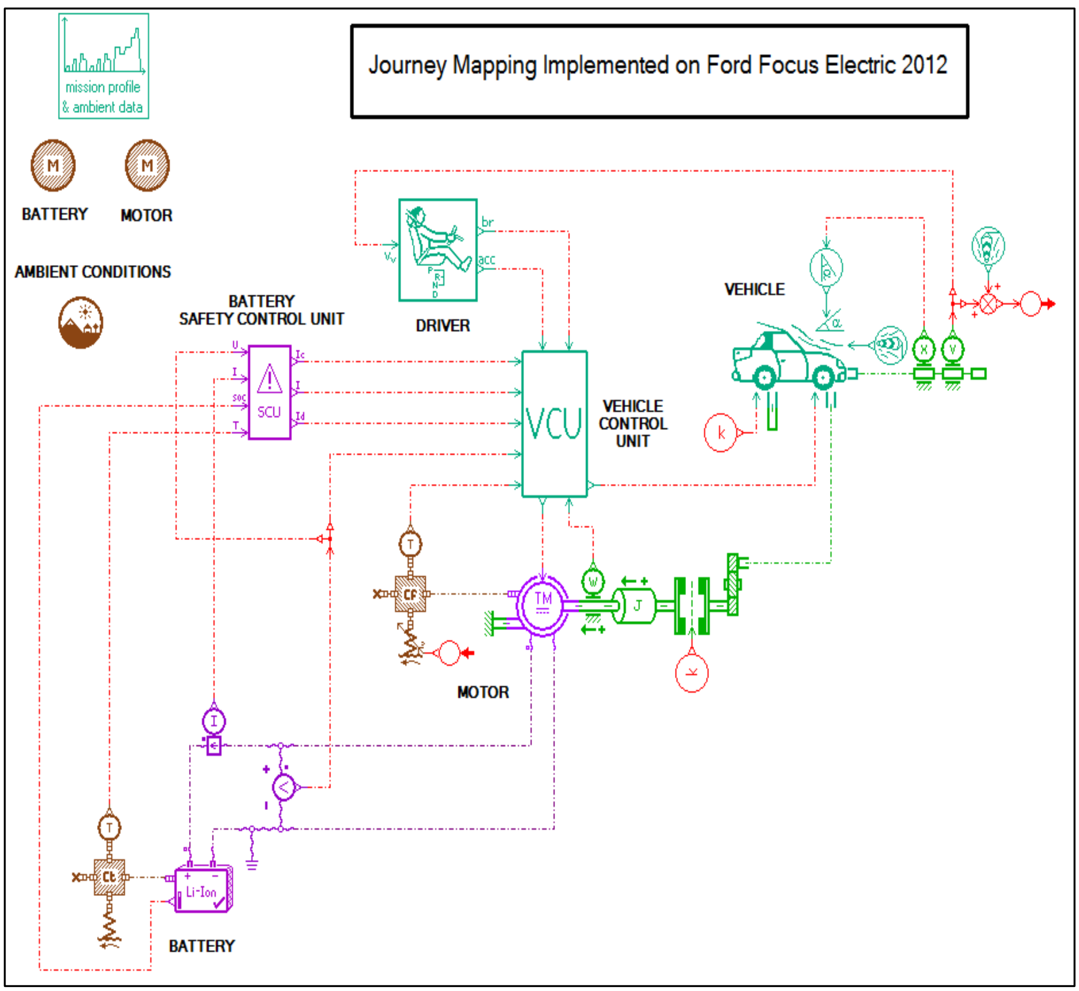

Figure 5.1: Journey Mapping Model Developed in AMESim

The description of various components, major user-defined parameters and conditions modeled through them for different Journey Mapping iterations is as follows.

The motor and battery models are inherent to the vehicle. As such, they are kept consistent throughout all the iterations.

Battery model: the battery parameters are as follows:

Title	**Value**	**Unit**	**Minimum (Min)**	**Default**	**Maximum (Max)**
state of Charge	100	%	0	60	100
diffusion overvoltage	0	V	-1.00E+06	0	1.00E-06
filtering capacitance	0.001	F	1.00E-30	0.001	1.00E+30
battery architecture:					
number of elements in series in one branch	100		1	1.00E+00	1.00E+08
number of branches in parallel	29		1	1.00E+00	1.00E+08
element nominal capacity	2.3	Ah	1.00E-06	2.3	1.00E+30
limits:					
limits management	warning message		1	2	3.00E+00
scope of the limits	pack		1	2	2.00E+00
state of charge range limitation	yes		1	1	2.00E+00
maximum temperature	1.00E+30	degC	-273.15	1.00E+30	1.00E+30
minimum temperature	-273.15	degC	-273.15	-273.15	1.00E+30
high current limit	1.00E+30	A		1.00E+30	
low current limit	-1.00E+30	A		-1.00E+30	
high voltage limit	1.00E+30	V		1.00E+30	
low voltage limit	0.00E+00	V		0.00E+00	
numerical parameters:					

charge/discharge transition type	sharp		1	1.00E+00	2
input voltage initialization	automatic		1	1.00E+00	2
interpolation parameters:					
discontinuity handling	active		1	2.00E+00	2

Table 5.2: AMESim Battery Parameters for Ford Focus Electric 2012

The Ford Focus Electric 2012 has a 23 kWh lithium-ion liquid cooled battery. The above battery has been modeled to have the same capacity as Ford Focus Electric. As such, the battery architecture has been adjusted accordingly. The rest of the parameters have been left as default. This battery pack consists of high power Lithium Iron Phosphate or LFP-C cells. Each cell's nominal capacity is 2.3 Ah.

The Battery's thermal properties are as described below.

Title	Value	Unit	Min	Default	Max
solid type index	1		1	1	99
material definition	user defined		1	2	17
type of definition	constant values		1	2	3
minimal temperature	-100	deg C	-273.15	-100	1.00E+06
maximal temperature	660	deg C	-273.15	660	1.00E+06
density of the material	2028	kg/m^3	0	2700	1.00E+06
specific heat of the material	2000	J/kg/K	0	900	1.00E+07
thermal conductivity of the material	23	W/m/K	0	150	1.00E+07
name of the solid	battery material			AMESim aluminum	

Table 5.3: AMESim Battery Thermal Parameters for Ford Focus Electric 2012

The Battery safety control unit's parameters are as follows. Most of the battery safety control unit's parameters were kept the same as default values; however, the battery architecture was modified to reflect the correct arrangement used in the battery model.

Title	Value	Unit	Min	Default	Max
element max continous charge current	20	A	1.00E-34	20	1.00E+34
element max pulse charge current	30	A	1.00E-34	30	1.00E+34
element max continous discharge current	20	A	1.00E-34	20	1.00E+34
element max pulse discharge current	30	A	1.00E-34	30	1.00E+34
pulse duration	10	s	1.00E-34	10	1.00E+03
element min voltage	2.95	V	1.00E-34	2.5	1.00E+34
element max voltage	3.65	V	1.00E-34	3.65	1.00E+34
max operating temperature	30	deg C	0.00E+00	30	1.00E+03
max temperature	65	deg C	0.00E+00	65	1.00E+03
battery characteristics:					
battery architecture:					
number of elements in series in one branch	100		1.00E+00	1	1.00E+08
number of branches in parallel	29		1.00E+00	1	1.00E+08
battery physical parameters:					
temperature dependence	yes		1	2	2
charge/discharge resistance modeling	yes		1	2	2
charge internal resistance data file	data_R_ch .data			0.005	
discharge internal resistance datafile	data_R_dc h.data			0.005	
numerical parameters:					
charge/discharge transition type	sharp		1	1	2
interpolation parameters:					
discontinuity handling	active		1	2	2

interpolation type	linear		1	1	2
datafile linear data out of range mode	extreme value		1	2	2

Table 5.4: AMESim Battery Safety Control Unit Parameters for Ford Focus Electric 2012

Motor model: The Ford Focus Electric has a 107 kW electric motor. The electric motor's specifications have been included in this model though a series of data tables as it can be seen below. The input voltage, rotary velocity and temperature are used to get the maximum motor and generator torque. The motor parameters are as follows:

Title	**Value**	**Unit**	**Min**	**Default**	**Max**
torque	0	Nm	-1.00E+16	0	1.00E+16
max/min electromagnetic torque as a function of	input voltage, rotary velocity and temperature		1	1	4
losses as a function of	input voltage, torque, rotary velocity and temperature		1	1	4
torque time constant	0.01	s	1.00E-16	0.1	1.00E+16
max motor torque datafile	TM_TorqueMax_UWT.data			TM_TorqueMax_UWT.data	
max generator torque data file	TM_TorqueMin_UWT.data			TM_TorqueMin_UWT.data	
losses datafile	TM_Losses_UWT.data			TM_Losses_UWT.data	
interpolation parameters:					
interpolation type	linear		1	1	2
linear data out of range mode	linear extrapolation		1	1	2

discontinuity handling	inactive		1	2	2
numerical parameters:					
motor/generator transition type	smooth		1	1	3
min speed for motor/generator transition	0.1	rev/min	1.00E-12	0.1	10
min voltage	0.01	V	1.00E-06	0.001	1

Table 5.5: AMESim Motor Parameters for Ford Focus Electric 2012

The electric motor's thermal properties were left to be as default. They are as follows:

Title	**Value**	**Unit**	**Min**	**Default**	**Max**
solid type index	2		1	1	99
material definition	user defined		1	2	17
type of definition	constant values		1	2	3
min temperature	-100	deg C	-273.15	-100	1.00E+06
max temperature	660	deg C	-273.15	660	1.00E+06
density of the material	2700	kg/m^3	0	2700	1.00E+06
specific heat of the material	900	J/kg/K	0	900	1.00E+07
thermal conductivity of the material	150	W/m/K	0	150	1.00E+07
name of the solid	motor material			AMESim aluminum	

Table 5.6: AMESim Motor Thermal Parameters for Ford Focus Electric 2012

The parameters specific to the vehicle were used consistently throughout all the iterations of the simulations. However, certain parameters are modified for every iteration of the Journey Mapping as well as standard drive cycle simulations. Firstly, the various Journey Mapping iterations, conditions governing them and the parameters used to model those conditions would be described. Then, the various standard drive cycles and the parameters used to model those would be shown.

The Journey Mapping data for the Ford Focus Electric was collected over the span of about ten months. An attempt was made to collect data over varying external conditions. Based on the real-life conditions observed, the Journey Mapping simulation parameters were modified accordingly to understand the effect of these parameters on the vehicle performance. The route for all these iterations was kept constant, only the different varying external conditions were evaluated. The route was kept constant in order to make sure that the results, mainly in terms of energy consumption, were not biased. Even though the route was kept constant, it was selected such that drastically varying terrain could be experienced. For the driver behavior data collection described in this thesis, two different drivers have driven the test vehicles. They will be referred to as driver 1 and driver 2.

The Journey Mapping route, from the origin, MARC (43.2591280, -79.9023940) situated at 200 Longwood Road South, Hamilton, Ontario to the destination, Mohawk College (43.2393830, -79.8876790) situated at 135 Fennell Avenue West, Hamilton, Ontario is as shown in Figure 5.7. It is to be noted here that the trip for Journey Mapping was only a one-way trip and not a round trip. As highlighted in the future work section, this study could be extended to include a round trip in order to increase the reliability of the results.

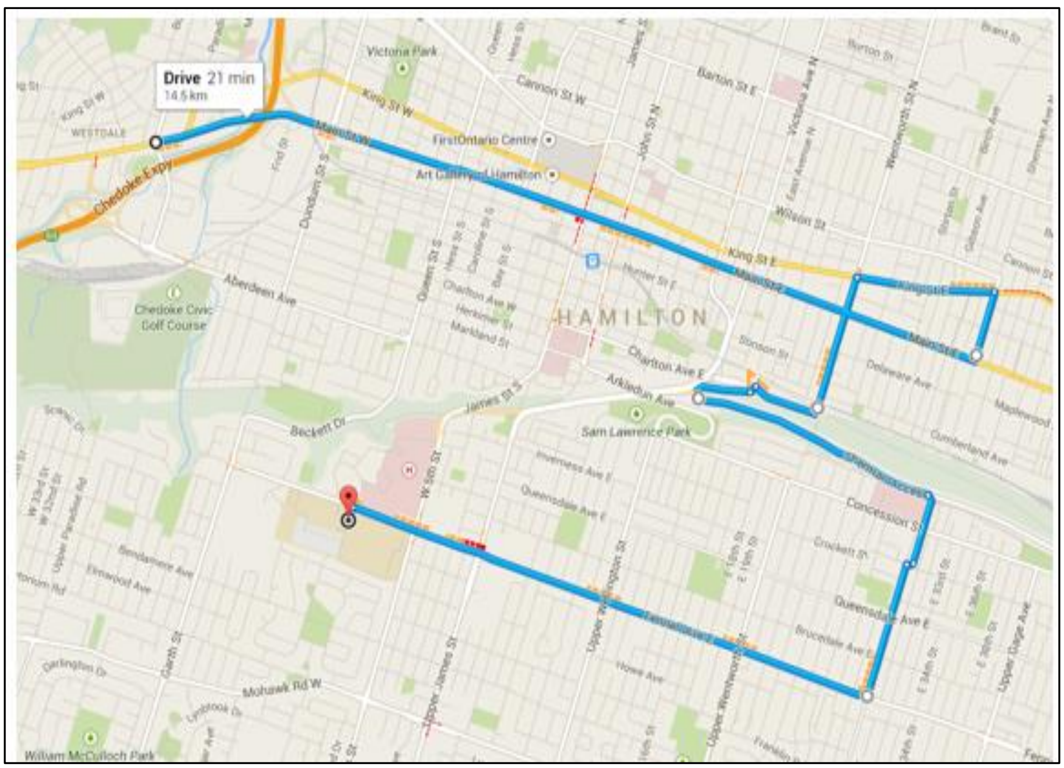

Figure 5.7: Route for Journey Mapping

The Journey Mapping conditions for various iterations as well as their respective simulation parameters are described below. For every iteration of Journey Mapping, corresponding actual results from the CAN data logger have also been recorded. Only Journey Mapping 1 does not have corresponding data logger results as the data logger was not purchased at that time of the iterations. The actual results and their comparison to the Journey Mapping results will be described in the Simulation Results section.

Journey Mapping 1:

The data for the first Journey Mapping iteration was collected on 24 February, 2014 between 1:35 p.m. to 1:59 p.m. It was clear sky with not too much snow on the roads. The average outside temperature was -8 degrees Celsius and the average wind speed was 29 km/h. The Ford Focus Electric was being driven by driver 1 for this iteration. Although, traffic conditions have not been incorporated into the current simulation model, they were observed for any relevant future work. The traffic during this iteration was seen to be moderate. There were a few spots with traffic congestion due to ongoing construction work. The parameters used to reflect the above drive’s conditions are described below.

Mission Profile: The wind speed, air density, ambient temperature as well as the road grade, gearbox ratio and vehicle velocity profiles were modified from the default values to reflect this iteration of Journey Mapping.

Title	**Value**	**Unit**	**Min**	**Default**	**Max**
driving cycle	personal		1	2	10
data out of range mode	extreme value		1	2	3
discontinuity handling	active		1	2	2
vehicle load profile between two stops	constant		1	1	2
wind speed	29	km/h	-150	0	150
air density	1.307	kg/m^3	0	1.205	2000
ambient temperature	-8.5	deg C	0	25	50
filename for road slope [%] = f(vehicle displacement: x[m])	JourneyMapping1 roadslopefinal.data			0*x+0	
filename for vehicle load [kg] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle velocity [m/s] = f(time[s])	JourneyMapping1 Velocity.data			MyVelocityFile. data	
filename for gearbox ratio [null] = f(time[s])	JourneyMapping1 GearRatio.data			GearRatioFile. data	

Table 5.8: Mission Profile Parameters for Journey Mapping 1

Ambient Conditions: This block helps in modeling weather conditions. The parameters are as follows:

Title	Value	Unit	Min	Default	Max
ambient conditions index	1		1	1	99
solar variables	all by correlation		1	1	3
calculation mode					
solar calculations parameters:					
altitude of observation	126.023	m	0	6	2500
albedo (ground reflection coefficient)	0.2	null	0	0.2	1
Linke turbidity factor	4.5	null	0	3	10
cloud cover factor	0.3			0	
localization:					
position setting	GPS coordinates		1	2	2
latitude	43.2591	degree	-90	45.78	90
longitude	-79.9024	degree	-180	4.85	180
time zone (GMT+ or -)	-4	null	-12	0	14
daylight saving time	observed		1	1	2
starting time and date					
year	2014		1900	2000	2099
month	February		1	1	12
day	25		1	1	31
hour	1		0	0	23
minute	37		0	0	59
second	0		0	0	59

Table 5.9: Ambient Conditions Parameters for Journey Mapping 1

The albedo coefficient, linke turbidity factor and cloud cover factor have been selected based on manual observation of weather during the various Journey Mapping iterations. They have been selected for every iteration relatively to the other iterations. The albedo or ground reflection coefficient signifies the reflection of sunlight by the ground. It ranges from 0 to 1 where 0 is a ground fully absorbing sunlight and 1 is a ground completely reflecting sunlight. Linke Turbidity factor deals with the haziness of atmosphere in the sky or in other words, the amount of particles in the atmosphere. This ranges from 3 to 7, where 3 is a completely clear atmosphere and 7 is an atmosphere with most particles. Finally, the cloud cover coefficient explains the coverage of clouds in the sky. It ranges from 0 to 1, where 0 is a completely clear sky and 1 is a completely dark sky. In addition, time and space localization parameters are set in order to synchronize with the corresponding simulation time.

Based on these parameters entered, the solar radiation angles – solar altitude and solar azimuth are calculated in the background. These angles are calculated using a "set_sun_angles" utility in AMESim which uses various astronomical equations [28].

Driver behavior model: The driver model incorporated in this simulation is a generic driver model. The anticipative, integral and proportional gains for acceleration and braking control have been selected in order to give the closest vehicle speed in relation to the vehicle control speed. As such, the driver parameters enabling a successful simulation were selected through manual tuning.

Title	**Value**	**Unit**	**Min**	**Default**	**Max**
cycle type	cycle with slopes		1	1	2
advance time for control anticipation	2	s	1.00E-05	2	5
acceleration control:					
integral part	0	m	-1.00E+06	0	1.00E+06
anticipative gain	0.75	1/(m/s/s)	0	0.25	1.00E+06

proportional gain	0.62	1/(m/s)	0.00E+00	0.5	1.00E+06
integral gain	0	1/m	0	0	1.00E+06
braking control:					
integral part	0	m	-1.00E+06	0	1.00E+06
anticipative gain	0.75	1/(m/s/s)	0	0.25	1.00E+06
proportional gain	0.62	1/(m/s)	0	0.5	1.00E+06
integral gain	0	1/m	0	0	1.00E+06
stops:					
braking when vehicle stopped	yes		1	2	2.00E+00
duration between pull away beginning and braking pedal lift	0.5	s	0.2	0.5	1.00E+00

Table 5.10: Driver Behavior Parameters for Journey Mapping 1

Based on the above provided parameters, the driver acceleration control and the braking control are calculated in the background as follows [29]:

First, the error signal is evaluated as follows:

$$err = V_{cont} - V_{veh}$$

The acceleration control is then calculated as follows [29]:

$$acc = GP_{acc} * err + GI_{acc} * \int err. dt + GA_{acc} * dv_{cont}Ant$$

Where,

$$dv_{cont}Ant = \frac{V_{cont}Ant - V_{cont}}{advAnt}$$

Similarly, the braking control is calculated as follows [29]:

$$brak = -GP_{br} * err - GI_{br} * \int err.dt - GA_{br} * dv_{cont}Ant$$

The true driver behavior could not be incorporated into this model because of AMESim library model's limitations. In addition, there was a discrepancy between the metrics that have been used by the CAN data logger to acquire driver behavior information, when compared to the ones used by AMESim. As CAN data could not be collected for the first iteration, the true driver behavior will be described from the next iteration onwards.

Vehicle model:

Some of the parameters in this model are inherent to the vehicle; whereas, the others are used to model road and vehicle conditions. The parameters are as follows:

Title	Value	Unit	Min	Default	Max
vehicle linear velocity	0	m/s	-1.00E+06	0.00E+00	1.00E+06
vehicle linear displacement	0	m	-1.00E+06	0.00E+00	1.00E+06
vehicle index	1		1	1	100
vehicle configuration	road		1	1	2
longitudinal slip configuration	slip		1	1	2
total vehicle mass	1674	kg	0	1	1.00E+06
mass distribution	50	%	0	50	100
wheel inertia	0.747	kgm^2	-1.00E+06	0.5	1.00E+06
tyre width	225	mm	50	195	500
tyre height	50	%	25	65	8.50E+01
wheel rim diameter	17	in	10	15	23
wheel dynamic radius	0.97*Rw			0.97*Rw	

aerodynamic and rolling parameters:					
coulomb friction coefficient (rolling resistance)	0.05	null	0	0.01	1.00E+06
viscous friction coefficient (rolling resistance)	0	1/(m/s)	0	0	1.00E+06
windage coefficient (rolling resistance)	0	1/(m/s)^2	0	0	1.00E+06
air penetration coefficient (Cx)	0.295	null	0	0.3	1.00E+03
vehicle active area for aerodynamic drag	4685.1	in^2	0	2	1.00E+06
stiction coefficient	1.2	null	1	1.2	1.00E+02
brake characteristics:					
maximum braking torque on rear axle	3000	Nm	-1.00E+06	1000	1.00E+06
maximum braking torque on front axle	3000	Nm	-1.00E+06	1000	1.00E+06
rotary stick velocity threshold for brake	1.00E-06	rev/min	0	1.00E-06	1.00E+06
tyre longitudinal slip parameters:					
tyre/ground grip coefficient	0.8	null	0	1	1.00E+06
rotary stick velocity threshold for longitudinal slip	0.01	rev/min	0	0.01	1.00E+06

Table 5.11: Vehicle Parameters for Journey Mapping 1

The vehicle mass, tire width, height, wheel rim diameter, air penetration coefficient and aerodynamic drag area were modeled according to the Ford Focus Electric 2012’s specifications [27]. The wheel inertia was calculated as follows:

$R_w = S_w/24$

$M_w = W_w/32.2$

$$M_t = W_t/32.2$$

$$H_{ts} = (T_{wi} * (\frac{AR}{100})/25.3995)/12$$

$$R_t = R_w + H_{ts}$$

$$RI_w = 0.5 * M_w * R_w^2$$

$$RI_t = 0.5 * M_t * (R_w^2 + R_t^2)$$

$$WI = RI_w + RI_t$$

The various coefficients of friction such as coulomb, stiction and tire to ground grip coefficients were selected relatively for each iteration in order to model the applicable drive conditions. The various calculations relating to vehicle, road and aerodynamic conditions are as follows [30]. These calculations happen in the background of the model simulation in order to display the final vehicle performance results.

The vehicle characteristics are calculated as follows [30]:

$$R_{ws} = 0.5 * D_{rim} + 0.01 * height * width$$

$$m_{veh} = mass + 4 * J_w/{R_{ws}}^2$$

The driving forces are calculated as follows, when longitudinal slip is taken into account while implementing Journey Mapping [30]:

$$S_L = 100 * \frac{R_{dyn} * \omega_W * \frac{\pi}{30} - v}{v}$$

The Normal forces are calculated as follows [30]:

$$F_{N,front} = mass * g * \cos(\arctan(0.01 * \alpha)) * (\frac{m_{distrib}}{100})$$

$$F_{N,rear} = mass * g * \cos(\arctan(0.01 * \alpha)) * (1 - \frac{m_{distrib}}{100})$$

The longitudinal slip and then driving force is calculated as follows [30]:

$$F_{L,front} = \mu * F_{N,front} * \tanh(2 * \frac{w_{rel}}{dw})$$

$$F_{L,rear} = \mu * F_{N,rear} * \tanh(2 * \frac{w_{rel}}{dw})$$

$$F_{dr} = F_{L,front} + F_{L,rear}$$

The road as well as vehicle conditions are also modeled using the resistive forces such as climbing resistance, aerodynamic drag and rolling resistance. They are calculated as follows [30]:

$$F_{cl} = mass * g * \sin(\arctan(0.01 * \alpha))$$

$$F_{aero} = 0.5 * \rho_{air} * C_x * S * (v + v_{wind})^2$$

$$F_{roll} = mass * g * (f + k * v + wind * v^2)$$

$$F_{res} = F_{cl} + F_{aero} + F_{roll}$$

The vehicle speed compared to the control speed shows a successful simulation:

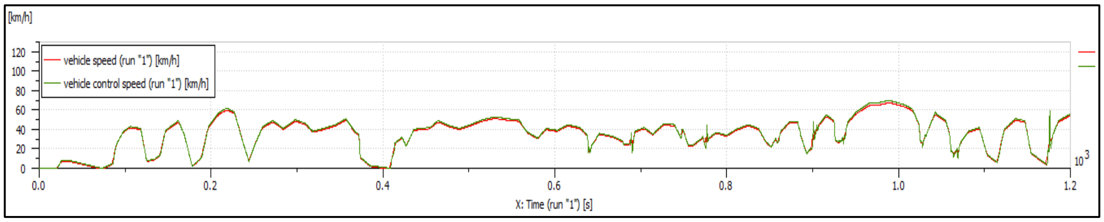

Figure 5.12: Vehicle and Control Speed for Journey Mapping 1

Journey Mapping 2:

The data for the second Journey Mapping iteration was collected on 29 April, 2014 between 11:09 a.m. to 11:38 a.m. It was extremely foggy and was raining very heavily. The average outside temperature was about 6.9 degrees Celsius and the average wind speed was 16 km/h. The Ford Focus Electric was being driven by driver 1 for this iteration. The traffic during this iteration was seen to be moderate. However, visibility was very poor due to the weather conditions. The parameters that have changed from the previous Journey Mapping iteration are described below:

Mission profile:

The wind speed, air density, ambient temperature and the velocity profile was modified to represent the respective drive conditions.The parameters for mission profile are as follows:

Title	Value	Unit	Min	Default	Max
driving cycle	personal		1	2	10
data out of range mode	extreme value		1	2	3
discontinuity handling	active		1	2	2
vehicle load profile between two stops	constant		1	1	2
wind speed	16	km/h	-150	0	150
air density	1.237	kg/m^3	0	1.205	2000
ambient temperature	6.91951	deg C	0	25	50
filename for road slope [%] = f(vehicle displacement: x[m])	JourneyMapping1 roadslopefinal.data			0*x+0	
filename for vehicle load [kg] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle velocity [m/s] = f(time[s])	JourneyMapping2 Velocity.data			MyVelocity File.data	
filename for gearbox ratio [null] = f(time[s])	JourneyMapping1 GearRatio.data			GearRatio File.data	

Table 5.13: Mission Profile Parameters for Journey Mapping 2

Ambient Conditions: The weather parameters such as albedo coefficient, linke turbidity factor and cloud cover factor in addition to the altitude of observation as well as the date and time parameters were modified according to the observed conditions. This iteration simulates an extreme weather condition with very poor visibility.

Title	Value	Unit	Min	Default	Max
ambient conditions index	1		1	1	99
solar variables	all by correlation		1	1	3
calculation mode					
solar calculations parameters:					
altitude of observation	102.718	m	0	6	2500
albedo (ground reflection coefficient)	0.4	null	0	0.2	1
Linke turbidity factor	6.5	null	0	3	10
cloud cover factor	0.85			0	
localization:					
position setting	GPS coordinates		1	2	2
latitude	43.2591	degree	-90	45.78	90
longitude	-79.9024	degree	-180	4.85	180
time zone (GMT+ or -)	-4	null	-12	0	14
daylight saving time	observed		1	1	2
starting time and date					
year	2014		1900	2000	2099
month	April		1	1	12
day	29		1	1	31
hour	11		0	0	23
minute	9		0	0	59
second	0		0	0	59

Table 5.14: Ambient Conditions Parameters for Journey Mapping 2

Vehicle model: The road conditions which were also affected by the weather conditions in addition to the vehicle and aerodynamic conditions' parameters were modified to model the real driving situation during this iteration of Journey Mapping. The coulomb friction, stiction and tire to ground grip coefficients were modified accordingly.

Title	Value	Unit	Min	Default	Max
vehicle linear velocity	0	m/s	-1.00E+06	0	1.00E+06
vehicle linear displacement	0	m	-1.00E+06	0	1.00E+06
vehicle index	1		1	1	100
vehicle configuration	road		1	1	2
longitudinal slip configuration	slip		1	1	2
total vehicle mass	1674	kg	0	1	1.00E+06
mass distribution	50	%	0	50	100
wheel inertia	0.747	kgm^2	-1.00E+06	0.5	1.00E+06
tyre width	225	mm	50	195	500
tyre height	50	%	25	65	8.50E+01
wheel rim diameter	17	in	10	15	23
expression for wheel dynamic radius	0.97* Rw			0.97*R w	
aerodynamic and rolling parameters:					
coulomb friction coefficient (rolling resistance)	0.065	null	0	0.01	1.00E+06
viscous friction coefficient (rolling resistance)	0	1/(m/s)	0	0	1.00E+06
windage coefficient (rolling resistance)	0	1/(m/s)^ 2	0	0	1.00E+06
air penetration coefficient (Cx)	0.295	null	0	0.3	1.00E+03
vehicle active area for aerodynamic drag	4685.1	in^2	0	2	1.00E+06
stiction coefficient	1	null	1	1.2	1.00E+02
brake characteristics:					
maximum braking torque on rear axle	3000	Nm	-1.00E+06	1000	1.00E+06
maximum braking torque on front axle	3000	Nm	-1.00E+06	1000	1.00E+06
rotary stick velocity threshold for brake	1.00E-06	rev/min	0	1.00E-06	1.00E+06
tyre longitudinal slip parameters:					
tyre/ground grip coefficient	0.7	null	0	1	1.00E+06
rotary stick velocity threshold for longitudinal slip	0.01	rev/min	0	0.01	1.00E+06

Table 5.15: Vehicle Parameters for Journey Mapping 2

Driver behavior: Although, the driver model used in the AMESim simulation was not modified compared to the previous Journey Mapping iteration; since, the CAN data logger data was available during this iteration, the true driver behavior data was measured. As previously stated, the test drives were done by one of the two drivers. Their information is as follows:

Driver 1:

Age: 32

Driving Experience: 14 years

Driver 2:

Age: 64

Driving Experience: 48 years

For this iteration of Journey Mapping, driver 1's eco-driving score was calculated as 66.66%. The % hard acceleration, % hard braking and number of idle events during the trip were found to be 7, 4 and 2 respectively. The graph showing the comparison between vehicle speed and the control speed shows a successful simulation:

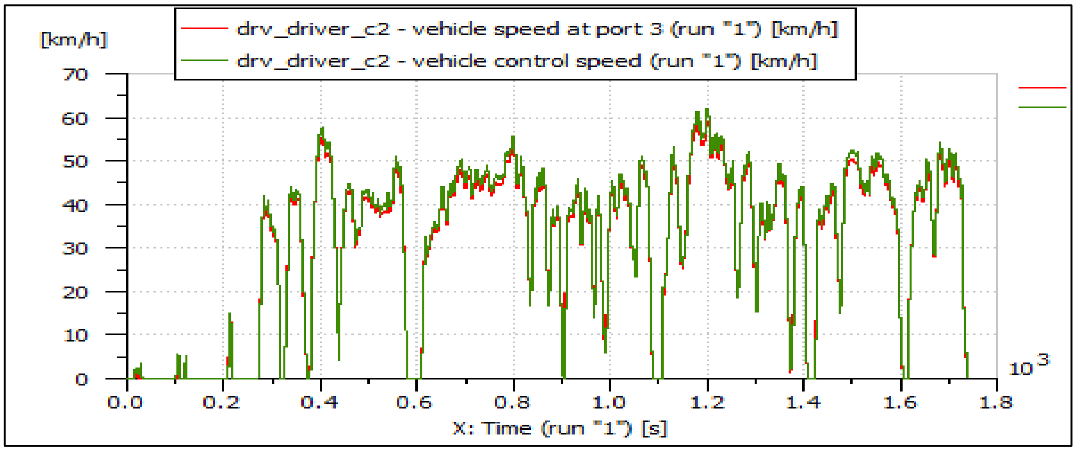

Figure 5.16: Vehicle and Control Speed for Journey Mapping 2

Journey Mapping 3:

The data for the third Journey Mapping iteration was collected on 24 July, 2014 between 12:09 p.m. to 12:37 p.m. It was a very bright and sunny day. The visibility was excellent. The average outside temperature was about 22.3 degrees Celsius and the average wind speed was 9 km/h. The Ford Focus Electric was being driven by driver 1 for this iteration. The traffic during this iteration was seen to be quite heavy due to lunch hour rush. The parameters that have changed from the previous Journey Mapping iterations are described below:

Mission Profile:

The wind speed, air density, ambient temperature and velocity profile were modified according to the drive conditions. The parameters are as follows:

Title	Value	Unit	Min	Default	Max
driving cycle	personal		1	2	10
data out of range mode	extreme value		1	2	3
discontinuity handling	active		1	2	2
vehicle load profile between two stops	constant		1	1	2
wind speed	9	km/h	-150	0	150
air density	1.171	kg/m^3	0	1.205	2000
ambient temperature	22.3	deg C	0	25	50
filename for road slope [%] = f(vehicle displacement: x[m])	JourneyMapping1 roadslopefinal.data			0*x+0	
filename for vehicle load [kg] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle velocity [m/s] = f(time[s])	JourneyMapping3 Velocity.data			MyVelocity File.data	
filename for gearbox ratio [null] = f(time[s])	JourneyMapping1 GearRatio.data			GearRatio File.data	

Table 5.17: Mission Profile Parameters for Journey Mapping 3

Ambient Conditions: The altitude of observation and weather parameters such as albedo coefficient, linke turbidity factor and the cloud cover factor in addition to the date and time settings were modified to model the conditions observed during the drive for this iteration of Journey Mapping. The parameters for this model are as follows:

Title	Value	Unit	Min	Default	Max
ambient conditions index	1		1	1	99
solar variables	all by correlation		1	1	3
calculation mode					
solar calculations parameters:					
altitude of observation	110.154	m	0	6	2500
albedo (ground reflection coefficient)	0.1	null	0	0.2	1
Linke turbidity factor	3.5	null	0	3	10
cloud cover factor	0.1			0	
localization:					
position setting	GPS coordinates		1	2	2
latitude	43.2591	degree	-90	45.78	90
longitude	-79.9024	degree	-180	4.85	180
time zone (GMT+ or -)	-4	null	-12	0	14
daylight saving time	observed		1	1	2
starting time and date					
year	2014		1900	2000	2099
month	July		1	1	12
day	24		1	1	31
hour	12		0	0	23
minute	9		0	0	59
second	0		0	0	59

Table 5.18: Ambient Conditions Parameters for Journey Mapping 3

Vehicle model:

The coulomb friction, stiction and tire to ground grip coefficients were modified to reflect the drive conditions for this iteration. The parameters are as follows:

Title	Value	Unit	Min	Default	Max
vehicle linear velocity	0	m/s	-1.00E+06	0	1.00E+06
vehicle linear displacement	0	m	-1.00E+06	0	1.00E+06
vehicle index	1		1	1	100
vehicle configuration	road		1	1	2
longitudinal slip configuration	slip		1	1	2
total vehicle mass	1674	kg	0	1	1.00E+06
mass distribution	50	%	0	50	100
wheel inertia	0.747	kgm^2	-1.00E+06	0.5	1.00E+06
tyre width	225	mm	50	195	500
tyre height	50	%	25	65	8.50E+01
wheel rim diameter	17	in	10	15	23
expression for wheel dynamic radius	0.97* Rw			0.97* Rw	
aerodynamic and rolling parameters:					
coulomb friction coefficient (rolling resistance)	0.027	null	0	0.01	1.00E+06
viscous friction coefficient (rolling resistance)	0	1/(m/s)	0	0	1.00E+06
windage coefficient (rolling resistance)	0	1/(m/s)^2	0	0	1.00E+06
air penetration coefficient (Cx)	0.295	null	0	0.3	1.00E+03
vehicle active area for aerodynamic drag	4685.1	in^2	0	2	1.00E+06
stiction coefficient	1.3	null	1	1.2	1.00E+02
brake characteristics:					
maximum braking torque on rear axle	3000	Nm	-1.00E+06	1000	1.00E+06
maximum braking torque on front axle	3000	Nm	-1.00E+06	1000	1.00E+06
rotary stick velocity threshold for brake	1.00E-06	rev/min	0	1.00E-06	1.00E+06
tyre longitudinal slip parameters:					
tyre/ground grip coefficient	1	null	0	1	1.00E+06
rotary stick velocity threshold for longitudinal slip	0.01	rev/min	0	0.01	1.00E+06

Table 5.19: Vehicle Parameters for Journey Mapping 3

Driver Behavior model:

The anticipative and proportional gains were modified. The parameters are as follows:

Title	Value	Unit	Min	Default	Max
cycle type	cycle with slopes		1	1	2
advance time for control anticipation	2	s	1.00E-05	2	5
acceleration control:					
integral part	0	m	-1.00E+06	0	1.00E+06
anticipative gain	0.75	1/(m/s/s)	0	0.25	1.00E+06
proportional gain	0.8	1/(m/s)	0.00E+00	0.5	1.00E+06
integral gain	0	1/m	0	0	1.00E+06
braking control:					
integral part	0	m	-1.00E+06	0	1.00E+06
anticipative gain	0.75	1/(m/s/s)	0	0.25	1.00E+06
proportional gain	0.8	1/(m/s)	0	0.5	1.00E+06
integral gain	0	1/m	0	0	1.00E+06
stops:					
braking when vehicle stopped	yes		1	2	2.00E+00
duration between pull away beginning and braking pedal lift	0.5	s	0.2	0.5	1.00E+00

Table 5.20: Driver Behavior Parameters for Journey Mapping 3

The driver 1's eco-driving score was observed to be 53.98% for this iteration of Journey Mapping. The % hard acceleration, % hard braking and number of idle events during the trip were seen to be 14, 17 and 3 respectively.

The graph comparing the vehicle and control speed shows a successful simulation:

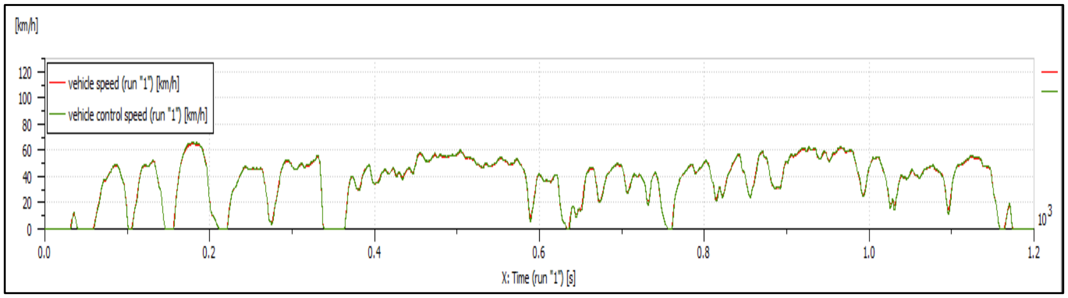

Figure 5.21: Vehicle and Control Speed for Journey Mapping 3

Journey Mapping 4:

The data for the fourth Journey Mapping iteration was collected on 23 September, 2014 between 11:14 a.m. to 11:44 p.m. It was a sunny day with clear sky but was slightly chilly. The average outside temperature was about 19.38 degrees Celsius and the average wind speed was 9 km/h. The Ford Focus Electric was being driven by driver 1 for this iteration. The traffic during this iteration was seen to be moderate. The parameters that have changed from the previous Journey Mapping iterations are described below:

Mission profile:

The weather parameters such as wind speed, air density and the ambient temperature were modified in addition to the applicable velocity profile for this iteration. The parameters are as follows:

Title	Value	Unit	Min	Default	Max
driving cycle	personal		1	2	10
data out of range mode	extreme value		1	2	3
discontinuity handling	active		1	2	2
vehicle load profile between two stops	constant		1	1	2
wind speed	9	km/h	-150	0	150
air density	1.183	kg/m^3	0	1.205	2000
ambient temperature	19.38	deg C	0	25	50
filename for road slope [%] = f(vehicle displacement: x[m])	JourneyMapping1 roadslopefinal.data			0*x+0	
filename for vehicle load [kg] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle velocity [m/s] = f(time[s])	JourneyMapping4 Velocity.data			MyVelocity File.data	
filename for gearbox ratio [null] = f(time[s])	JourneyMapping1 GearRatio.data			GearRatio File.data	

Table 5.22: Mission Profile Parameters for Journey Mapping 4

Ambient Conditions: Once again, the weather parameters such as albedo coefficient, linke turbidity factor and the cloud cover factor were modified according to the observed conditions. Also, the altitude of observation and the date and time settings were modified accordingly.

Title	Value	Unit	Min	Default	Max
ambient conditions index	1		1	1	99
solar variables	all by correlation		1	1	3
calculation mode					
solar calculations parameters:					
altitude of observation	108.92	m	0	6	2500
albedo (ground reflection coefficient)	0.3	null	0	0.2	1
Linke turbidity factor	5	null	0	3	10
cloud cover factor	0.25			0	
localization:					
position setting	GPS coordinates		1	2	2
latitude	43.2591	degree	-90	45.78	90
longitude	-79.9024	degree	-180	4.85	180
time zone (GMT+ or -)	-4	null	-12	0	14
daylight saving time	observed		1	1	2
starting time and date					
year	2014		1900	2000	2099
month	July		1	1	12
day	23		1	1	31
hour	11		0	0	23
minute	14		0	0	59
second	0		0	0	59

Table 5.23: Ambient Conditions Parameters for Journey Mapping 4

Vehicle model: The coloumb friction, stiction and tire to ground grip coefficients were re-assigend according to the conditions observed during this iteration of Journey Mapping. The parameters are as follows:

Title	Value	Unit	Min	Default	Max
vehicle linear velocity	0	m/s	-1.00E+06	0	1.00E+06
vehicle linear displacement	0	m	-1.00E+06	0	1.00E+06
vehicle index	1		1	1	100
vehicle configuration	road		1	1	2
longitudinal slip configuration	slip		1	1	2
total vehicle mass	1674	kg	0	1	1.00E+06
mass distribution	50	%	0	50	100
wheel inertia	0.747	kgm^2	-1.00E+06	0.5	1.00E+06
tyre width	225	mm	50	195	500
tyre height	50	%	25	65	8.50E+01
wheel rim diameter	17	in	10	15	23
expression for wheel dynamic radius	0.97* Rw			0.97* Rw	
aerodynamic and rolling parameters:					
coulomb friction coefficient (rolling resistance)	0.025	null	0	0.01	1.00E+06
viscous friction coefficient (rolling resistance)	0	1/(m/s)	0	0	1.00E+06
windage coefficient (rolling resistance)	0	1/(m/s)^2	0	0	1.00E+06
air penetration coefficient (Cx)	0.295	null	0	0.3	1.00E+03
vehicle active area for aerodynamic drag	4685.1	in^2	0	2	1.00E+06
stiction coefficient	1.2	null	1	1.2	1.00E+02
brake characteristics:					
maximum braking torque on rear axle	3000	Nm	-1.00E+06	1000	1.00E+06
maximum braking torque on front axle	3000	Nm	-1.00E+06	1000	1.00E+06
rotary stick velocity threshold for brake	1.00E-06	rev/min	0	1.00E-06	1.00E+06
tyre longitudinal slip parameters:					
tyre/ground grip coefficient	1	null	0	1	1.00E+06
rotary stick velocity threshold for longitudinal slip	0.01	rev/min	0	0.01	1.00E+06

Table 5.24: Vehicle Parameters for Journey Mapping 4

Driver Behavior: The driver model's parameters were kept the same as the previous iteration. However, there was a difference in the true driver data that was measured for driver 1. The eco driving score, % hard acceleration, % hard braking and number of idle events was seen to be 63.88%, 6, 10 and 7 respectively.

The comparison of the vehicle and the control speed below shows a successful simulation:

Figure 5.25: Vehicle and Control Speed for Journey Mapping 4

In addition to the Journey Mapping simulations described above, the Ford Focus Electric 2012 was also tested against five different standard driving cycles to provide a basis for comparison. The AMESim model used for all the standard drive cycle simulations is the same:

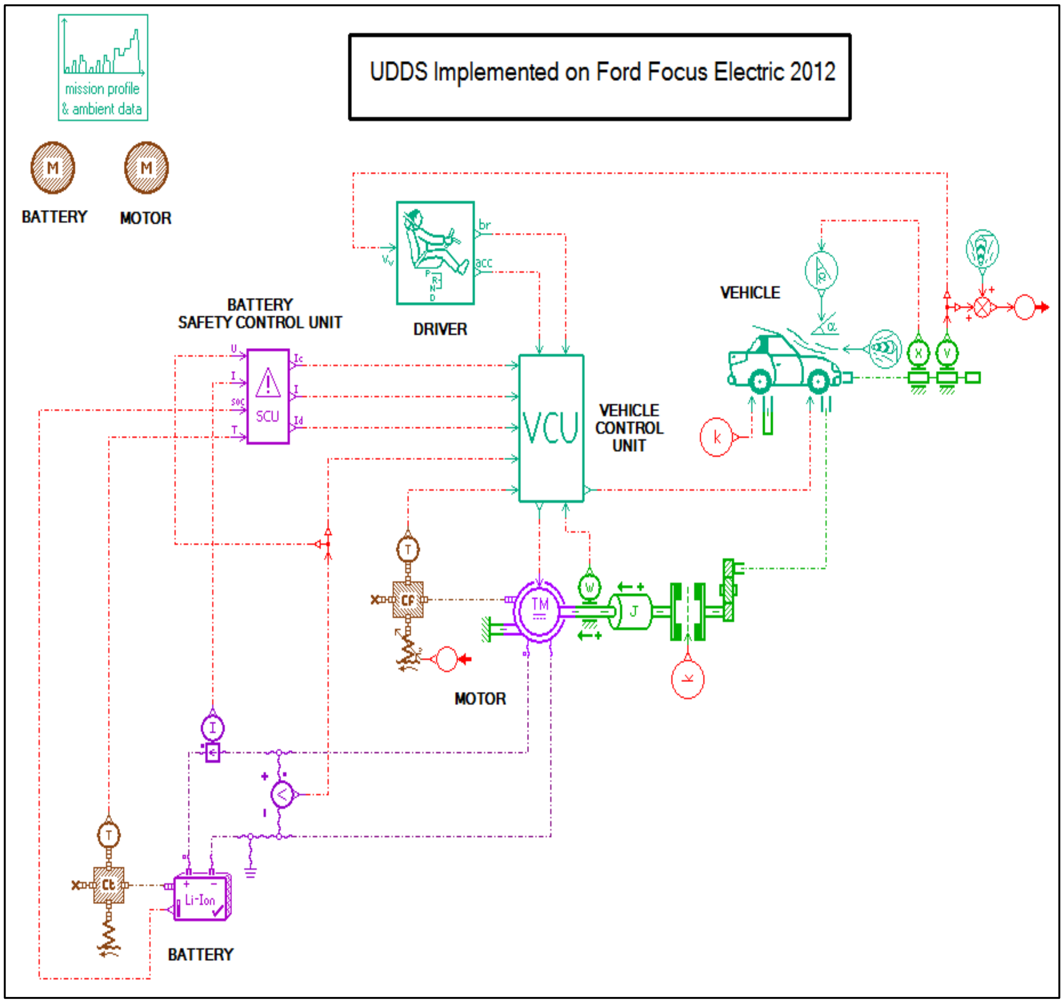

Figure 5.26: AMESim Model for Testing Against Standard Drive Cycles

In addition, the vehicle models and driver models are as shown below. They have also been used onsistently for all the drive cycle simulations. The motor and battery model, being inherent to the vehicle, have not been modified.

Vehicle parameters: The external conditions have been left as default for the following simulations. The vehicle parameters used for standard drive cycle testing are as follows:

Title	Value	Unit	Min	Default	Max
vehicle linear velocity	0	m/s	-1.00E+06	0.00E+00	1.00E+06
vehicle linear displacement	0	m	-1.00E+06	0.00E+00	1.00E+06
vehicle index	1		1	1	100
vehicle configuration	road		1	1	2
longitudinal slip configuration	without slip		1	1	2
total vehicle mass	1674	kg	0	1	1.00E+06
mass distribution	50	%	0	50	100
wheel inertia	0.747	kgm^2	-1.00E+06	0.5	1.00E+06
tyre width	225	mm	50	195	500
tyre height	50	%	25	65	8.50E+01
wheel rim diameter	17	in	10	15	23
expression for wheel dynamic radius	0.97*Rw			0.97*Rw	
aerodynamic and rolling parameters:					
coulomb friction coefficient (rolling resistance)	0.01	null	0	0.01	1.00E+06
viscous friction coefficient	0	1/(m/s)	0	0	1.00E+06
windage coefficient	0	1/(m/s)^2	0	0	1.00E+06
air penetration coefficient (Cx)	0.295	null	0	0.3	1.00E+03
vehicle active area for aerodynamic drag	4685.1	in^2	0	2	1.00E+06
stiction coefficient	1.2	null	1	1.2	1.00E+02
brake characteristics:					
maximum braking torque on rear axle	1000	Nm	-1.00E+06	1000	1.00E+06
maximum braking torque on front axle	1000	Nm	-1.00E+06	1000	1.00E+06
rotary stick velocity threshold for brake	1.00E-06	rev/min	0	1.00E-06	1.00E+06

Table 5.27: Vehicle Parameters for Standard Drive Cycle Testing

Driver behavior model:

Similarly, the driver parameters have also been left as default. They are as follows:

Title	Value	Unit	Min	Default	Max
cycle type	cycle with slopes		1	1	2
advance time for control anticipation	2	s	1.00E-05	2	5
acceleration control:					
integral part	0	m	-1.00E+06	0	1.00E+06
anticipative gain	0.25	1/(m/s/s)	0	0.25	1.00E+06
proportional gain	0.5	1/(m/s)	0.00E+00	0.5	1.00E+06
integral gain	0	1/m	0	0	1.00E+06
braking control:					
integral part	0	m	-1.00E+06	0	1.00E+06
anticipative gain	0.25	1/(m/s/s)	0	0.25	1.00E+06
proportional gain	0.5	1/(m/s)	0	0.5	1.00E+06
integral gain	0	1/m	0	0	1.00E+06
stops:					
braking when vehicle stopped	no		1	2	2.00E+00

Table 5.28: Driver Behavior Parameters for Standard Drive Cycle Testing

Mission Profile:

The only parameters that have been changing for the various standard drive cycles are the mission profile parameters – vehicle velocity and gearbox ratio profiles. The parameters are as follows:

UDDS:

Title	Value	Unit	Min	Default	Max
driving cycle	personal		1	2	10
data out of range mode	extreme value		1	2	3
discontinuity handling	active		1	2	2
vehicle load profile between two stops	constant		1	1	2
wind speed	0	km/h	-150	0	150
air density	1.205	kg/m^3	0	1.205	2000
ambient temperature	25	deg C	0	25	50
filename for road slope [%] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle load [kg] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle velocity [m/s] = f(time[s])	cyc_UDDS.data			MyVelocity File.data	
filename for gearbox ratio [null] = f(time[s])	gear_UDDS .data			GearRatio File.data	

Table 5.29: Mission Profile Parameters for UDDS

The vehicle speed compared to the control speed showing a successful UDDS drive cycle simulation is as follows:

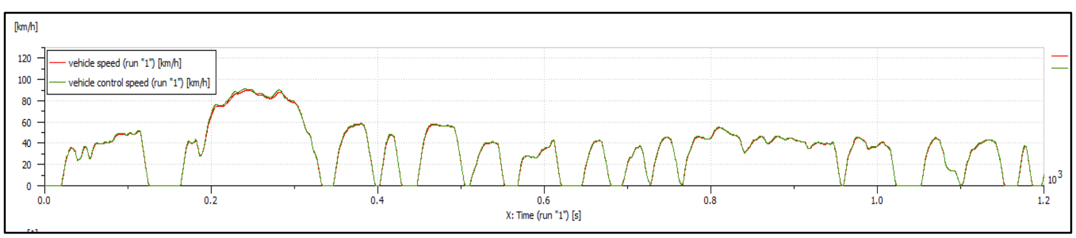

Figure 5.30: Vehicle and Control Speed for UDDS

NEDC:

Title	Value	Unit	Min	Default	Max
driving cycle	NEDC		1	2	10
NEDC transmission type	automatic		1	1	2
data out of range mode	extreme value		1	2	3
discontinuity handling	active		1	2	2
vehicle load profile between two stops	constant		1	1	2
wind speed	0	km/h	-150	0	150
air density	1.205	kg/m^3	0	1.205	2000
ambient temperature	25	deg C	0	25	50
filename for road slope [%] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle load [kg] = f(vehicle displacement: x[m])	0*x+0			0*x+0	

Table 5.31: Mission Profile Parameters for NEDC

The vehicle speed compared to the control speed showing a successful NEDC drive cycle simulation is as follows:

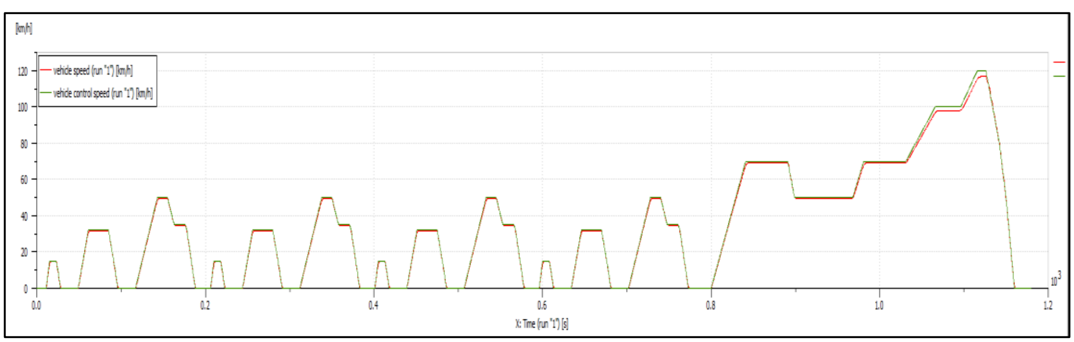

Figure 5.32: Vehicle and Control Speed for NEDC

JC08:

Title	Value	Unit	Min	Default	Max
driving cycle	JC08		1	2	10
engine temperature at cycle start	cold		1	1	2
transmission type	automatic		1	1	4
data out of range mode	extreme value		1	2	3
discontinuity handling	active		1	2	2
vehicle load profile between two stops	constant		1	1	2
wind speed	0	km/h	-150	0	150
air density	1.205	kg/m^3	0	1.205	2000
ambient temperature	25	deg C	0	25	50
filename for road slope [%] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle load [kg] = f(vehicle displacement: x[m])	0*x+0			0*x+0	

Table 5.33: Mission Profile Parameters for JC08

The vehicle speed compared to the control speed showing a successful JC08 drive cycle simulation is as follows:

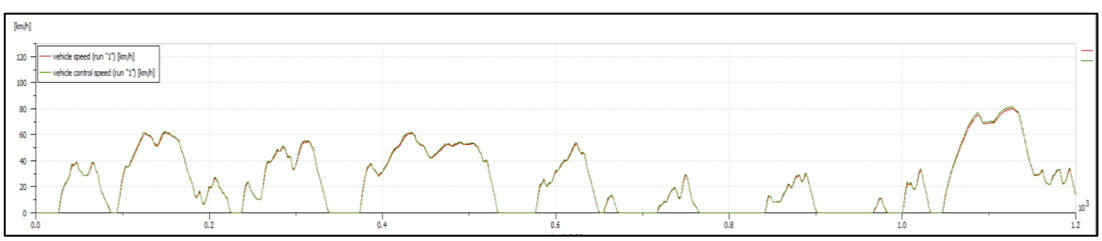

Figure 5.34: Vehicle and Control Speed for JC08

FTP 75:

Title	Value	Unit	Min	Default	Max
driving cycle	FTP-75		1	2	10
data out of range mode	extreme value		1	2	3
discontinuity handling	active		1	2	2
vehicle load profile between two stops	constant		1	1	2
wind speed	0	km/h	-150	0	150
air density	1.205	kg/m^3	0	1.205	2000
ambient temperature	25	deg C	0	25	50
filename for road slope [%] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle load [kg] = f(vehicle displacement: x[m])	0*x+0			0*x+0	

Table 5.35: Mission Profile Parameters for FTP 75

The vehicle speed compared to the control speed showing a successful FTP 75 drive cycle simulation is as follows:

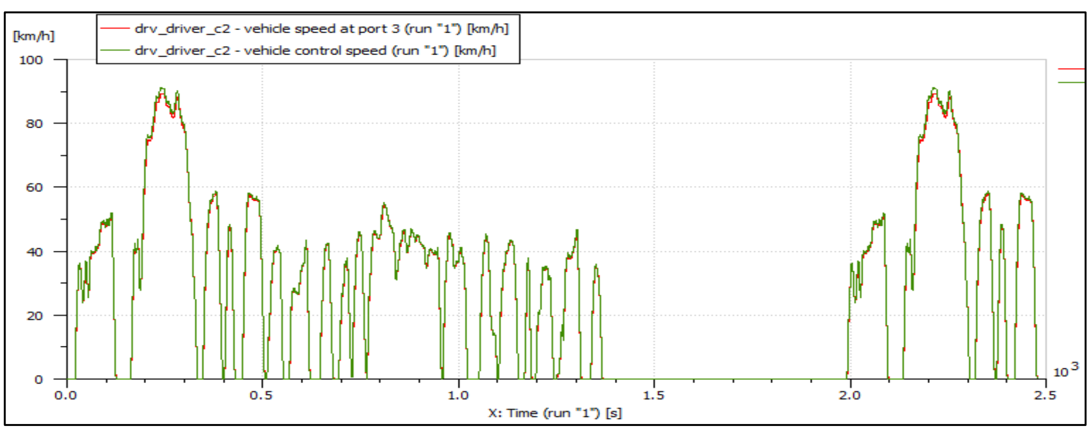

Figure 5.36: Vehicle and Control Speed for FTP75

US06:

Title	Value	Unit	Min	Default	Max
driving cycle	SFTP-US06		1	2	10
data out of range mode	extreme value		1	2	3
discontinuity handling	active		1	2	2
vehicle load profile between two stops	constant		1	1	2
wind speed	0	km/h	-150	0	150
air density	1.205	kg/m^3	0	1.205	2000
ambient temperature	25	deg C	0	25	50
filename for road slope [%] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle load [kg] = f(vehicle displacement: x[m])	0*x+0			0*x+0	

Table 5.37: Mission Profile Parameters for US06

The vehicle speed compared to the control speed showing a successful US06 drive cycle simulation is as follows:

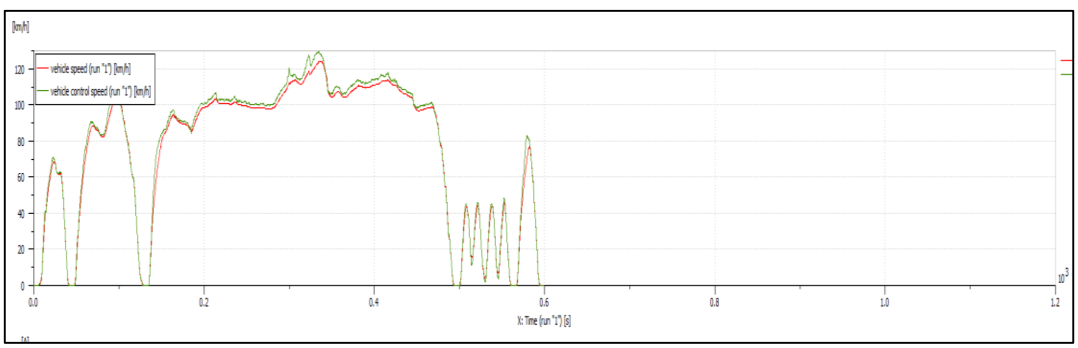

Figure 5.38: Vehicle and Control Speed for US06

Autonomie Simulation for Ford Focus Electric 2012:

A model for the Ford Focus Electric 2012 was also built on Autonomie to test against the standard drive cycles. The Autonomie simulation for the Ford Focus Electric is as described below. Since Autonomie libraries were not powerful enough to model the exact vehicle parameters, an approximate model was created using an Autonomie template for a mid-sized electric vehicle with fixed gear and two-wheel drive. The simulation details are as follows:

Vehicle system:

A block diagram showing the connection of various components is as follows:

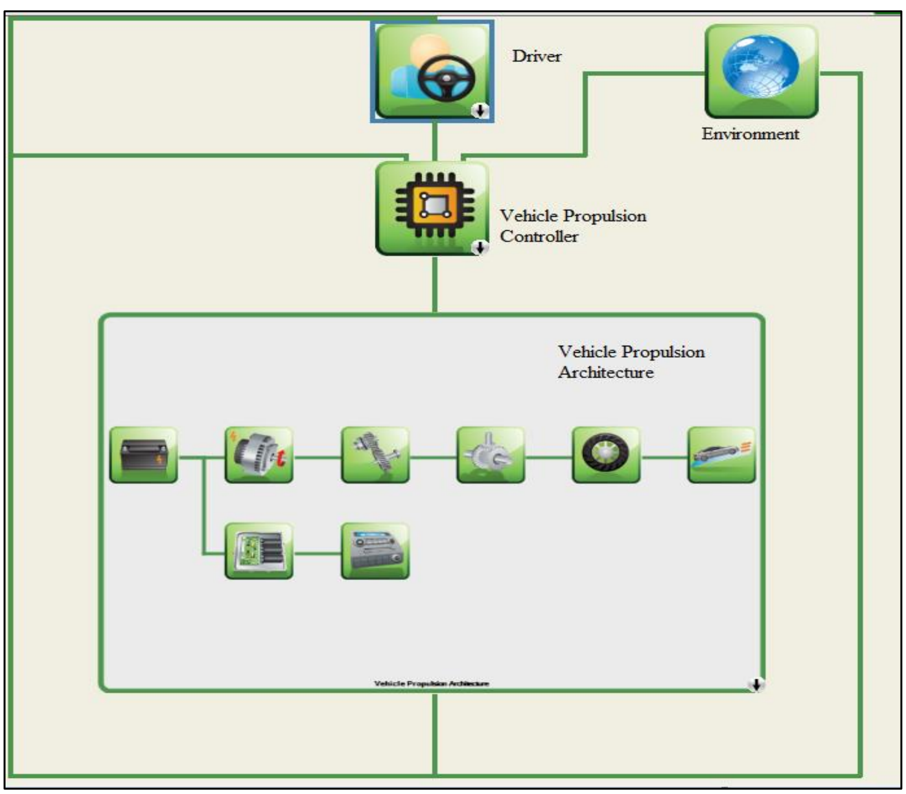

Figure 5.39: Autonomie model for Ford Focus Electric

Vehicle Propulsion Architecture:

The various components that are a part of the vehicle propulsion architecture have been highlighted below.

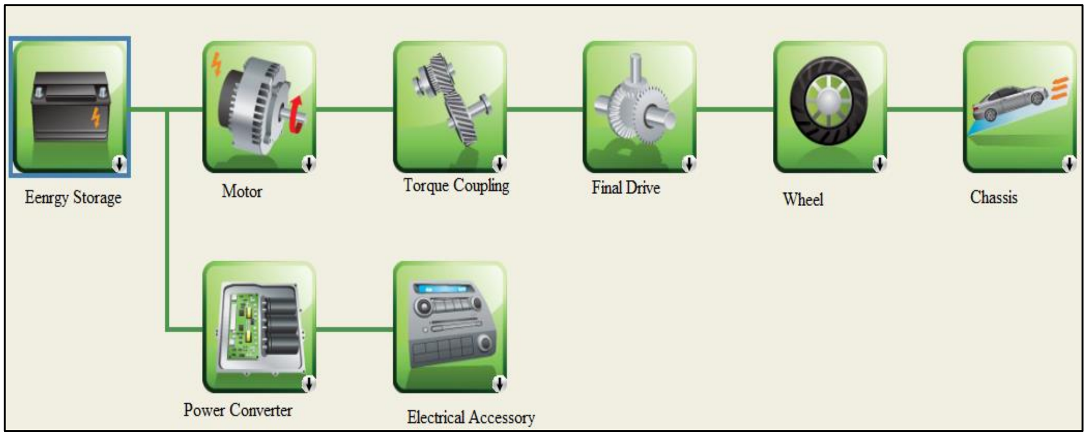

Figure 5.40: Vehicle Propulsion Architecture for Ford Focus Electric

The model shown above was used consistently for testing against UDDS, NEDC, JC08, FTP75 and US06. The appropriate drive cycle was tested for the standard runs in order to acquire the relevant results. The next section on simulation results will compare the results for these standard drive cycles with AMESim simulations against the same standard drive cycles.

5.2 Toyota Prius Model

A Similar analysis was done with the Toyota Prius 2006 by testing against the same standard drive cycles as above – UDDS, NEDC, JC08, FTP75 and US06. A simulation model was again built in AMESim as well as Autonomie. The AMESim model was tested against NEDC and the Autonomie model was tested against the five standard drive cycles mentined above. In addition, the CAN data logger for Ford Focus Electric 2012 was also modified to acquire data from the Toyota Prius. These results will be compared in the next section on simulation results.

AMESim model for Toyota Prius 2006:

The AMESim model for Toyota Prius was acquired from AMESim libraries. Although, the model is for a 2004 Prius model, it could still be used for the present analysis due to the similarity of the components. The default parameters already model the real vehicle. As such, they have not been modified. In addition, the model parameters have been configured such that it runs the NEDC drive cycle as default. Although, the provided parameters have not been modified, they have been listed here, in order to compare with the above described Ford Focus Electric model parameters.

The AMESim model for the Toyota Prius shown in Figure 5.41 has been acquired from the AMESim automotive vehicle integration library. This model offers a visual flow chart for hybrid vehicle thermal management. This model offers the capability needed in this thesis in order to evaluate the Toyota Prius in addition to modeling Prius like components.

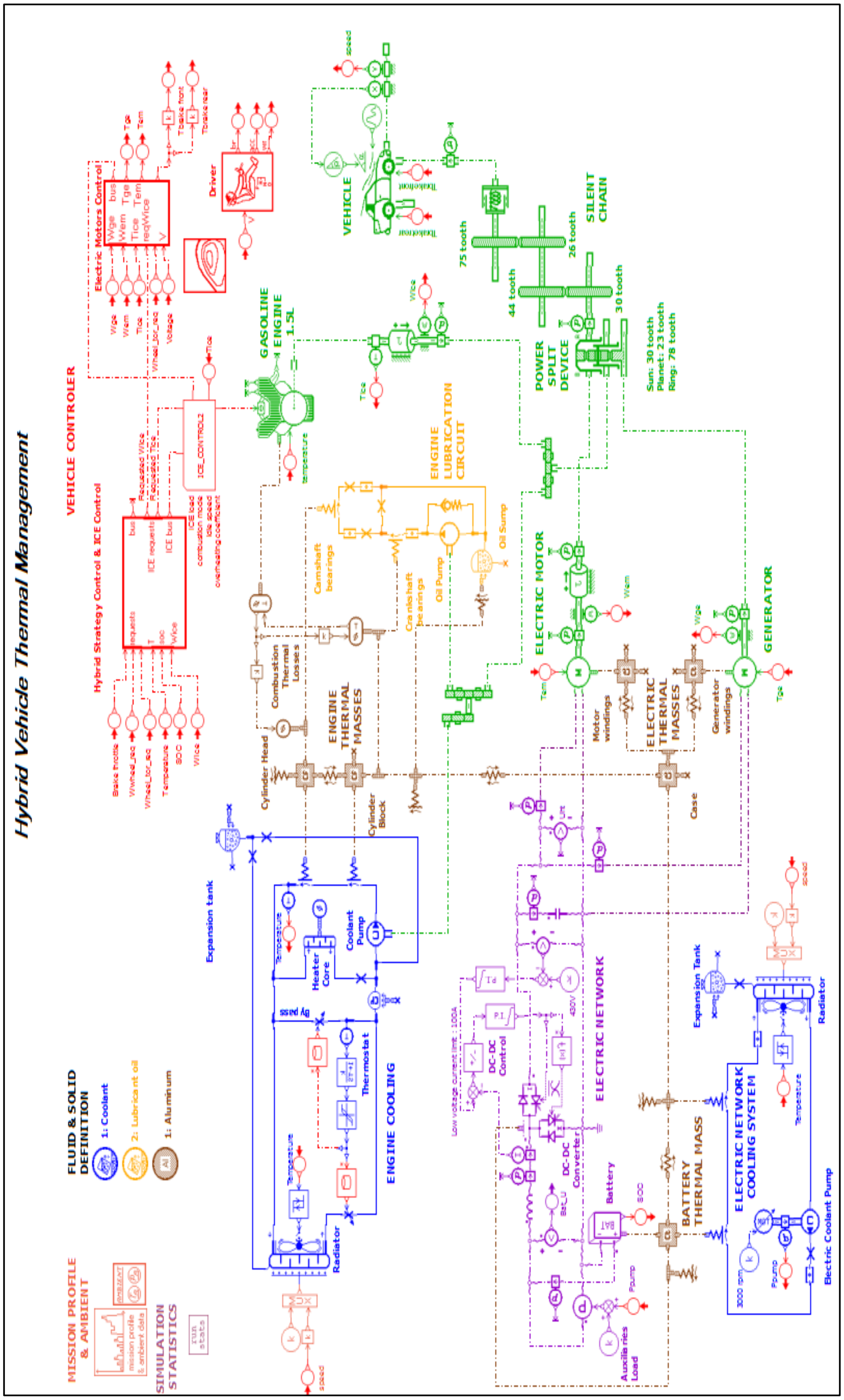

Figure 5.41: AMESim Model for Toyota Prius

Mission Profile: This model simulates a NEDC drive cycle. The parameters are as shown below.

Title	Value	Unit	Min	Default	Max
driving cycle	NEDC		1	2	10
NEDC transmission type	manual		1	1	2
data out of range mode	extreme value		1	2	3
discontinuity handling	active		1	2	2
vehicle load profile between two stops	constant		1	1	2
wind speed	0	km/h	-150	0	150
air density	1.205	kg/m^3	0	1.205	2000
ambient temperature	Tamb	deg C	0	25	50
filename for road slope [%] = f(vehicle displacement: x[m])	0*x+0			0*x+0	
filename for vehicle load [kg] = f(vehicle displacement: x[m])	0*x+0			0*x+0	

Table 5.42: Mission Profile Parameters for Toyota Prius

Vehicle model: The parameters of the vehicle model are as follows. They have not been modified as they reflect Toyota Prius already.

Title	Value	Unit	Min	Default	Max
vehicle linear velocity	0	m/s	-1.00E+06	0	1.00E+06
vehicle linear displacement	0	m	-1.00E+06	0	1.00E+06
vehicle index	1		1	1	100
vehicle configuration	road		1	1	2
longitudinal slip configuration	slip		1	1	2
total vehicle mass	1.36	tonne	0	1	1.00E+06
mass distribution	50	%	0	50	100
wheel inertia	0.5	kgm^2	-1.00E+06	0.5	1.00E+06
tyre width	195	mm	50	195	500
tyre height	65/ 1.08	%	25	65	8.50E+01
wheel rim diameter	15	in	10	15	23

expression for wheel dynamic radius	0.97*R w			0.97* Rw	
aerodynamic and rolling parameters:					
coulomb friction coefficient (rolling resistance)	0	null	0	0.01	1.00E+06
viscous friction coefficient (rolling resistance)	0	1/(m/s)	0	0	1.00E+06
windage coefficient (rolling resistance)	0	1/(m/s)^2	0	0	1.00E+06
air penetration coefficient (Cx)	0.29	null	0	0.3	1.00E+03
vehicle active area for aerodynamic drag	1.2	m^2	0	2	1.00E+06
stiction coefficient	1.2	null	1	1.2	1.00E+02
brake characteristics:					
maximum braking torque on rear axle	5000	Nm	-1.00E+06	1000	1.00E+06
maximum braking torque on front axle	5000	Nm	-1.00E+06	1000	1.00E+06
rotary stick velocity threshold for brake	1.00E-06	rev/min	0	1.00E-06	1.00E+06
tyre longitudinal slip parameters:					
tyre/ground grip coefficient	1	null	0	1	1.00E+06
rotary stick velocity threshold for longitudinal slip	0.01	rev/min	0	0.01	1.00E+06

Table 5.43: Vehicle Parameters for Toyota Prius

Driver behavior model:

The driver behavior has been modeled in AMESim libraries using a PID controller as shown below.

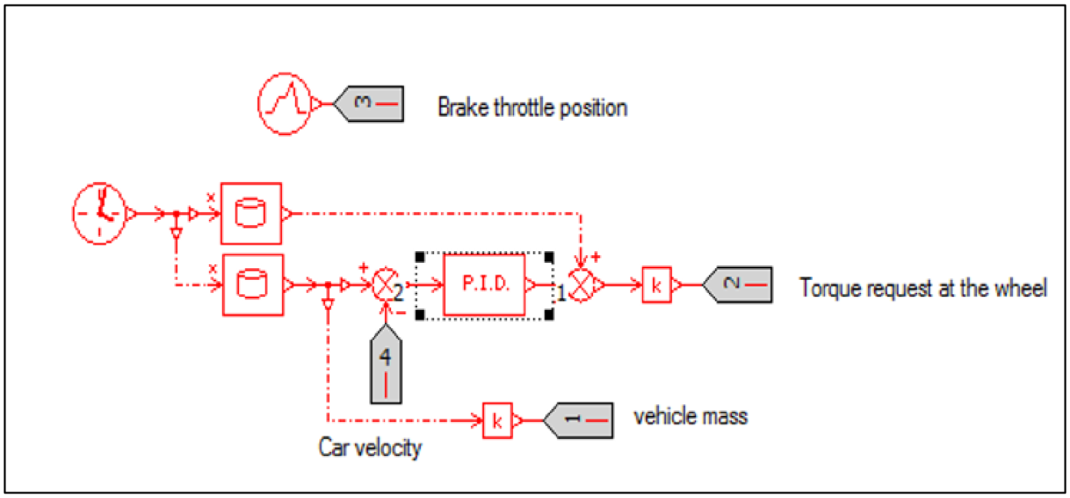

Figure 5.44: Driver Model for Toyota Prius

The parameters for the PID controller are as follows. These values have also been left as is.

Title	Value	Unit	Min	Default
dummy state variable for estimating derivative part	1.39E-06	1/s	-1.00E+30	1.39E-06
integral part	-4.89E-05	null	-1.00E+30	-4.88E-05
controller type	PID		1	1
limit output	no		1	1
proportional gain	5	null	-1.00E+30	2*1
integral gain	0.1	null	-1.00E+30	0.1
derivative gain	3	null	-1.00E+30	0
time constant for first order lag used to estimate derivative	0.001	null	1.00E-30	0.001

Table 5.45: Driver Behavior Parameters for Toyota Prius

Autonomie model for the Toyota Prius 2006:

An existing Toyota Prius 2004 model in the Autonomie libraries was used for the analysis. Similar to the AMESim model, the 2004 Autonomie model could be used to represent a 2006 model due to the similarity in the components. The model is as follows:

Vehicle system:

The vehicle system for the Toyota Prius is as shown below. A power split architecture is shown in Figure 5.46.

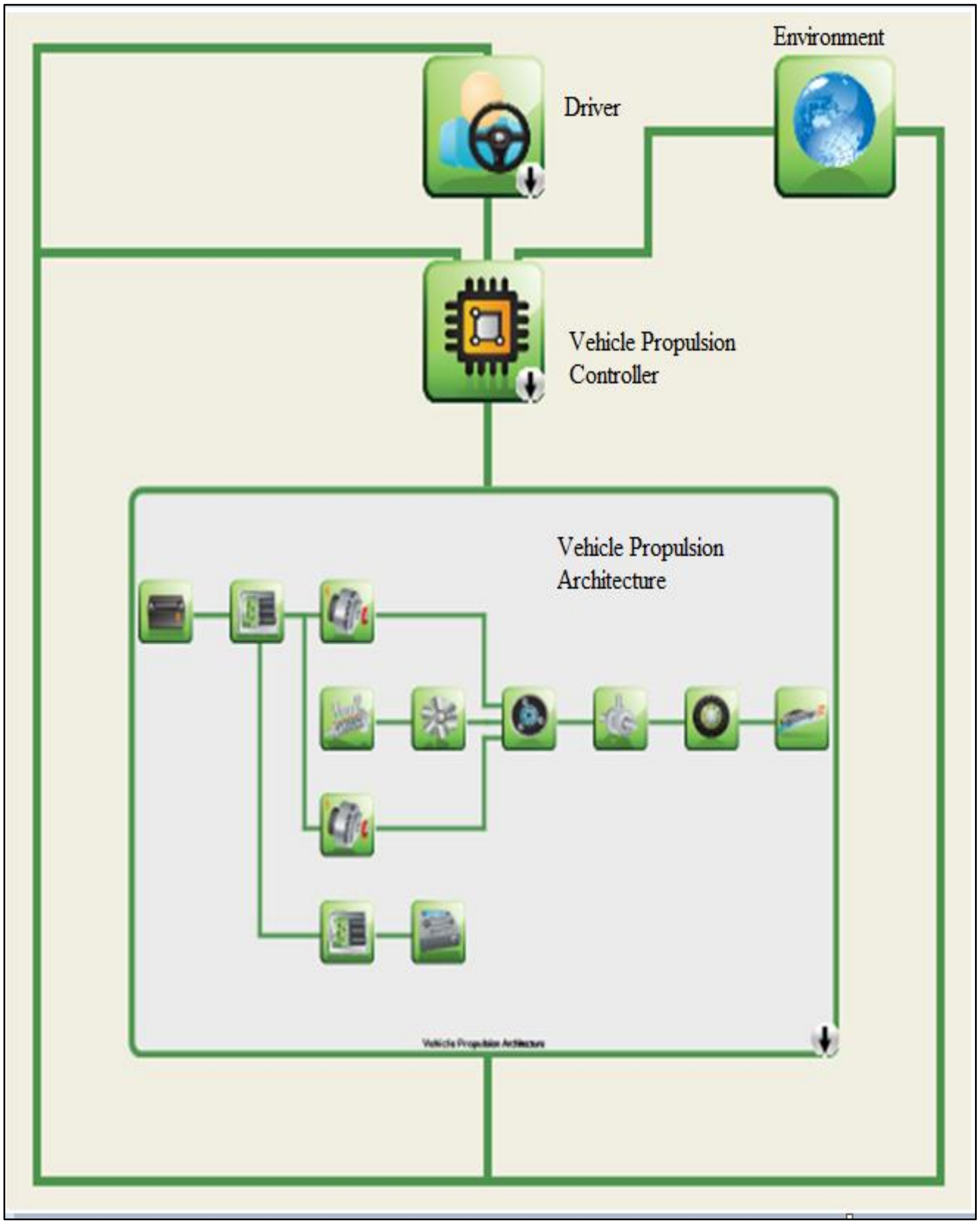

Figure 5.46: Autonomie Model for Toyota Prius

Vehicle Propulsion Architecture:

The vehicle propulsion architecture components are as shown below:

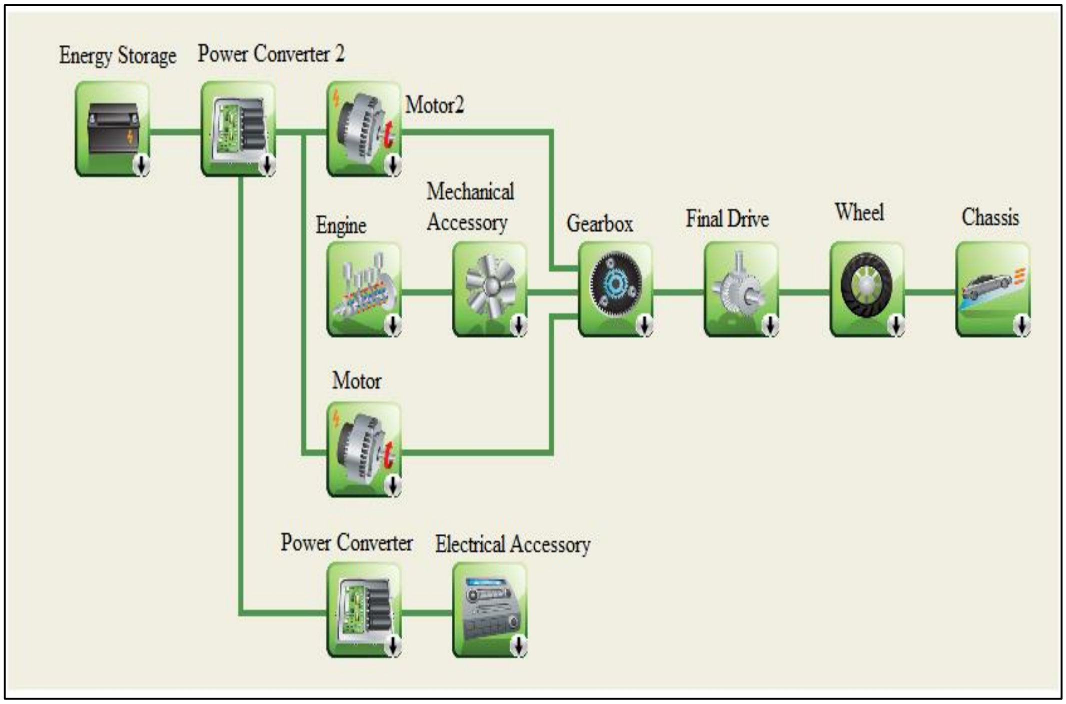

Figure 5.47: Vehicle Propulsion Architecture for Toyota Prius

The above described Autonomie model for Toyota Prius was evaluated against the standard drive cycles – UDDS, NEDC, JC08, FTP75 and US06. The results for these simulations will be described in the next section on simulation results.

5.3 Simulation Results

Ford Focus Electric 2012 AMESim and CAN results:

The main metric that was used for analyzing the Ford Focus Electric's results was energy consumption in kWh/100 mi as well as the MPGe. Please refer to Appendix B for a detailed table highlighting the results for all the Journey Mapping iterations, corresponding CAN data logger values collected as well as the results obtained when simulated against UDDS, NEDC, JC08, FTP75 and US06.

A summary of the energy consumption and MPGe values for various Journey Mapping iterations have been compared with their corresponding CAN data logger results as well as the standard drive cycle test results and the EPA values for the Ford Focus Electric 2012 [31]

	Energy Consumption (kWh/100 mi)	**MPGe**
JM1	56.58	59.56
JM2	66.50	50.67
CAN2	59.14	56.98
JM3	47.19	71.42
CAN3	48.89	68.93
JM4	44.32	76.04
CAN4	44.69	75.40
UDDS	33.48	100.64
NEDC	31.25	107.85
JC08	32.05	105.14
FTP75	34.40	97.97
US 06	45.28	74.42
EPA	32.00	110

Table 5.48: Energy Consumption Results

The above results have been graphically represented as follows:

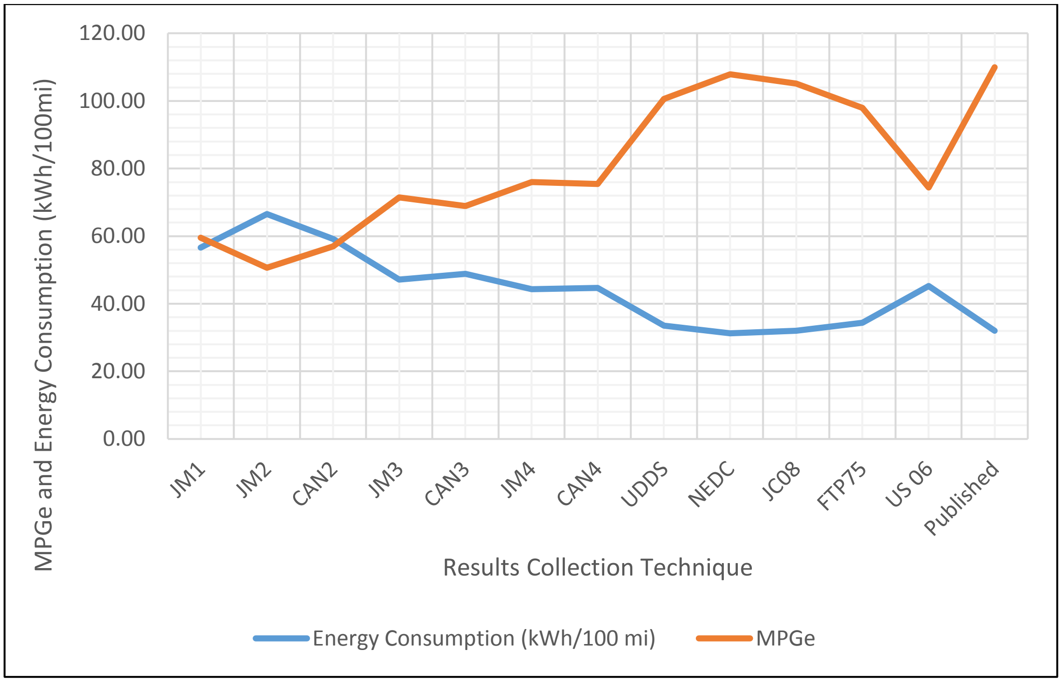

Figure 5.49: Energy Consumption Results Graph

From above, it can be seen that the actual energy consumption was much more than the EPA value or the ones predicted using the standard drive cycles. As such, on similar terms, the actual MPGe was noticed to be much lower than the EPA value or the ones predicted using the standard drive cycles. However, the Journey Mapping models have been able to predict the respective energy consumption and MPGe values quite closely to the actual values. This % error between the true and the predicted as well as the EPA values are shown numerically in the table below:

Iteration #	**JM and CAN**	**UDDS and CAN**	**NEDC and CAN**	**JC08 and CAN**	**FTP75 and CAN**	**US06 and CAN**	**EPA and CAN**
2	11.07	76.63	89.27	84.53	71.93	30.60	93.05
3	3.61	46.01	56.46	52.54	42.13	7.97	59.59
4	0.84	33.47	43.03	39.44	29.92	1.31	45.88
average % error	**5.17**	**52.04**	**62.92**	**58.84**	**47.99**	**13.29**	**66.17**

Table 5.50: Energy Consumption Deviation

Thus, from the above table it can be seen that the % error between the Journey Mapping and the true CAN data logger values is about 5% on average. The standard deviation was seen to be about 8.7 for the various Journey Mapping iterations. The % error was noticed to be the highest between the EPA labels and the CAN data logger values. Amongst the various standard drive cycles tested, US06 was seen to model the true vehicle performance most accurately. It is to be noted here that the route selected for Journey Mapping was not a round trip. As such, certain drive cycles might be less applicable than the others. This also contributed to some deviation between the simulated and the actual results. This variation in the percent error can be visualized through the graph as follows:

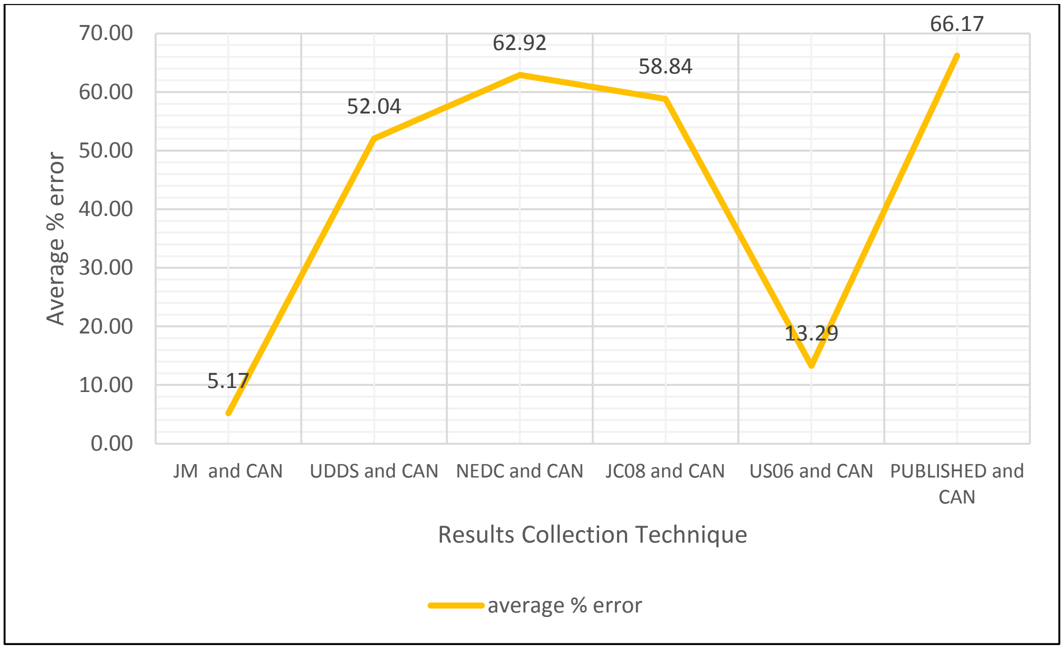

Figure 5.51: Energy Consumption Deviation Graph

The individual vehicle results have been compared below for the various Journey Mapping iterations as well as the corresponding CAN data logger values and the results acquired from testing against the standard drive cycles.

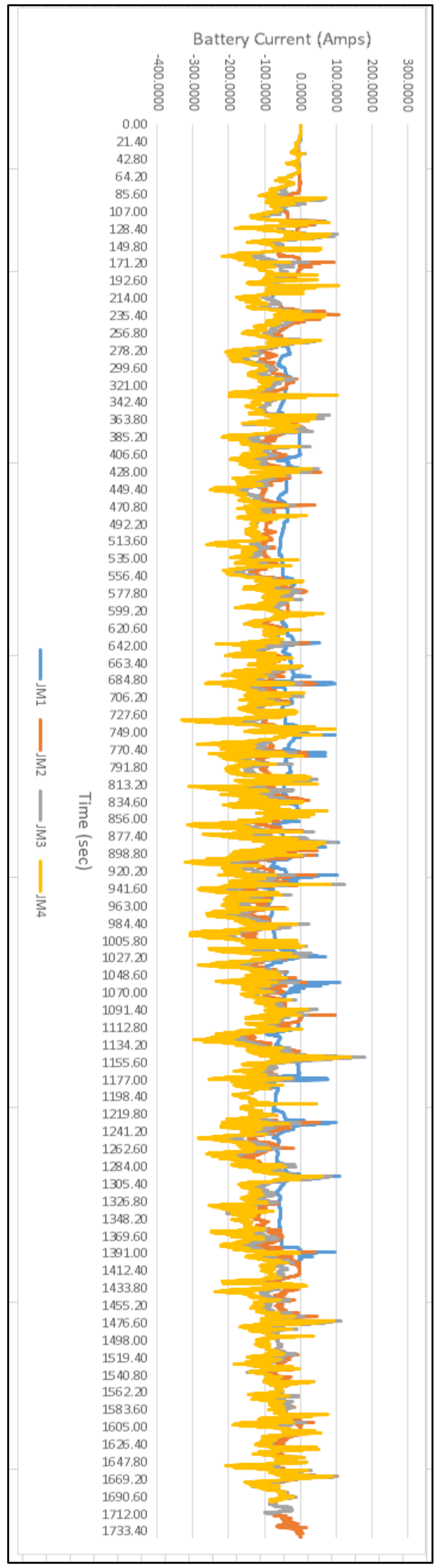

Figure 5.52: Journey Mapping Battery Current

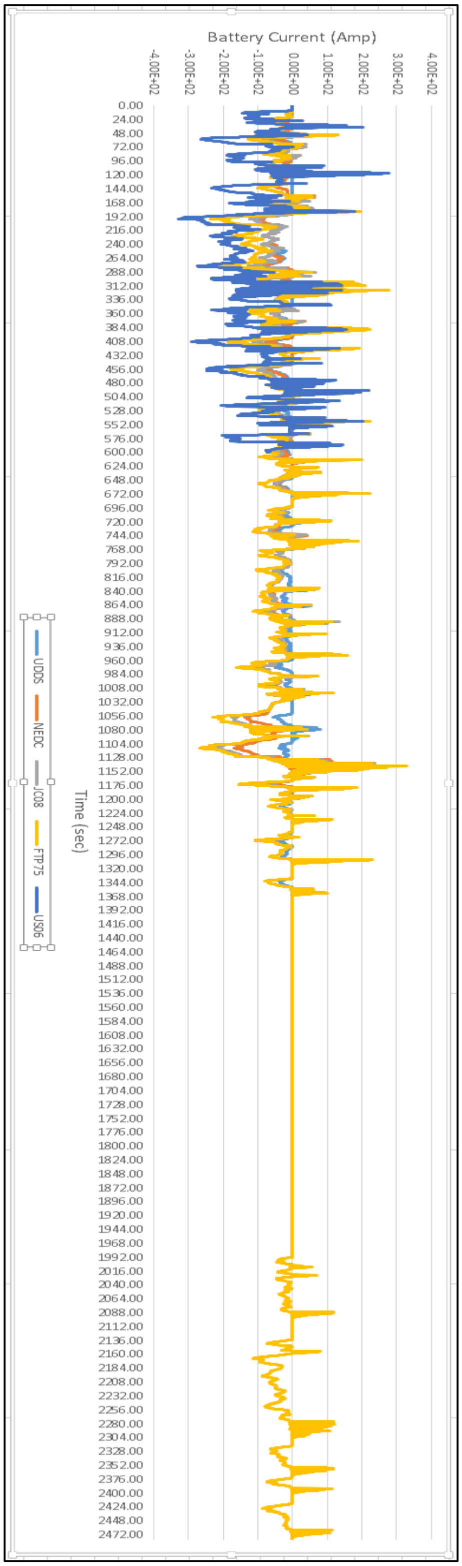

Figure 5.53: Standard Drive Cycles' Battery Current

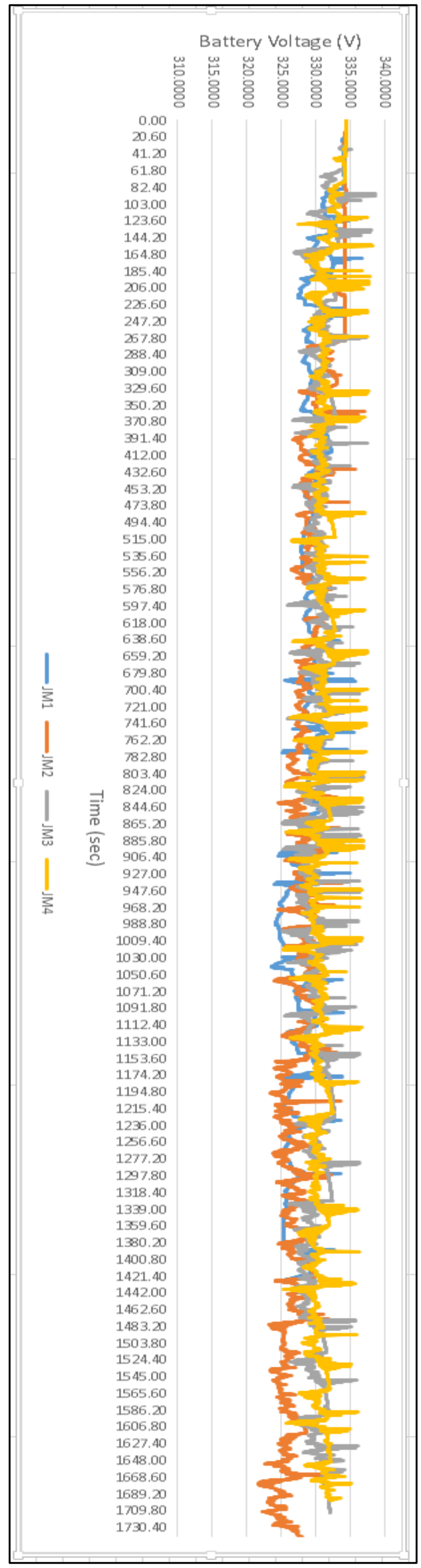

Figure 5.54: Journey Mapping Battery Voltage

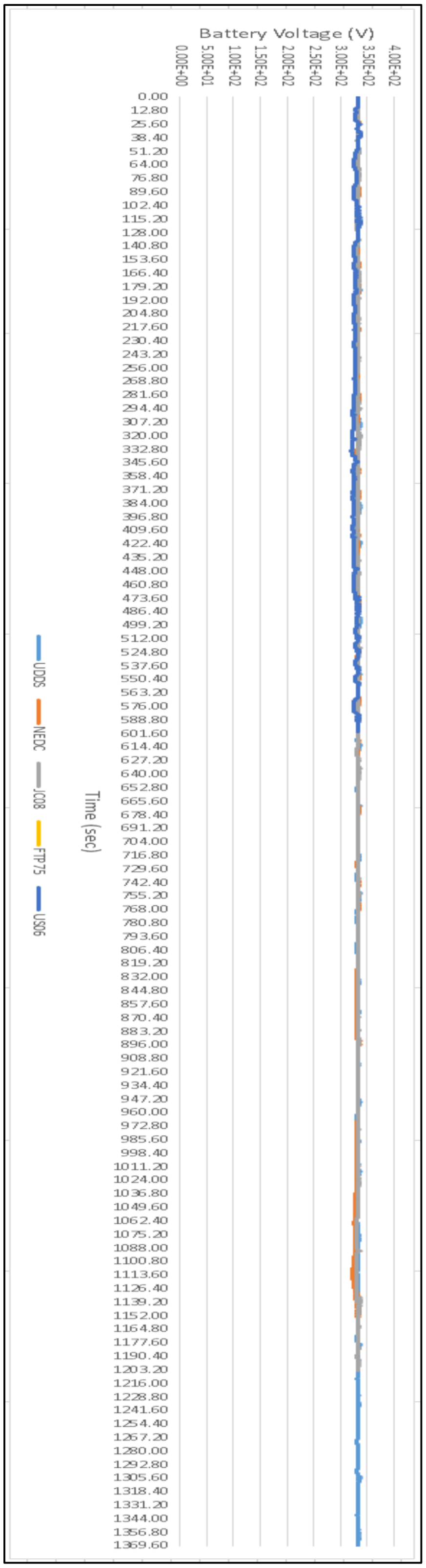

Figure 5.55: Standard Drive Cycles' Battery Voltage

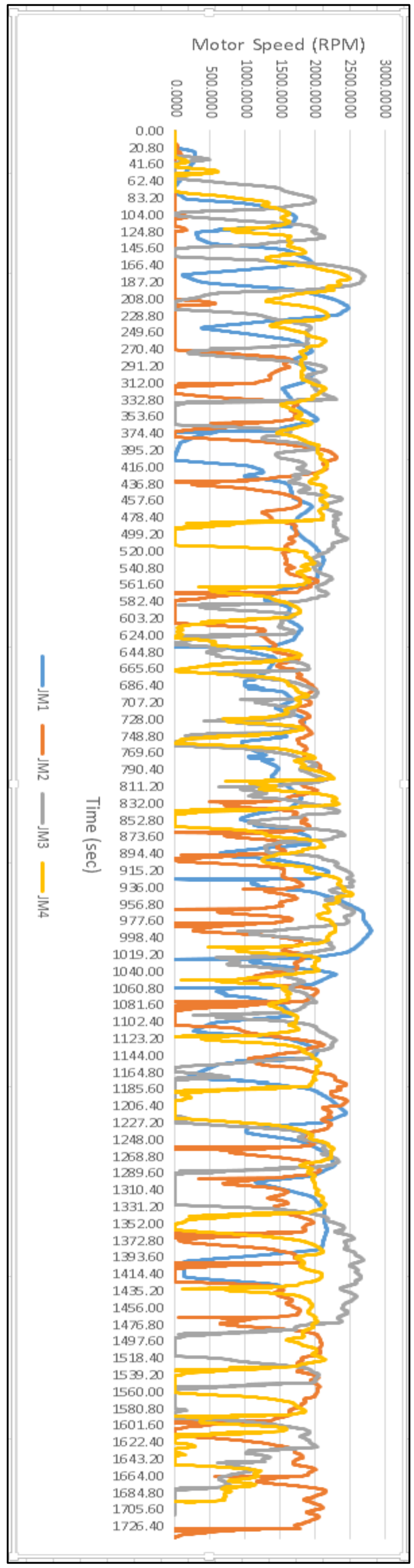

Figure 5.56: Journey Mapping Motor Speed

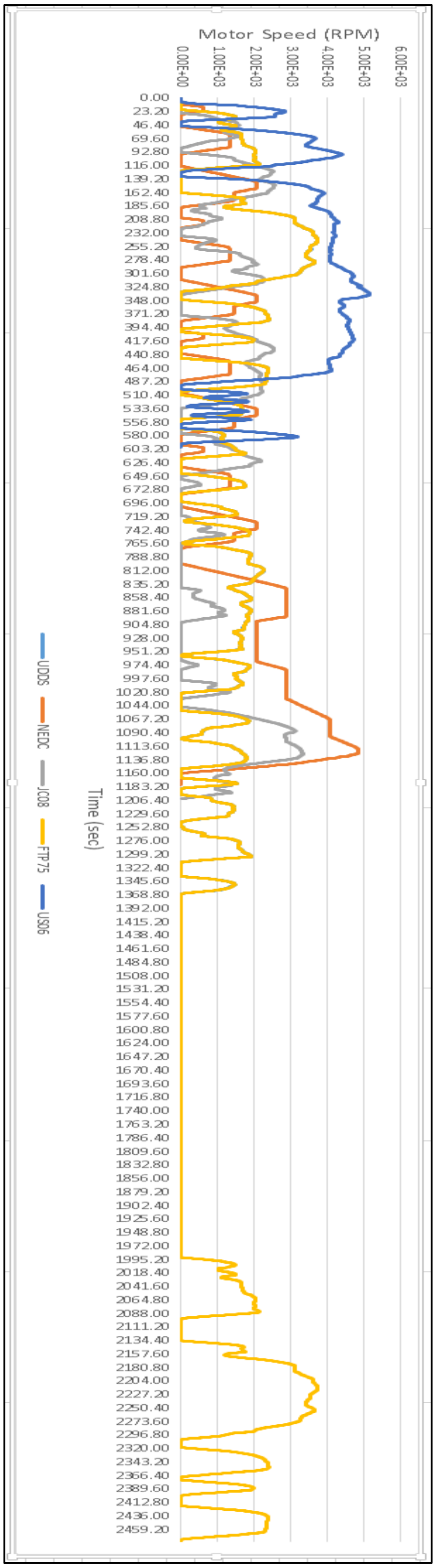

Figure 5.57: Standard Drive Cycles' Motor Speed

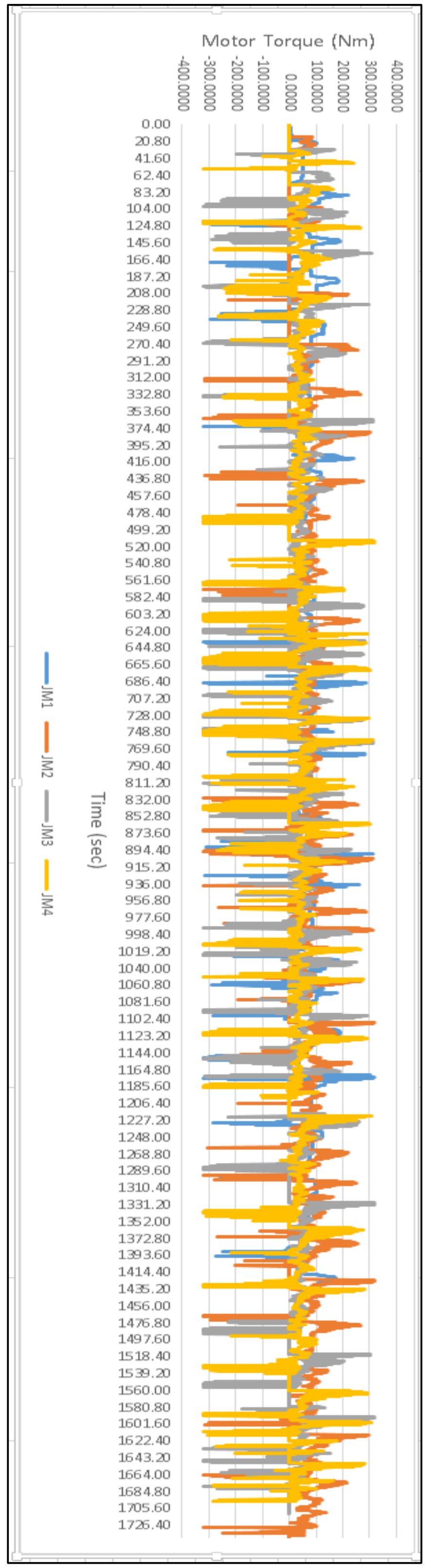

Figure 5.58: Journey Mapping Motor Torque

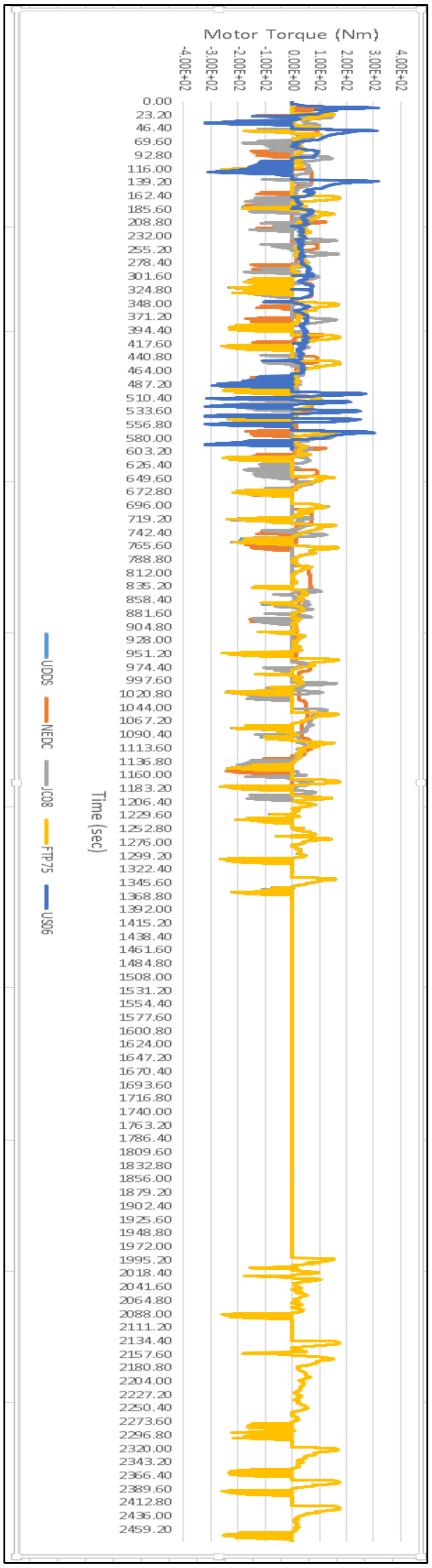

Figure 5.59: Standard Drive Cycles' Motor Torque

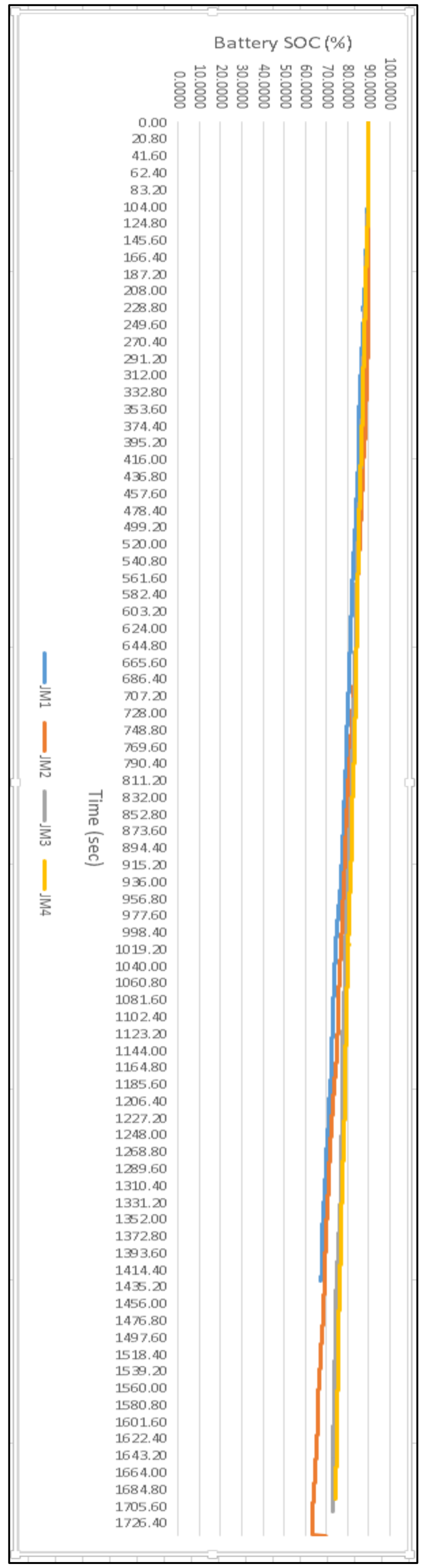

Figure 5.60: Journey Mapping Battery SOC

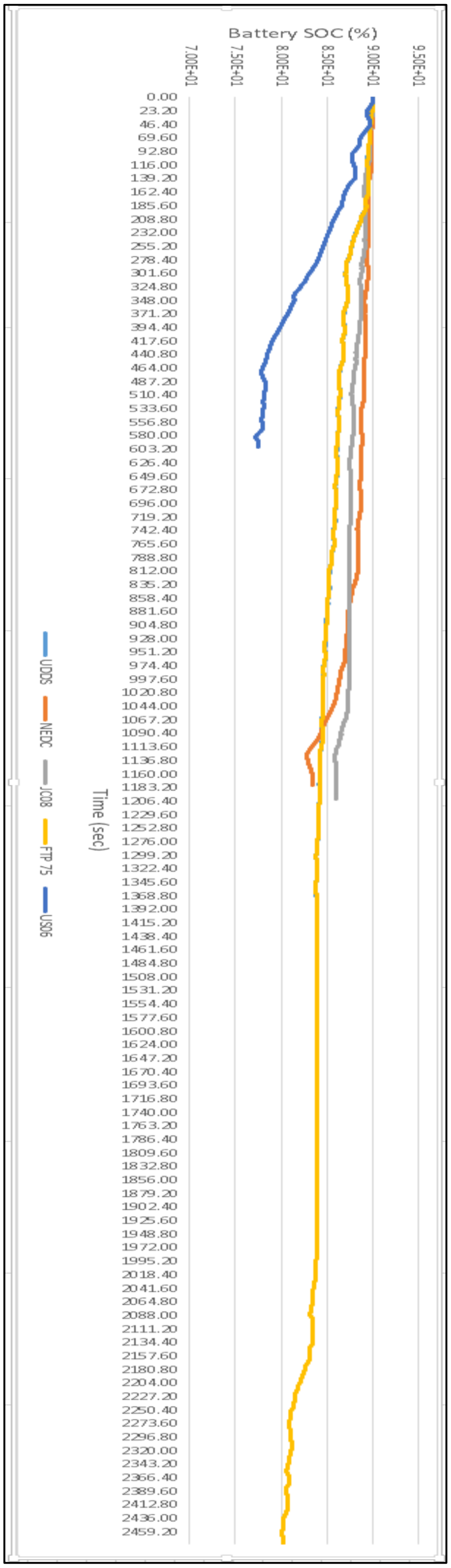

Figure 5.61: Standard Drive Cycles' Battery SOC

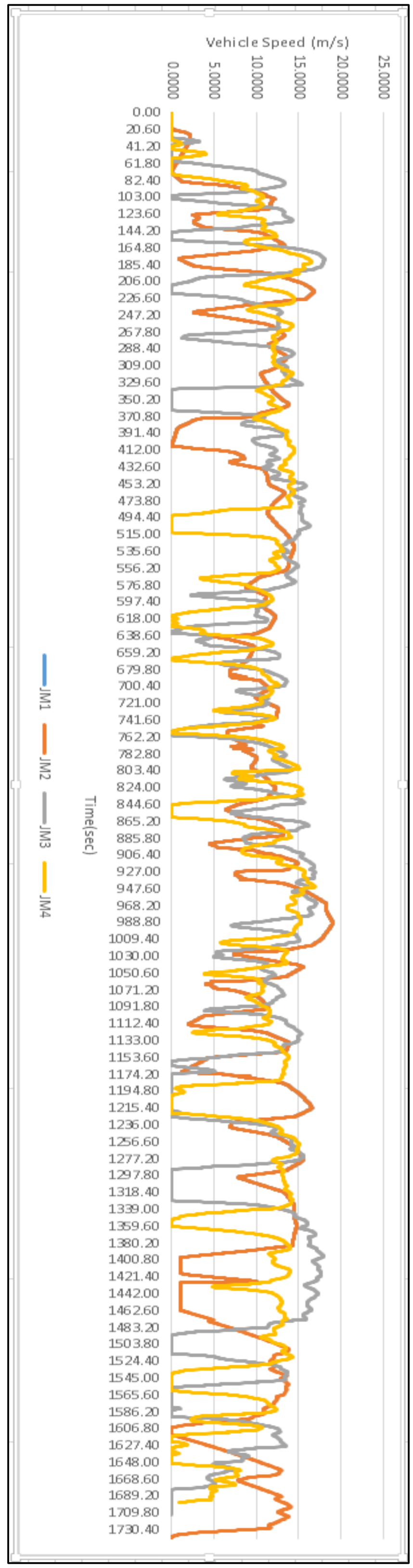

Figure 5.62: Journey Mapping Velocity Profile

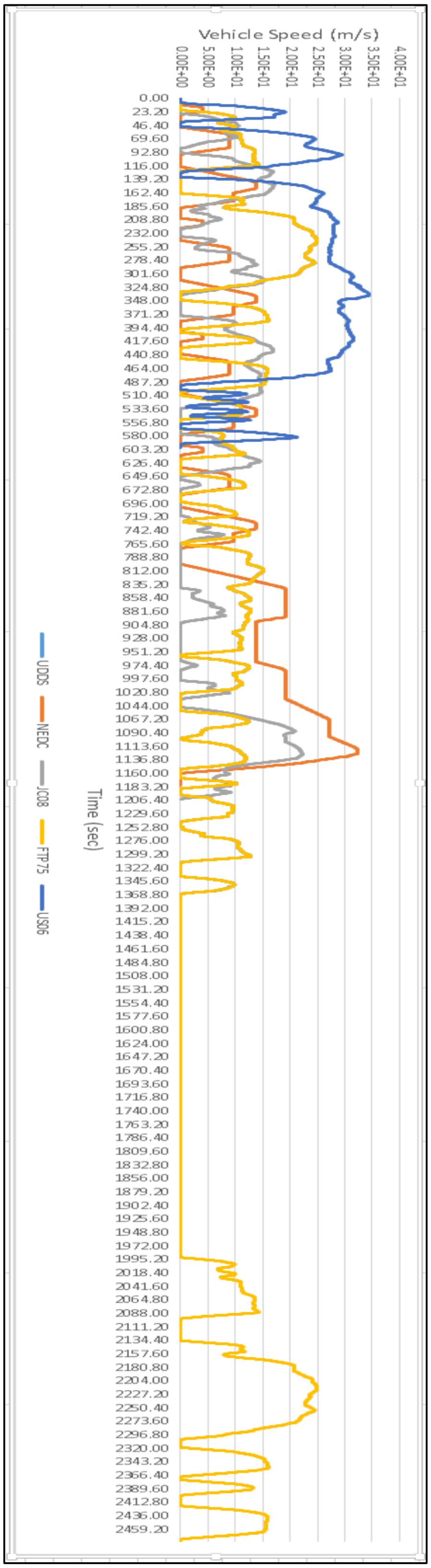

Figure 5.63: Standard Drive Cycles' Velocity Profile

The vehicle results collected from the CAN data logger for Ford Focus Electric 2012 are graphed below:

Results for the second iteration – CAN 2, third iteration – CAN 3 and the fourth iteration – CAN 4 are as follows:

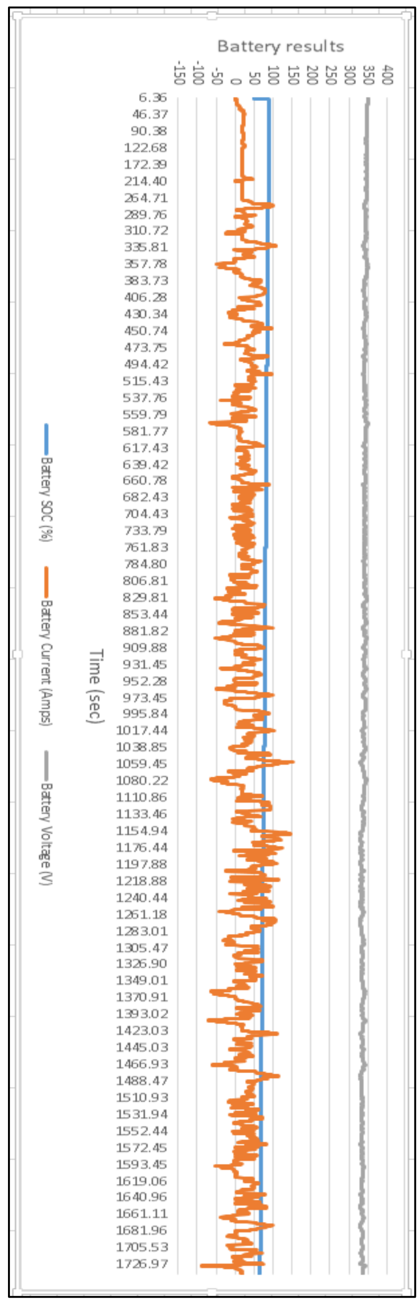

Figure 5.64: CAN2 Battery Results

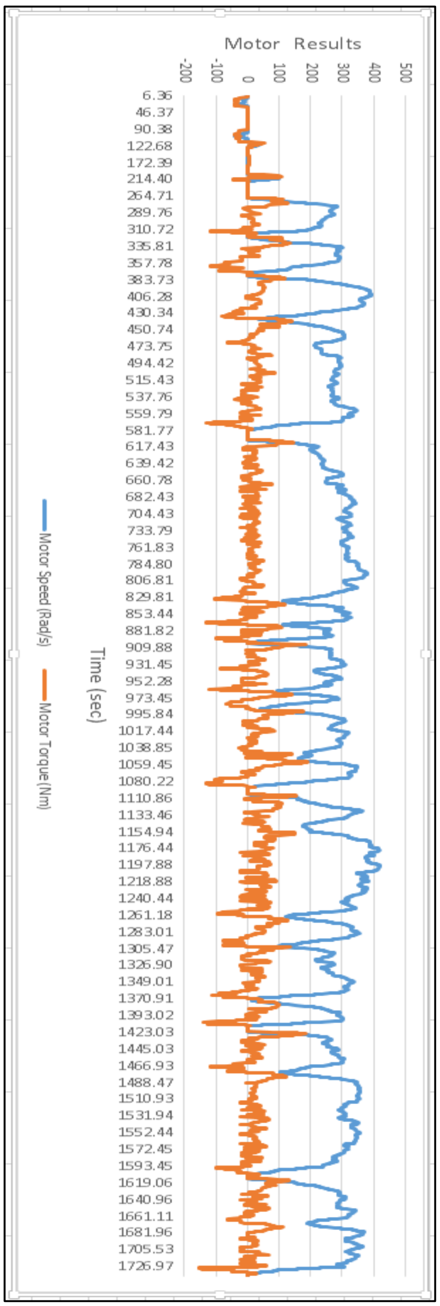

Figure 5.65: CAN2 Motor Results

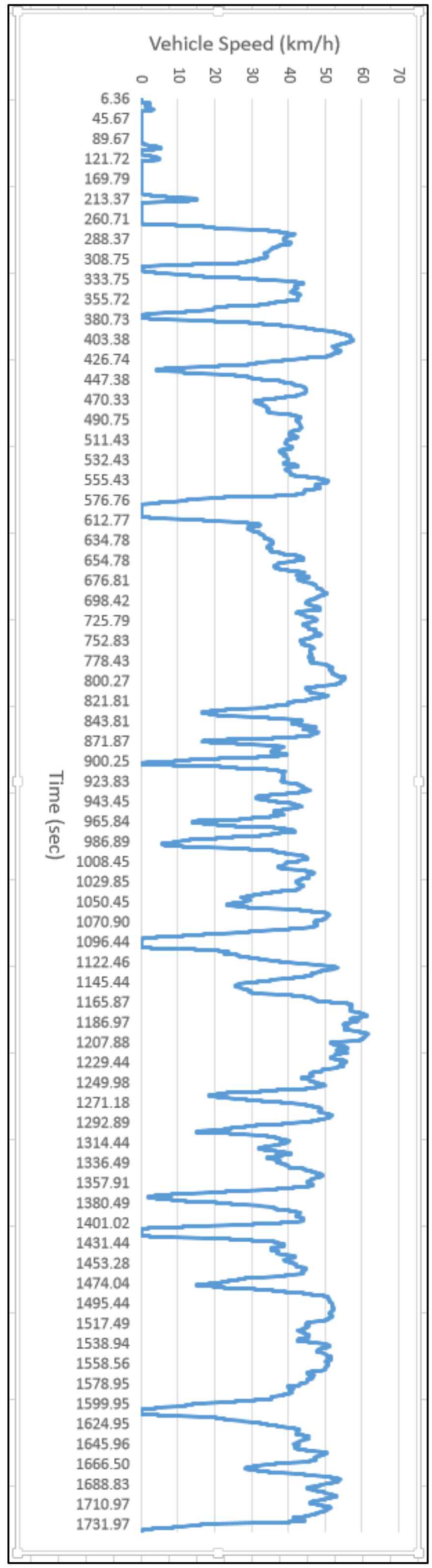

Figure 5.66: CAN2 Velocity Profile

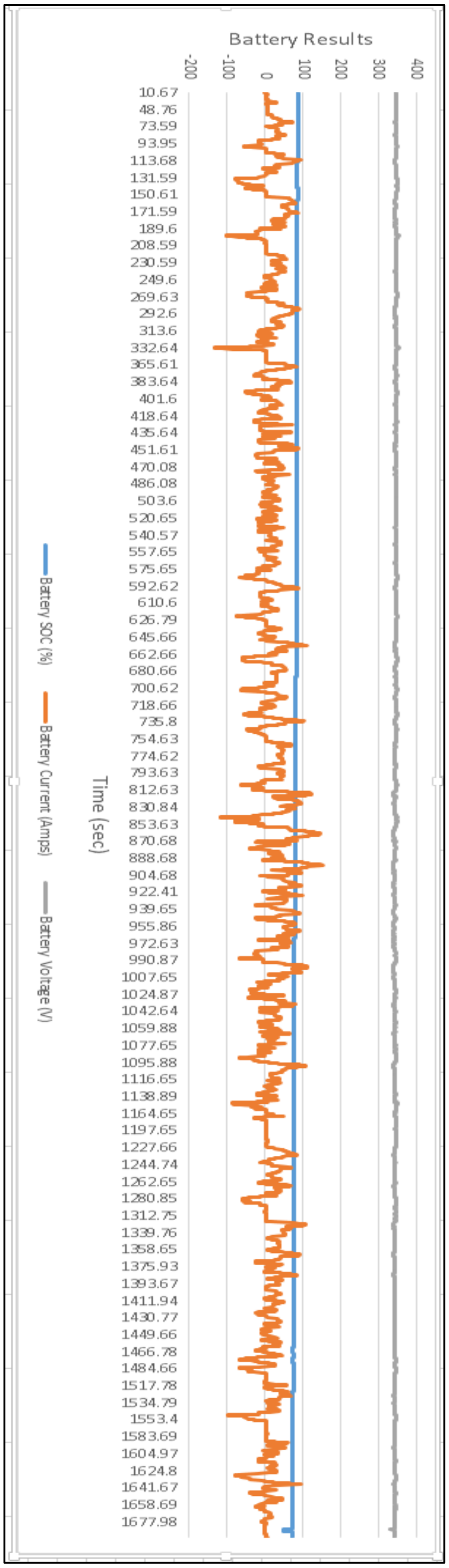

Figure 5.67: CAN3 Battery Results

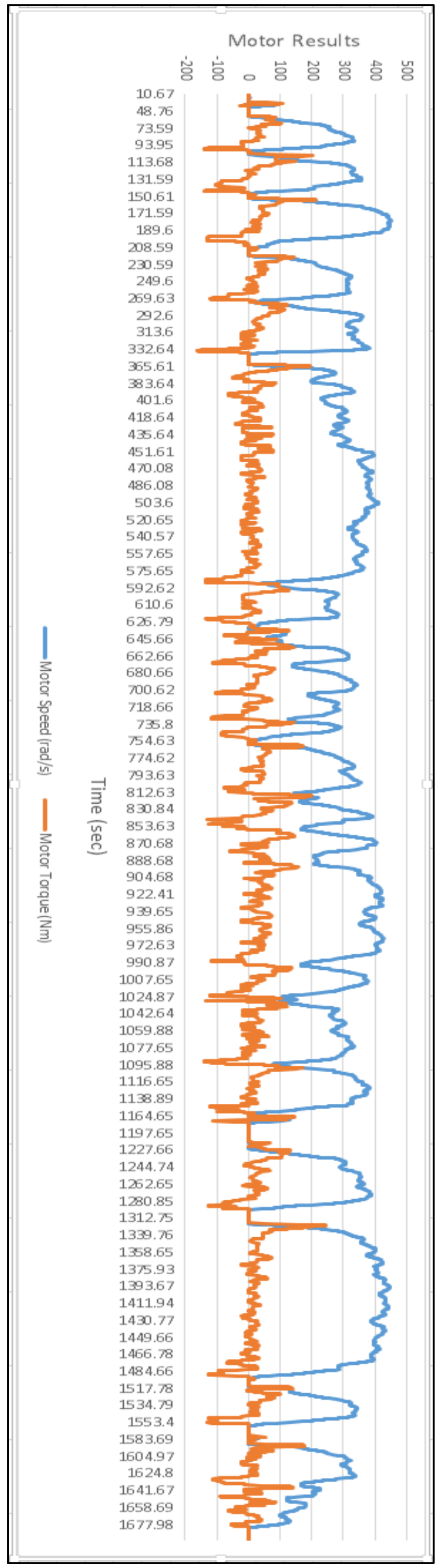

Figure 5.68: CAN3 Motor Results

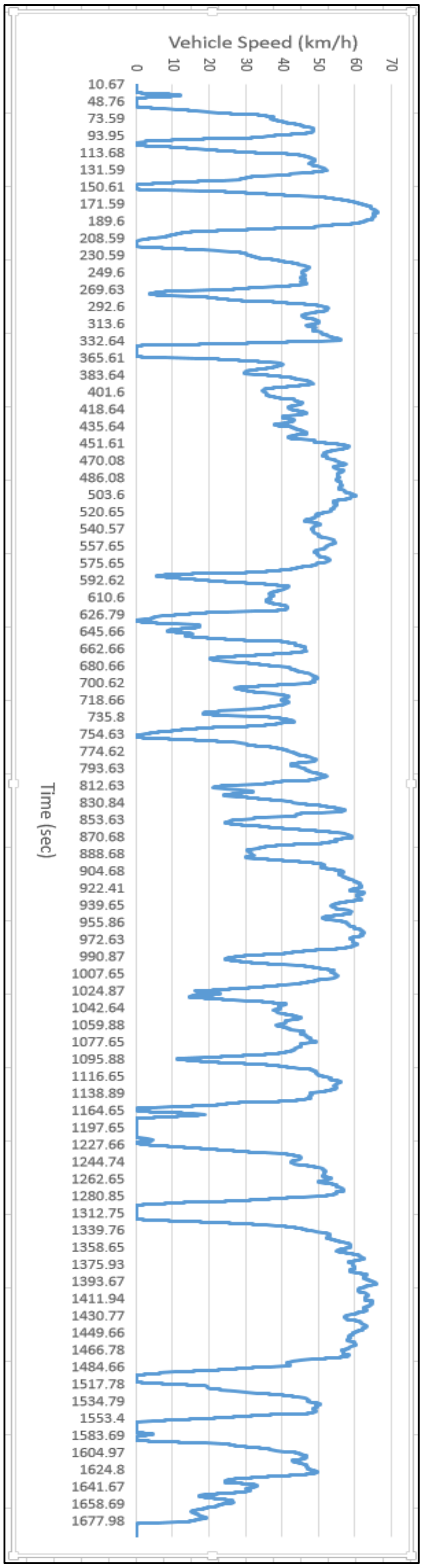

Figure 5.69: CAN3 Velocity Profile

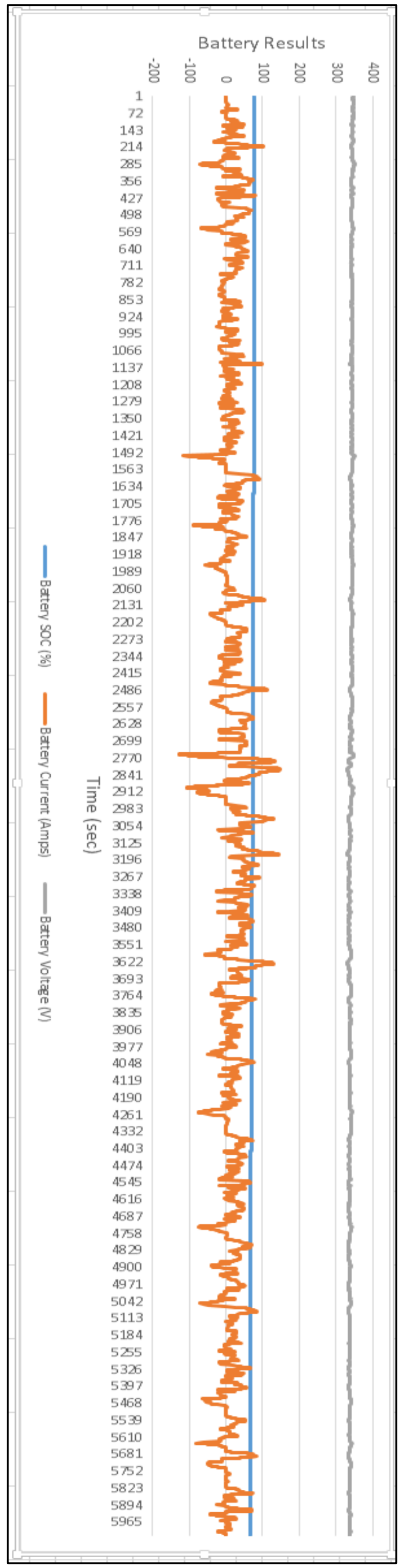

Figure 5.70: CAN 4 Battery Results

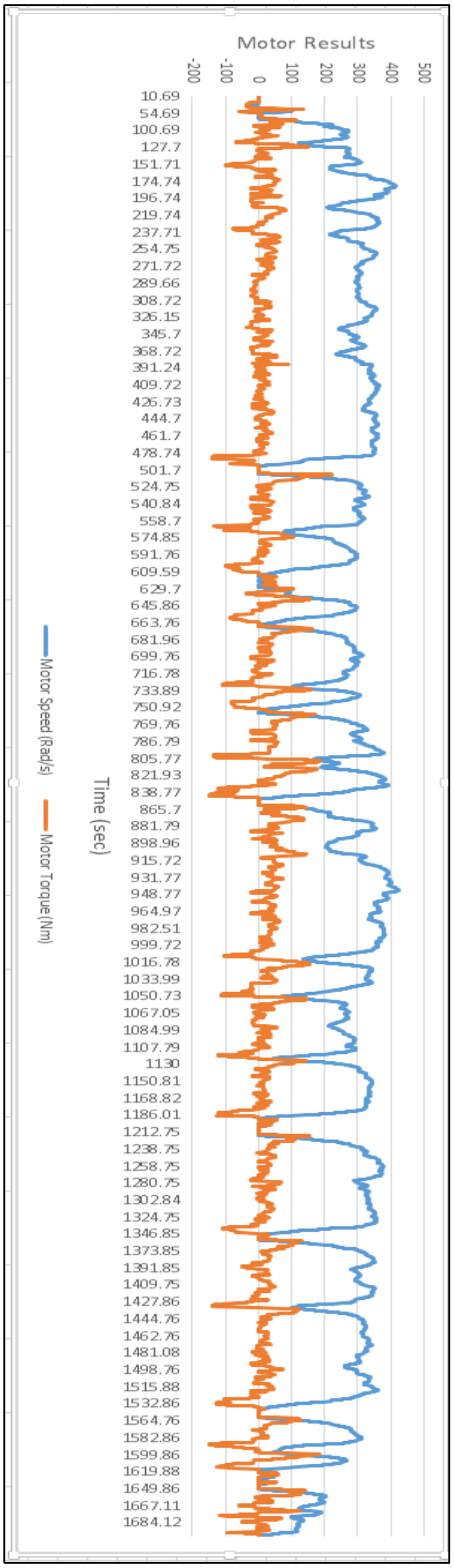

Figure 5.71: CAN 4 Motor Results

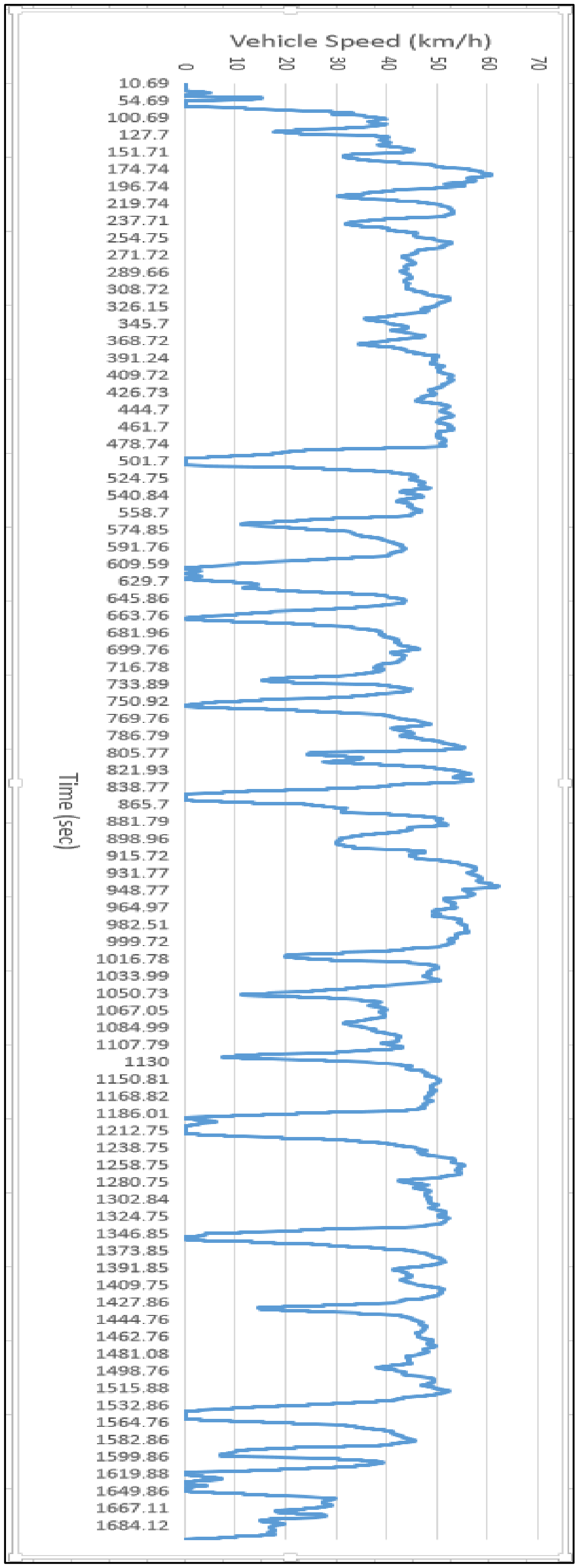

Figure 5.72: CAN 4 Velocity Profile

Ford Focus Electric 2012 Autonomie Results:

The overall energy consumption and the MPGe was seen as shown in the table below. The Autonomie results were compared to the AMESim results for the standard drive cycle simulations. It was seen that the AMESim results were more accurate or were more closer to the true CAN data logger values. This could mainly be because the AMESim model represents the real Ford Focus Electric vehicle more closely when compared to the Autonomie model. In addition, the simulation and modeling capabilities are much higher for AMESim.

Drive Cycle	Autonomie Energy	Autonomie MPGe	AMESim MPGe	Average CAN MPGe	Published MPGe	Autonomie/CAN % error	AMESim/CAN % error
UDDS	26.3340	127.9714	100.6430	67.1000	110.0000	90.7175	49.9896
NEDC	27.3410	123.2581	107.8461	67.1000	110.0000	83.6932	60.7244
JC08	26.3700	127.7967	105.1449	67.1000	110.0000	90.4571	56.6988
FTP75	27.1110	124.3038	97.9655	67.1000	110.0000	85.2515	45.9993
US06	39.2840	85.7856	74.4191	67.1000	110.0000	27.8473	10.9077

Table 5.73: Comparison between Autonomie, AMESim and True Results

The above table has been graphically represented below:

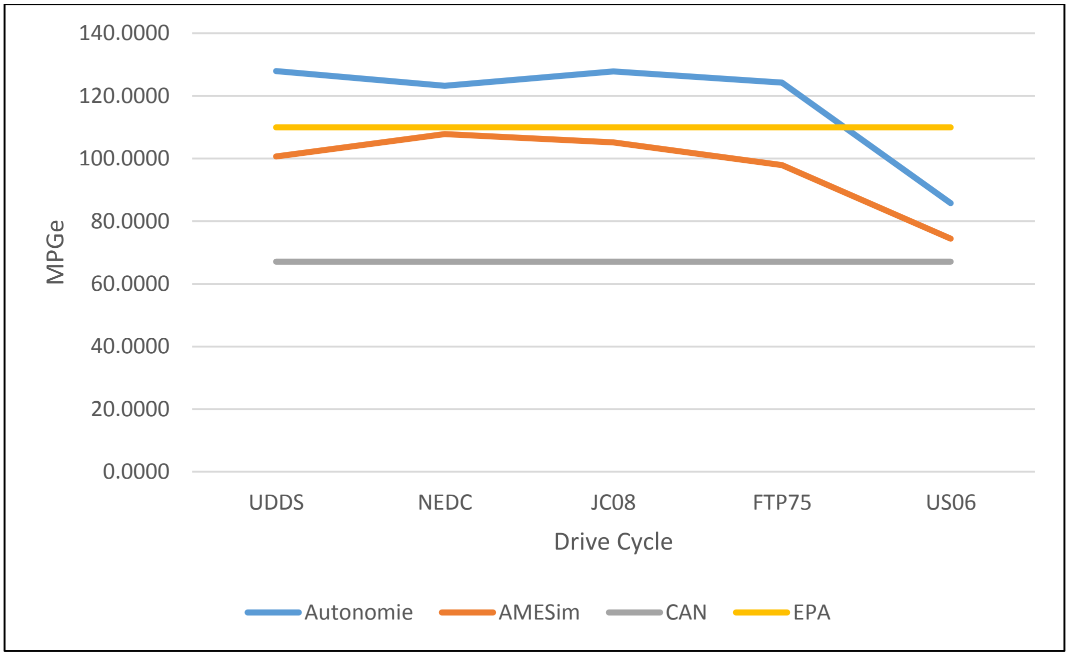

Figure 5.74: Graph Comparing Autonomie, AMESim and True Results

The percent error between the Autonomie and AMESim results compared with the true results is shown in Figure 5.75:

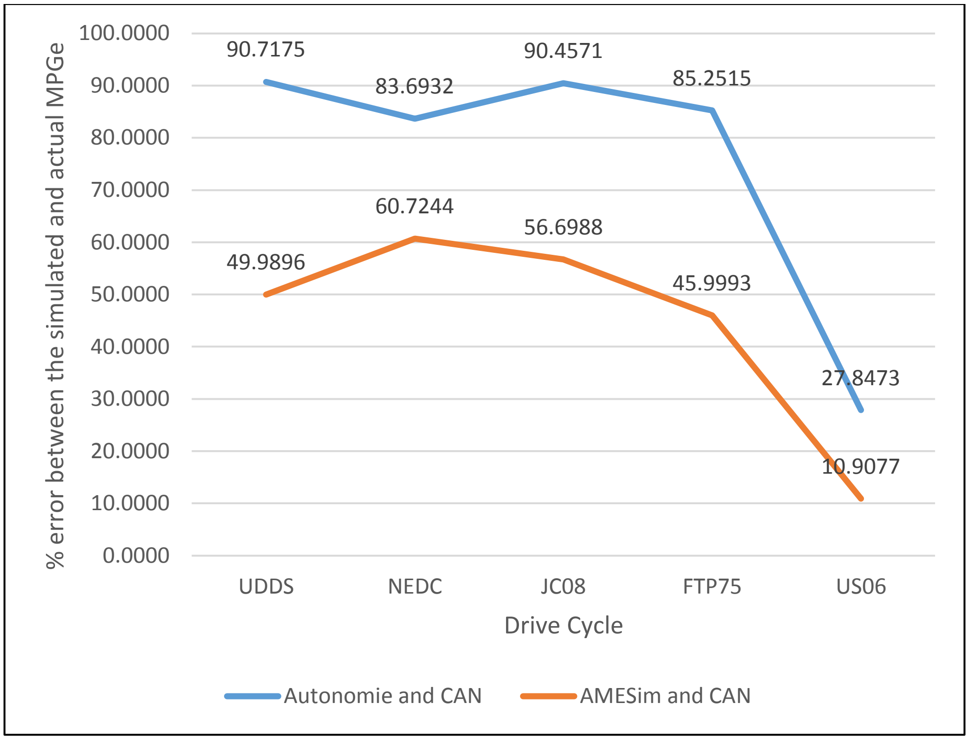

Figure 5.75: Graph Comparing Autonomie and AMESim results with the true results

As stated above, the AMESim simulations were seem to be more accurate. In addition to the difference in the overall energy consumption, it was also noticed that certain vehicle results calculated by Autonomie were quite unrealistic, especially the Battery Voltage. As such, it has not been shown here.

The rest of the vehicle results calculated in Autonomie for various standard drive cycles are shown in Figures 7.21-7.35 in Appendix C.

AMESim results for Toyota Prius:

The previously described Toyota Prius model was tested against NEDC drive cycle in AMESim. The vehicle results obtained from the simulation are as follows:

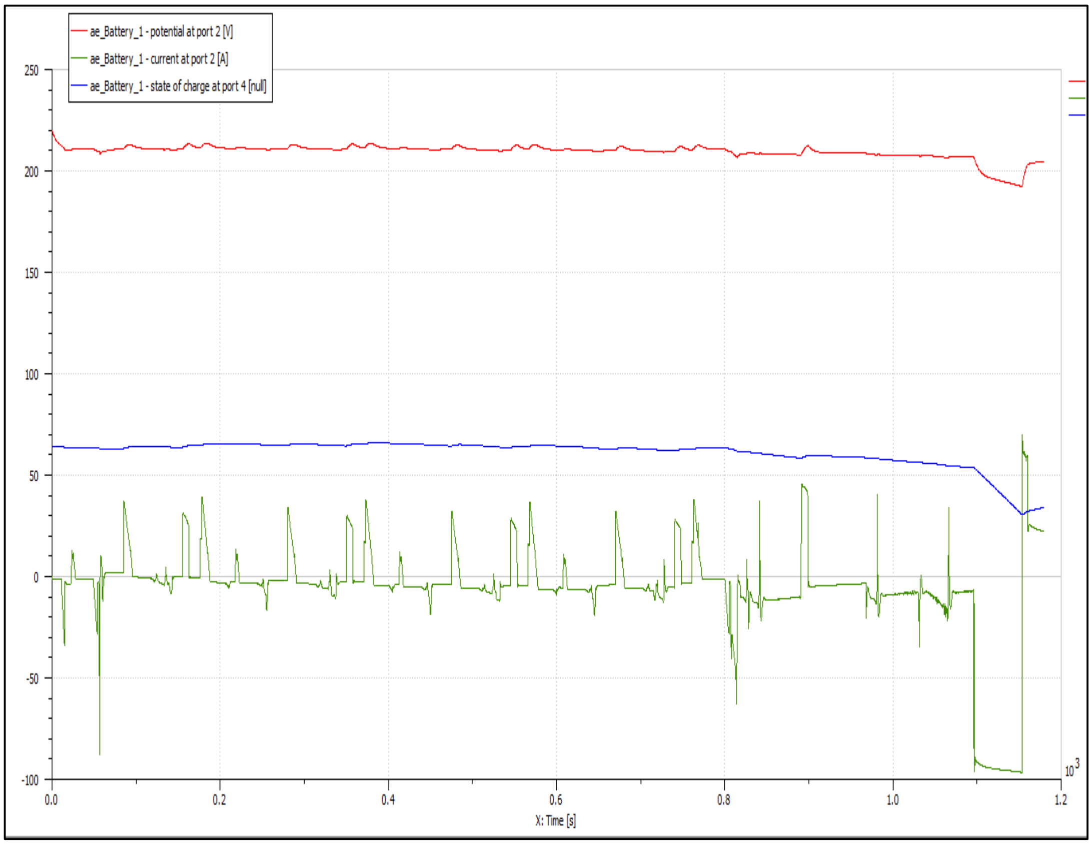

Figure 5.76: AMESim Toyota Prius' NEDC Results for Battery current, voltage and SOC

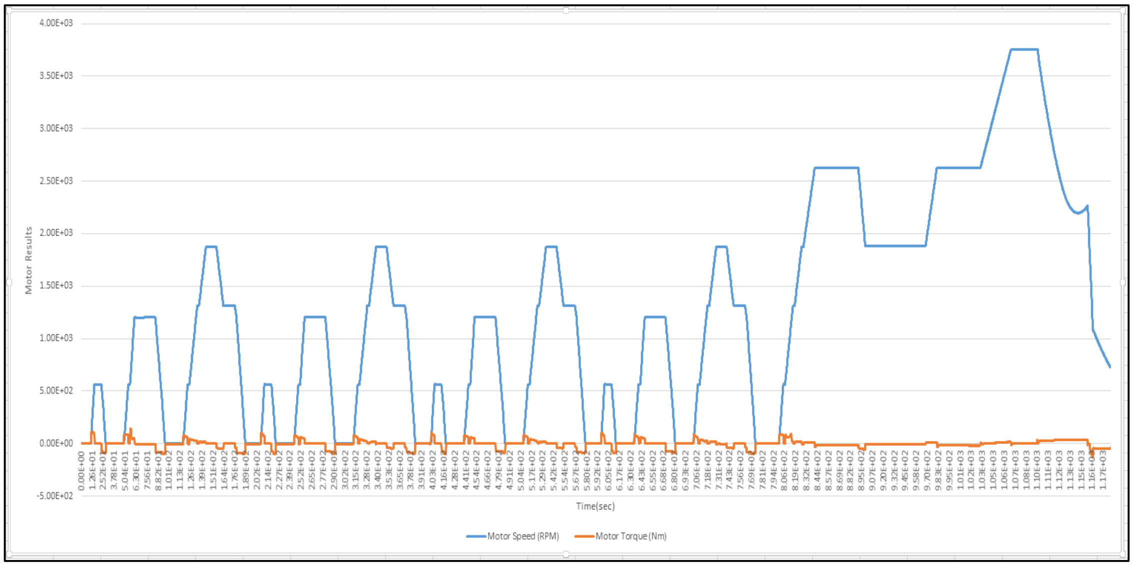

Figure 5.77: AMESim Toyota Prius' NEDC Results for Electric motor speed and torque

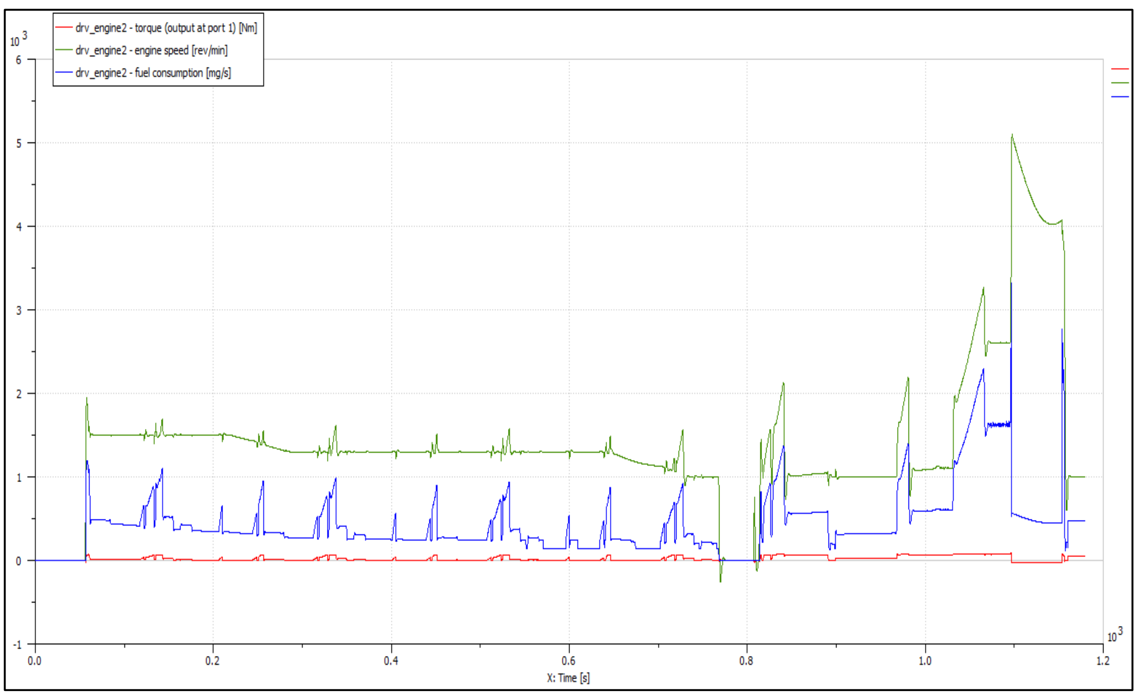

Figure 5.78: AMESim Toyota Prius' NEDC Results for Engine speed, Torque and Fuel Consumption

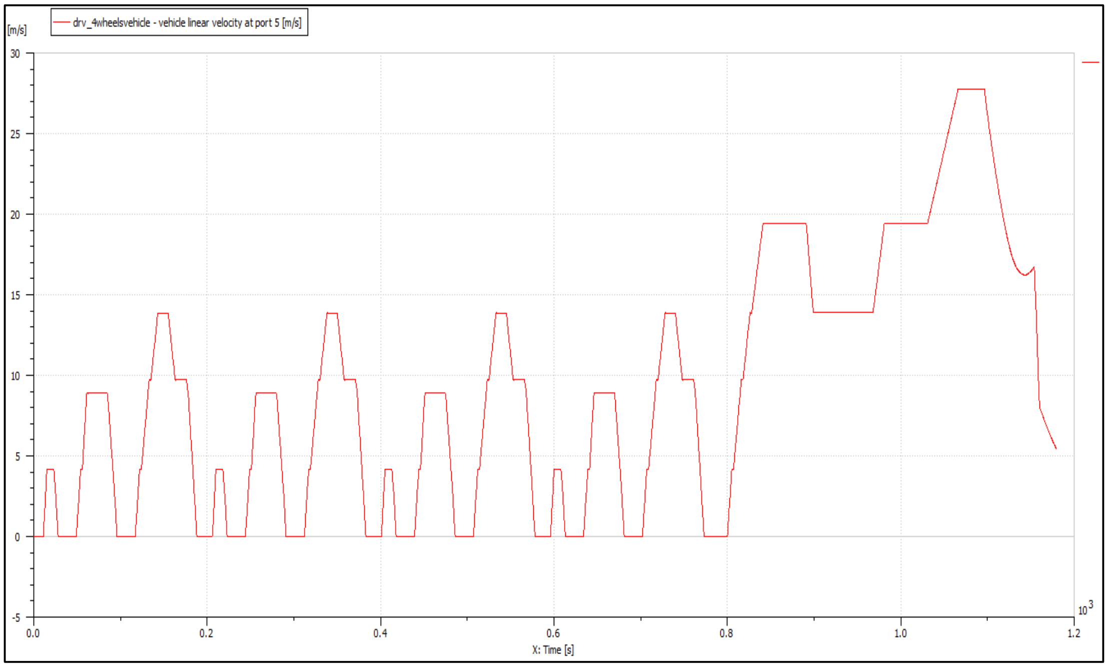

Figure 5.79: AMESim Toyota Prius' NEDC Results for Velocity Profile

The data logger that was initially used for the Ford Focus Electric 2012 was also modified to record data from Toyota Prius 2006. This data was recorded on Nov 20, 2014 between 12:09 p.m. and 12:39 p.m. There were light snow flurries. However, there was already a lot of snow accumulated on the roads. As such, the roads were very slippery and wet. Driver 2 was driving the car for this test on Toyota Prius. The true results collected with the CAN data logger are graphed as below:

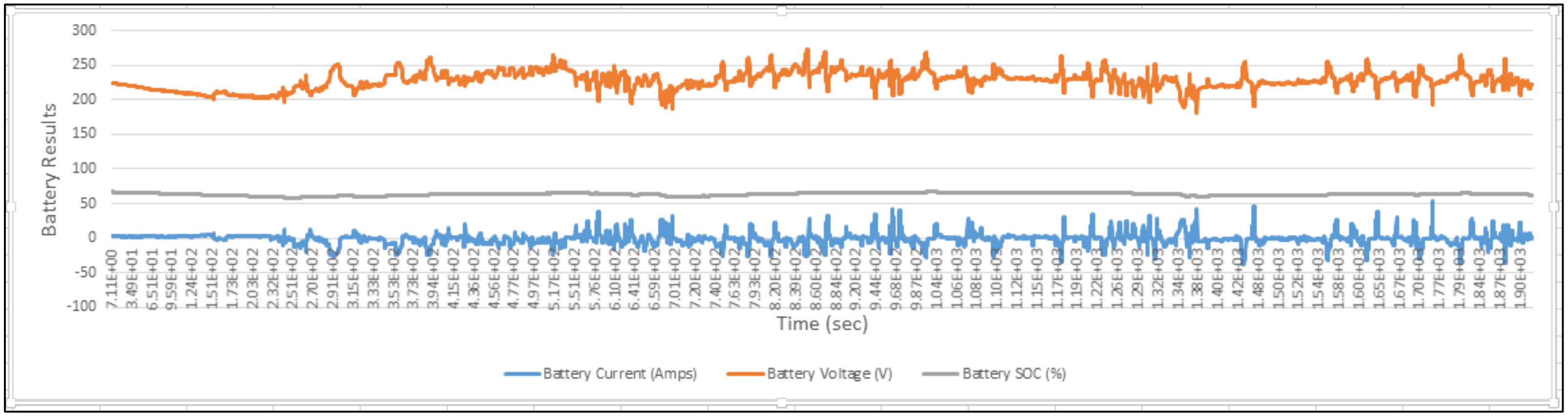

Figure 5.80: Toyota Prius CAN Results for Battery current, voltage and SOC

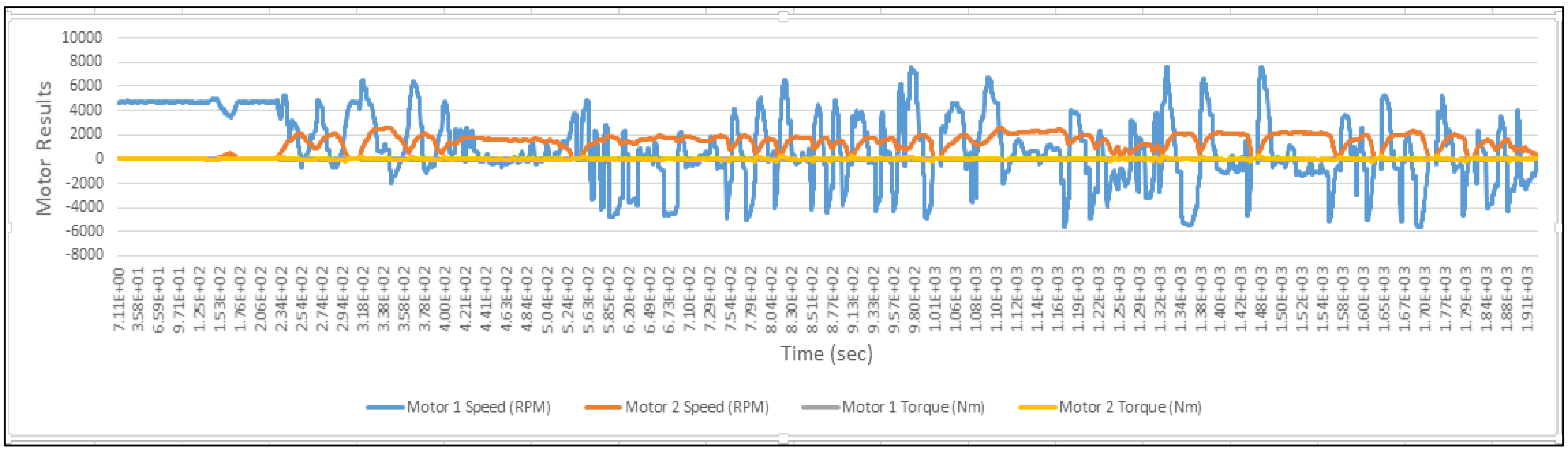

Figure 5.81: Toyota Prius CAN Results for Motors' speed and torque

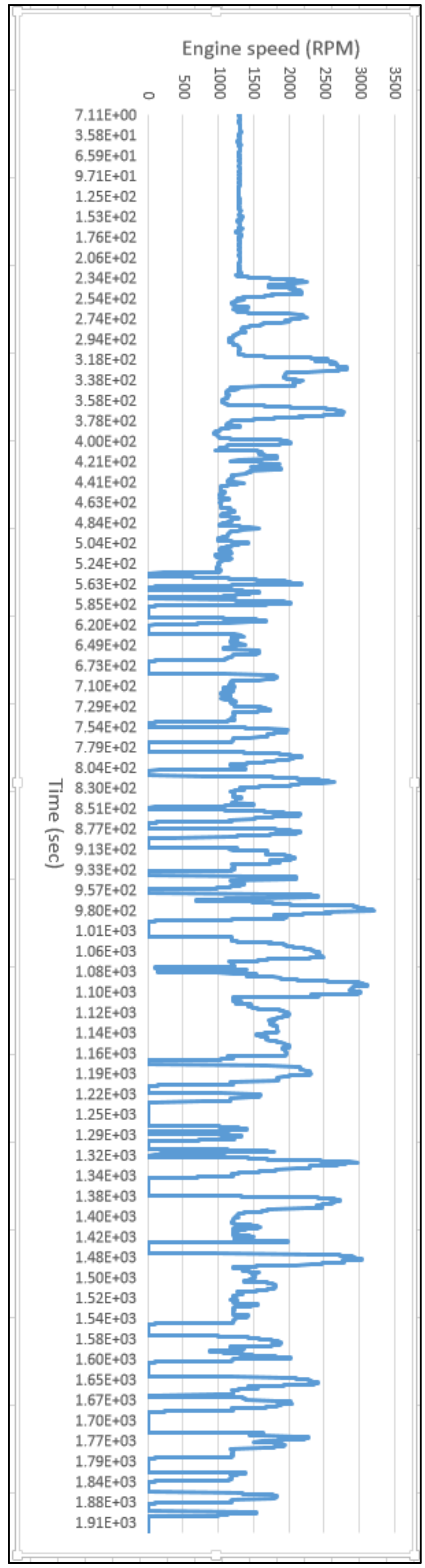

Figure 5.82: Toyota Prius CAN Results for Engine Speed

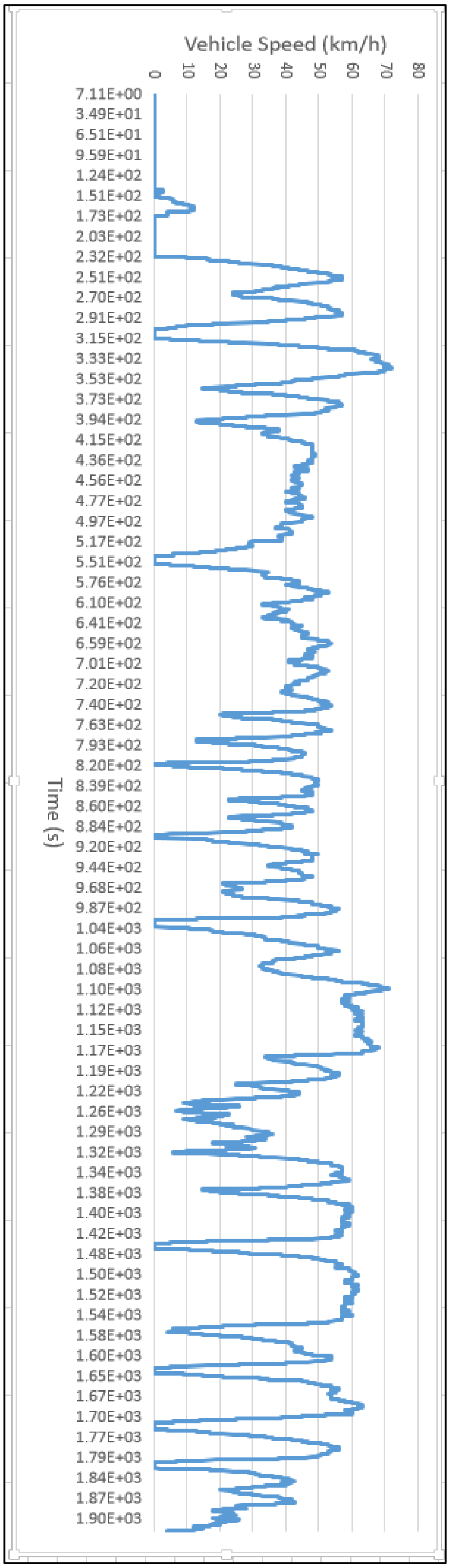

Figure 5.83: Toyota Prius CAN Results for Velocity Profile

Please refer to Appendix D for the true vehicle results calculated for Toyota Prius using a data logger. The fuel economy was calculated from the CAN data logger results. These results will be compared with each other as well as the EPA values after discussing Autonomie simulation results for Toyota Prius 2006. The analysis conducted on Toyota Prius is not as detailed as for Ford Focus Electric 2012. This is only a generic analysis in order to provide an overall basis for comparison between an all-electric and a hybrid-electric vehicle. The Autonomie model for Toyota Prius was tested on standard drive cycles – UDDS, NEDC, JC08, FTP75 and US06. The results for these simulations are shown in Figures 7.36-7.55 in Appendix C.

The fuel economy numbers calculated from the Autonomie Simulations in addition to the true values recorded from the CAN data logger are compared in the table below:

Drive Cycle	Autonomie MPG	CAN MPG	Published MPG	Autonomie/ CAN % error
UDDS	74.8900	34.4500	48.0000	117.3875
NEDC	69.3500	34.4500	48.0000	101.3062
JC08	82.0100	34.4500	48.0000	138.0552
FTP75	69.5400	34.4500	48.0000	101.8578
US06	43.8700	34.4500	48.0000	27.3440

Table 5.84: Comparing True and Autonomie MPG results for various drive cycles

From the above table, it can be seen that there is a lot of difference between the fuel economy values predicted by Autonomie and the true values recorded by the CAN data logger. In addition, deviation can also be noticed between the true CAN data and the EPA fuel economy labels. These deviations demonstrate the need for a revised drive cycle definition.

The above fuel economy numbers are represented in graphical format as follows:

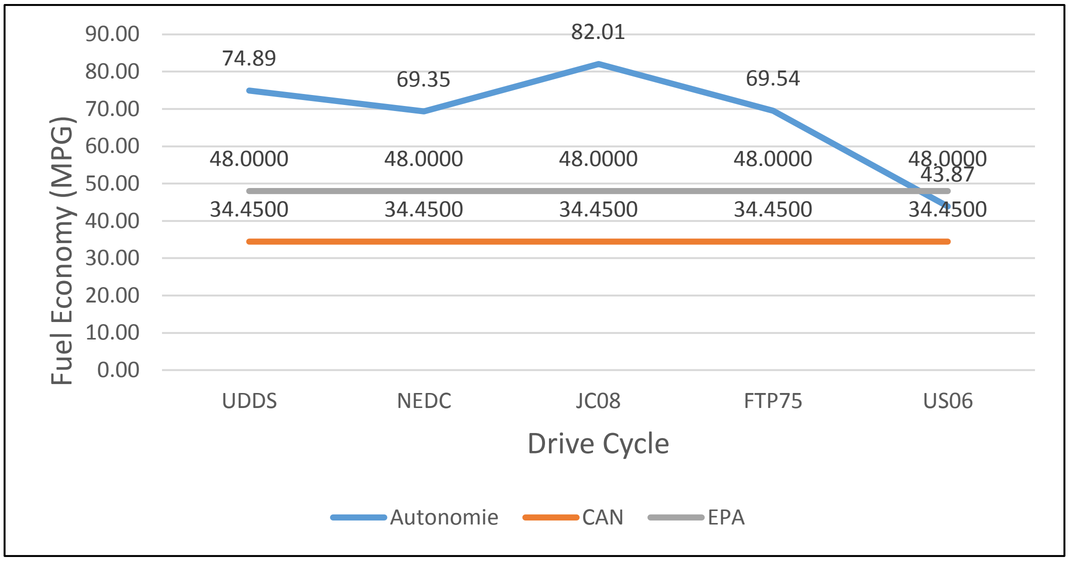

Figure 5.85: Graph Comparing True and Autonomie MPG results for Toyota Prius

A comparison is also done between the MPG values of Toyota Prius and MPGe values of Ford Focus Electric as follows:

	Ford Focus Electric 2012 (MPGe)	Toyota Prius 2006 (MPG)
UDDS	100.64	74.89
NEDC	107.85	69.35
JC08	105.14	82.01
FTP75	97.97	69.54
US06	74.42	43.87
CAN Average	67.10	34.45
EPA Label	110.00	48.00

Figure 5.86: Comparison Between Ford Focus Electric and Toyota Prius MPG

From the above it can be seen that, as expected, Ford Focus Electric offers a better fuel or energy economy being an all-electric car. This information is also visually represented below:

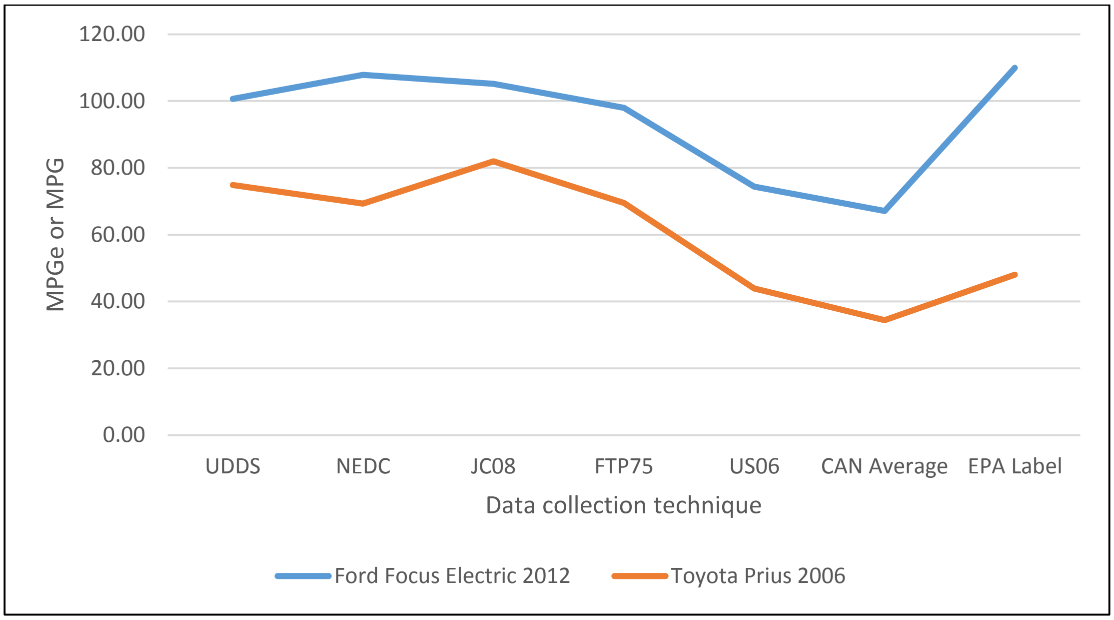

Figure 5.87: Graph Comparing the MPGe and MPG for Ford Focus Electric and Toyota Prius respectively

Overall, from this simulation results section, some important conclusions could be drawn. From the two vehicle simulation software packages used, AMESim was seen to more accurately represent the real-life scenario. In addition, from the standard drive cycles used, US06 drive cycle was seen to model Ford Focus Electric's as well as Toyota Prius' performance most accurately. The Journey Mapping test on Ford Focus Electric showed that it was able to model the real-life conditions very accurately with only an average error of about 5 percent. As previously stated, from the two test vehicles, Ford Focus Electric, being an all-electric vehicle was seen to have a higher fuel or energy economy compared to Toyota Prius. In addition, it was alarming to see a significant percent deviation between the EPA fuel and energy economy labels and the true data logger values. The energy consumption and the fuel consumption was noticed to be much higher than the EPA label values. Also, a major deviation was noticed between the values predicted by the standard drive cycles such as UDDS, NEDC, JC08, FTP75 and US06 and the true data logger values. These deviations between the true and the predicted or EPA label values demonstrate a major necessity of re-defining drive cycles. Journey Mapping's implementation on Ford Focus Electric 2012 shows its realistic, accurate and practical approach of modeling as well as testing vehicles for their performance.

5.4 Sensitivity Analysis:

The concept of journey mapping is governed by many different external conditions such as weather, terrain, road, vehicle, aerodynamic, driver behavior, traffic, et cetera. As previously described, many different parameters have been used in the Journey Mapping simulation model in order to implement these real-life conditions. The concept of Journey Mapping has been implemented from the perspective of energy consumption. The goal of Journey Mapping is not to predict the lowest energy consumption values possible but to predict accurate values that are as close as possible to the true values. In other words, Journey Mapping aims to predict the vehicle performance accurately based on the conditions that the vehicle might be influenced during its trip.

Although, a lot of conditions affect a vehicle's performance, not all conditions affect it equally. Some conditions have a bigger impact than the others. As such, it is very important to carry out a sensitivity analysis to understand the relative influence of each of the known factors on energy consumption.

Since, Journey Mapping results were collected through the CAN data logger as well as calculated using the AMESim Journey Mapping model, two different sensitivity analyses had to be carried out in order to understand the importance of all the different simulated as well as real-life parameters. Both these sensitivity analyses could not be combined, but had to be carried out separately because of a difference between the time intervals of the measured results. This sensitivity analysis was carried out by comparing the deviations between the various external parameters to the deviation between the energy consumption. Deviations were calculated between the neighboring time stamps.

Sensitivity analysis for the Journey Mapping parameters modeled in AMESim for Ford Focus Electric is as follows. The values shown below are a summary of the results calculated through a detailed sensitivity analysis.

VARIABLES	JM1	JM2	JM3	JM4	Sensitivity Percent
Braking Force	74.0709	60.0658	89.6702	87.3332	77.7850
Driving Force	18.5760	12.7834	10.0944	12.4203	13.4685
Climbing resistance	6.9106	4.8102	0.0721	0.0868	2.9699
Aerodynamic Drag	0.3636	0.2081	0.0407	0.0357	0.1620
Front axle slip	0.0448	0.3608	0.0390	0.0483	0.1232
Velocity profile	0.0189	0.0111	0.0035	0.0032	0.0092
Driver baking control	0.0086	0.0090	0.0137	0.0141	0.0113
Driver accelaration control	0.0033	0.0025	0.0019	0.0027	0.0026
Rolling resistance	0.0030	21.7452	0.0645	0.0555	5.4671
Solar Azimuth Angle (Degrees)	0.0003	0.0021	0.0001	0.0000	0.0006
Solar Altitude (Degrees)	0.0000	0.0019	0.0000	0.0000	0.0005
Rear axle slip	0.0000	0.0000	0.0000	0.0000	0.0000

Table 5.88: Sensitivity Analysis Results for Simulation Parameters

As it can be seen from the above table, braking force has the most influence on the energy consumption out of all the variable simulation parameters considered. The influence distribution of various simulation parameters can be visualized from the chart shown in Figure 5.89.

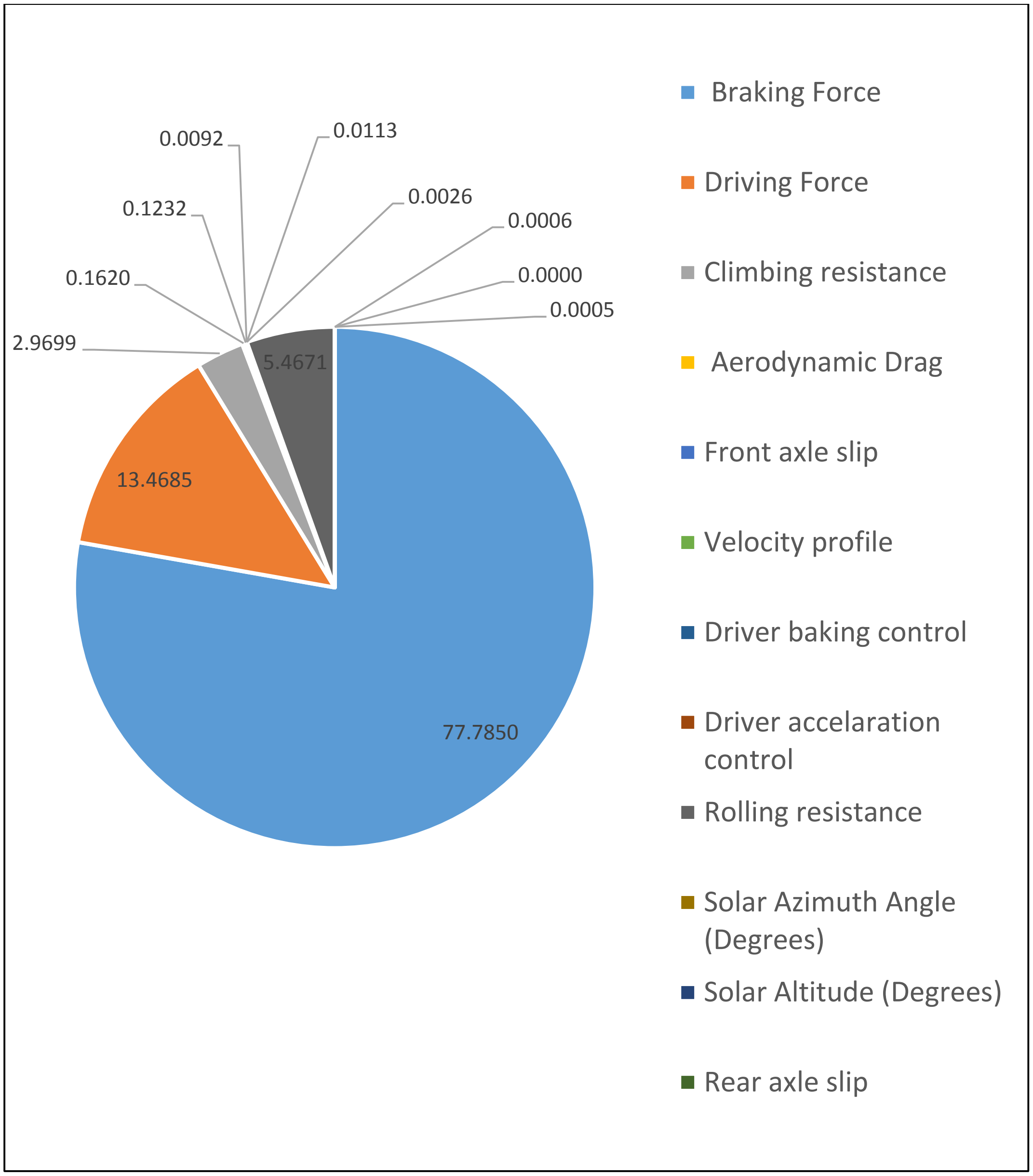

Figure 5.89: Sensitivity Analysis Chart for Simulation Parameters

Similarly, sensitivity analysis was carried out for the real parameters collected by the CAN data logger. A summary of the results is displayed in the table below:

VARIABLES	CAN2	CAN3	CAN4	Sensitivity Percent
Grade	30.83	80.37	98.54	69.91
Outside Air temperature	0.01	0.00	0.17	0.06
Auxiliary Power	68.15	19.53	0.00	29.23
Vehicle velocity	0.11	0.06	0.13	0.10
Traffic conditions	0.90	0.04	1.16	0.70

Table 5.90: Sensitivity Analysis Results for True CAN Parameters

From the above, it can be seen that terrain, represented as the road grade has the biggest impact on energy consumption out of the real-life parameters collected using the CAN data logger. A visual representation of the above tabulated sensitivity analysis results are as follows:

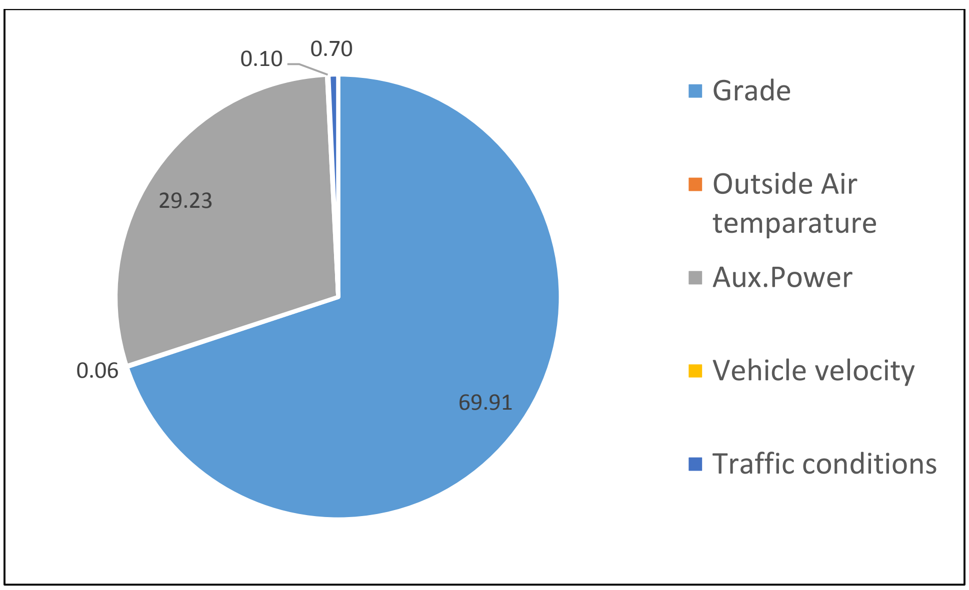

Figure 5.91: Sensitivity Analysis Chart for True CAN Parameters

The above described parameters are variable parameters that change throughout the trip with respect to time. However, there are also some parameters that stay constant throughout a trip but change with every iteration. Such parameters might also influence energy consumption. However, they could not be included in the above sensitivity analysis. This is mainly because the deviation according to the variation in each parameter was studied. As such, if there is no variation in the parameter it could not be included as part of the above sensitivity analysis. Some such simulation parameters include wind speed, air density, albedo coefficient, linke turbidity factor and the cloud cover coefficient. However, these parameters already play a role in the variables included in the above analysis. As such, their influence has been indirectly accounted for. Similarly, for the results acquired from the CAN data logger, the driver behavior parameters such as % hard acceleration, % hard braking and the number of idle events were found constant for the whole trip although, they varied for every iteration. Once again, due to invariability of these parameters, they could not be included in the sensitivity analysis above. However, a brief description of the driver behavior monitoring is given below.

The CAN data logger was able to estimate the driver behavior using an eco-driving score which was calculated based on % hard acceleration, % hard braking, number of idle events and average vehicle speed. The driver behavior monitored from two different trips is compared below. Both these trips were done through

Toyota Prius. Different drivers were driving the vehicle for different trips. As such, their behavior and their impact on fuel economy is evaluated here.

	Driver 1	Driver 2
Age	32	64
Driving experience in years	14	48
% Hard acceleration	2	10
% Hard braking	5	10
Number of idle events	4	7
Eco-driving score	64.96	63.53
Fuel Economy (MPG)	48.81	39.46

Table 5.92: Driver Behavior Comparison for Toyota Prius

Although, the above comparison is not enough to make conclusions about the effect of driver behavior on fuel economy, a generic trend can be noticed where a higher fuel economy can be seen when the driver with a higher eco-driving score drove the test vehicle. It is to be noted here that the age and driving experience of the driver has only been included for information purposes. Their impact on fuel economy was not studied and hence not implied. The difference in eco-driving scores are not significant to make any strong sensitivity conclusions. In addition, many other external parameters discussed previously, could also have impacted the driver behavior during the trips.

In overall, it could be generally concluded that terrain in addition to the road and vehicle conditions are the biggest influencers of energy consumption. In other words, energy consumption is the most sensitive to slightest changes in these conditions. The effect of terrain could be studied through the sensitivity analysis conducted on the CAN data logger results. The braking force is modeled as a result of road and vehicle conditions in the AMESim Journey Mapping model. As such, they could also be generalized as influencers of energy consumption.

5.5 Discussion

The main aim of the Journey Mapping concept was to re-define drive cycles in order to provide a more realistic, accurate and practical method of estimating vehicle performance. This goal was successfully accomplished; however a lot of challenges were faced during the process.

A major challenge faced was the data acquisition. The Journey Mapping concept needs accurate real-time variable data with many different external conditions. However, due to the unavailability of such sophisticated equipment that was capable of making all measurements, different means of data collection were exercised. The data integration from all the different sources was a major challenge because of the large amounts of unsynchronized data with respect to time.

In addition, the unavailability of all the data needed contributed to many challenges. Not all the data that was collected could be incorporated into the currently existing vehicle simulation software packages. On similar terms, the various simulation parameters needed to model the real-life scenario as closely as possible could not be collected in real-time due to the lack of such equipment. As such, those parameters had to be manually estimated by observation or through online databases available.

Also, modeling of the complete vehicles to reflect the real test vehicles as closely as possible was another major challenge. Every vehicle consists of many sub components and it was very difficult to find detailed information about all the components. As such, some approximations had to be made as applicable.

In addition, collection as well as modeling of numerous parameters simultaneously was also very difficult. Understanding the impact of all the parameters on every component of the test vehicles was needed to finish the simulations successfully.

Also, many problems were faced with the values collected from the data logger. Sometimes, the logger was seen to record null or inappropriate values. However, despite of many challenges, the main goals were successfully accomplished.

6 Conclusion and Future Work

6.1 Conclusions

In overall, it could be seen that the main aim of re-defining drive cycles using the concept of Journey Mapping and testing its implementation on Ford Focus Electric was successfully fulfilled. The Journey Mapping model was able to predict the energy consumption accurately with about 5 percent error on average when compared to the true consumption and the standard deviation for the various Journey Mapping iterations was noticed to be about 8.7. In addition, a major need for re-defining drive cycles was demonstrated by displaying the significant deviations between the EPA labels and the true measurements.

The Journey Mapping model provided a realistic and accurate approach of vehicle testing and performance prediction within the considered scope. There was also a major deviation noticed between the standard drive cycles considered in this thesis and the true CAN values. As such, Journey Mapping attempted to identify means to fill that gap. It is to be noted here that the goal of this thesis was not to prove that Journey Mapping is a better technique for defining drive cycles than all the currently existing ones, but to demonstrate a significant need for re-defining drive cycles by conducting a preliminary study of the various external factors that could impact a drive.

In addition, various parameters were also assessed for their sensitivity from an energy consumption perspective. Terrain, road and vehicle conditions were found to be the biggest factors. Also, a comparative study was offered between the two test vehicles – Ford Focus Electric and Toyota Prius. The former, being an all-electric car was seen to be more fuel or energy efficient.

In conclusion, the Journey Mapping concept was developed as well as successfully tested within the defined scope. It was found to provide a new and realistic approach for vehicle testing and performance prediction.

6.2 Scope of Future Work

The real-time variable data collection as well as the implementation of driver behavior [32] and traffic data would be the biggest opportunity for improvement of the Journey Mapping model. An accurate real-time traffic data collection equipment needs to be used. A low-cost technique would be to simply use cellphone applications to collect traffic information [33].

In addition to above, the scope of the Journey Mapping concept could be extended to be implemented on conventional vehicles, off-road vehicles, aircrafts, bikes, under-water vehicles et cetera. Also, this concept could be extended to autonomous-capable vehicles [34]. Journey Mapping can provide means for estimating accurate vehicle behavior which could then be integrated with vehicle-to-vehicle as well as vehicle-to-infrastructure technology and advanced sensor technology in order to provide means for intelligent decision making for autonomous-capable vehicles.

Also, the accuracy of the model could be improved by collecting real-time detailed information about road [35], vehicle and weather conditions. This real-time information when incorporated into the simulation model could further improve the accuracy of the Journey Mapping model. In addition, the Journey Mapping route could be modified to include a round trip so that the results are more representative of the journey. It would also provide better means of comparison with the traditional drive cycles. The simulation models could further be improved by incorporating symbolic models from MapleSim, especially for modeling road conditions. In addition, the driver models could be improved by using an appropriate controller tuning technique rather than manual tuning. The simulation results can also be verified by testing the models using a dynamometer.

Furthermore, the study conducted in this thesis was majorly focused on Ford Focus Electric 2012. The study conducted on Toyota Prius 2006 was a very basic one due to the complexity of the model. As such, a detailed analysis could also be carried out with Toyota Prius in order to provide better means of comparison for the Journey Mapping model's implementation.

Lastly, the Journey Mapping concept could be extended to the commercialization stage where a simple web portal could be developed, which could enable the users to predict fuel economy, energy consumption or vehicle performance, in general, when the trip details such as trip date and time, route, origin, destination, type of driver and the vehicle being used are entered. For the implementation of this, Journey Mapping would have to be integrated with accurate weather and traffic prediction models.

Appendix A

This Appendix provides examples of some traditional drive cycles generated using Autonomie libraries. Please note that the x axis is time in seconds and the y axis is the vehicle speed in m/s.

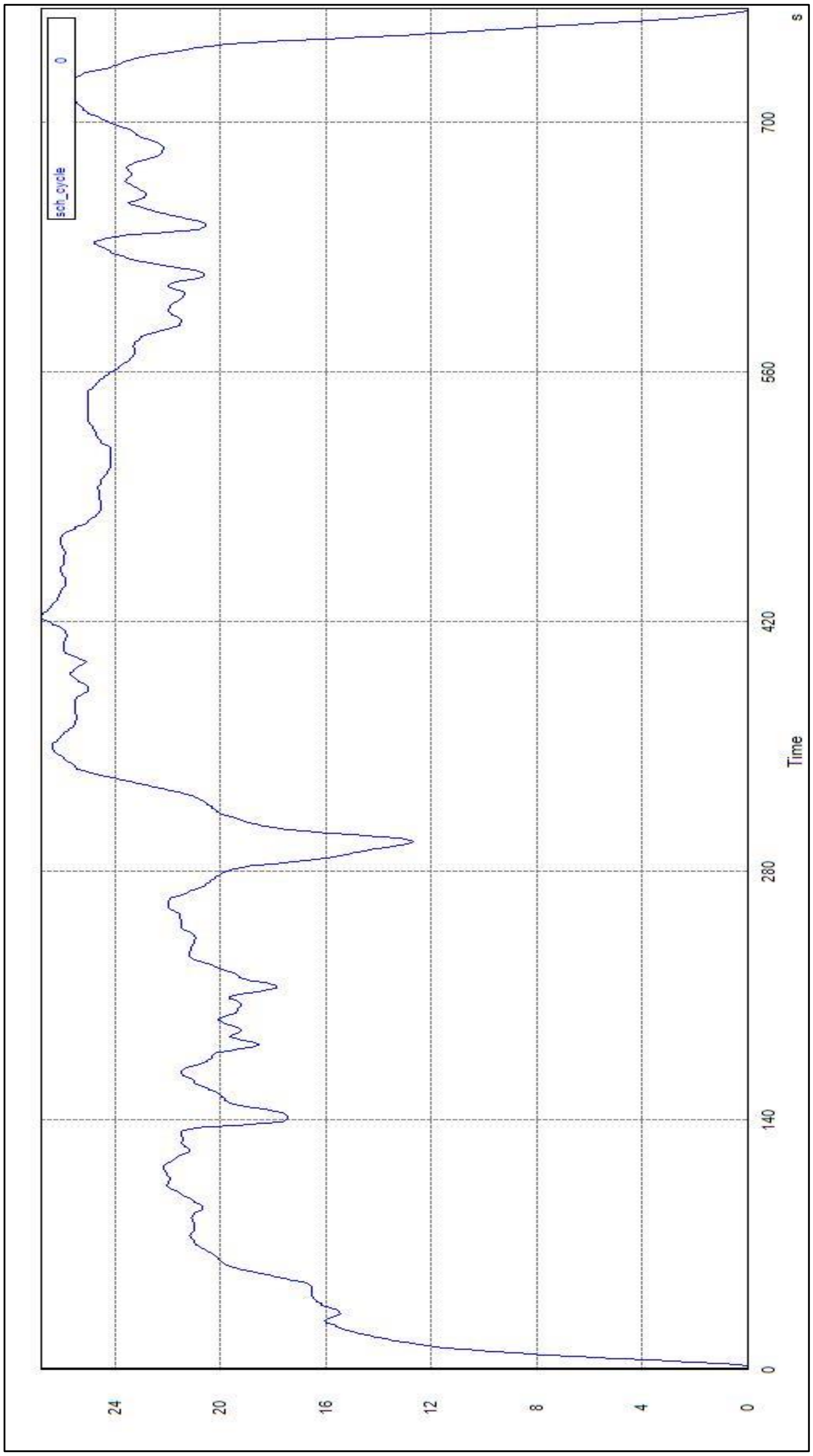

Figure 7.1: HWFET drive cycle generated in Autonomie

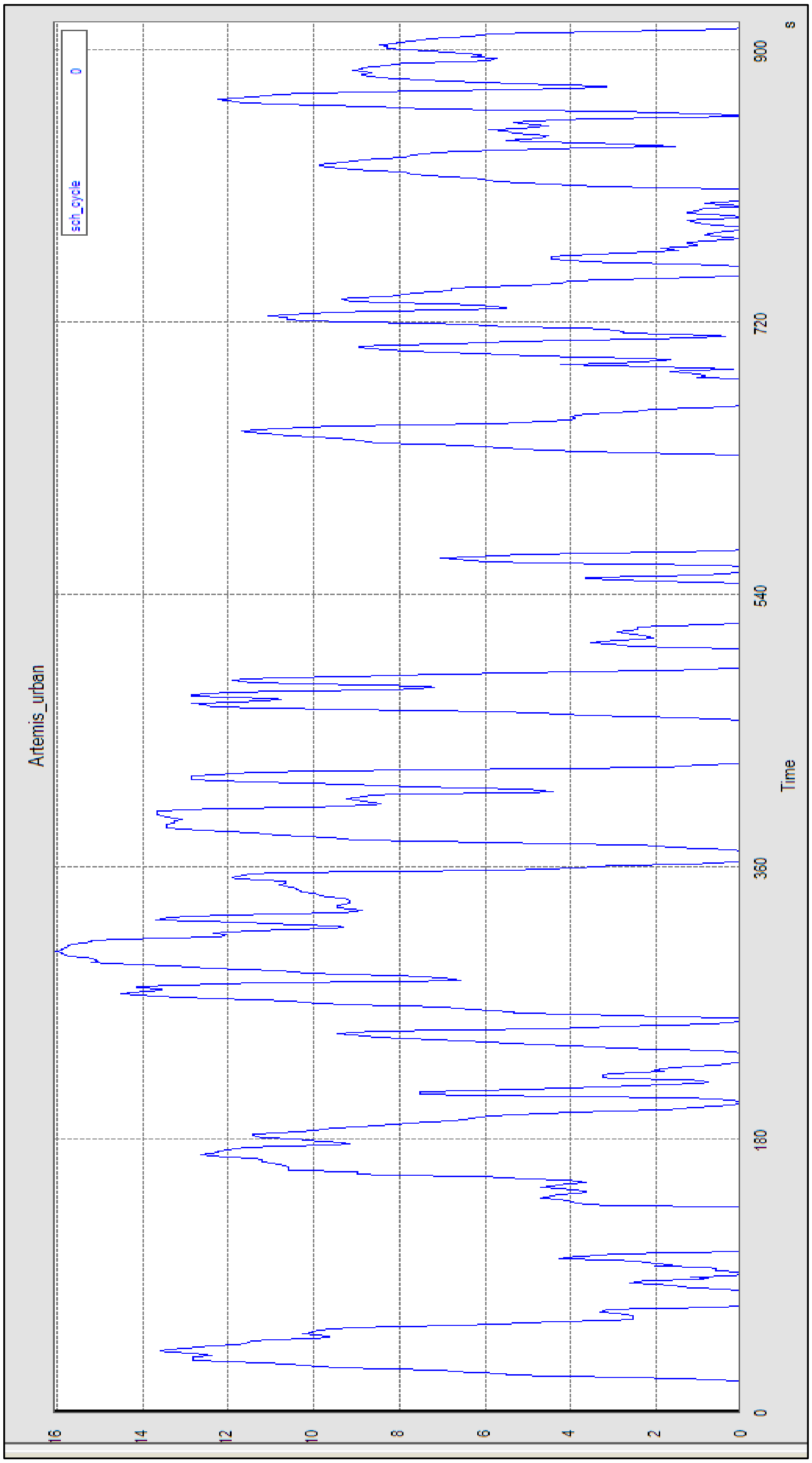

Figure 7.2: Artemis Urban driving cycle generated in Autonomie

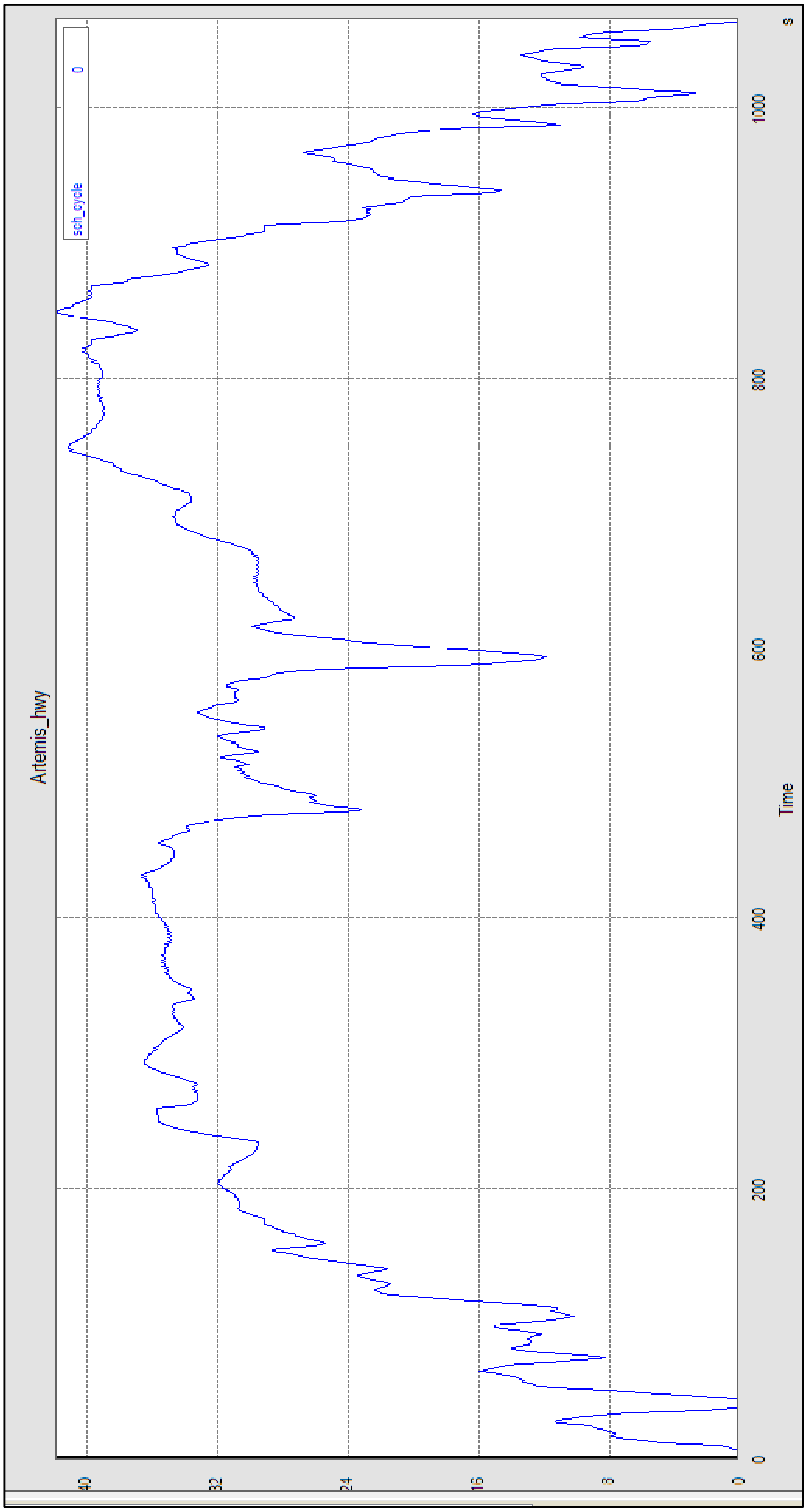

Figure 7.3: Artemis Highway driving cycle generated in Autonomie

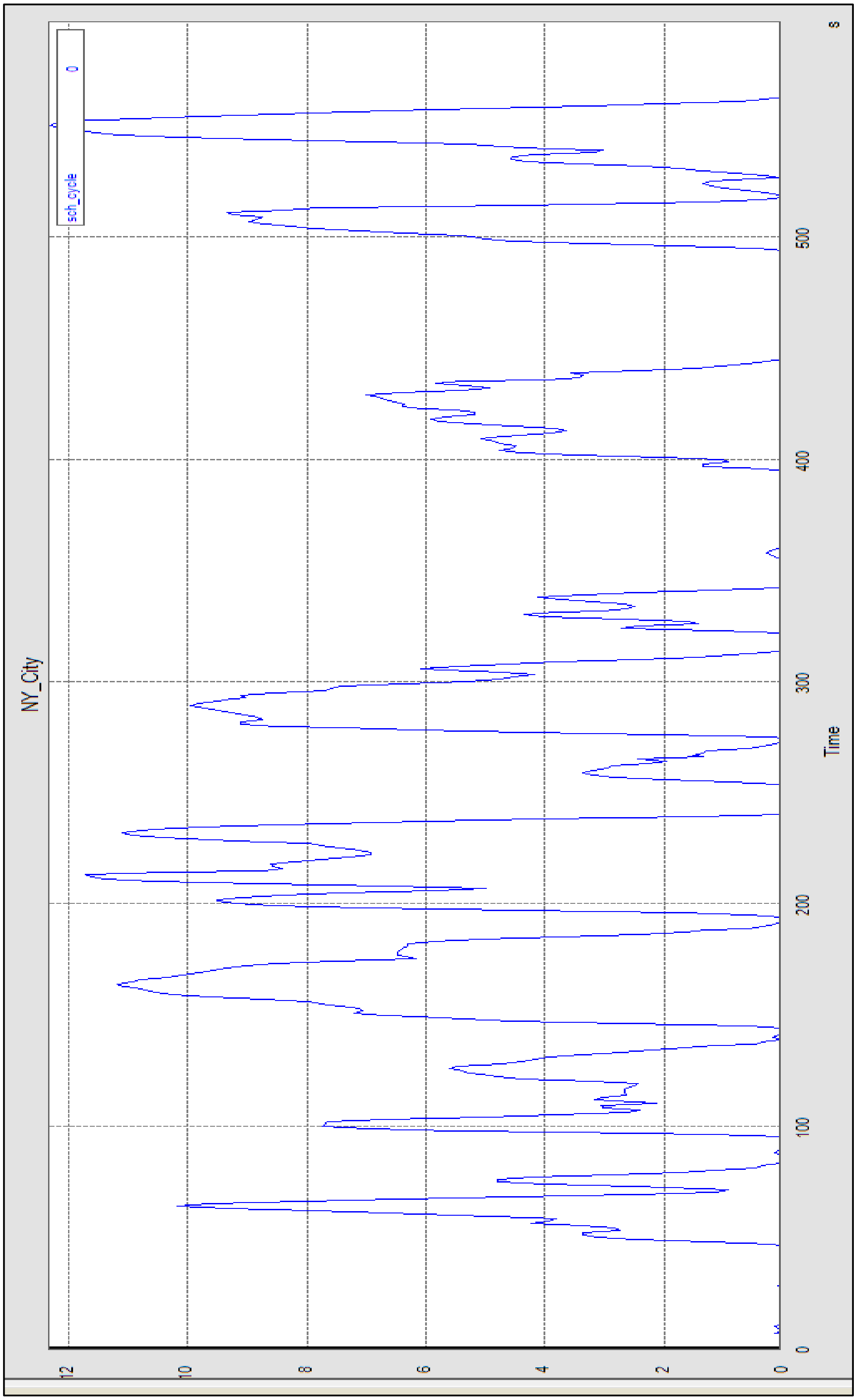

Figure 7.4: New York City driving cycle generated in Autonomie

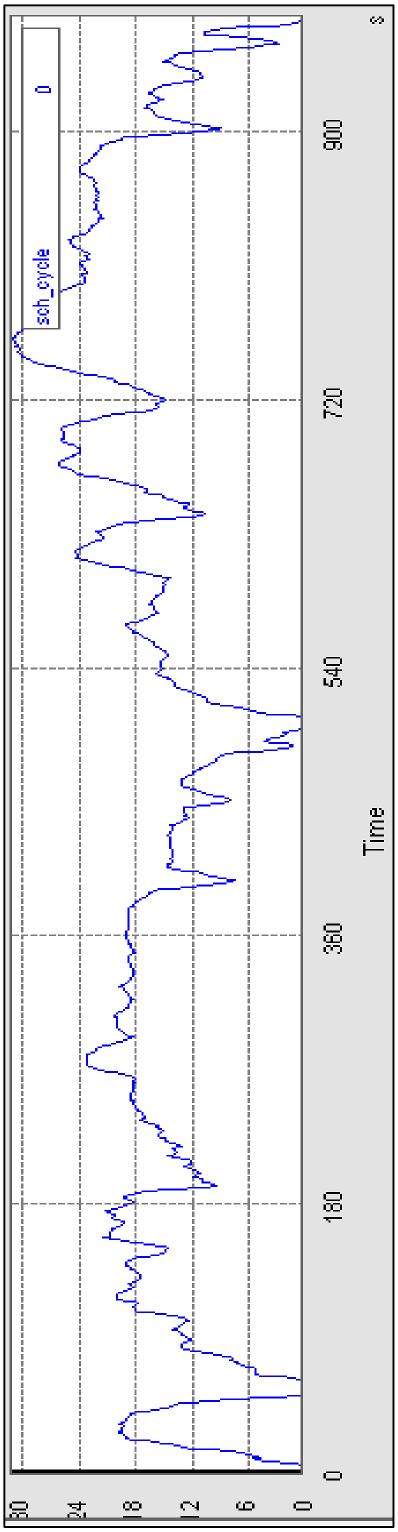

Figure 7.5: Artemis Extra Urban drive cycle generated in Autonomie

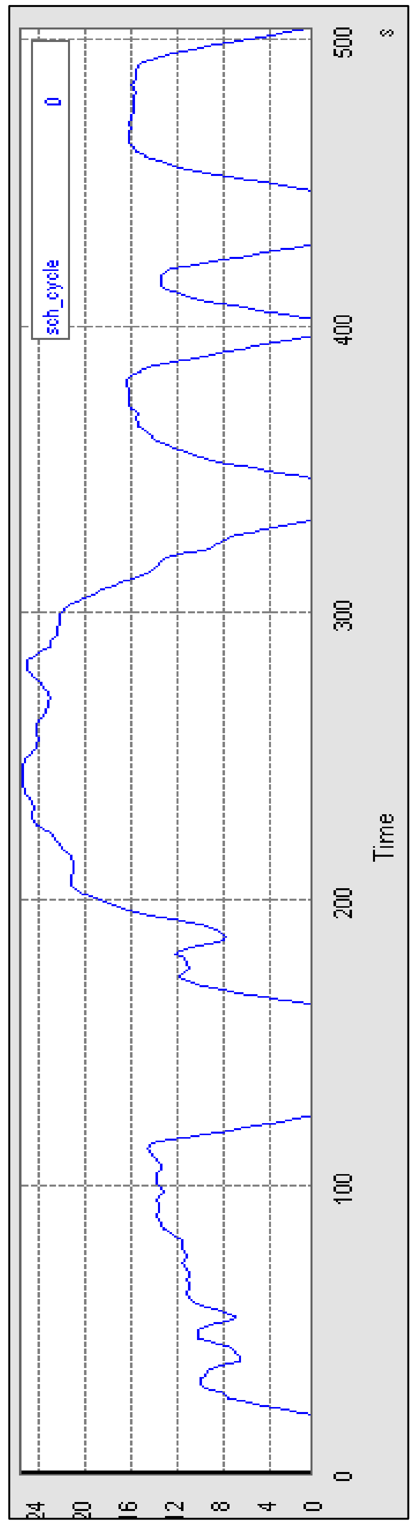

Figure 7.6: 505 drive cycle generated in Autonomie

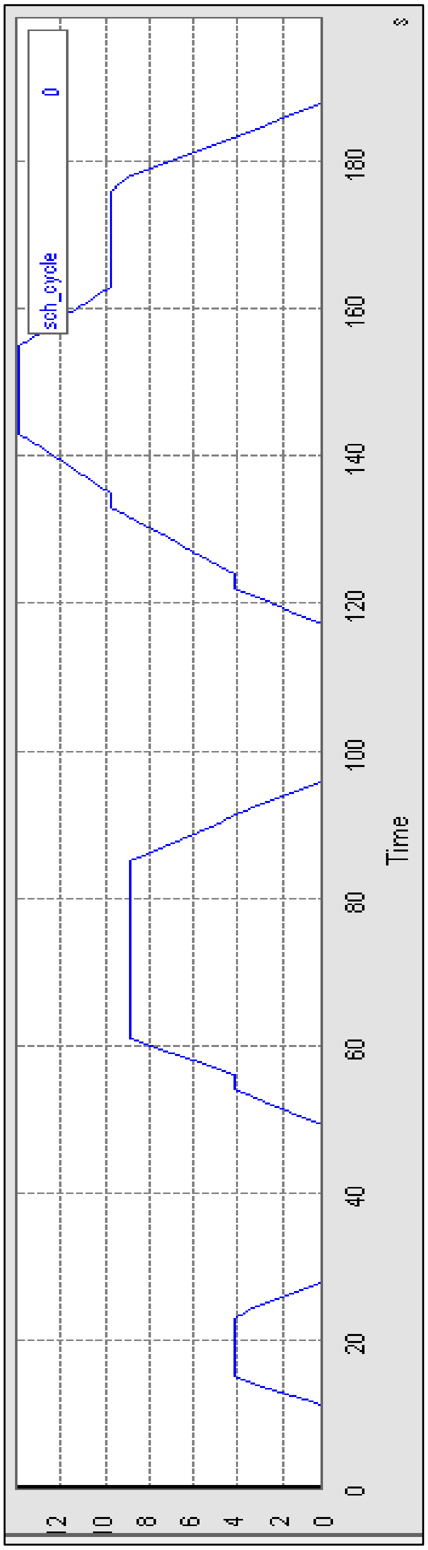

Figure 7.7: ECE drive cycle generated in Autonomie

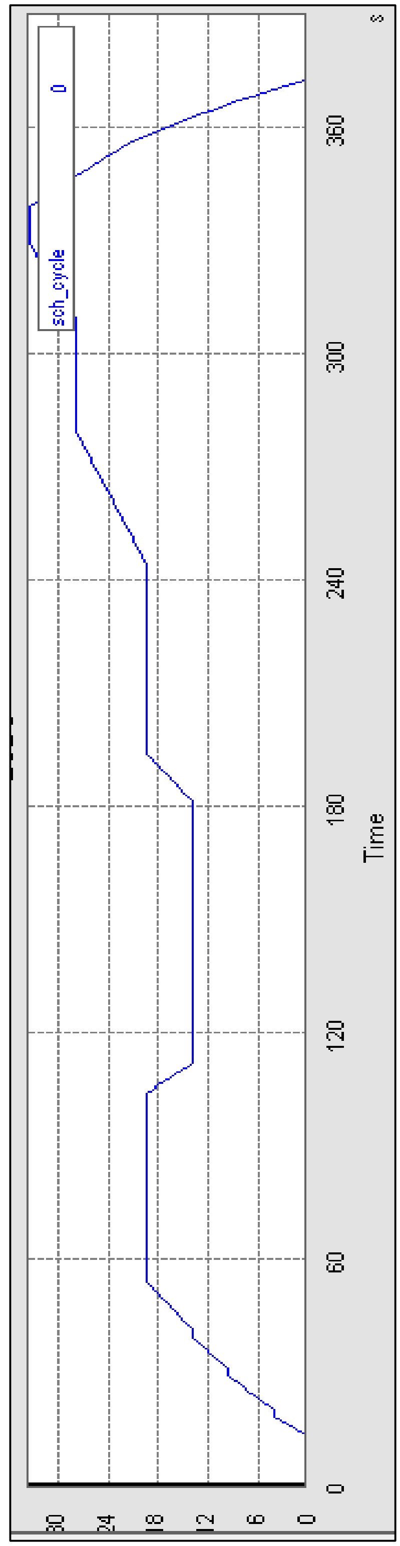

Figure 7.8: EUDC drive cycle generated in Autonomie

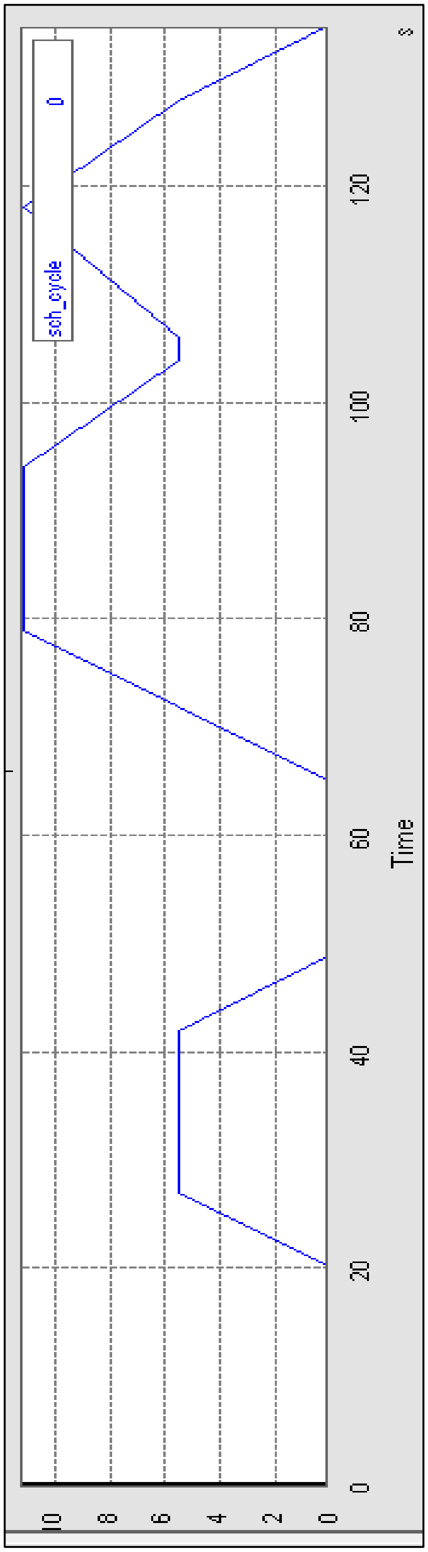

Figure 7.9: Japan 10 drive cycle generated in Autonomie

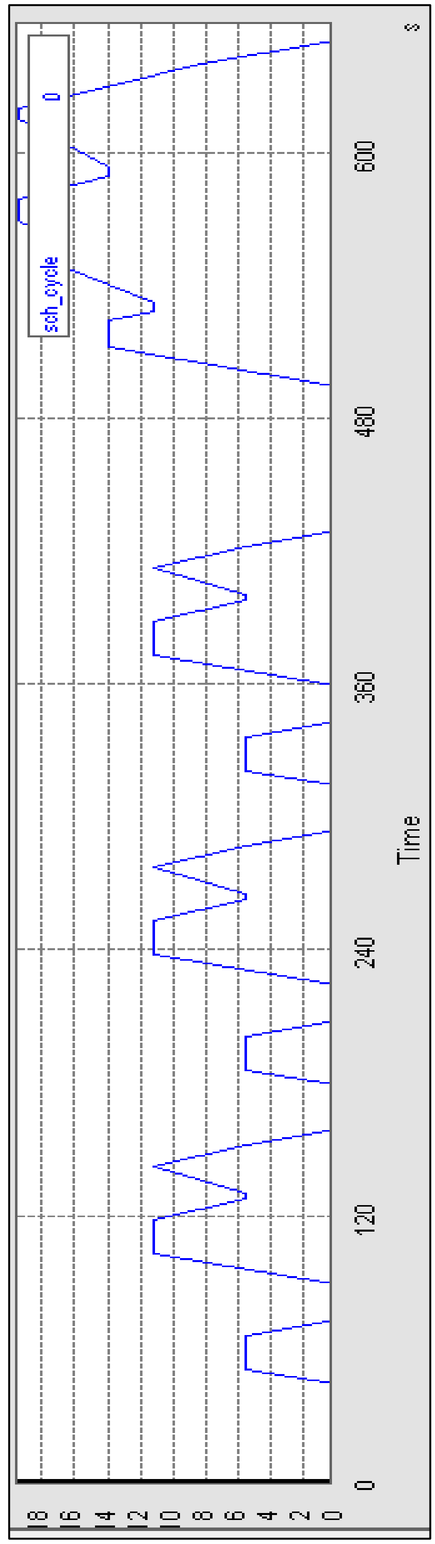

Figure 7.10: Japan 1015 drive cycle generated in Autonomie

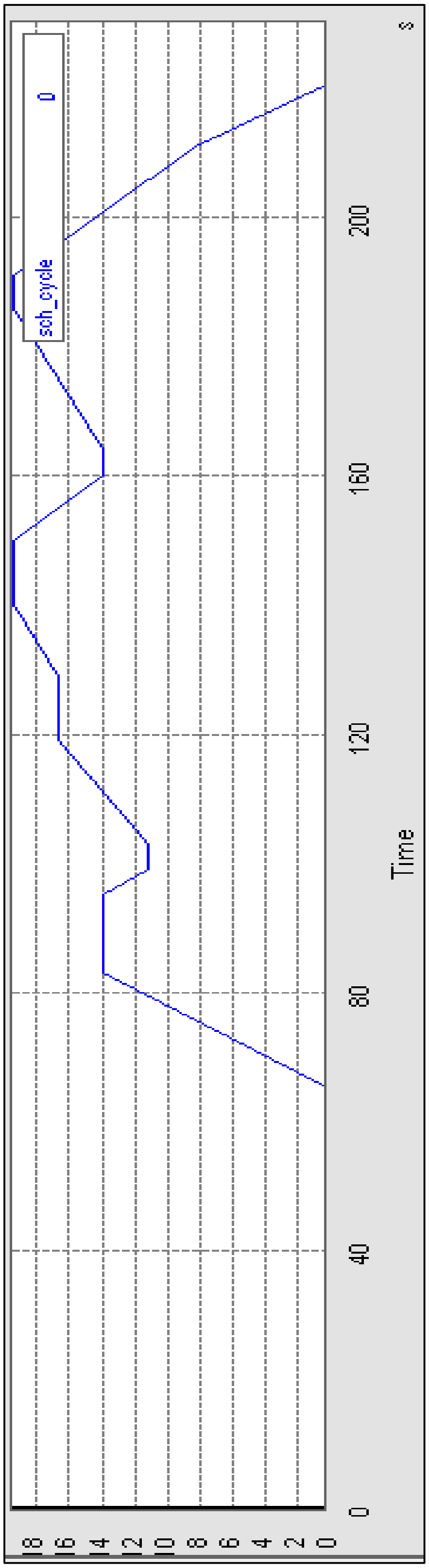

Figure 7.11: Japan 15 drive cycle generated in Autonomie

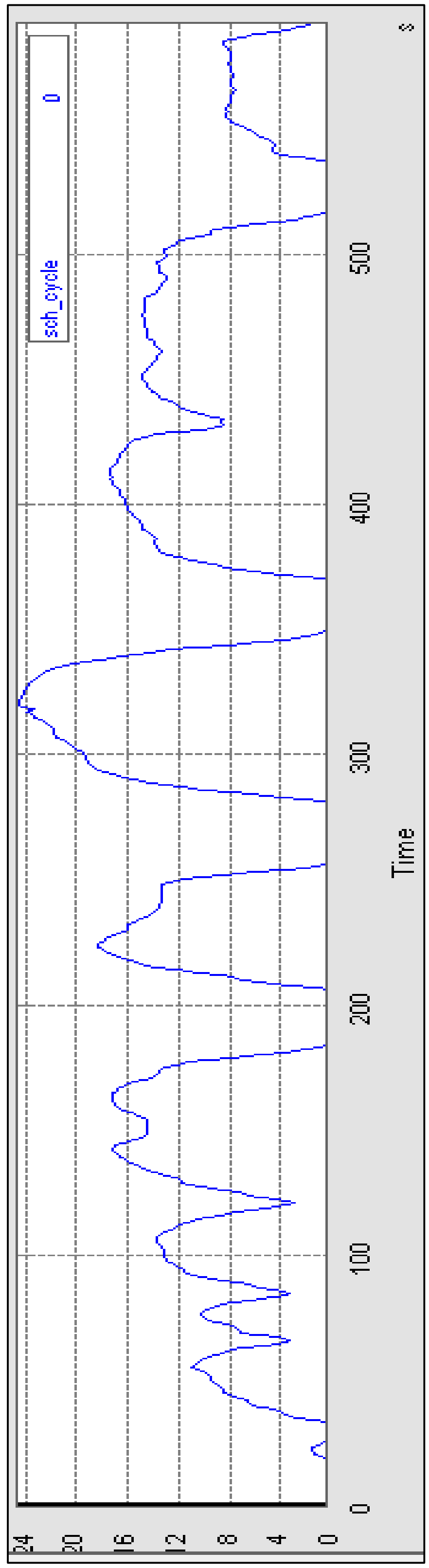

Figure 7.12: SC03 drive cycle generated in Autonomie

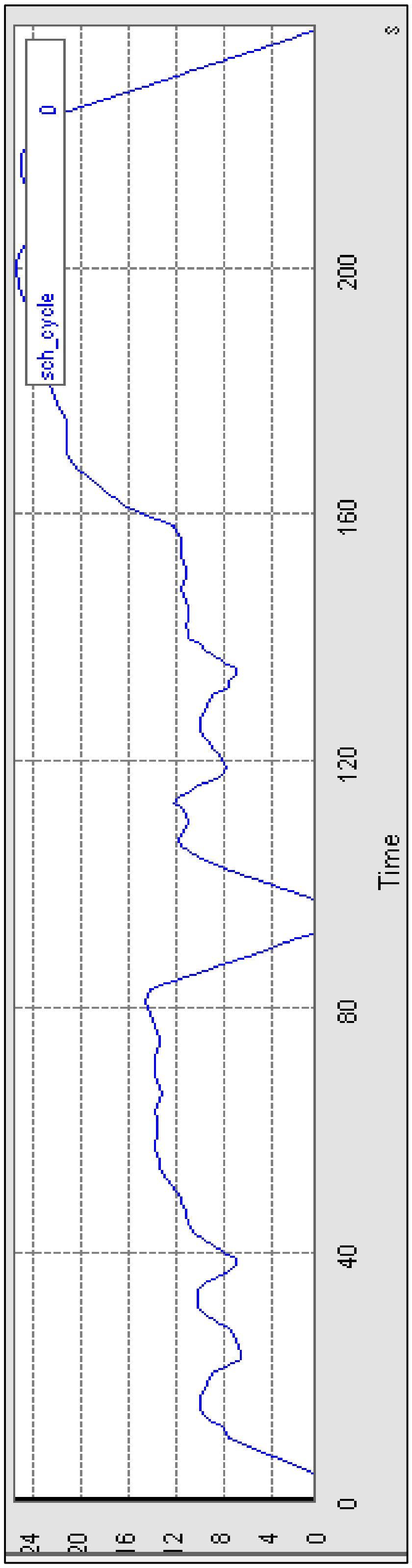

Figure 7.13: IM240 drive cycle generated in Autonomie

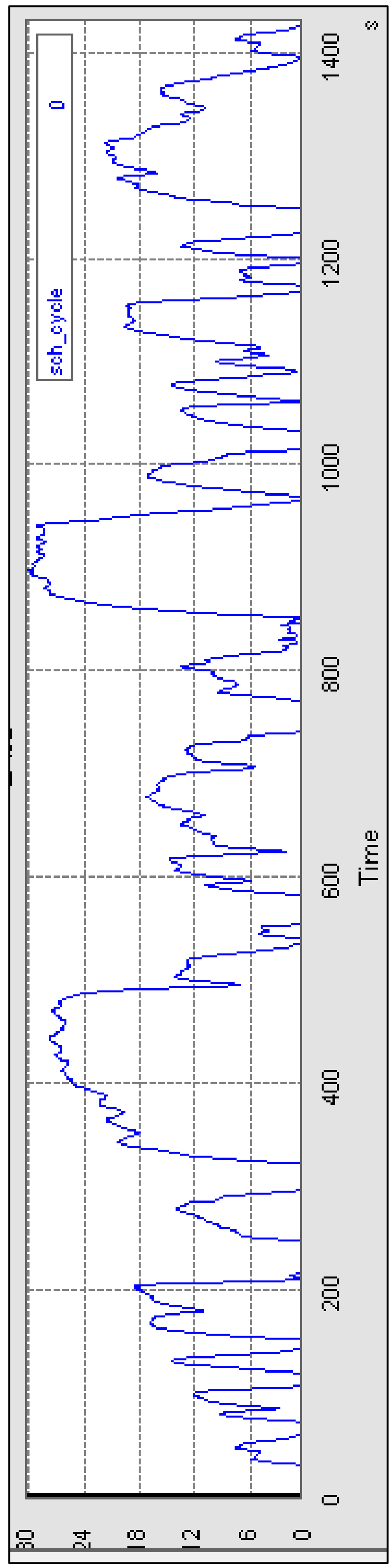

Figure 7.14: LA92 drive cycle generated in Autonomie

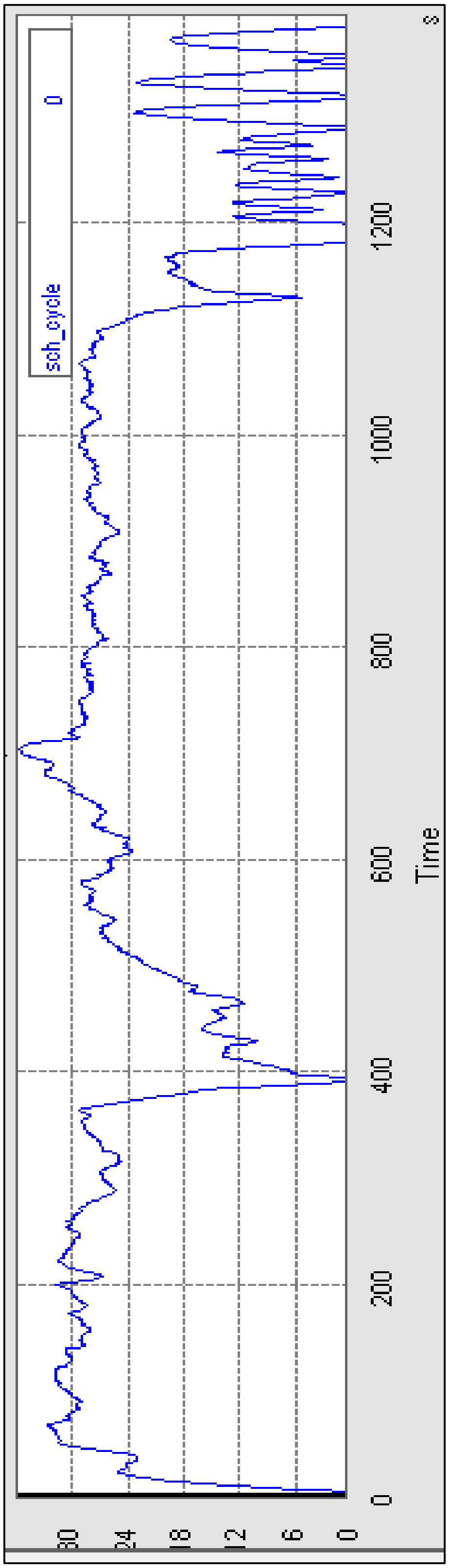

Figure 7.15: Rep05 drive cycle generated in Autonomie

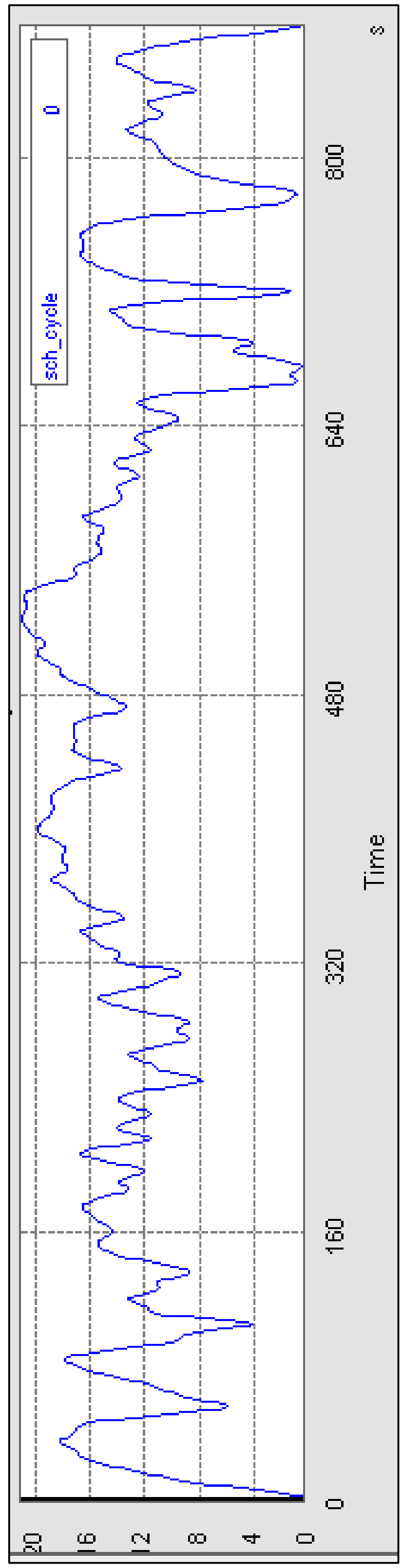

Figure 7.16: India highway drive cycle generated in Autonomie

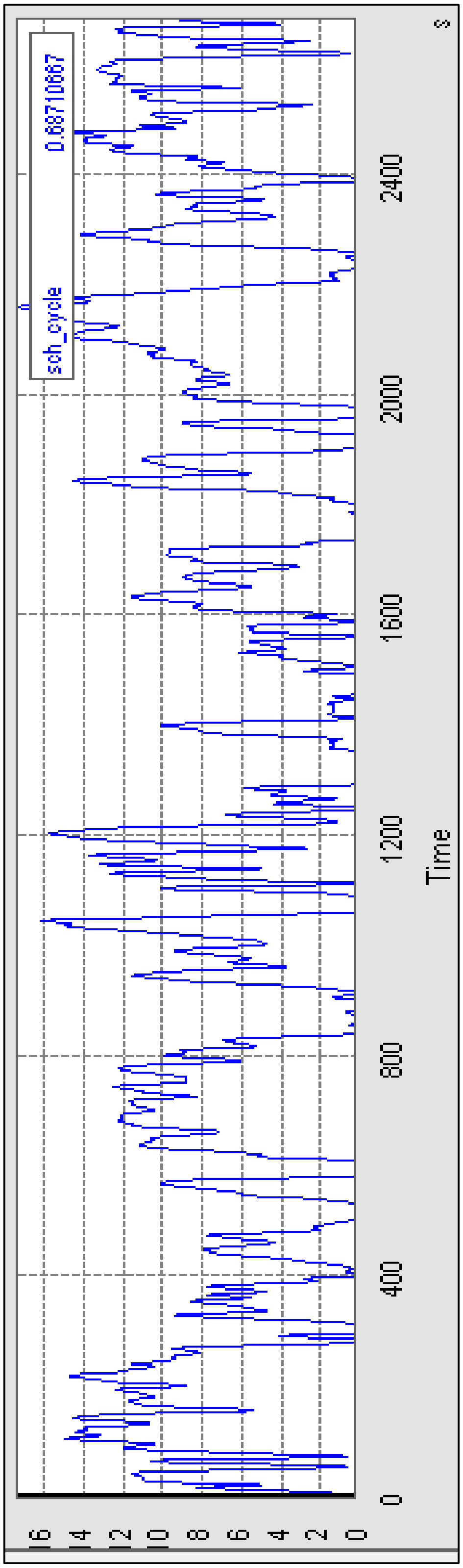

Figure 7.17: India urban drive cycle generated in Autonomie

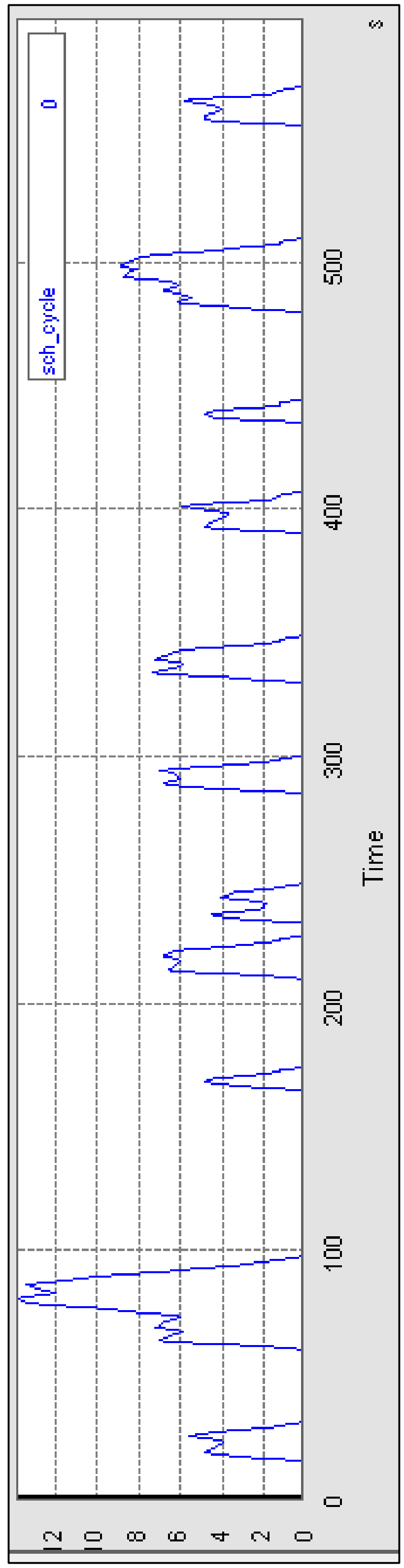

Figure 7.18: New York bus drive cycle generated in Autonomie

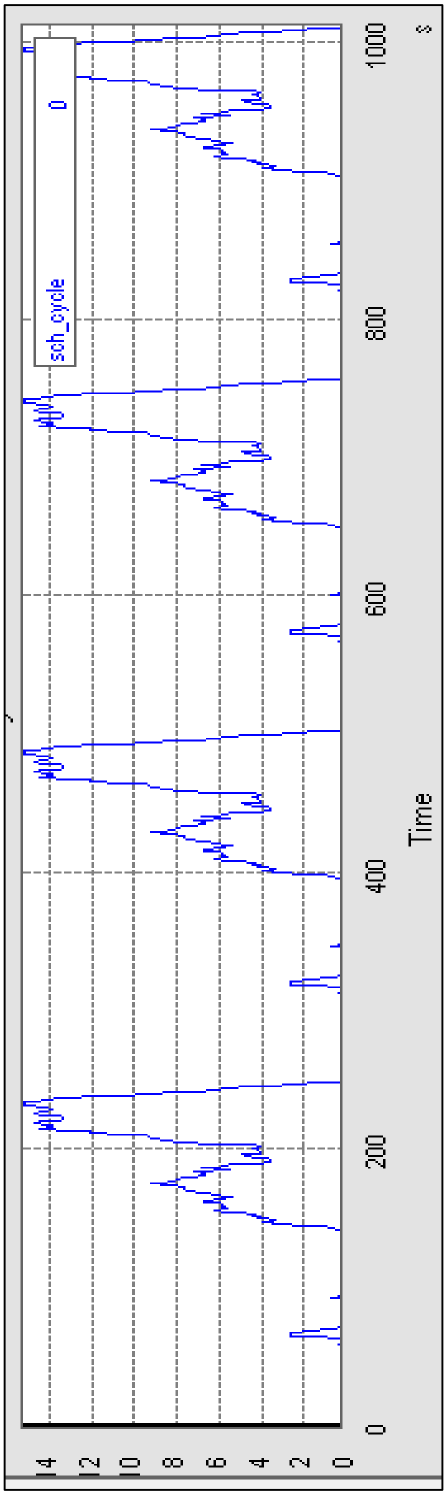

Figure 7.19: New York drive cycle generated in Autonomie

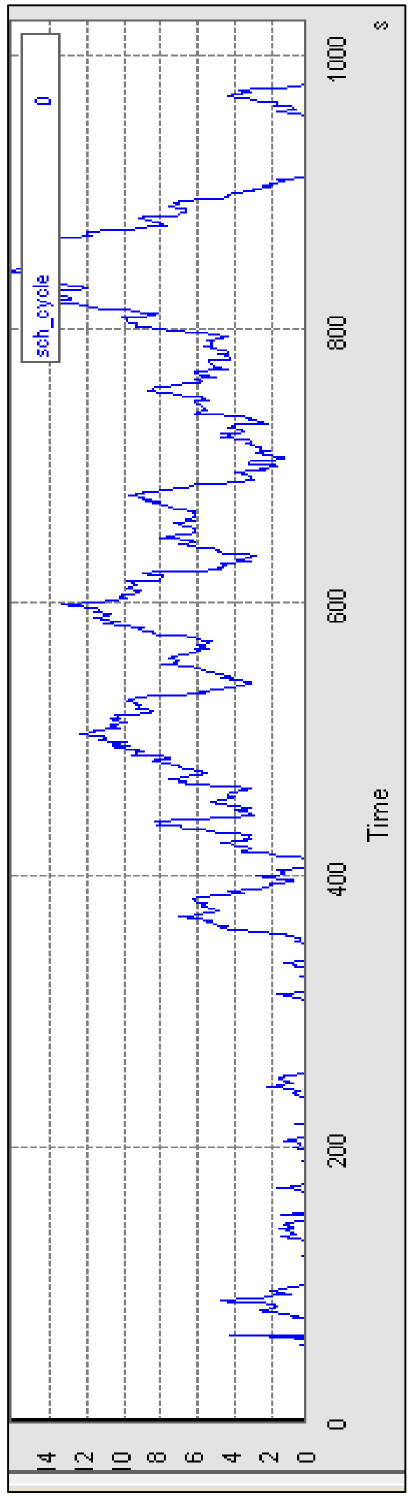

Figure 7.20: New York City composite truck drive cycle generated in Autonomie

Appendix B

This Appendix provides the Journey Mapping, CAN and the standard drive cycle tests – UDDS, NEDC, JC08, FTP75 and US06 results for Ford Focus Electric 2012. Although, the simulation results were calculated for every 0.2 seconds, due to the space limitations, the time interval has been increased in the tables here.

Time (s)	JM1 Battery Current (A)	JM1 Battery Voltage (V)	JM1 Motor Speed (Rev/min)	JM1 Motor Torque (Nm)	JM1 Battery SOC (%)	JM1 Velocity profile (m/s)	Driving Force (N)	Braking Force (N)	Climbing Resistance (N)	Rolling Resistance (N)
0.00	0.0000	334.3586	0.00	0.00	90.00	0.0000	0.0000	0.0000	0.0000	-37.8133
60.00	-2.1015	334.0872	-77.04	48.61	89.92	0.7252	766.1998	0.0000	0.0000	820.8166
120.00	76.9203	336.4968	-1186.45	-238.24	89.31	8.9296	-1003.8590	5496.8660	-6.8375	820.8165
180.00	-5.3495	332.4600	-138.22	79.08	88.73	1.1365	1229.4843	0.0000	3.3110	820.8166
240.00	55.7205	334.2066	-775.95	-294.10	87.59	5.2415	-4402.8591	1190.3707	0.7968	820.8166
300.00	-43.2209	328.9585	-1994.29	59.94	86.48	13.5766	945.2601	0.0000	-7.3451	820.8165
360.00	-22.2852	329.7535	-1931.90	30.10	85.43	13.3041	491.5340	0.0000	-1.7430	820.8166
420.00	-36.1588	330.4806	-1242.81	84.80	85.12	8.5020	1319.7687	0.0000	-1.0697	820.8166
480.00	-36.5928	329.5336	-1747.20	59.29	84.10	11.9055	934.3558	0.0000	-0.0499	820.8166
480.80	-36.3386	329.5438	-1739.14	59.20	84.08	11.8508	932.9160	0.0000	-0.6485	820.8166
540.80	-49.8553	328.0944	-2078.34	66.12	82.84	14.1484	1039.8479	0.0000	-1.2886	820.8166
600.80	-33.3722	329.2946	-1586.62	60.58	81.93	10.8183	953.2277	0.0000	0.0057	820.8166
660.80	-27.1225	329.7691	-1380.50	57.41	81.05	9.4277	904.0487	0.0000	0.4761	820.8166
720.80	-52.6863	328.5702	-1660.08	90.85	80.23	11.3113	1413.6546	0.0000	2.3427	820.8166
780.80	-37.4664	329.4390	-1310.01	83.33	79.45	8.9526	1297.8418	0.0000	3.0540	820.8166
840.80	-8.0002	330.4813	-1437.88	15.15	78.53	9.7723	262.3859	0.0000	9.9939	820.8165
900.80	-127.4483	325.0371	-1293.95	261.01	77.73	8.9327	3998.4424	0.0000	8.3236	820.8165
960.80	-88.6365	325.0683	-2573.35	93.46	76.15	17.5021	1458.2660	0.0000	0.2603	820.8166
1020.80	-11.5090	327.8107	-2129.66	10.15	74.34	14.3900	188.8429	0.0000	-17.3862	820.8161
1080.80	-45.4646	327.3598	-1520.65	86.14	73.37	10.3690	1341.2852	0.0000	0.0000	820.8166
1140.80	-47.4260	327.3854	-2021.76	64.61	72.48	13.7685	1016.7839	0.0000	6.6525	820.8165
1200.80	-68.6026	326.0717	-2267.31	82.83	71.53	15.4275	1294.9101	0.0000	0.0000	820.8166
1260.80	-66.1014	325.7882	-2082.66	87.64	70.32	14.1732	1366.9071	0.0000	0.5569	820.8166
1320.80	-55.6266	326.0233	-1994.33	77.18	69.14	13.5766	1207.4490	0.0000	0.0000	820.8166
1380.80	-52.4277	325.4117	-2101.02	68.10	67.74	14.3022	1069.9680	0.0000	-3.5086	820.8166

Time (s) JM!	Aerodynamic Drag (N)	Total Driving Resistance (N)	Rear Axle Longitudinal Slip (%)	Front Axle Longitudina l Slip (%)	Driver Acceleration Control	Driver Braking Control	Solar Azimuth Angle (Degrees)	Solar Altitude (Degrees)	Energy (Joules)	Energy Consumptio n (KWh)	abs energy consump (kWh)
0.00	37.8000	0.0000	0.00000	0.00000	0.00000	0.00500	2.1764	-55.8372	0.0000	0.0000	0.0000
60.00	42.8000	863.6077	0.00000	0.00039	0.15277	0.00000	2.6169	-55.8293	-140.4135	0.0000	0.0000
120.00	167.0000	981.4560	0.00002	0.00001	0.00000	1.00000	3.0573	-55.8200	5176.6865	0.0014	0.0014
180.00	47.0000	871.0909	-0.00001	0.00127	0.24955	0.00000	3.4975	-55.8093	-355.7020	-0.0001	0.0001
240.00	102.0000	923.6628	0.00003	0.00000	0.00000	0.61656	3.9374	-55.7972	3724.4311	0.0010	0.0010
300.00	266.0000	1079.3478	0.00000	0.00006	0.24719	0.00000	4.3771	-55.7837	-2843.5769	-0.0008	0.0008
360.00	256.0000	1074.6908	0.00000	0.00000	0.12058	0.00000	4.8164	-55.7688	-1469.7252	-0.0004	0.0004
420.00	156.0000	975.4590	0.00000	0.00020	0.26843	0.00000	5.2554	-55.7525	-2389.9554	-0.0007	0.0007
480.00	226.0000	1047.1877	0.00000	0.00006	0.22160	0.00000	5.6941	-55.7348	-2411.7147	-0.0007	0.0007
480.80	225.0000	1045.3553	0.00000	0.00006	0.22050	0.00000	5.6999	-55.7346	-2395.0301	-0.0007	0.0007
540.80	280.0000	1099.5457	0.00000	0.00007	0.28304	0.00000	6.1382	-55.7155	-3271.4511	-0.0009	0.0009
600.80	202.0000	1023.3010	0.00000	0.00007	0.21216	0.00000	6.5760	-55.6950	-2197.8542	-0.0006	0.0006
660.80	174.0000	994.9994	0.00000	0.00007	0.18668	0.00000	7.0134	-55.6732	-1788.8350	-0.0005	0.0005
720.80	213.0000	1036.4223	0.00000	0.00017	0.32842	0.00000	7.4504	-55.6499	-3462.2283	-0.0010	0.0010
780.80	164.0000	988.2403	0.00000	0.00018	0.26590	0.00000	7.8868	-55.6253	-2468.5813	-0.0007	0.0007
840.80	181.0000	1012.3076	0.00000	0.00000	0.05001	0.00000	8.3227	-55.5993	-528.7866	-0.0001	0.0001
900.80	162.0000	991.4059	-0.00001	0.00128	1.00000	0.00000	8.7580	-55.5719	-8285.0883	-0.0023	0.0023
960.80	371.0000	1191.8191	0.00000	0.00012	0.48231	0.00000	9.1927	-55.5432	-5762.5851	-0.0016	0.0016
1020.80	289.0000	1092.2678	0.00000	0.00000	0.04309	0.00000	9.6268	-55.5131	-754.5531	-0.0002	0.0002
1080.80	193.0000	1013.8449	0.00000	0.00017	0.29412	0.00000	10.0603	-55.4816	-2976.6560	-0.0008	0.0008
1140.80	270.0000	1097.9266	0.00000	0.00007	0.27032	0.00000	10.4932	-55.4488	-3105.3178	-0.0009	0.0009
1200.80	313.0000	1133.9684	0.00000	0.00011	0.38144	0.00000	10.9253	-55.4146	-4473.8724	-0.0012	0.0012
1260.80	281.0000	1102.1263	0.00000	0.00013	0.37643	0.00000	11.3567	-55.3791	-4307.0110	-0.0012	0.0012
1320.80	266.0000	1086.6974	0.00000	0.00011	0.31926	0.00000	11.7873	-55.3422	-3627.1157	-0.0010	0.0010
1380.80	284.0000	1101.2038	0.00000	0.00007	0.29417	0.00000	12.2172	-55.3040	-3412.1157	-0.0009	0.0009

Time (s)	JM2 Battery Current (A)	JM2 Battery Voltage (V)	JM2 Motor Speed (Rev/min)	JM2 Motor Torque (Nm)	JM2 Battery SOC (%)	JM2 Velocity profile (m/s)	Driving Force (N)	Braking Force (N)	Climbing Resistance (N)	Rolling Resistance (N)
0.00	0.0000	334.3586	0.0000	0.0000	90.0000	0.00	0.000	0.000	0.000	-10.894
60.00	0.0000	334.3329	0.0000	0.0000	89.9848	0.73	0.000	0.000	0.000	-10.894
120.00	-5.4977	334.0459	-113.7186	90.4490	89.9668	8.93	1408.997	0.000	0.000	1067.062
180.00	0.0000	334.3281	0.0000	0.0000	89.9597	1.14	0.000	0.000	0.000	-10.894
240.00	0.0000	334.2504	0.0000	0.0000	89.9107	5.24	0.000	0.000	0.000	-10.894
300.00	-30.2222	331.6308	-1400.2076	63.5322	89.3821	13.58	1002.493	0.000	-8.259	1067.061
360.00	-8.3357	331.7593	-1395.5132	16.5786	88.5793	13.30	289.515	0.000	12.256	1067.061
420.00	-48.6282	328.5812	-2118.6421	63.0764	87.3822	8.50	998.538	0.000	0.000	1067.062
480.00	-36.4594	329.5070	-1378.2680	77.2610	86.5207	11.91	1211.523	0.000	5.757	1067.062
480.80	-36.1839	329.5212	-1381.0930	76.5332	86.5085	11.85	1200.457	0.000	5.337	1067.062
540.80	-23.9899	329.7135	-1681.4290	39.9115	85.3731	14.15	644.739	0.000	0.685	1067.062
600.80	0.0000	331.9013	0.0000	0.0000	84.7247	10.82	0.000	0.000	-2.140	-8.754
660.80	-33.3119	329.8105	-1477.6395	65.7260	83.8438	9.43	1036.305	0.000	-1.369	1067.062
720.80	-62.9495	327.4438	-1879.8303	94.1066	82.5066	11.31	1469.162	0.000	0.000	1067.062
780.80	-78.3595	326.3509	-1953.5241	111.7608	81.2013	8.95	1737.811	0.000	0.996	1067.062
840.80	-99.8453	325.4945	-1607.6298	171.6470	79.9688	9.77	2646.618	0.000	-1.082	1067.062
900.80	-1.2986	330.5444	-147.5410	19.6964	78.9987	8.93	333.717	0.000	0.577	1067.062
960.80	-12.4847	329.7919	-1319.5596	26.9918	77.9193	17.50	447.174	0.000	1.241	1067.062
1020.80	-47.8318	327.8263	-1873.3592	71.4772	76.8410	14.39	1125.210	0.000	0.227	1067.062
1080.80	-17.9754	329.0856	-1182.6779	43.8586	75.7507	10.37	703.350	0.000	8.788	1067.061
1140.80	-10.3174	329.7027	-1582.5771	17.1787	74.9743	13.77	299.235	0.000	11.958	1067.061
1200.80	-64.3436	325.4624	-2457.8979	70.4155	73.3367	15.43	1112.290	0.000	20.432	1067.061
1260.80	-8.7965	328.2845	-953.2059	25.8587	72.0157	14.17	429.290	0.000	12.843	1067.061
1320.80	-62.7807	326.1532	-1350.7602	132.5072	70.8850	13.58	2050.919	0.000	0.000	1067.062
1380.80	-96.6753	324.8101	-1049.5732	247.1845	69.8572	14.30	3793.054	0.000	2.212	1067.062
1440.80	-47.5984	327.1667	-1493.7061	91.8145	69.0043	1.03	1433.110	0.000	6.263	1067.062
1500.80	-63.5123	325.2237	-2094.7692	83.3511	67.7335	11.69	1306.664	0.000	2.589	1067.062
1560.80	-49.2905	325.1357	-2033.2940	66.2373	66.3545	13.57	1046.199	0.000	-0.533	1067.062
1620.80	-70.9643	325.3968	-1035.1590	188.1645	65.6424	2.12	2895.919	0.000	0.000	1067.062
1680.80	-82.2592	323.4166	-2124.6874	105.9660	64.2606	10.66	1650.255	0.000	-5.396	1067.062
1740.80	0.0000	327.5472	0.0000	0.0000	63.1894	0.00	0.000	0.000	2.229	-13.123

Time (s) JM2	Aerodynamic Drag (N)	Total Driving Resistance(N)	Rear Axle Longitudinal Slip (%)	Front Axle Longitudinal Slip (%)	Driver Acceleration Control	Driver Braking Control	Solar Azimuth Angle (Degrees)	Solar Altitude (Degrees)	Energy (Joules)	Energy Consumption (KWh)	abs energy consump (kWh)
0.00	10.894	0.000	0.000	0.000	0.000	0.005	111.47	41.24	0.0000	0.0000	0.0000
60.00	10.894	0.000	0.000	0.000	0.000	0.005	111.70	41.41	0.0000	0.0000	0.0000
120.00	14.929	1081.990	0.000	0.006	0.288	0.000	111.93	41.58	-367.3000	-0.0001	0.0001
180.00	10.894	0.000	0.000	0.000	0.000	0.005	112.16	41.75	0.0000	0.0000	0.0000
240.00	10.894	0.000	0.000	0.000	0.000	0.005	112.40	41.92	0.0000	0.0000	0.0000
300.00	104.814	1163.617	0.000	0.000	0.203	0.000	112.63	42.08	-2004.5224	-0.0006	0.0006
360.00	104.341	1183.658	0.000	0.000	0.011	0.000	112.87	42.25	-553.0908	-0.0002	0.0002
420.00	190.368	1257.430	0.000	0.000	0.287	0.000	113.10	42.42	-3195.6613	-0.0009	0.0009
480.00	102.599	1175.418	0.000	0.000	0.249	0.000	113.34	42.59	-2402.7286	-0.0007	0.0007
480.80	102.883	1175.282	0.000	0.000	0.252	0.000	113.34	42.59	-2384.6740	-0.0007	0.0007
540.80	135.286	1203.033	0.000	0.000	0.162	0.000	113.58	42.76	-1581.9602	-0.0004	0.0004
600.80	10.894	0.000	0.000	0.000	0.000	0.005	113.82	42.93	0.0000	0.0000	0.0000
660.80	112.816	1178.509	0.000	0.000	0.228	0.000	114.06	43.09	-2197.3204	-0.0006	0.0006
720.80	159.116	1226.177	0.000	0.000	0.362	0.000	114.30	43.26	-4122.4812	-0.0011	0.0011
780.80	168.459	1236.517	0.000	0.000	0.434	0.000	114.55	43.43	-5114.5392	-0.0014	0.0014
840.80	126.906	1192.885	0.000	0.001	0.546	0.000	114.79	43.59	-6499.8166	-0.0018	0.0018
900.80	16.253	1083.892	0.000	0.001	0.094	0.000	115.04	43.76	-85.8497	0.0000	0.0000
960.80	96.794	1165.097	0.000	0.000	0.113	0.000	115.28	43.92	-823.4718	-0.0002	0.0002
1020.80	158.309	1225.599	0.000	0.000	0.284	0.000	115.53	44.09	-3136.1039	-0.0009	0.0009
1080.80	83.908	1159.757	0.000	0.000	0.175	0.000	115.78	44.25	-1183.0922	-0.0003	0.0003
1140.80	124.134	1203.153	0.000	0.000	0.090	0.000	116.03	44.42	-680.3357	-0.0002	0.0002
1200.80	239.577	1327.070	0.000	0.000	0.354	0.000	116.28	44.58	-4188.2832	-0.0012	0.0012
1260.80	64.373	1144.277	0.000	0.000	0.111	0.000	116.53	44.75	-577.5497	-0.0002	0.0002
1320.80	99.854	1166.915	0.000	0.001	0.403	0.000	116.78	44.91	-4095.2221	-0.0011	0.0011
1380.80	72.251	1141.525	0.000	0.002	0.696	0.000	117.04	45.07	-6280.2211	-0.0017	0.0017
1440.80	114.512	1187.837	0.000	0.000	0.303	0.000	117.29	45.23	-3114.5241	-0.0009	0.0009
1500.80	187.117	1256.768	0.000	0.000	0.358	0.000	117.55	45.40	-4131.1417	-0.0011	0.0011
1560.80	178.878	1245.407	0.000	0.000	0.283	0.000	117.81	45.56	-3205.2195	-0.0009	0.0009
1620.80	71.045	1138.107	0.000	0.001	0.542	0.000	118.07	45.72	-4618.3085	-0.0013	0.0013
1680.80	191.193	1252.858	0.000	0.000	0.449	0.000	118.33	45.88	-5320.8004	-0.0015	0.0015
1740.80	10.894	0.000	0.000	0.000	0.000	0.005	118.59	46.04	0.0000	0.0000	0.0000

Time (s)	JM3 Battery Current (A)	JM3 Battery Voltage (V)	JM3 Motor Speed (Rev/min)	JM3 Motor Torque (Nm)	JM3 Battery SOC (%)	JM3 Velocity profile (m/s)	Driving Force (N)	Braking Force (N)	Climbing Resistance (N)	Rolling Resistance (N)
0.00	0.0000	334.3586	0.0000	0.0000	90.0000	0.00	0.000	0.000	0.000	-3.263
60.00	-7.0903	333.9774	-143.8175	99.1838	90.0000	0.96	1521.687	0.000	0.000	443.241
120.00	-32.4261	331.4254	-1987.0689	44.6251	89.3000	13.26	696.325	0.000	-2.414	443.241
180.00	-48.5839	329.5935	-2714.9826	46.7736	88.5000	18.11	732.073	0.000	2.989	443.241
240.00	-46.0661	330.3356	-1862.7180	69.9246	88.1000	12.43	1080.546	0.000	1.501	443.241
300.00	-5.1728	331.9623	-1997.3385	2.3479	87.4000	13.33	53.691	0.000	-6.057	443.241
360.00	0.0000	332.7883	0.0000	0.0000	87.0000	0.00	0.000	0.000	-0.190	-3.073
420.00	-52.4763	329.8202	-1842.8055	80.7370	86.3000	12.29	1244.741	0.000	-0.789	443.241
480.00	-31.5459	330.2091	-2323.5000	34.6930	85.5000	15.50	546.701	0.000	0.000	443.241
480.80	-14.0611	331.0186	-2316.3975	11.7994	85.5000	15.45	198.728	0.000	0.000	443.241
540.80	-29.3227	330.3785	-1992.0355	39.4772	84.7000	13.29	618.177	0.000	0.000	443.241
600.80	-4.9422	331.5389	-1702.7192	5.0794	84.0000	11.36	94.495	0.000	1.741	443.241
660.80	-47.2414	329.8191	-1882.5997	70.6711	83.5000	12.56	1091.921	0.000	0.592	443.241
720.80	-42.0470	329.9471	-1689.5897	71.2603	82.9000	11.27	1100.292	0.000	1.656	443.241
780.80	-51.9373	329.4456	-1944.3805	74.9484	82.3000	12.97	1157.134	0.000	0.530	443.241
840.80	-47.3792	329.1867	-2327.7332	54.7452	81.6000	15.53	851.750	0.000	8.449	443.241
900.80	-56.5485	328.6929	-2120.2802	73.8163	80.8000	14.15	1140.625	0.000	2.970	443.241
960.80	-64.6818	327.7983	-2456.9586	71.4786	79.8000	16.39	1106.942	0.000	19.422	443.241
1020.80	89.2091	335.2958	-1090.7078	-316.2687	79.1000	9.85	-3751.996	4380.048	0.000	443.241
1080.80	-13.4801	330.7386	-1861.7046	17.4323	78.5000	12.42	282.753	0.000	2.179	443.241
1140.80	-29.0963	329.8017	-1972.5834	39.5516	77.7000	13.16	619.268	0.000	0.861	443.241
1200.80	0.0000	332.4480	0.0000	0.0000	77.6000	0.00	0.000	0.000	-0.250	-3.013
1260.80	-39.5752	329.7657	-2149.7088	49.7027	77.1000	14.34	774.156	0.000	0.000	443.241
1320.80	0.0000	332.3019	0.0000	0.0000	76.8000	0.00	0.000	0.000	-4.421	1.158
1380.80	-38.8544	328.9806	-2459.9382	40.7399	75.8000	16.41	639.153	0.000	-0.245	443.241
1440.80	-55.2291	327.6152	-2577.2375	56.8914	74.7000	17.19	885.207	0.000	2.229	443.241
1500.80	0.0000	331.2309	0.0000	0.0000	74.2000	0.00	0.000	0.000	2.229	-5.492
1560.80	0.0000	331.3352	0.0000	0.0000	73.7000	0.00	0.000	0.000	2.229	-5.492
1620.80	-28.4959	329.8145	-1923.9552	39.9907	73.3000	12.84	625.818	0.000	2.229	443.241
1680.80	-1.5743	331.5901	-141.8101	-267.9969	73.0000	0.95	-5776.733	2288.984	2.229	443.241

Time(s) JM3	Aerodynamic Drag (N)	Total Driving Resistance(N)	Rear Axle Longitudinal Slip (%)	Front Axle Longitudinal Slip (%)	Driver Acceleration Control	Driver Braking Control	Solar Azimuth Angle (Degrees)	Solar Altitude (Degrees)	Energy (Joules)	Energy Consumption (KWh)	abs energy consump (kWh)
0.00	3.263	0.000	0.000	0.000	0.000	0.005	119.48	53.57	0.00000	0.00000	0.00000
60.00	6.247	449.488	0.000	0.003	0.350	0.000	119.77	53.73	-473.60255	-0.00013	0.00013
120.00	129.621	570.448	0.000	0.000	0.172	0.000	120.07	53.89	-2149.36446	-0.00060	0.00060
180.00	221.834	668.064	0.000	0.000	0.249	0.000	120.37	54.05	-3202.58673	-0.00089	0.00089
240.00	116.329	561.071	0.000	0.000	0.247	0.000	120.67	54.20	-3043.45174	-0.00085	0.00085
300.00	130.753	567.937	0.000	0.000	0.028	0.000	120.97	54.36	-343.43641	-0.00010	0.00010
360.00	3.263	0.000	0.000	0.000	0.000	0.005	121.27	54.52	0.00000	0.00000	0.00000
420.00	114.267	556.719	0.000	0.000	0.280	0.000	121.58	54.67	-3461.54696	-0.00096	0.00096
480.00	169.181	612.422	0.000	0.000	0.166	0.000	121.89	54.83	-2083.35122	-0.00058	0.00058
480.80	168.293	611.534	0.000	0.000	0.046	0.000	121.89	54.83	-930.89944	-0.00026	0.00026
540.80	130.167	573.408	0.000	0.000	0.164	0.000	122.20	54.99	-1937.52109	-0.00054	0.00054
600.80	100.290	545.272	0.000	0.000	0.000	0.000	122.51	55.14	-327.70835	-0.00009	0.00009
660.80	118.406	562.239	0.000	0.000	0.286	0.000	122.83	55.29	-3116.22610	-0.00087	0.00087
720.80	99.023	543.920	0.000	0.000	0.273	0.000	123.14	55.45	-2774.65893	-0.00077	0.00077
780.80	124.976	568.747	0.000	0.000	0.317	0.000	123.46	55.60	-3422.10248	-0.00095	0.00095
840.80	169.711	621.401	0.000	0.000	0.250	0.000	123.78	55.75	-3119.32247	-0.00087	0.00087
900.80	144.654	590.864	0.000	0.000	0.350	0.000	124.10	55.90	-3717.41513	-0.00103	0.00103
960.80	186.328	648.991	0.000	0.000	0.369	0.000	124.43	56.05	-4240.51837	-0.00118	0.00118
1020.80	79.638	522.879	0.000	-26.120	0.000	1.000	124.75	56.20	5982.29020	0.00166	0.00166
1080.80	116.227	561.647	0.000	0.000	0.075	0.000	125.08	56.35	-891.67616	-0.00025	0.00025
1140.80	128.036	572.138	0.000	0.000	0.161	0.000	125.41	56.50	-1919.20034	-0.00053	0.00053
1200.80	3.263	0.000	0.000	0.000	0.000	0.005	125.75	56.65	0.00000	0.00000	0.00000
1260.80	148.088	591.329	0.000	0.000	0.224	0.000	126.08	56.80	-2610.11004	-0.00073	0.00073
1320.80	3.263	0.000	0.000	0.000	0.000	0.005	126.42	56.94	0.00000	0.00000	0.00000
1380.80	186.723	629.719	0.000	0.000	0.200	0.000	126.76	57.09	-2556.46755	-0.00071	0.00071
1440.80	202.494	647.965	0.000	0.000	0.311	0.000	127.10	57.24	-3618.77795	-0.00101	0.00101
1500.80	3.263	0.000	0.000	0.000	0.000	0.005	127.45	57.38	0.00000	0.00000	0.00000
1560.80	3.263	0.000	0.000	0.000	0.000	0.005	127.79	57.53	0.00000	0.00000	0.00000
1620.80	122.786	568.256	0.000	0.000	0.158	0.000	128.14	57.67	-1879.67556	-0.00052	0.00052
1680.80	6.206	451.676	0.000	-0.048	0.000	0.690	128.49	57.81	-104.40562	-0.00003	0.00003

Time (s)	JM4 Battery Current (A)	JM4 Battery Voltage (V)	JM4 Motor Speed (Rev/min)	JM4 Motor Torque (Nm)	JM4 Battery SOC (%)	JM4 Velocity profile (m/s)	Driving Force (N)	Braking Force (N)	Climbing Resistance (N)	Rolling Resistance (N)
0.00	0.0000	334.3586	0.0000	0.0000	90.0000	0.00	0.000	0.000	0.000	-3.296
60.00	0.0000	334.2495	0.0000	0.0000	89.9563	0.00	0.000	0.000	0.000	-3.296
120.00	-7.3106	333.2634	-1209.2839	16.8337	89.6072	8.07	270.585	0.000	-4.402	410.408
180.00	-51.2227	329.9354	-2463.0540	56.0412	88.8014	16.39	870.752	0.000	0.000	410.408
240.00	-1.4891	332.4290	-1387.9340	1.5886	88.2440	9.25	39.585	0.000	3.493	410.408
300.00	-24.5650	331.2383	-1811.4345	37.1602	87.5907	12.06	581.305	0.000	-1.468	410.408
360.00	-42.1522	330.3474	-1914.5740	61.6726	86.9749	12.74	954.166	0.000	-2.610	410.408
420.00	-19.8294	331.1394	-2109.4520	22.8964	86.3027	14.04	365.571	0.000	-0.865	410.408
480.00	-40.7235	330.0264	-2105.9317	52.7436	85.5988	14.02	819.220	0.000	0.018	410.408
480.80	-17.2356	331.1071	-2115.1312	19.0054	85.5873	14.08	306.480	0.000	-0.556	410.408
540.80	-35.0314	330.5346	-1894.4345	51.3303	85.1448	12.61	796.919	0.000	-1.965	410.408
600.80	-9.5930	331.7804	-1663.2971	14.3535	84.6167	11.07	234.296	0.000	0.776	410.408
660.80	24.6647	333.7773	-428.3670	-320.8640	84.3296	4.10	-4519.382	3613.421	2.306	410.408
720.80	-10.1615	331.8857	-1604.7971	16.5975	83.7810	10.68	268.321	0.000	3.687	410.408
780.80	-40.6276	330.1832	-1748.3090	66.1288	83.1959	11.64	1022.043	0.000	20.316	410.408
840.80	58.3789	334.3730	-766.6224	-320.9413	82.4021	7.18	-3752.470	4380.030	10.350	410.408
900.80	-9.4315	331.6415	-1269.0417	20.9734	81.9476	8.44	333.700	0.000	-3.262	410.408
960.80	-37.7264	329.6126	-2171.0446	46.5081	81.0213	14.45	725.347	0.000	21.046	410.408
1020.80	-54.6660	328.8323	-1898.6072	81.0057	80.2925	12.63	1247.980	0.000	-0.301	410.408
1080.80	-9.4578	331.4171	-1335.6352	19.9168	79.7897	8.88	317.913	0.000	0.592	410.408
1140.80	-34.2303	330.0271	-1884.0377	50.3086	79.1692	12.54	781.585	0.000	5.635	410.408
1200.80	-0.0016	332.0695	-0.0004	0.6427	78.7168	0.00	10.088	0.000	0.880	5.912
1260.80	-27.5712	330.1560	-2258.5413	30.7228	78.0790	15.03	485.219	0.000	2.939	410.408
1320.80	-28.9740	329.9503	-2120.5578	35.6336	77.4212	14.11	559.230	0.000	0.000	410.408
1380.80	-33.0023	329.8322	-2050.3283	43.2325	76.8978	13.65	674.483	0.000	0.844	410.408
1440.80	-32.8521	329.7396	-1740.8960	53.2087	76.2762	11.59	825.095	0.000	2.229	410.408
1500.80	-25.0576	330.1246	-1798.1467	38.1615	75.6524	11.97	596.596	0.000	2.229	410.408
1560.80	0.0000	332.0709	0.0000	0.0000	75.3662	0.00	0.000	0.000	2.229	-5.526
1620.80	0.0000	331.7716	0.0000	0.0000	74.8331	0.00	0.000	0.000	2.229	-5.526
1680.80	-8.3539	331.6723	-711.7409	33.0390	74.6185	4.72	516.111	0.000	2.229	410.408

Time (s) JM4	Aerodynamic Drag (N)	Total Driving Resistance (N)	Rear Axle Longitudinal Slip (%)	Front Axle Longitudinal Slip (%)	Driver Acceleration Control	Driver Braking Control	Solar Azimuth Angle (Degrees)	Solar Altitude (Degrees)	Energy (Joules)	Energy Consumption (KWh)	abs energy consump (kWh)
0.00	3.296	0.000	0.00000	0.00000	0.000	0.005	125.13	31.21	0.00000	0.00000	0.00000
60.00	3.296	0.000	0.00000	0.00000	0.000	0.005	125.36	31.36	0.00000	0.00000	0.00000
120.00	58.903	464.909	0.00000	0.00007	0.070	0.000	125.60	31.51	-487.27138	-0.00014	0.00014
180.00	189.050	599.458	0.00000	0.00011	0.268	0.000	125.84	31.65	-3380.03321	-0.00094	0.00094
240.00	72.940	486.841	0.00000	0.00001	0.000	0.000	126.07	31.80	-99.00637	-0.00003	0.00003
300.00	112.198	521.138	0.00000	0.00010	0.140	0.000	126.31	31.95	-1627.37440	-0.00045	0.00045
360.00	123.033	530.831	0.00000	0.00015	0.233	0.000	126.55	32.10	-2784.97478	-0.00077	0.00077
420.00	144.873	554.416	0.00000	0.00005	0.106	0.000	126.79	32.24	-1313.25678	-0.00037	0.00037
480.00	144.461	554.888	0.00000	0.00012	0.222	0.000	127.04	32.39	-2687.96810	-0.00075	0.00075
480.80	145.537	555.390	0.00000	0.00004	0.011	0.000	127.04	32.39	-1141.36641	-0.00032	0.00032
540.80	120.878	529.321	0.00000	0.00013	0.240	0.000	127.28	32.53	-2315.82102	-0.00064	0.00064
600.80	97.508	508.693	0.00000	0.00004	0.000	0.000	127.52	32.68	-636.55097	-0.00018	0.00018
660.80	23.137	435.851	0.00004	-30.66255	0.000	0.918	127.77	32.82	1646.50185	0.00046	0.00046
720.80	91.991	506.086	0.00000	0.00005	0.000	0.000	128.01	32.97	-674.48818	-0.00019	0.00019
780.80	105.810	536.534	0.00000	0.00018	0.363	0.000	128.26	33.11	-2682.90965	-0.00075	0.00075
840.80	49.652	470.411	0.00002	-28.97621	0.000	1.000	128.50	33.25	3904.06683	0.00109	0.00109
900.80	63.431	470.578	0.00000	0.00008	0.020	0.000	128.75	33.40	-625.57736	-0.00017	0.00017
960.80	152.145	583.599	0.00000	0.00010	0.266	0.000	129.00	33.54	-2487.02199	-0.00069	0.00069
1020.80	121.321	531.429	0.00000	0.00020	0.487	0.000	129.25	33.68	-3595.19059	-0.00100	0.00100
1080.80	68.675	479.675	0.00000	0.00007	0.076	0.000	129.50	33.82	-626.89638	-0.00017	0.00017
1140.80	119.773	535.816	0.00000	0.00013	0.309	0.000	129.75	33.96	-2259.38624	-0.00063	0.00063
1200.80	3.296	10.088	0.00000	0.00020	0.001	0.000	130.00	34.10	-0.10365	0.00000	0.00000
1260.80	162.784	576.132	0.00000	0.00007	0.076	0.000	130.25	34.24	-1820.55835	-0.00051	0.00051
1320.80	146.171	556.579	0.00000	0.00008	0.135	0.000	130.50	34.38	-1911.99561	-0.00053	0.00053
1380.80	138.058	549.310	0.00000	0.00010	0.212	0.000	130.76	34.52	-2177.04329	-0.00061	0.00061
1440.80	105.073	517.711	0.00000	0.00015	0.280	0.000	131.01	34.66	-2166.53050	-0.00060	0.00060
1500.80	110.838	523.475	0.00000	0.00010	0.154	0.000	131.27	34.79	-1654.42626	-0.00046	0.00046
1560.80	3.296	0.000	0.00000	0.00000	0.000	0.000	131.52	34.93	0.00000	0.00000	0.00000
1620.80	3.296	0.000	0.00000	0.00000	0.000	0.005	131.78	35.07	0.00000	0.00000	0.00000
1680.80	27.710	440.348	0.00000	0.00022	0.082	0.000	132.04	35.20	-554.15429	-0.00015	0.00015

Time (s) CAN2	AC HV Power [Watts]	GPS_Alt_ Meters	GPS_Lat_ Deg	GPS_Lon_ Deg	Horizontal Distance Meter	Vertical distance	Grade Rise / Run	Traffic score	Outside Air Temp [degC]
6.36	0.000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	3.0	0.0
104.36	360.000	62.00000	43.25583	-79.90215	0.00000	0.00000	0.00000	3.0	9.8
208.37	360.000	65.00000	43.25579	-79.90211	0.00000	0.00000	0.00000	3.0	9.0
290.71	280.000	64.00000	43.25691	-79.90133	0.00000	0.00000	0.00000	3.0	7.8
344.37	200.000	66.00000	43.25925	-79.90108	0.00000	0.00000	0.00000	3.0	7.3
400.73	160.000	47.00000	43.26043	-79.89502	0.00000	0.00000	0.00000	4.0	7.0
452.74	160.000	61.00000	43.25961	-79.88831	0.00000	0.00000	0.00000	4.0	7.0
503.39	0.000	68.00000	43.25815	-79.88174	0.00000	0.00000	0.00000	4.0	7.0
555.39	0.000	74.00000	43.25668	-79.87513	0.00000	0.00000	0.00000	4.0	7.0
620.43	0.000	72.00000	43.25560	-79.87067	0.00000	0.00000	0.00000	3.0	7.0
670.78	120.000	64.00000	43.25405	-79.86447	0.00000	0.00000	0.00000	3.0	6.8
728.82	0.000	57.00000	43.25209	-79.85709	0.00000	0.00000	0.00000	4.0	6.5
788.80	0.000	54.00000	43.24979	-79.84807	0.00000	0.00000	0.00000	4.0	6.8
840.26	200.000	64.00000	43.24805	-79.83975	0.04518	10.00000	221.33235	4.0	7.0
906.87	200.000	63.00000	43.25133	-79.84140	0.00000	0.00000	0.00000	3.0	7.0
956.88	0.000	55.00000	43.25181	-79.84715	0.00000	0.00000	0.00000	3.0	7.0
1007.89	160.000	49.00000	43.24992	-79.84990	0.00000	0.00000	0.00000	3.0	7.0
1057.65	0.000	69.00000	43.24510	-79.85200	0.00000	0.00000	0.00000	4.0	6.8
1116.86	0.000	79.00000	43.24623	-79.85636	0.00000	0.00000	0.00000	4.0	7.0
1168.44	120.000	95.00000	43.24561	-79.86024	0.00000	0.00000	0.00000	4.0	6.8
1217.97	160.000	129.00000	43.24328	-79.85106	0.00000	0.00000	0.00000	4.0	6.3
1267.98	0.000	146.00000	43.24065	-79.84346	0.00000	0.00000	0.00000	4.0	6.3
1319.47	160.000	164.00000	43.23666	-79.84378	0.00000	0.00000	0.00000	4.0	6.3
1370.91	0.000	155.00000	43.23513	-79.83705	0.00000	0.00000	0.00000	4.0	6.3
1430.56	160.000	162.00000	43.23212	-79.83728	0.04967	0.00000	0.00000	3.0	6.5
1481.49	0.000	159.00000	43.22816	-79.83947	0.00000	0.00000	0.00000	4.0	6.3
1532.94	120.000	158.00000	43.22995	-79.84739	0.00000	0.00000	0.00000	3.0	6.3
1580.95	0.000	163.00000	43.23156	-79.85372	0.00000	0.00000	0.00000	4.0	6.3
1635.08	0.000	168.00000	43.23290	-79.85893	0.00000	0.00000	0.00000	4.0	6.5
1683.53	0.000	165.00000	43.23460	-79.86584	0.00000	0.00000	0.00000	4.0	6.3
1736.97	0.000	164.00000	43.23655	-79.87359	0.00000	0.00000	0.00000	4.0	6.5

Time (s) CAN2	HV Batt_Current [Amps]	HV Batt_Voltage[Volts]	Motor1_ Power [kW]	Motor1_ Speed [rad/s]	Motor1_ Torque[Nm]	HV Batt_ SOC [%]	vehicle speed (m/s)	Energy (Joules)	Energy Consumption (KWh)	abs energy consump (kWh)
6.36	0.1500	350.0000	0.0000	0.0000	0.0000	50.0000	0.00	0.000	0.00000	0.00000
104.36	23.2500	347.0000	1.0000	-21.6000	-39.3000	89.3000	1.13	5405.393	0.00150	0.00150
208.37	18.3500	346.5000	0.0000	0.2000	5.0000	88.3000	0.18	4260.044	0.00118	0.00118
290.71	53.8000	343.0000	7.0000	274.4000	41.4000	87.3000	10.99	5720.554	0.00159	0.00159
344.37	22.2000	344.5000	1.0000	286.0000	4.8000	86.5000	11.54	4741.698	0.00132	0.00132
400.73	73.5500	339.5000	21.0000	388.0000	45.6000	85.8000	15.78	8240.174	0.00229	0.00229
452.74	46.8000	341.5000	15.0000	288.2000	30.7000	84.7000	11.66	5274.126	0.00147	0.00147
503.39	66.1500	339.5000	17.0000	279.0000	55.8000	83.8000	11.37	13699.334	0.00381	0.00381
555.39	48.5500	341.0000	11.0000	344.4000	30.9000	83.1000	14.14	9933.330	0.00276	0.00276
620.43	5.2500	345.0000	-3.0000	204.4000	-13.0000	82.5000	8.19	54.337	0.00002	0.00002
670.78	47.2000	341.0000	-6.0000	290.6000	43.2000	81.8000	11.70	804.760	0.00022	0.00022
728.82	1.0500	344.0000	-7.0000	308.2000	-19.8000	81.0000	12.67	10.836	0.00000	0.00000
788.80	38.7500	341.0000	8.0000	352.0000	22.4000	80.1000	14.34	4756.950	0.00132	0.00132
840.26	76.6000	338.5000	25.0000	254.6000	91.4000	79.6000	9.64	10371.640	0.00288	0.00288
906.87	59.5000	339.5000	19.0000	134.4000	125.4000	78.9000	4.44	808.010	0.00022	0.00022
956.88	55.4000	339.0000	6.0000	264.8000	25.9000	78.1000	10.56	939.030	0.00026	0.00026
1007.89	34.7500	340.0000	4.0000	286.2000	16.3000	77.5000	11.78	590.750	0.00016	0.00016
1057.65	139.3000	331.0000	49.0000	258.6000	173.2000	76.5000	11.01	9221.660	0.00256	0.00256
1116.86	67.6000	337.0000	11.0000	194.2000	101.7000	75.9000	7.45	9112.480	0.00253	0.00253
1168.44	73.4000	333.5000	23.0000	386.8000	58.1000	74.4000	15.56	12239.450	0.00340	0.00340
1217.97	115.6500	329.5000	37.0000	383.6000	91.3000	73.0000	15.35	1905.334	0.00053	0.00053
1267.98	101.9500	330.5000	30.0000	212.8000	127.0000	72.1000	7.93	3032.503	0.00084	0.00084
1319.47	6.3000	337.0000	-4.0000	225.0000	-14.5000	71.1000	9.01	63.693	0.00002	0.00002
1370.91	1.9000	339.0000	0.0000	14.4000	35.4000	70.5000	1.04	270.522	0.00008	0.00008
1430.56	34.2000	335.5000	10.0000	254.2000	36.9000	69.8000	10.40	803.187	0.00022	0.00022
1481.49	113.2500	330.0000	31.0000	231.6000	121.8000	69.4000	9.90	1868.625	0.00052	0.00052
1532.94	-14.4500	338.0000	3.0000	297.8000	-19.9000	68.5000	12.50	-2149.004	-0.00060	0.00060
1580.95	0.6000	336.5000	-6.0000	275.8000	-18.0000	67.7000	11.50	90.855	0.00003	0.00003
1635.08	25.2000	335.0000	11.0000	287.2000	32.6000	67.3000	11.71	1013.040	0.00028	0.00028
1683.53	2.7500	336.0000	0.0000	366.4000	1.3000	66.6000	14.91	27.720	0.00001	0.00001
1736.97	18.6500	335.5000	0.0000	16.4000	29.6000	66.2000	0.86	2940.825	0.00082	0.00082

Time (s) CAN3	AC_HVPower [Watts]	GPS_Alt_ Metres	GPS_Lat_ Deg	GPS_Lon_ Deg	Horizontal Distance Meter	Vertical distance	Grade Rise / Run	Traffic score	Outside Air_ Temp [degC]
59.65	1480.00	53.00000	43.25567	-79.90189	9191.762	53.00000	0.00577	3.0	23.8
80.06	640.00	53.00000	43.25692	-79.90140	0.10949	1.00000	9.13354	3.0	23.5
379.60	440.00	81.00000	43.25615	-79.87299	0.10045	1.00000	9.95554	4.0	23.3
470.58	360.00	68.00000	43.25277	-79.85970	0.14827	1.00000	6.74466	4.0	23.0
480.58	360.00	69.00000	43.25233	-79.85788	0.15543	1.00000	6.43361	3.0	22.5
510.57	360.00	64.00000	43.25089	-79.85234	0.16095	1.00000	6.21302	3.0	22.5
520.57	320.00	65.00000	43.25045	-79.85056	0.15224	1.00000	6.56864	3.0	22.5
540.57	360.00	64.00000	43.24964	-79.84739	0.13605	1.00000	7.35007	3.0	22.8
560.56	360.00	61.00000	43.24879	-79.84400	0.14999	1.00000	6.66731	3.0	22.8
580.56	360.00	60.00000	43.24795	-79.84071	0.14010	1.00000	7.13765	3.0	22.5
689.95	280.00	62.00000	43.25138	-79.84333	0.12352	1.00000	8.09610	4.0	22.8
699.95	240.00	63.00000	43.25156	-79.84501	0.13715	1.00000	7.29114	4.0	22.5
730.53	280.00	65.00000	43.25200	-79.84880	0.10166	1.00000	9.83653	4.0	22.5
809.94	400.00	78.00000	43.24569	-79.85174	0.13150	1.00000	7.60470	3.0	23.0
990.91	240.00	154.00000	43.24062	-79.84340	0.11671	1.00000	8.56857	4.0	21.0
1080.88	240.00	159.00000	43.23531	-79.83788	0.13325	1.00000	7.50481	4.0	21.0
1090.88	240.00	158.00000	43.23498	-79.83649	0.11893	1.00000	8.40808	4.0	20.8
1120.89	240.00	159.00000	43.23228	-79.83720	0.14404	1.00000	6.94233	4.0	21.3
1140.87	240.00	160.00000	43.22971	-79.83829	0.14510	1.00000	6.89156	4.0	21.3
1150.87	280.00	159.00000	43.22867	-79.83881	0.12294	1.00000	8.13406	4.0	21.3
1240.87	400.00	162.00000	43.22833	-79.84044	0.10623	1.00000	9.41375	4.0	22.5
1250.87	360.00	161.00000	43.22868	-79.84185	0.12132	1.00000	8.24293	4.0	22.0
1260.85	320.00	160.00000	43.22911	-79.84353	0.14376	1.00000	6.95620	4.0	21.8
1280.85	280.00	161.00000	43.22986	-79.84713	0.15524	1.00000	6.44183	4.0	21.3
1350.42	280.00	161.00000	43.23083	-79.85089	0.14743	1.00000	6.78271	3.0	21.8
1360.42	280.00	162.00000	43.23133	-79.85275	0.16125	1.00000	6.20137	3.0	21.5
1380.42	240.00	166.00000	43.23232	-79.85662	0.16626	1.00000	6.01455	4.0	21.3
1430.41	0.00	167.00000	43.23486	-79.86687	0.17282	1.00000	5.78630	3.0	21.5
1470.40	240.00	164.00000	43.23681	-79.87464	0.16238	1.00000	6.15827	4.0	21.3
1620.79	320.00	167.00000	43.23957	-79.88543	0.12528	1.00000	7.98238	4.0	22.8

Time (s) CAN3	HVBatt_Current[Amps]	HVBatt_Voltage[Volts]	Motor1_Power Elec[kW]	Motor1_Speed [rad/s]	Motor1_Torque[Nm]	HVBatt_SOC [%]	veh speed (m/s)	Energy (Joules)	Energy Consumption (KWh)	abs energy consump (kWh)
59.65	9.7000	347.5000	1.0000	8.0000	70.7000	86.7000	0.16	168.5375	0.0000	0.0000
80.06	38.1500	345.5000	12.0000	301.2000	36.2000	86.5000	12.15	1449.8907	0.0004	0.0004
379.60	5.2000	347.5000	-1.0000	205.8000	-11.0000	84.3000	8.42	1554.0200	0.0004	0.0004
470.58	39.7500	345.0000	16.0000	375.6000	36.9000	83.6000	15.18	6856.8750	0.0019	0.0019
480.58	-3.4500	347.0000	-2.0000	386.2000	-4.2000	83.5000	15.71	-981.6630	-0.0003	0.0003
510.57	31.2500	345.5000	10.0000	369.0000	26.0000	83.3000	15.06	4318.7500	0.0012	0.0012
520.57	-3.9500	347.0000	-2.0000	362.2000	-5.1000	83.2000	14.81	-1096.5200	-0.0003	0.0003
540.57	14.5000	346.5000	4.0000	329.4000	12.6000	83.2000	13.45	4622.3100	0.0013	0.0013
560.56	-0.2000	346.5000	-1.0000	350.8000	-1.8000	83.0000	14.29	-63.0630	0.0000	0.0000
580.56	-16.7000	348.0000	-7.0000	307.4000	-20.4000	82.9000	12.62	-5288.5560	-0.0015	0.0015
689.95	29.5500	345.0000	9.0000	326.8000	26.8000	82.3000	13.26	2956.4775	0.0008	0.0008
699.95	-17.7500	347.5000	-7.0000	324.2000	-21.6000	82.2000	13.28	-1788.7563	-0.0005	0.0005
730.53	-43.9500	349.0000	-10.0000	145.0000	-114.1000	82.1000	6.28	-11197.1415	-0.0031	0.0031
809.94	-5.7500	346.5000	-4.0000	239.2000	-13.5000	81.4000	9.86	-537.9413	-0.0001	0.0001
990.91	-4.4000	345.0000	-2.0000	181.6000	-11.7000	78.2000	7.56	-60.7200	0.0000	0.0000
1080.88	26.4000	343.0000	5.0000	308.4000	23.5000	77.3000	12.51	1539.3840	0.0004	0.0004
1090.88	-46.8000	347.0000	-24.0000	232.6000	-90.9000	77.3000	9.88	-2760.7320	-0.0008	0.0008
1120.89	33.7000	341.5000	10.0000	368.6000	27.3000	77.0000	14.91	1956.4535	0.0005	0.0005
1140.87	23.3000	343.5000	7.0000	329.4000	20.3000	76.9000	13.36	1200.5325	0.0003	0.0003
1150.87	-14.5000	346.0000	-12.0000	187.4000	-41.7000	76.8000	7.83	-752.5500	-0.0002	0.0002
1240.87	10.7500	343.5000	2.0000	309.2000	9.0000	76.5000	12.55	480.0412	0.0001	0.0001
1250.87	43.3000	342.0000	13.0000	345.6000	37.2000	76.5000	13.97	1925.1180	0.0005	0.0005
1260.85	43.3500	341.0000	12.0000	360.0000	36.6000	76.3000	14.56	1626.0585	0.0005	0.0005
1280.85	-43.6500	346.5000	-11.0000	330.6000	-50.1000	76.1000	13.77	-1512.4725	-0.0004	0.0004
1350.42	37.2000	342.0000	10.0000	375.8000	28.5000	75.8000	15.20	6233.9760	0.0017	0.0017
1360.42	18.5500	343.0000	9.0000	381.2000	19.7000	75.6000	15.63	3117.6985	0.0009	0.0009
1380.42	14.3000	342.0000	4.0000	409.4000	10.1000	75.4000	16.67	2396.3940	0.0007	0.0007
1430.41	4.0000	343.5000	1.0000	394.0000	2.5000	74.9000	16.14	879.3600	0.0002	0.0002
1470.40	40.8000	341.0000	14.0000	391.4000	33.3000	74.7000	15.83	6260.7600	0.0017	0.0017
1620.79	24.4500	342.5000	5.0000	319.0000	12.3000	74.3000	13.02	837.4125	0.0002	0.0002

Time (s) CAN4	AC_HV Power[Watts]	GPS_Alt_ Metres	GPS_Lat_ Deg	GPS_Lon_ Deg	Horizontal Distance Meter	Vertical distance	Grade Rise/Run	Traffic score	Outside_Air_ Temp[degC]
79.09	0	8.08000	43.25560	-79.90252	9191.81168	8.08000	0.00088	3.0	19.8
139.69	0	64.16000	43.25940	-79.90039	0.12081	0.57000	4.71801	3.0	19.0
219.67	0	61.31000	43.25966	-79.88831	0.11014	0.65000	5.90141	3.0	19.8
229.66	0	62.03000	43.25928	-79.88659	0.14514	0.72000	4.96062	3.0	19.5
249.66	0.00000000	62.91000	43.25867	-79.88389	0.10572	0.06000	0.56753	3.0	20.0
319.65	0.00000000	80.83000	43.25620	-79.87324	0.13840	0.11000	0.79480	4.0	20.3
329.65	0.00000000	81.19000	43.25583	-79.87158	0.14013	0.36000	2.56913	4.0	20.0
439.62	0.00000000	64.19000	43.25166	-79.85515	0.13298	0.40000	3.00807	4.0	20.3
710.02	0.00000000	65.09000	43.25181	-79.84658	0.11966	0.47000	3.92781	4.0	19.3
720.01	0.00000000	64.58000	43.25198	-79.84793	0.11102	0.51000	4.59375	4.0	19.3
730.04	0.00000000	64.30000	43.25208	-79.84893	0.08223	0.28000	3.40492	4.0	19.3
800.01	0.00000000	77.69000	43.24608	-79.85164	0.14569	0.01000	0.06864	4.0	19.3
1080.51	0.00000000	156.59000	43.23617	-79.84133	0.10165	0.36000	3.54158	4.0	19.3
1100.51	0.00000000	155.08000	43.23558	-79.83879	0.11605	0.69000	5.94573	4.0	19.3
1120.50	0.00000000	154.16000	43.23499	-79.83632	0.09479	0.01000	0.10549	4.0	19.3
1140.50	0.00000000	153.39000	43.23356	-79.83671	0.12094	0.26000	2.14982	4.0	19.3
1150.50	0.00000000	153.58000	43.23240	-79.83721	0.13561	0.19000	1.40111	4.0	19.0
1160.49	0.00000000	154.30000	43.23119	-79.83772	0.14061	0.72000	5.12056	4.0	18.8
1170.49	0.00000000	154.66000	43.23001	-79.83823	0.13744	0.36000	2.61931	4.0	18.8
1180.49	0.00000000	154.52000	43.22886	-79.83872	0.13415	0.14000	1.04359	4.0	18.8
1269.90	0.00000000	162.97000	43.22969	-79.84612	0.15546	0.33000	2.12272	4.0	18.5
1280.47	0.00000000	162.78000	43.23006	-79.84777	0.13999	0.19000	1.35728	4.0	18.8
1290.47	0.00000000	162.66000	43.23042	-79.84929	0.12952	0.12000	0.92648	4.0	18.5
1300.47	0.00000000	162.61000	43.23083	-79.85085	0.13417	0.05000	0.37266	4.0	18.5
1409.88	0.00000000	166.52000	43.23427	-79.86428	0.12690	0.67000	5.27979	4.0	18.8
1420.87	0.00000000	166.94000	43.23470	-79.86607	0.15274	0.42000	2.74982	4.0	18.8
1430.86	0.00000000	166.91000	43.23507	-79.86746	0.12065	0.03000	0.24866	4.0	18.8
1450.86	0.00000000	165.64000	43.23564	-79.86982	0.12543	0.49000	3.90669	3.0	19.0
1530.42	0.00000000	171.05000	43.23866	-79.88183	0.12301	0.61000	4.95890	4.0	18.8
1600.82	0.00000000	167.11000	43.23973	-79.88583	0.02983	0.14000	4.69365	4.0	19.0

Time (s) CAN4	HVBatt_ Current [Amps]	HVBatt_ Voltage [Volts]	Motor1_Power[kW]	Motor1_Speed [rad/s]	Motor1_Torque[Nm]	HVBatt_SOC [%]	veh speed (m/s)	Energy (Joules)	Energy Consumption (KWh)	abs energy consump (kWh)
79.09	24.7500	345.0000	8.0000	58.2000	112.9000	78.0000	2.08	3330.11250	0.00093	0.00093
139.69	-2.6500	345.5000	0.0000	272.0000	-4.0000	77.6000	11.18	-906.41925	-0.00025	0.00025
219.67	46.2500	341.5000	14.0000	332.4000	42.3000	77.2000	13.44	14688.76875	0.00408	0.00408
229.66	20.0500	343.0000	6.0000	364.0000	16.3000	77.0000	14.75	6326.97800	0.00176	0.00176
249.66	52.6500	341.0000	17.0000	304.4000	53.3000	77.0000	12.27	16337.82150	0.00454	0.00454
319.65	6.2500	344.0000	1.0000	355.8000	5.1000	76.5000	14.50	1913.50000	0.00053	0.00053
329.65	33.0000	342.5000	11.0000	323.0000	31.5000	76.4000	13.11	10059.22500	0.00280	0.00280
439.62	18.3000	343.0000	5.0000	354.8000	14.7000	75.9000	14.43	5021.52000	0.00140	0.00140
710.02	1.3500	343.0000	0.0000	289.0000	1.1000	74.5000	11.83	60.19650	0.00002	0.00002
720.01	13.1000	342.5000	2.0000	267.4000	11.7000	74.5000	10.85	538.41000	0.00015	0.00015
730.04	-0.0500	344.0000	0.0000	106.2000	0.3000	74.5000	4.35	-2.58000	0.00000	0.00000
800.01	39.9500	339.0000	12.0000	380.0000	32.1000	73.7000	15.39	2979.47100	0.00083	0.00083
1080.51	-8.4500	339.5000	-3.0000	218.2000	-13.8000	69.6000	8.94	-1491.76300	-0.00041	0.00041
1100.51	8.6500	338.5000	3.0000	287.2000	9.0000	69.4000	11.70	1493.29275	0.00042	0.00042
1120.50	-18.7000	341.0000	-8.0000	123.0000	-56.9000	69.3000	5.24	-3188.35000	-0.00089	0.00089
1140.50	32.0000	337.0000	10.0000	307.4000	32.1000	69.1000	12.51	7440.96000	0.00207	0.00207
1150.50	18.0000	337.5000	5.0000	342.4000	15.1000	69.0000	13.89	3037.50000	0.00084	0.00084
1160.49	18.1000	336.5000	6.0000	334.6000	18.1000	68.9000	13.61	2923.51200	0.00081	0.00081
1170.49	13.6000	337.0000	6.0000	326.8000	14.6000	68.9000	13.31	2199.93600	0.00061	0.00061
1180.49	6.8000	338.5000	-4.0000	322.4000	1.7000	68.8000	13.16	1104.86400	0.00031	0.00031
1269.90	6.7500	337.5000	6.0000	369.8000	2.6000	68.1000	15.05	136.68750	0.00004	0.00004
1280.47	61.6000	334.5000	21.0000	299.4000	67.2000	68.1000	12.07	8654.18400	0.00241	0.00241
1290.47	35.2000	336.0000	6.0000	326.8000	30.8000	68.0000	13.30	4967.42400	0.00138	0.00138
1300.47	20.0500	337.0000	2.0000	331.8000	13.6000	67.8000	13.48	2837.87700	0.00079	0.00079
1409.88	49.4000	335.0000	12.0000	327.2000	48.1000	67.0000	13.21	330.98000	0.00009	0.00009
1420.87	-15.4000	339.0000	-3.0000	334.4000	-15.9000	66.9000	13.68	-52.20600	-0.00001	0.00001
1430.86	-60.7500	342.5000	-24.0000	176.6000	-130.0000	66.9000	7.62	-208.06875	-0.00006	0.00006
1450.86	17.3000	337.0000	5.0000	322.2000	17.8000	66.8000	13.28	58.30100	0.00002	0.00002
1530.42	-55.8500	341.5000	-17.0000	219.8000	-91.3000	66.3000	9.27	-6294.01575	-0.00175	0.00175
1600.82	76.3500	333.5000	25.0000	143.6000	152.4000	66.2000	5.38	1527.76350	0.00042	0.00042

Time (s) UDDS	JM1 Battery Current (A)	JM1 Battery Voltage (V)	JM1 Motor Speed (Rev/min)	JM1 Motor Torque (Nm)	JM1 Battery SOC (%)	JM1 Velocity profile (m/s)	Energy (Joules)	Energy Consumption (KWh)	abs energy consump
0.00	0.000	334.359	0.000	0.0000	90.00	0.0000	0.0000	0.0000	0.0000
45.60	-41.782	332.038	-1313.518	93.4198	89.84	8.7630	-2774.6528	-0.0008	0.0008
91.20	-10.978	332.961	-2026.149	11.2145	89.54	13.5177	-731.0520	-0.0002	0.0002
136.80	0.000	334.007	0.000	0.0000	89.54	0.0000	0.0000	0.0000	0.0000
182.40	87.114	337.640	-1741.311	-179.4996	89.31	11.6180	5882.6345	0.0016	0.0016
228.00	-67.047	328.496	-3577.472	48.3192	88.29	23.8675	-4404.9167	-0.0012	0.0012
273.60	-58.108	328.616	-3434.599	42.8659	87.47	22.9143	-3819.0310	-0.0011	0.0011
319.20	-3.209	332.355	-1902.460	0.0000	87.19	12.6926	-213.2967	-0.0001	0.0001
364.80	-42.747	330.679	-2236.848	51.6304	86.98	14.9233	-2827.1336	-0.0008	0.0008
410.40	-58.738	330.350	-1636.470	103.2139	86.83	10.9176	-3880.8157	-0.0011	0.0011
456.00	-67.502	329.979	-1804.245	106.3078	86.66	12.0369	-4454.8566	-0.0012	0.0012
501.60	23.686	334.507	-549.322	-178.2129	86.45	3.6655	1584.6110	0.0004	0.0004
547.20	-0.581	333.381	-1071.825	0.0000	86.28	7.1508	-38.7183	0.0000	0.0000
592.80	-16.240	332.742	-1158.552	40.7880	86.19	7.7293	-1080.7725	-0.0003	0.0003
638.40	0.000	333.742	-0.001	0.000	86.16	0.0000	0.0000	0.0000	0.0000
684.00	0.000	333.704	-0.001	0.0000	86.03	0.0000	0.0000	0.0000	0.0000
729.60	-19.832	332.776	-305.004	150.6505	85.94	2.0344	-1319.8982	-0.0004	0.0004
775.20	-33.854	331.762	-1375.722	72.3298	85.68	9.1781	-2246.2983	-0.0006	0.0006
820.80	-6.524	332.536	-2094.845	3.5016	85.29	13.9761	-433.8684	-0.0001	0.0001
866.40	20.659	334.013	-1713.662	-43.2205	85.14	11.4331	1380.0534	0.0004	0.0004
912.00	-8.638	332.658	-1711.077	11.8015	84.92	11.4157	-574.7163	-0.0002	0.0002
957.60	-0.005	333.512	-10.678	0.0000	84.89	0.0712	-0.3581	0.0000	0.0000
1003.20	-17.268	332.300	-1645.607	29.0839	84.58	10.9788	-1147.6091	-0.0003	0.0003
1048.80	0.000	333.624	-0.001	0.0000	84.64	0.0000	0.0000	0.0000	0.0000
1094.40	14.755	334.214	-515.801	-111.7283	84.49	3.4416	986.2885	0.0003	0.0003
1140.00	-2.338	332.971	-1737.267	0.0097	84.22	11.5904	-155.6729	0.0000	0.0000
1185.60	1.545	333.578	-133.191	-113.9100	84.25	0.8890	103.0450	0.0000	0.0000
1231.20	-10.636	332.809	-1298.866	23.3679	84.08	8.6655	-707.9289	-0.0002	0.0002
1276.80	-22.874	332.149	-1544.806	42.8320	83.98	10.3063	-1519.5112	-0.0004	0.0004
1322.40	0.000	333.520	-0.002	0.0000	83.94	0.0000	-0.0001	0.0000	0.0000
1368.00	-0.005	333.534	-9.022	0.0000	83.85	0.0602	-0.3025	0.0000	0.0000

Time (s) NEDC	JM1 Battery Current (A)	JM1 Battery Voltage (V)	JM1 Motor Speed (Rev/min)	JM1 Motor Torque (Nm)	JM1 Battery SOC (%)	JM1 Velocity profile (m/s)	Energy (Joules)	Energy Consumption (KWh)	abs energy consump
0.00	0.0000	334.3586	0.0000	0.00	90.0000	0.00000	0.00000	0.00000	0.00000
45.60	0.0000	334.3211	-0.0001	0.00	89.9781	0.00000	0.00000	0.00000	0.00000
91.20	13.6493	334.7856	-605.5869	-83.51	89.8569	4.04054	913.91820	0.00025	0.00025
136.80	-37.7334	332.0794	-1551.5251	71.11	89.7123	10.35100	-2506.09547	-0.00070	0.00070
182.40	17.9666	334.8218	-735.3725	-88.71	89.5956	4.90644	1203.12137	0.00033	0.00033
228.00	0.0000	334.1490	-0.0006	0.00	89.5914	0.00000	-0.00002	0.00000	0.00000
273.60	-6.3559	333.5829	-1319.7649	13.11	89.4365	8.80497	-424.04706	-0.00012	0.00012
319.20	-13.8379	333.4832	-550.8678	69.61	89.4597	3.67496	-922.94429	-0.00026	0.00026
364.80	-7.2583	333.3732	-1443.6799	13.63	89.1719	9.63168	-483.94736	-0.00013	0.00013
410.40	-2.5907	333.9118	-614.1231	11.04	89.1949	4.09717	-173.01367	-0.00005	0.00005
456.00	-6.3617	333.5533	-1319.7565	13.12	89.0823	8.80491	-424.39632	-0.00012	0.00012
501.60	0.0000	334.1252	-0.0012	0.00	89.0939	0.00000	-0.00004	0.00000	0.00000
547.20	25.4276	334.6330	-1895.2825	-48.86	88.7573	12.64482	1701.77981	0.00047	0.00047
592.80	0.0000	334.0425	-0.0013	0.00	88.8380	0.00000	-0.00004	0.00000	0.00000
638.40	-15.7961	333.3376	-457.1029	92.18	88.8004	3.04932	-1053.08946	-0.00029	0.00029
684.00	0.0000	334.0511	-0.0016	0.00	88.7058	0.00000	-0.00005	0.00000	0.00000
729.60	-19.4350	332.4743	-2053.0411	23.53	88.4184	13.69709	-1292.32856	-0.00036	0.00036
775.20	0.0000	333.9542	-0.0018	0.00	88.4497	0.00000	-0.00006	0.00000	0.00000
820.80	-31.8380	332.2209	-1449.5493	64.59	88.3104	9.67067	-2115.45284	-0.00059	0.00059
866.40	-29.0386	331.0200	-2875.0552	23.05	87.5487	19.18128	-1922.46952	-0.00053	0.00053
912.00	-15.1798	332.1304	-2060.2199	16.93	87.2832	13.74501	-1008.33163	-0.00028	0.00028
957.60	-15.1761	332.1893	-2060.2199	16.93	86.9950	13.74501	-1008.26648	-0.00028	0.00028
1003.20	-29.1194	330.7408	-2875.0552	23.05	86.3403	19.18128	-1926.19434	-0.00054	0.00054
1048.80	-71.2727	327.9673	-3458.1495	53.60	85.5529	23.07139	-4675.01977	-0.00130	0.00130
1094.40	-61.6336	327.0931	-4078.1503	37.00	84.2434	27.20787	-4031.98704	-0.00112	0.00112
1140.00	97.3035	334.2780	-3536.6714	-101.08	82.9687	23.59577	6505.28309	0.00181	0.00181

Time (s) JC08	JM1 Battery Current (A)	JM1 Battery Voltage (V)	JM1 Motor Speed (Rev/min)	JM1 Motor Torque (Nm)	JM1 Battery SOC (%)	JM1 Velocity profile (m/s)	Energy (Joules)	Energy Consumption (KWh)	abs energy consump
0.00	0.0000	334.3586	0.0000	0.0000	90.0000	0.0000	0.0000	0.0000	0.0000
45.60	-20.8276	332.9324	-1563.6041	38.3916	89.8000	10.4317	-1386.8365	-0.0004	0.0004
91.20	0.0000	334.2010	-0.0001	0.0000	89.8000	0.0000	0.0000	0.0000	0.0000
131.20	-18.5629	332.2314	-2447.4328	16.3767	89.3000	16.3284	-1233.4378	-0.0003	0.0003
176.80	31.3201	335.0640	-1198.7127	-91.1068	89.2000	7.9977	2098.8444	0.0006	0.0006
222.40	5.6008	334.2127	-249.2150	-111.5284	89.2000	1.6630	374.3716	0.0001	0.0001
262.40	-51.2449	331.5326	-885.3721	161.1277	89.1000	5.9064	-3397.8704	-0.0009	0.0009
308.00	-33.6616	331.5822	-2221.1966	40.0982	88.7000	14.8189	-2232.3198	-0.0006	0.0006
353.60	0.0000	333.9500	-0.0004	0.0000	88.8000	0.0000	0.0000	0.0000	0.0000
393.60	-0.7136	333.7204	-1264.9567	0.0333	88.6000	8.4393	-47.6290	0.0000	0.0000
439.20	10.8688	333.5049	-2295.1242	-22.1881	88.2000	15.3123	724.9564	0.0002	0.0002
484.80	-21.9788	331.9831	-2183.3132	24.7366	87.9000	14.5662	-1459.3196	-0.0004	0.0004
524.80	25.3627	334.6992	-1056.4127	-84.3211	87.8000	7.0483	1697.7748	0.0005	0.0005
570.40	0.0000	333.9232	-0.0006	0.0000	87.9000	0.0000	0.0000	0.0000	0.0000
616.00	-34.4089	331.7928	-1824.4216	53.0869	87.6000	12.1717	-2283.3232	-0.0006	0.0006
656.00	-4.0640	333.6570	-76.6747	83.8217	87.6000	0.5113	-271.1973	-0.0001	0.0001
701.60	0.0000	333.9760	-0.0009	0.0000	87.6000	0.0000	0.0000	0.0000	0.0000
747.20	-38.5813	332.0528	-935.8788	117.3375	87.5000	6.2435	-2562.2055	-0.0007	0.0007
787.20	0.0000	334.0092	-0.0010	0.0000	87.5000	0.0000	0.0000	0.0000	0.0000
832.80	0.0000	334.0664	-0.0010	0.0000	87.5000	0.0000	0.0000	0.0000	0.0000
878.40	-11.0459	333.2822	-1166.7707	27.2047	87.4000	7.7842	-736.2780	-0.0002	0.0002
918.40	0.0000	333.9958	-0.0012	0.0000	87.4000	0.0000	0.0000	0.0000	0.0000
964.00	0.0000	334.0552	-0.0012	0.0000	87.4000	0.0000	0.0000	0.0000	0.0000
1009.60	-4.9521	333.6531	-932.8292	14.4989	87.4000	6.2235	-330.4540	-0.0001	0.0001
1049.60	-22.0692	332.9021	-514.8758	114.3139	87.3000	3.4347	-1469.3762	-0.0004	0.0004
1095.20	-29.3171	330.9532	-2858.4918	23.5076	86.5000	19.0708	-1940.5156	-0.0005	0.0005
1140.80	118.8202	337.7615	-2453.3142	-180.7109	86.0000	16.3683	8026.5798	0.0022	0.0022
1180.80	-10.1204	332.6753	-1365.8384	21.0126	86.0000	9.1123	-673.3623	-0.0002	0.0002

Time (s) FTP75	JM1 Battery Current (A)	JM1 Battery Voltage (V)	JM1 Motor Speed (Rev/min)	JM1 Motor Torque (Nm)	JM1 Battery SOC (%)	JM1 Velocity profile (m/s)	Energy (Joules)	Energy Consumptio n (KWh)	abs energy consump
0.00	0.0000	334.3586	0.0000	0.0000	90.0000	0.0000	0.0000	0.0000	0.0000
82.60	-30.9212	332.2065	-1794.9630	48.5544	89.6000	11.9752	-2054.4423	-0.0006	0.0006
165.20	-29.9450	332.6890	-433.5919	171.8611	89.5000	2.8922	-1992.4725	-0.0006	0.0006
247.80	-44.6764	329.1177	-3713.4010	28.1894	87.8000	24.7744	-2940.7557	-0.0008	0.0008
330.40	19.1631	334.0193	-446.3706	-192.9136	87.3000	2.9787	1280.1722	0.0004	0.0004
413.00	-50.4839	330.6054	-1872.5314	76.3140	86.8000	12.4926	-3338.0523	-0.0009	0.0009
495.60	104.6073	337.8201	-1787.6710	-215.7361	86.3000	11.9274	7067.6871	0.0020	0.0020
578.20	-10.7041	332.9717	-1154.6636	26.5654	86.2000	7.7034	-712.8305	-0.0002	0.0002
660.80	-19.1927	332.3932	-1706.4309	30.9257	86.0000	11.3846	-1275.9064	-0.0004	0.0004
743.40	-24.5538	332.0196	-1826.8368	36.7539	85.7000	12.1879	-1630.4717	-0.0005	0.0005
826.00	-11.2229	332.3805	-1987.1232	11.9361	85.3000	13.2573	-746.0535	-0.0002	0.0002
908.60	-4.7101	332.8343	-1718.3157	4.5290	84.9000	11.4640	-313.5339	-0.0001	0.0001
991.20	-14.8037	332.4880	-1457.0682	29.2440	84.7000	9.7209	-984.4075	-0.0003	0.0003
1073.80	-2.6727	332.9477	-1803.3672	0.0000	84.4000	12.0314	-177.9747	0.0000	0.0000
1156.40	0.0000	333.5321	-0.0016	0.0000	84.3000	0.0000	-0.0001	0.0000	0.0000
1239.00	12.7060	334.0912	-516.4948	-94.4582	84.1000	3.4462	848.9945	0.0002	0.0002
1321.60	0.0000	333.5158	-0.0021	0.0000	83.9000	0.0000	-0.0001	0.0000	0.0000
1404.20	0.0000	333.6487	-0.0022	0.0000	83.9000	0.0000	-0.0001	0.0000	0.0000
1486.80	0.0000	333.7451	-0.0022	0.0000	83.9000	0.0000	-0.0001	0.0000	0.0000
1569.40	0.0000	333.7670	-0.0022	0.0000	83.9000	0.0000	-0.0001	0.0000	0.0000
1652.00	0.0000	333.7721	-0.0022	0.0000	83.9000	0.0000	-0.0001	0.0000	0.0000
1734.60	0.0000	333.7733	-0.0022	0.0000	83.9000	0.0000	-0.0001	0.0000	0.0000
1817.20	0.0000	333.7736	-0.0022	0.0000	83.9000	0.0000	-0.0001	0.0000	0.0000
1899.80	0.0000	333.7738	-0.0022	0.0000	83.9000	0.0000	-0.0001	0.0000	0.0000
1982.40	0.0000	333.7739	-0.0022	0.0000	83.9000	0.0000	-0.0001	0.0000	0.0000
2065.00	-14.9234	332.1901	-2018.1347	17.2302	83.4000	13.4642	-991.4836	-0.0003	0.0003
2147.60	-2.0649	332.9561	-1685.5147	0.0000	83.2000	11.2452	-137.5068	0.0000	0.0000
2230.20	-48.4972	328.4684	-3550.6106	32.9431	81.5000	23.6883	-3185.9578	-0.0009	0.0009
2312.80	0.0000	332.8006	-0.0025	0.0000	81.2000	0.0000	-0.0001	0.0000	0.0000
2395.40	73.0406	336.1261	-1150.1976	-235.5952	80.6000	7.6745	4910.1716	0.0014	0.0014
2478.00	-0.0012	332.9824	-2.4218	0.0000	80.3000	0.0161	-0.0812	0.0000	0.0000

Time (s) US06	JM1 Battery Current (A)	JM1 Battery Voltage (V)	JM1 Motor Speed (Rev/min)	JM1 Motor Torque (Nm)	JM1 Battery SOC (%)	JM1 Velocity profile (m/s)	Energy (Joules)	Energy Consumption (KWh)	abs energy consump
0.0000	0.0000	334.3586	0.0000	0.0000	90.0000	0.0000	0.0000	0.0000	0.0000
20.0000	-93.0048	328.8178	-2584.9019	99.3541	89.5781	17.2452	-6116.3281	-0.0017	0.0017
40.0000	1.6396	333.8670	-141.7404	-163.2957	89.6571	0.9462	109.4843	0.0000	0.0000
60.0000	-134.7622	326.2090	-2835.1955	127.5007	89.1455	18.9150	-8792.1253	-0.0024	0.0024
80.0000	-32.0927	330.1061	-3431.6264	20.2482	88.5816	22.8946	-2118.7989	-0.0006	0.0006
100.0000	-12.3505	329.5848	-4285.5467	0.0000	87.7500	28.5917	-814.1076	-0.0002	0.0002
120.0000	111.2709	337.4580	-1650.2899	-253.8308	88.0963	11.0110	7509.8542	0.0021	0.0021
140.0000	-131.5444	326.5228	-1636.0562	214.7524	88.0251	10.9145	-8590.4478	-0.0024	0.0024
160.0000	-92.3138	326.3515	-3797.6640	63.8269	87.0936	25.3365	-6025.3498	-0.0017	0.0017
180.0000	-40.5675	328.7518	-3695.7475	24.7719	86.7021	24.6567	-2667.3294	-0.0007	0.0007
200.0000	-64.1777	327.0433	-4096.9008	38.6120	86.0995	27.3330	-4197.7784	-0.0012	0.0012
220.0000	-71.4403	326.3822	-4198.6022	42.5054	85.5198	28.0115	-4663.3662	-0.0013	0.0013
240.0000	-60.2394	326.7872	-4176.8956	34.8482	84.9957	27.8667	-3937.0910	-0.0011	0.0011
260.0000	-67.1905	326.5126	-4091.4043	40.7517	84.5174	27.2963	-4387.7103	-0.0012	0.0012
280.0000	-63.1229	326.6600	-4084.1505	37.8902	84.0167	27.2479	-4123.9472	-0.0011	0.0011
300.0000	-136.8580	322.2970	-4663.7472	76.0550	83.1699	31.1147	-8821.7843	-0.0025	0.0025
320.0000	-136.6679	321.8072	-4823.3237	73.3166	82.3931	32.1793	-8796.1416	-0.0024	0.0024
340.0000	-14.9758	326.5058	-5084.5936	0.0019	81.4282	33.9226	-977.9384	-0.0003	0.0003
360.0000	-45.7820	326.0848	-4428.8060	22.4355	81.0697	29.5474	-2985.7625	-0.0008	0.0008
380.0000	-98.5922	323.5202	-4586.9097	54.9567	80.3868	30.6021	-6379.3140	-0.0018	0.0018
400.0000	-82.6823	324.1505	-4624.4644	44.6276	79.7136	30.8527	-5360.2991	-0.0015	0.0015
420.0000	-54.5368	325.2836	-4651.5530	26.5615	79.0105	31.0335	-3547.9862	-0.0010	0.0010
440.0000	-60.0018	325.4850	-4369.4189	32.5494	78.5117	29.1511	-3905.9393	-0.0011	0.0011
460.0000	-65.9026	325.7559	-4070.6970	39.8749	78.1130	27.1581	-4293.6288	-0.0012	0.0012
480.0000	121.8937	335.4346	-3009.9042	-150.9978	77.9984	20.0815	8177.4748	0.0023	0.0023
500.0000	0.0000	331.8090	-0.0004	0.0000	78.2986	0.0000	0.0000	0.0000	0.0000
520.0000	-77.7926	328.1029	-1694.2503	129.4582	78.0429	11.3030	-5104.7980	-0.0014	0.0014
540.0000	110.5567	336.7027	-1645.0266	-254.0890	77.9347	10.9759	7444.9499	0.0021	0.0021
560.0000	-0.0071	332.2423	-46.9278	-1.3930	77.9297	0.3131	-0.4708	0.0000	0.0000
580.0000	-136.1538	324.7008	-2997.3052	120.0623	77.3403	19.9966	-8841.8499	-0.0025	0.0025
600.0000	0.0000	332.1676	-0.0007	0.0000	77.5547	0.0000	0.0000	0.0000	0.0000

Appendix C:

This Appendix provides the Autonomie results for Ford Focus Electric 2012 and Toyota Prius 2006 when tested against some traditional drive cycles. Please note that the x axis is time in seconds for the graphs included in this appendix.

UDDS:

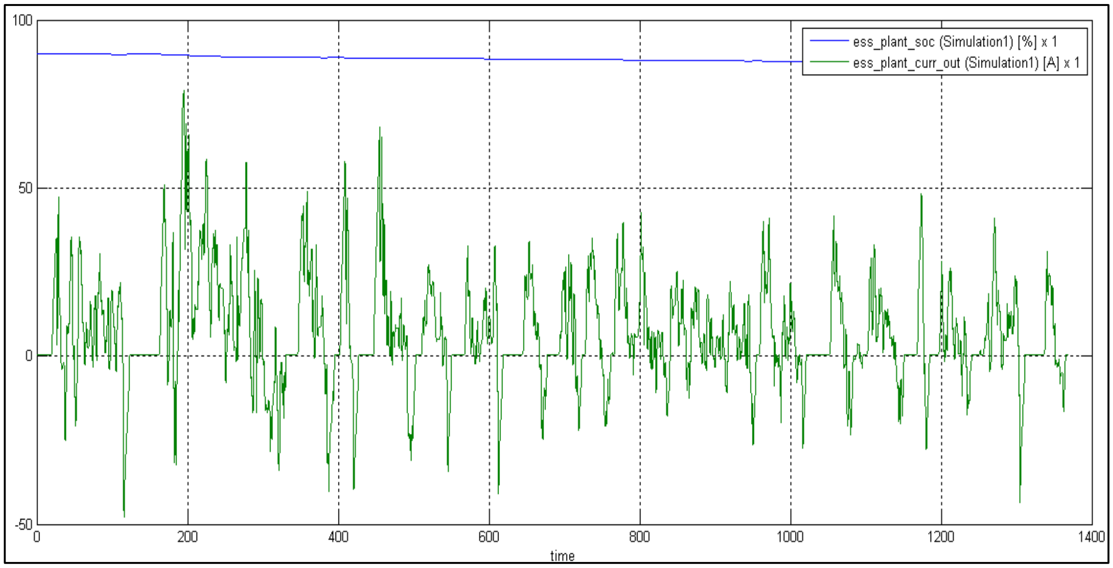

Figure 7.21: Autonomie Ford Focus Electric's UDDS Results for Battery Current and SOC

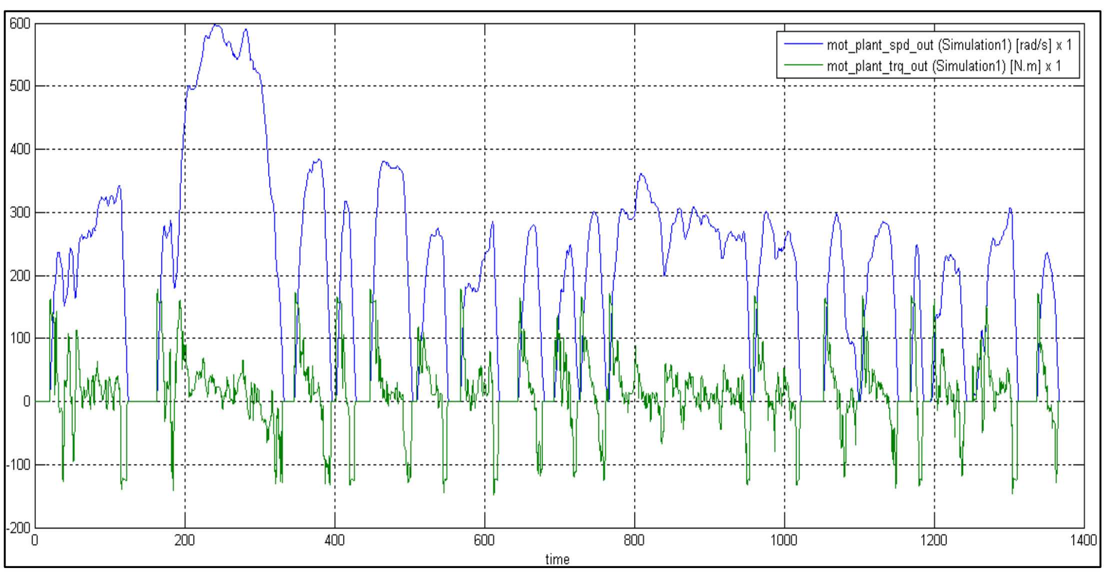

Figure 7.22: Autonomie Ford Focus Electric's UDDS Results for Motor Speed and Torque

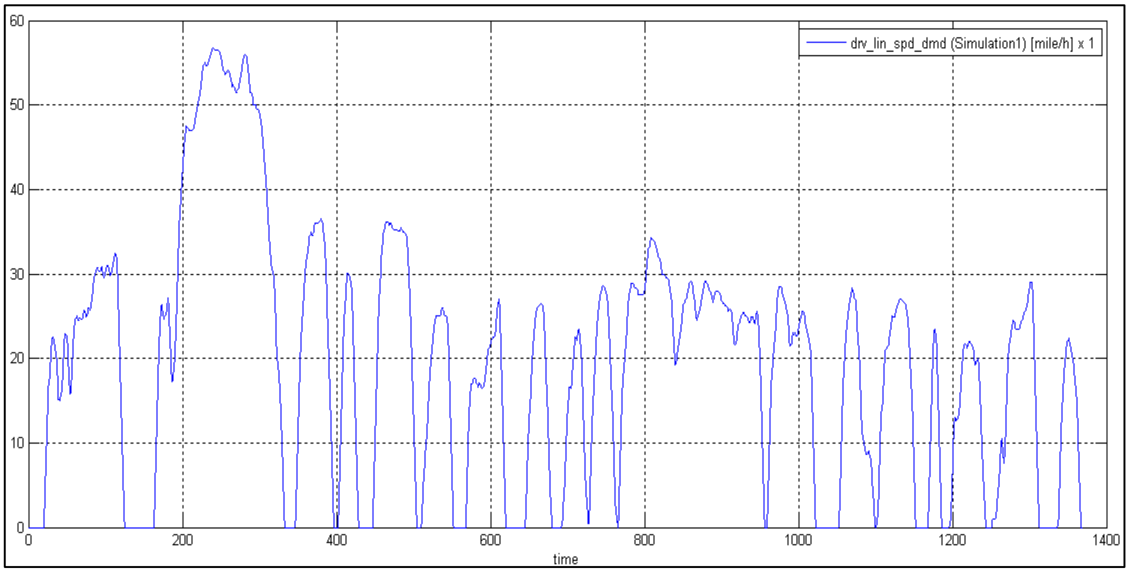

Figure 7.23: Autonomie Ford Focus Electric's UDDS Result for Velocity Profile

NEDC:

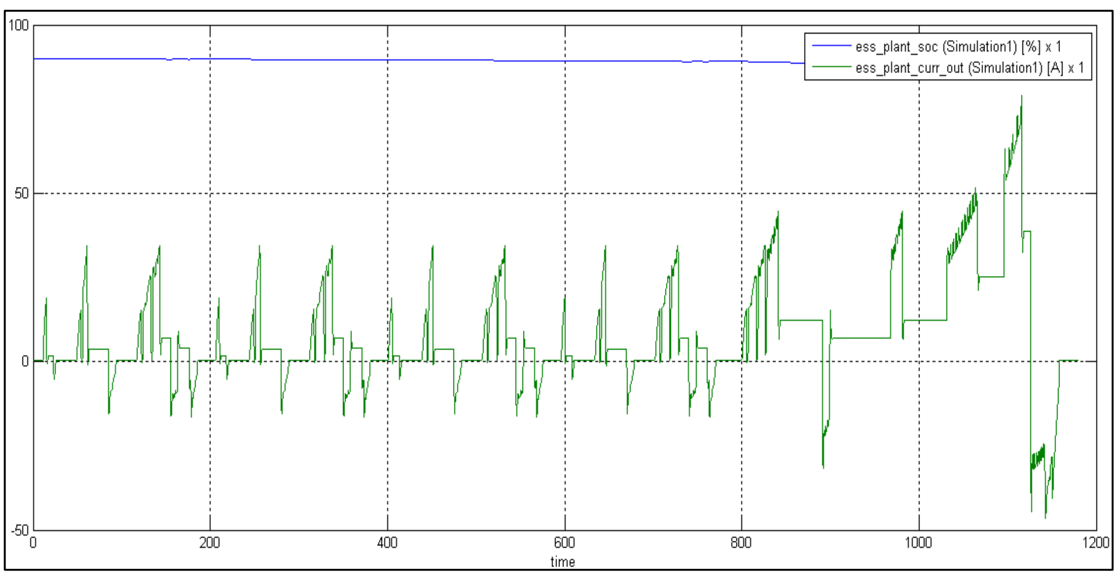

Figure 7.24: Autonomie Ford Focus Electric's NEDC Results for Battery Current and SOC

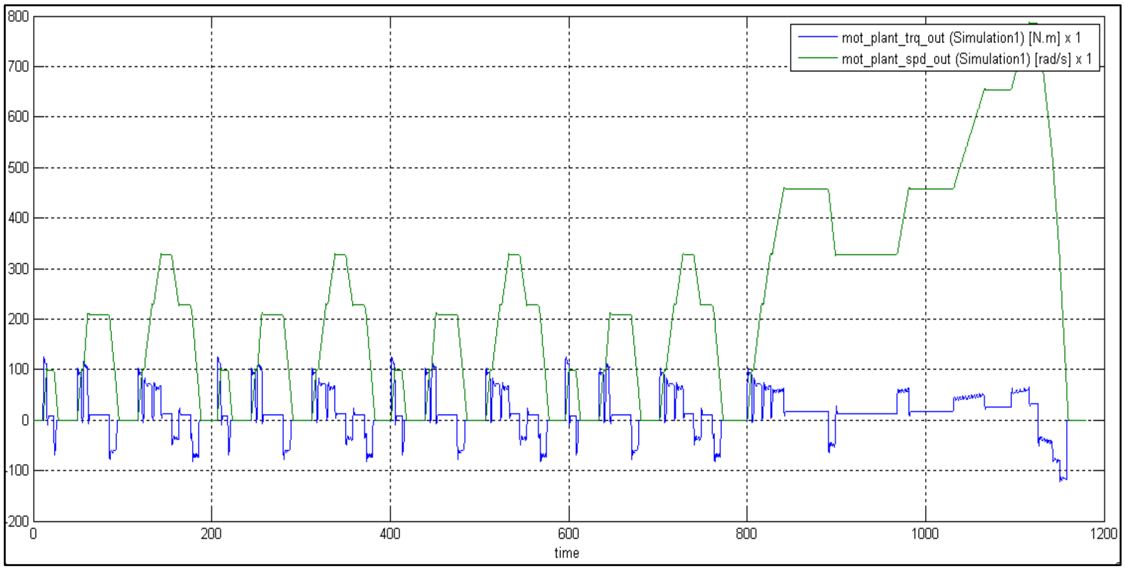

Figure 7.25: Autonomie Ford Focus Electric's NEDC Results for Motor Speed and Torque

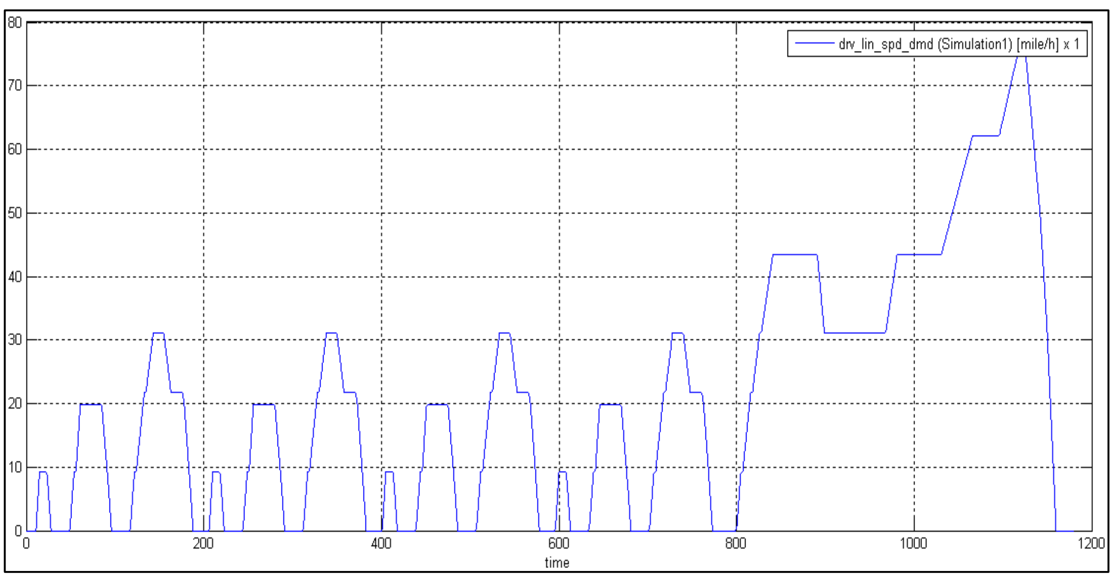

Figure 7.26: Autonomie Ford Focus Electric's NEDC Results for Velocity Profile

JC08:

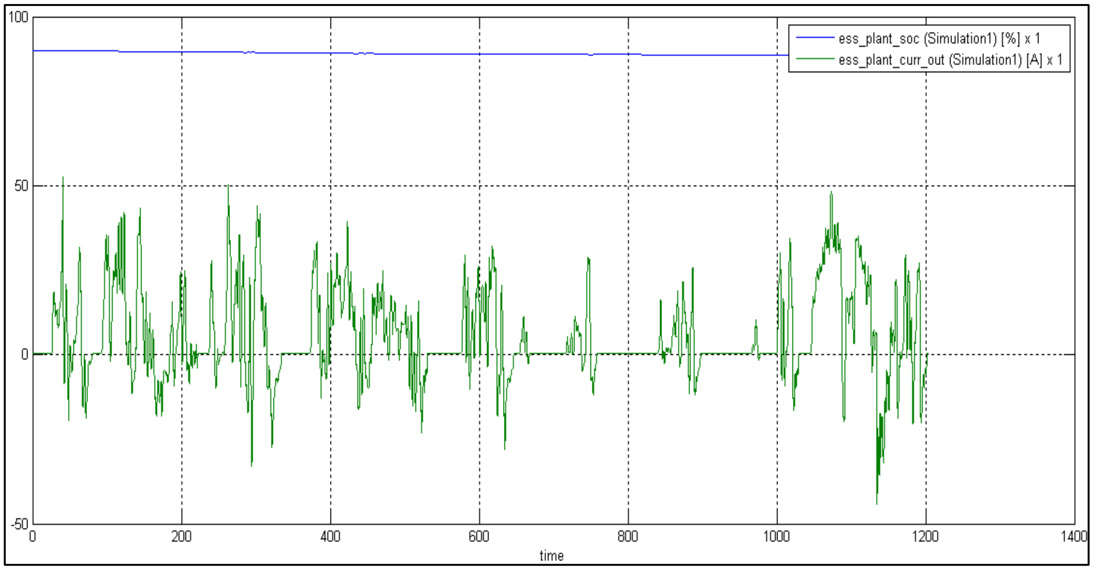

Figure 7.27: Autonomie Ford Focus Electric's JC08 Results for Battery current and SOC

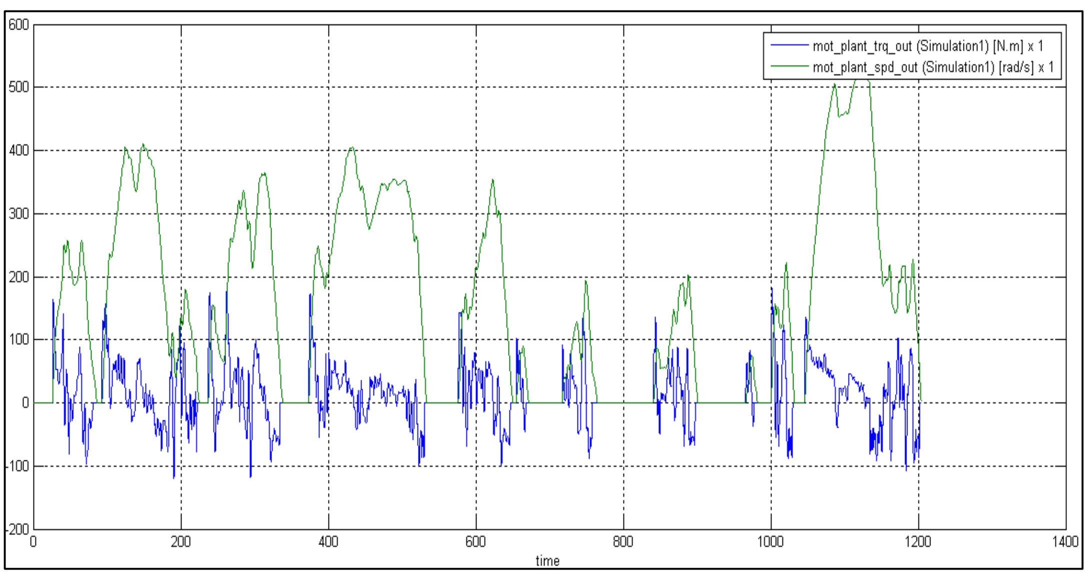

Figure 7.28: Autonomie Ford Focus Electric's JC08 Results for Motor speed and torque

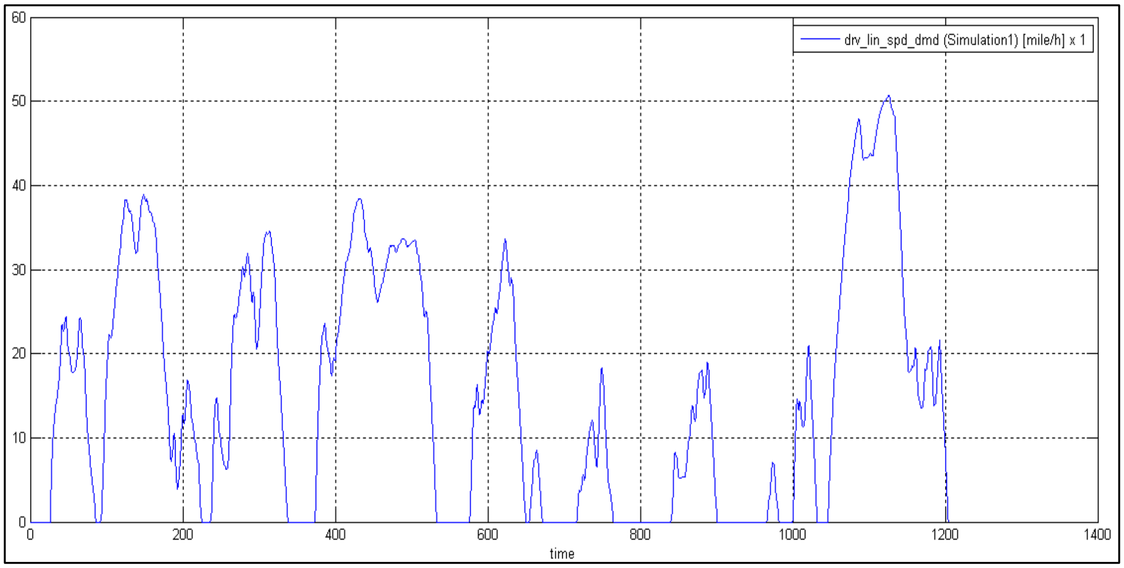

Figure 7.29: Autonomie Ford Focus Electric's JC08 Results for Velocity Profile

FTP 75:

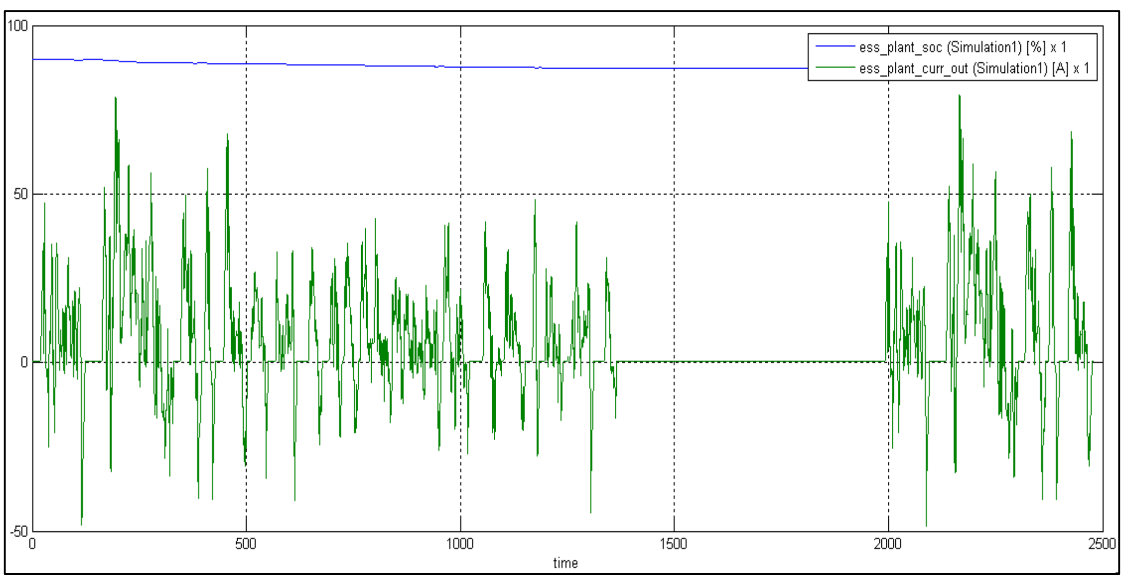

Figure 7.30: Autonomie Ford Focus Electric's FTP 75 Results for Battery Current and SOC

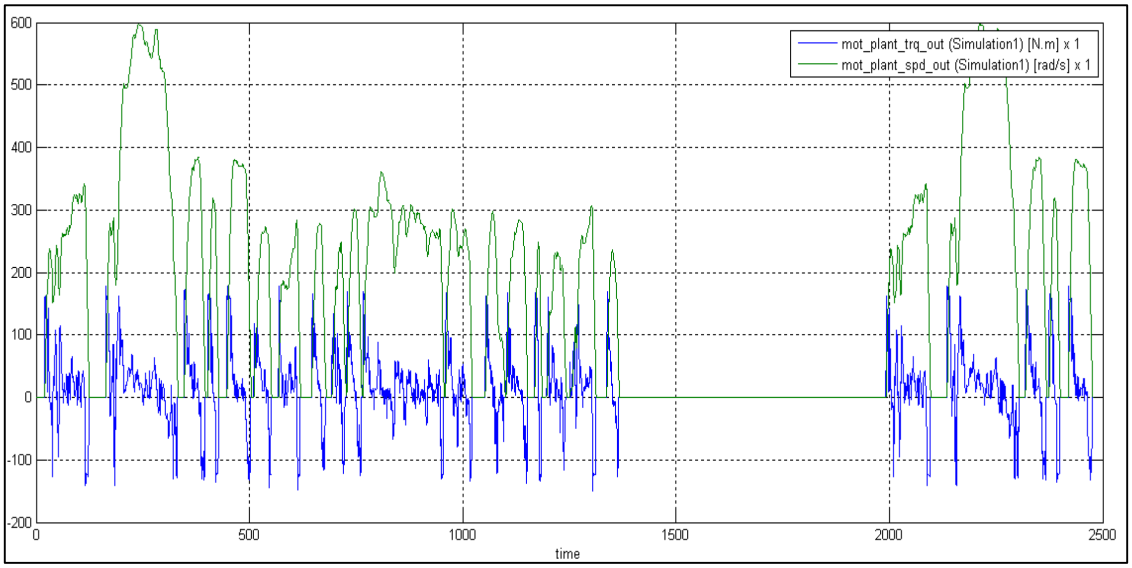

Figure 7.31: Autonomie Ford Focus Electric's FTP 75 Results for Motor Speed and Torque

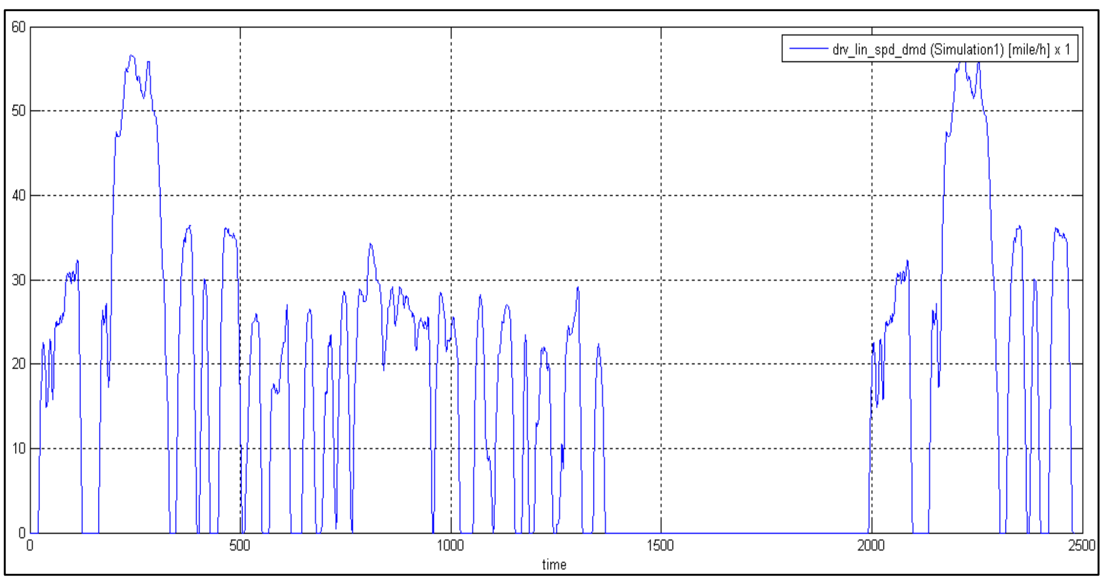

Figure 7.32: Autonomie Ford Focus Electric's FTP 75 Results for Velocity Profile

US06:

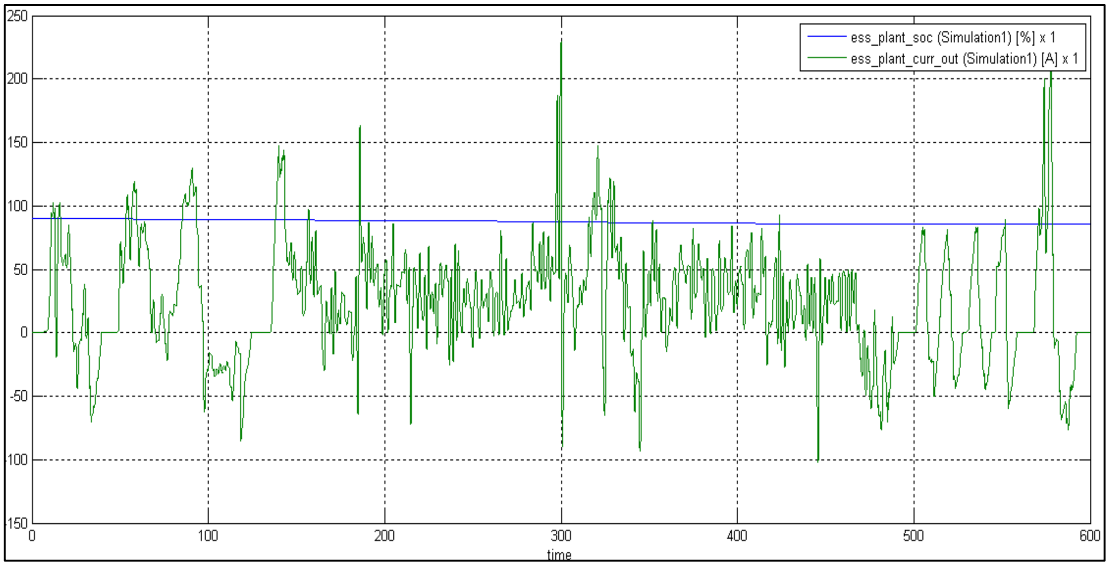

Figure 7.33: Autonomie Ford Focus Electric's US06 Results for Battery current and SOC

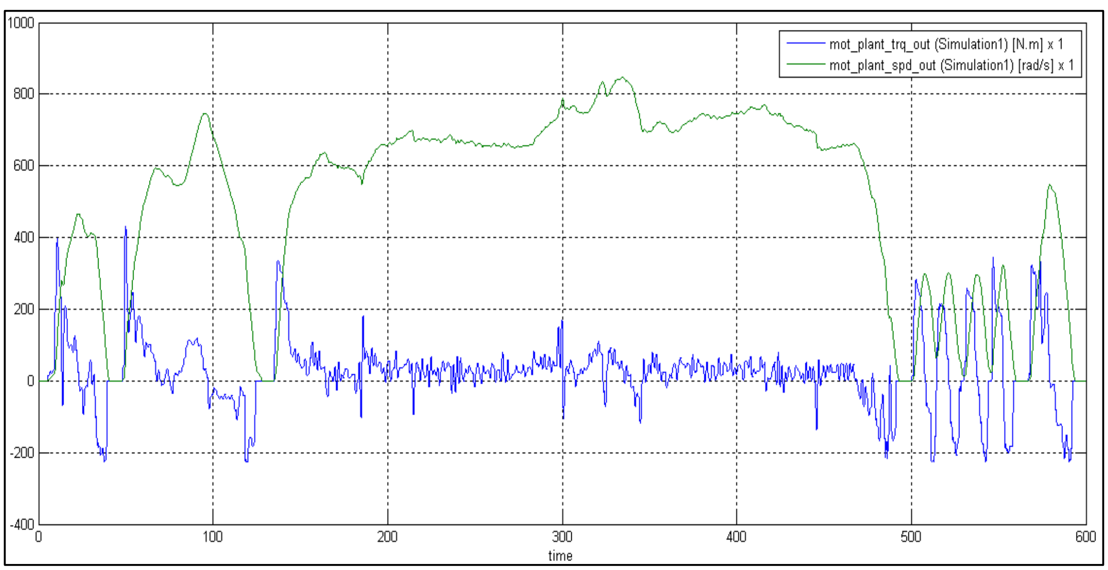

Figure 7.34: Autonomie Ford Focus Electric's US06 Results for Motor speed and torque

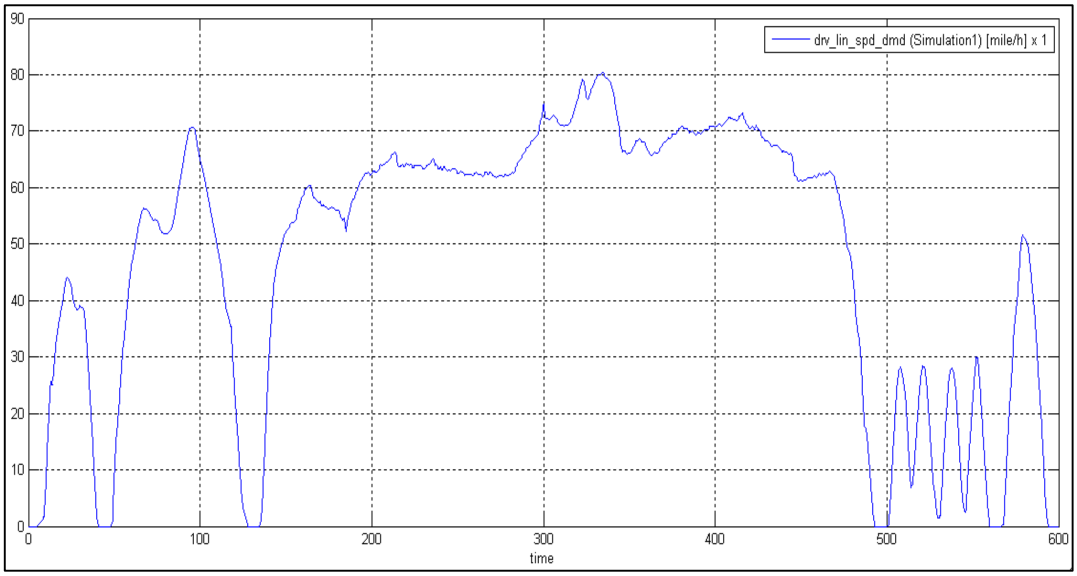

Figure 7.35: Autonomie Ford Focus Electric's US06 Results for Velocity Profile

UDDS:

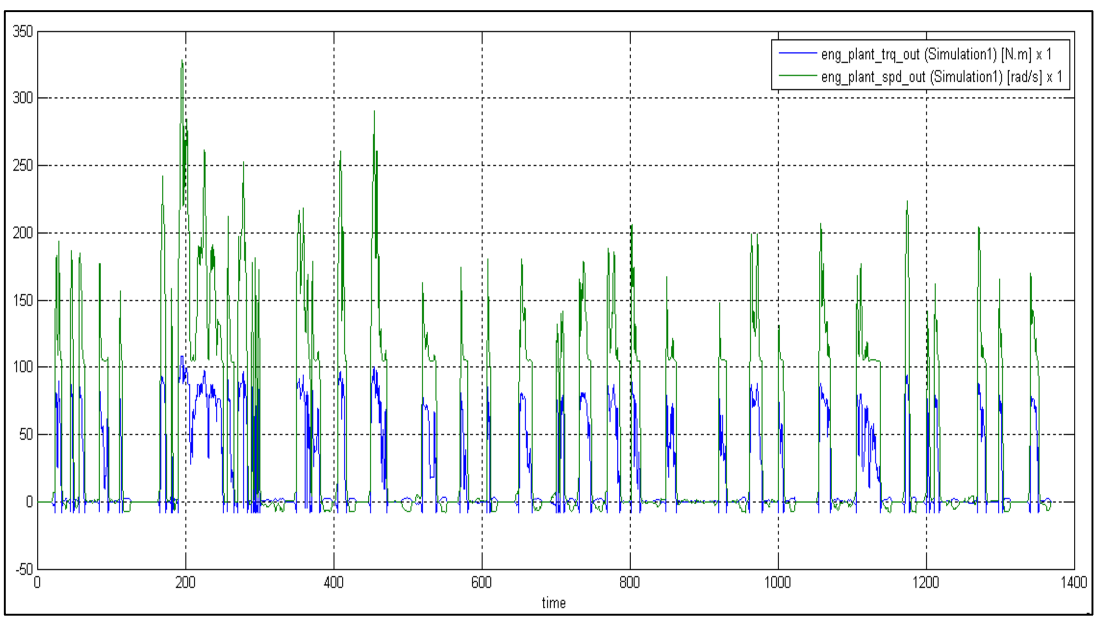

Figure 7.36: Autonomie Toyota Prius' UDDS Results for Engine Speed and Torque

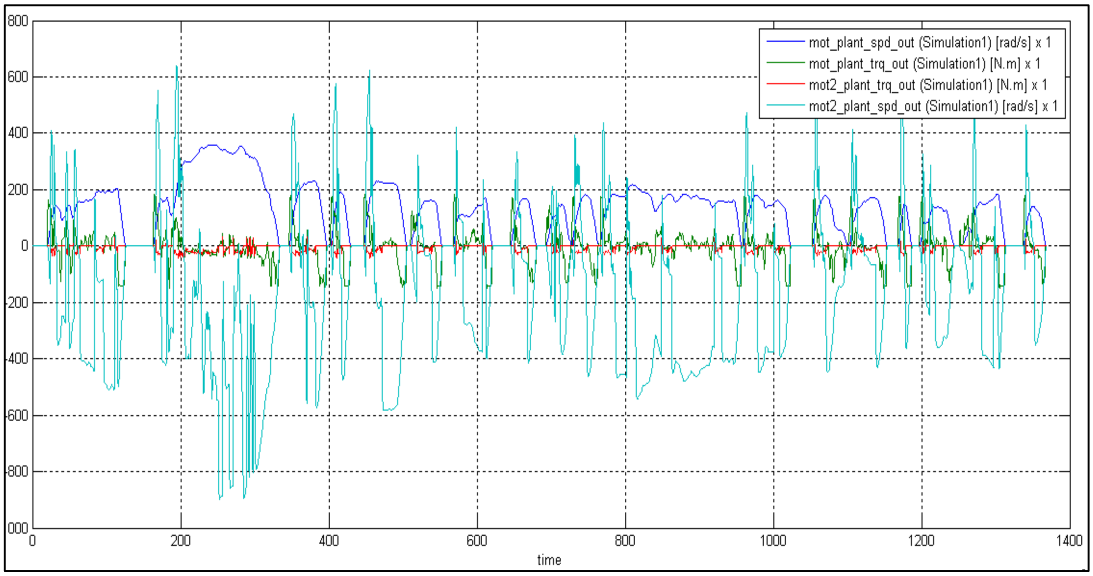

Figure 7.37: Autonomie Toyota Prius' UDDS Results for Motors' speed and torque

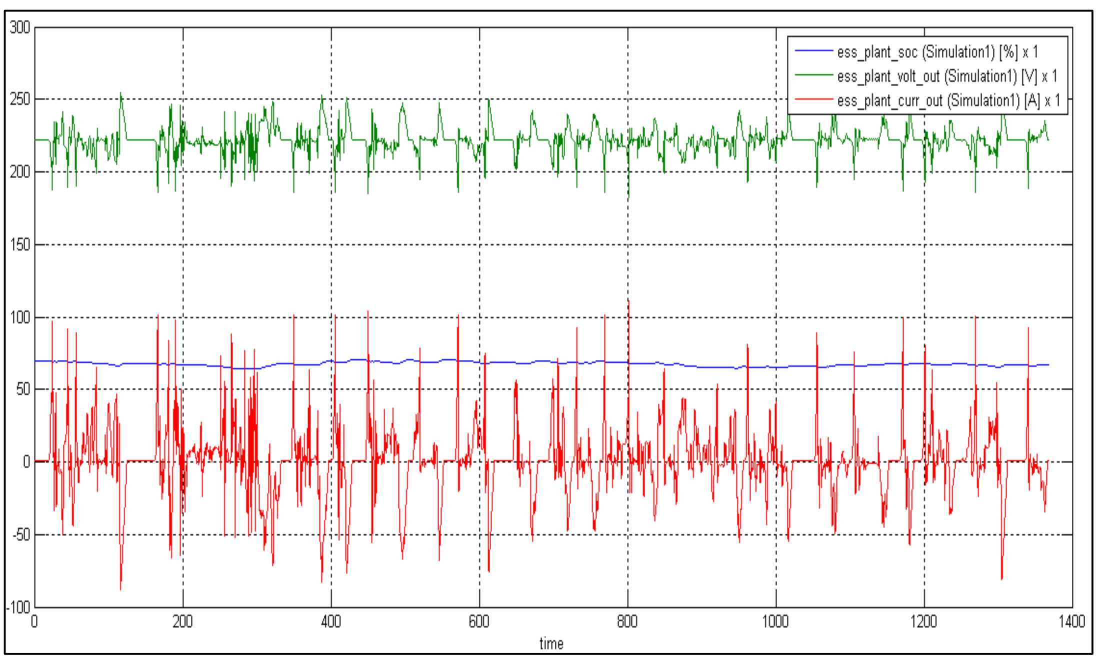

Figure 7.38: Autonomie Toyota Prius' UDDS Results for Battery SOC, voltage and current

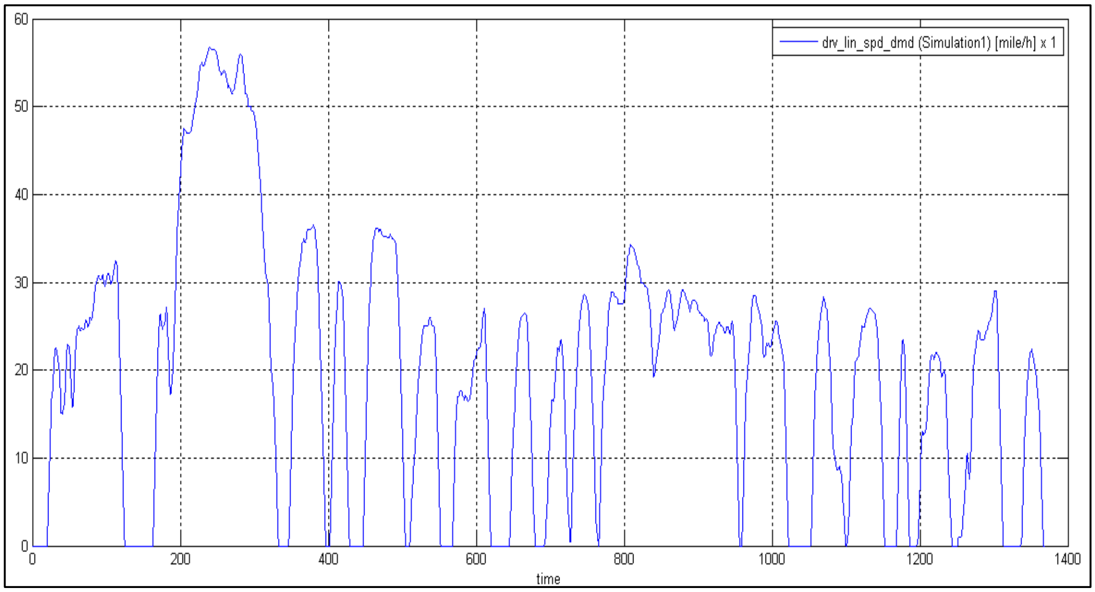

Figure 7.39: Autonomie Toyota Prius' UDDS Results for Velocity Profile

NEDC:

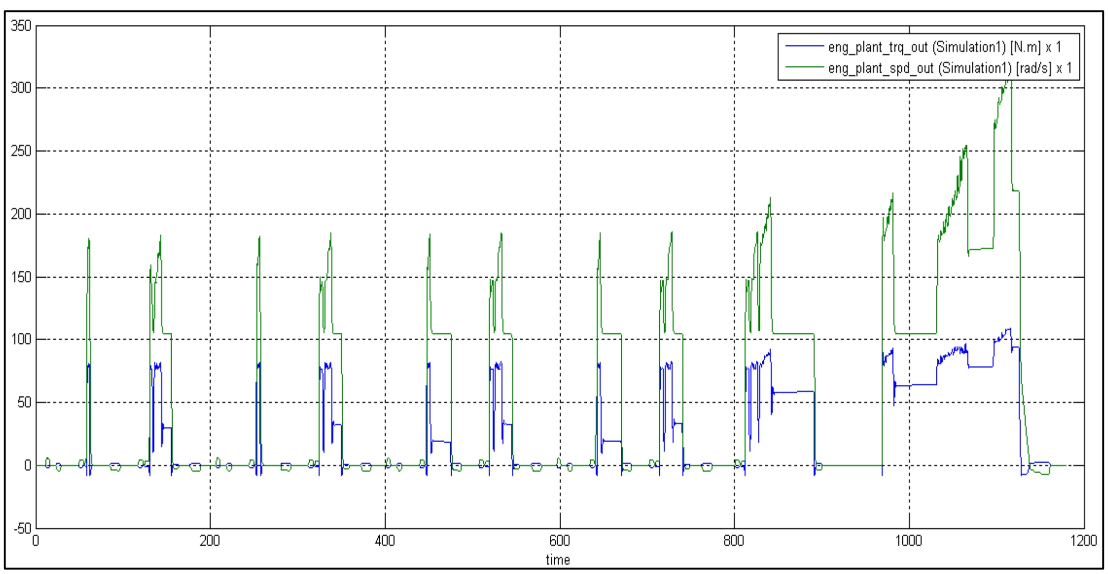

Figure 7.40: Autonomie Toyota Prius' NEDC Results for Engine speed and torque

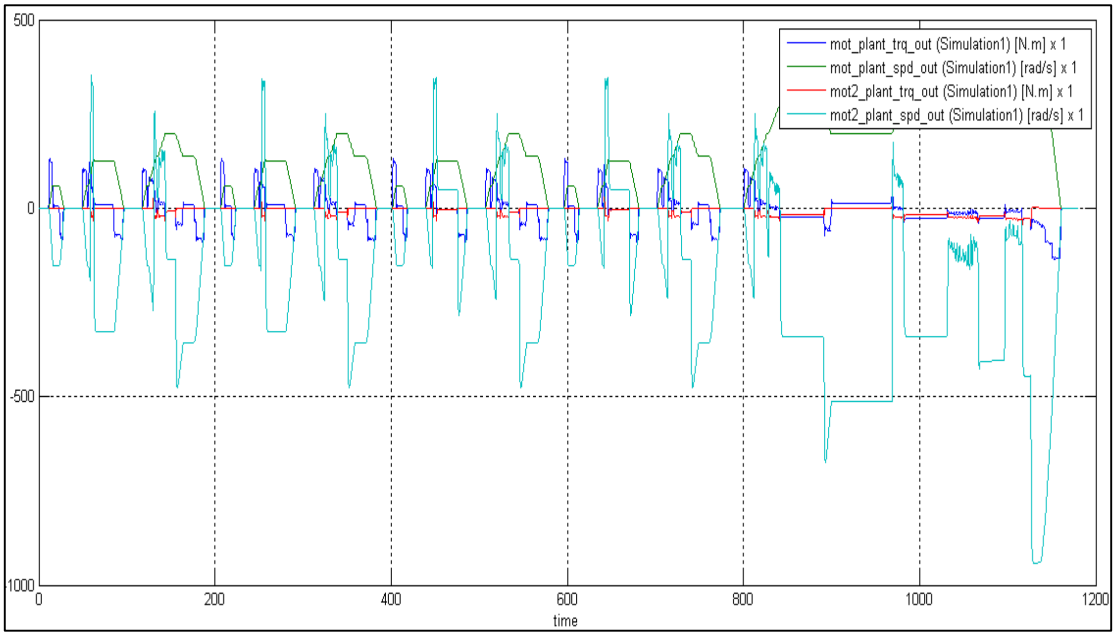

Figure 7.41: Autonomie Toyota Prius' NEDC Results for Motors' speed and torque

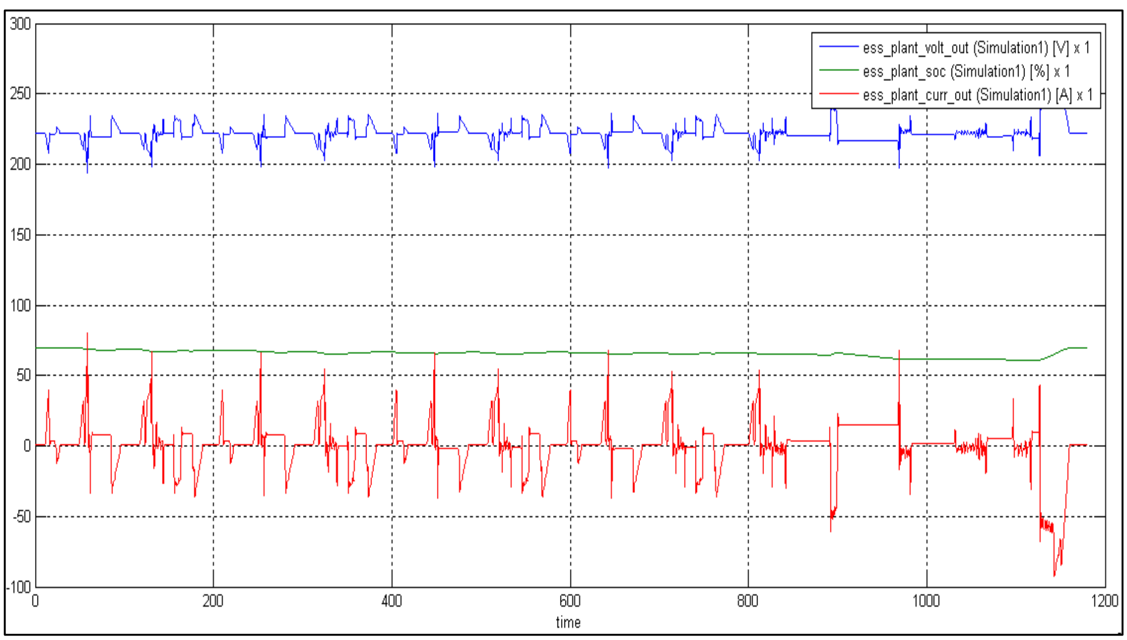

Figure 7.42: Autonomie Toyota Prius' NEDC Results for Battery SOC, voltage and current

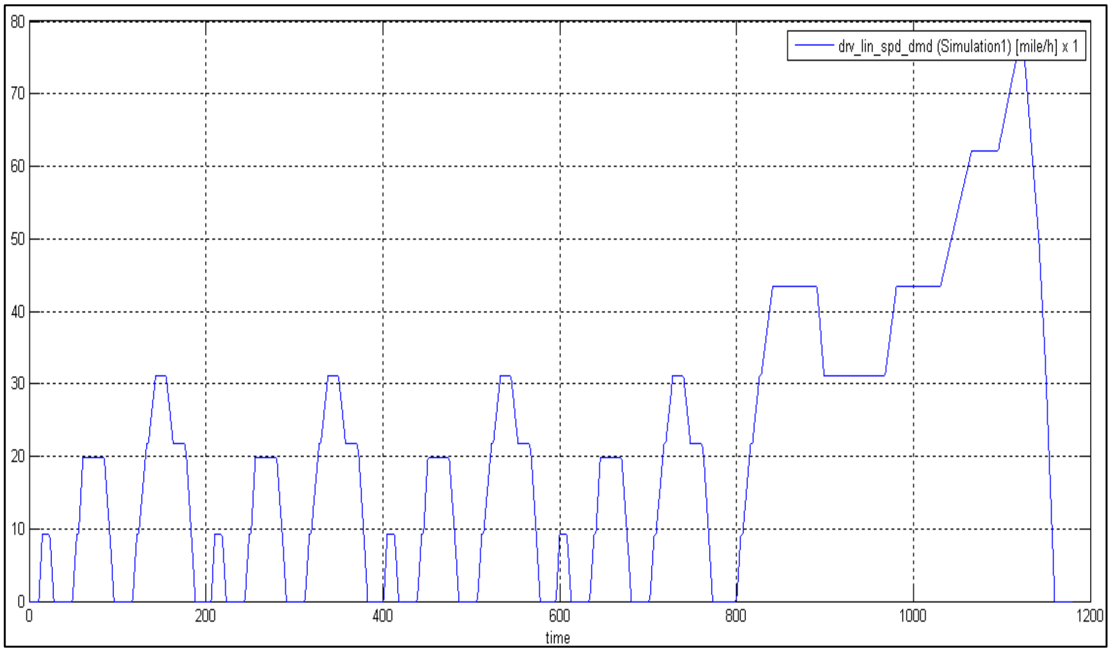

Figure 7.43: Autonomie Toyota Prius' NEDC Results for Velocity Profile

JC08:

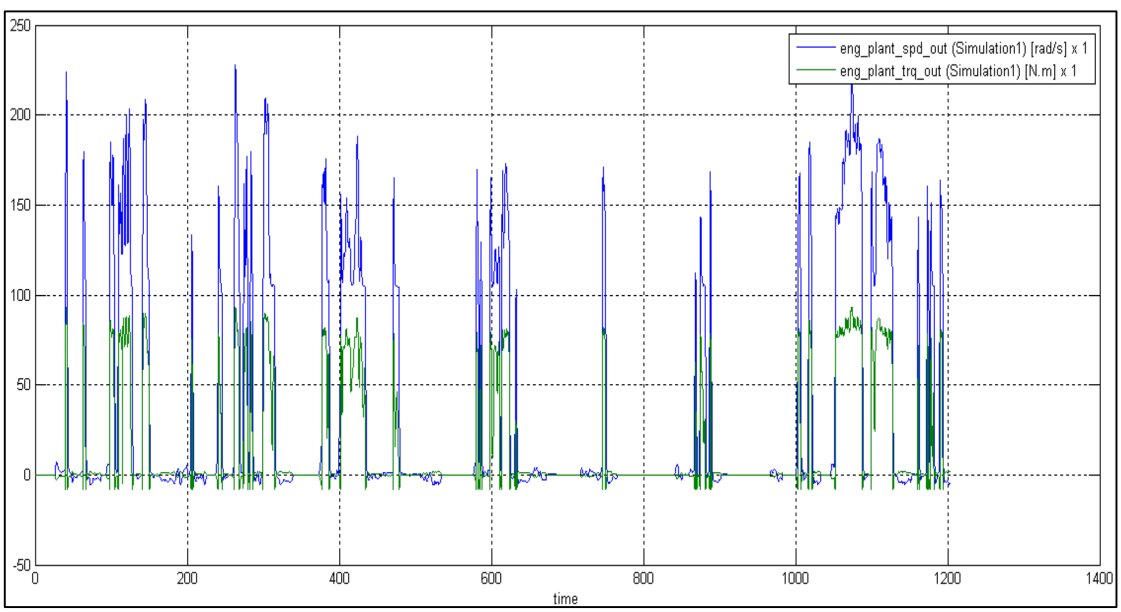

Figure 7.44: Autonomie Toyota Prius' JC08 Results for Engine speed and torque

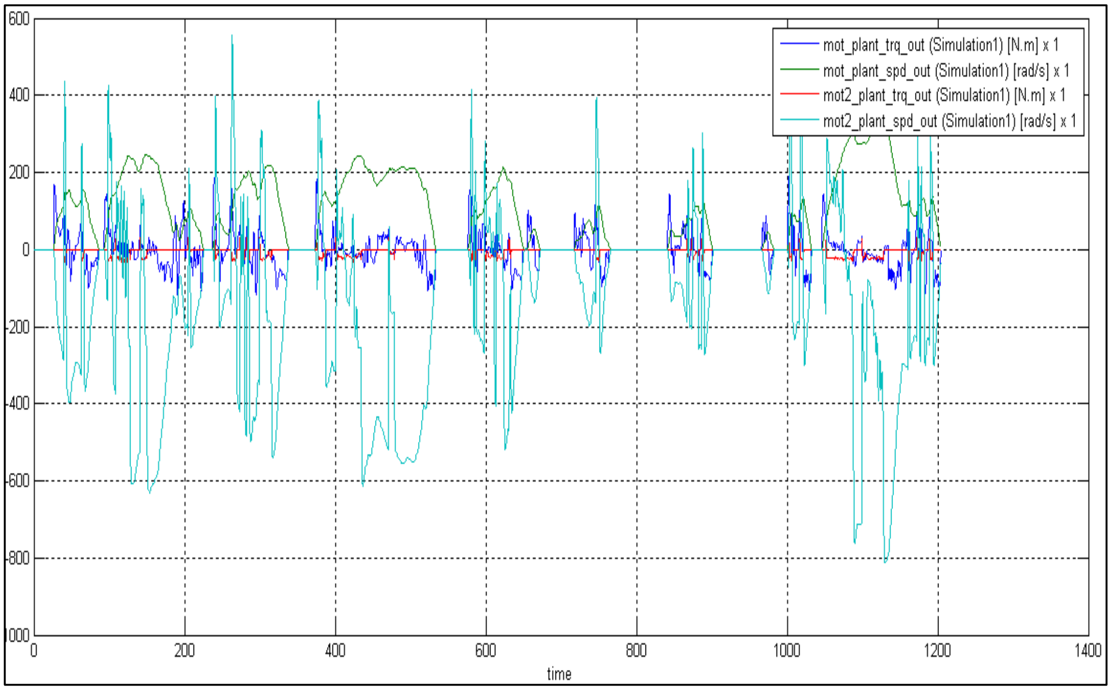

Figure 7.45: Autonomie Toyota Prius' JC08 Results for Motors' speed and torque

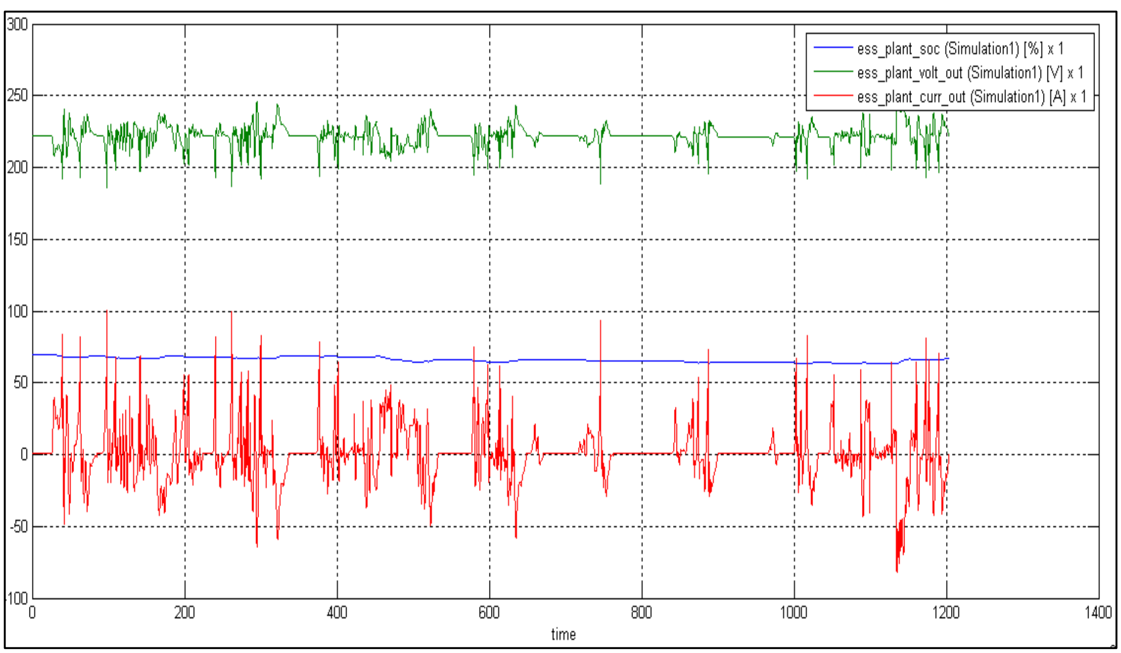

Figure 7.46: Autonomie Toyota Prius' JC08 Results for Battery SOC, voltage and current

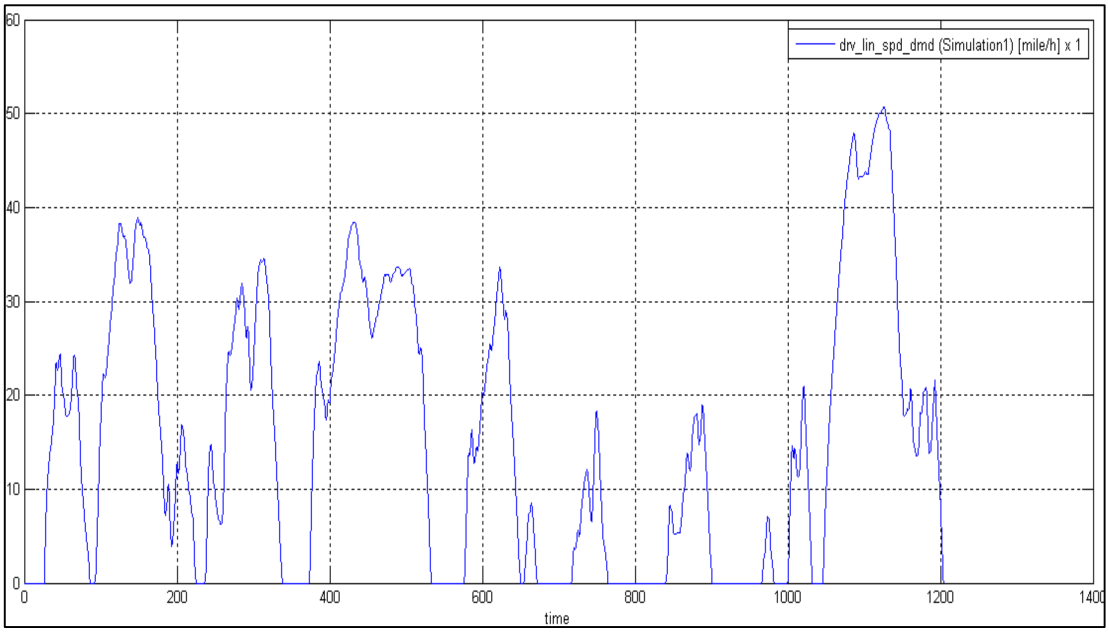

Figure 7.47: Autonomie Toyota Prius' JC08 Results for Velocity Profile

FTP75:

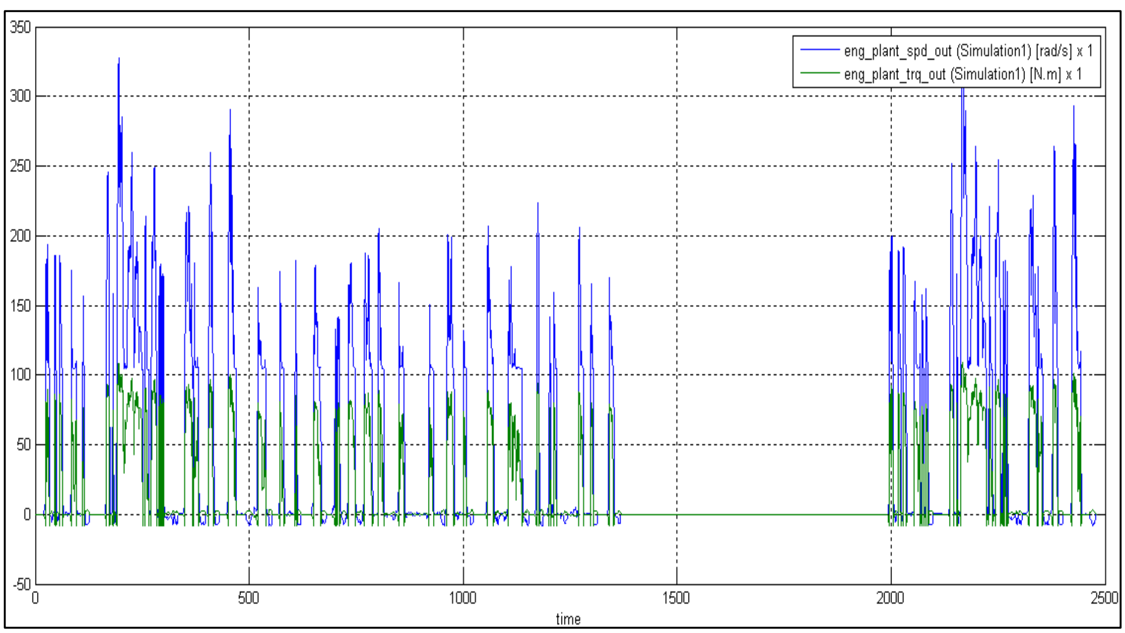

Figure 7.48: Autonomie Toyota Prius' FTP75 Results for Engine speed

and torque

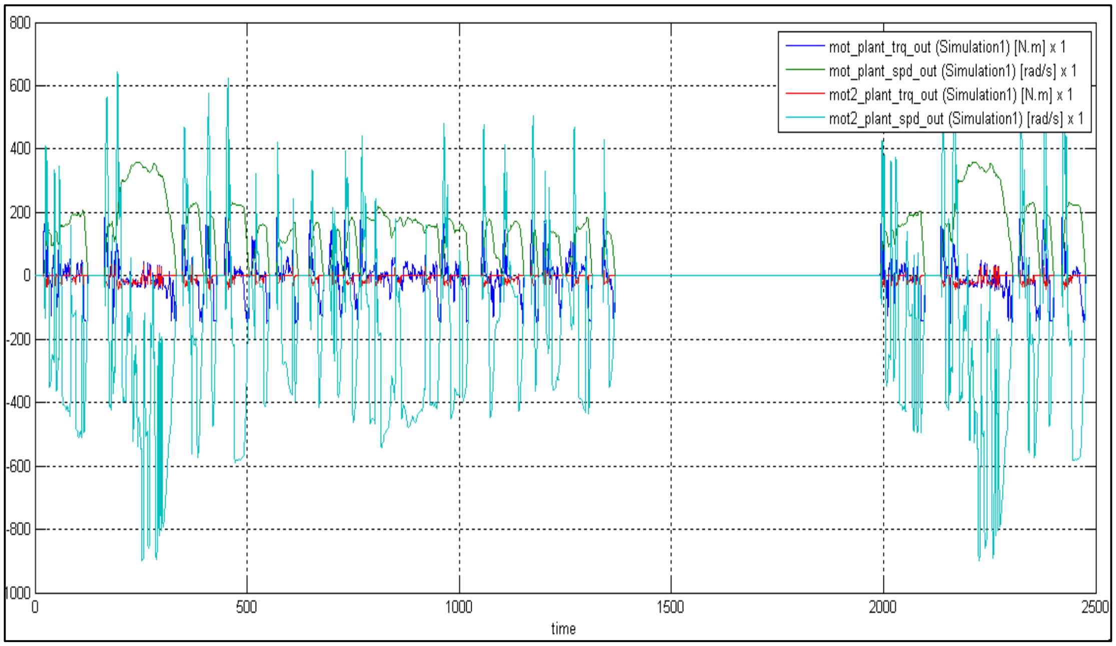

Figure 7.49: Autonomie Toyota Prius' FTP75 Results for Motor speed and torque

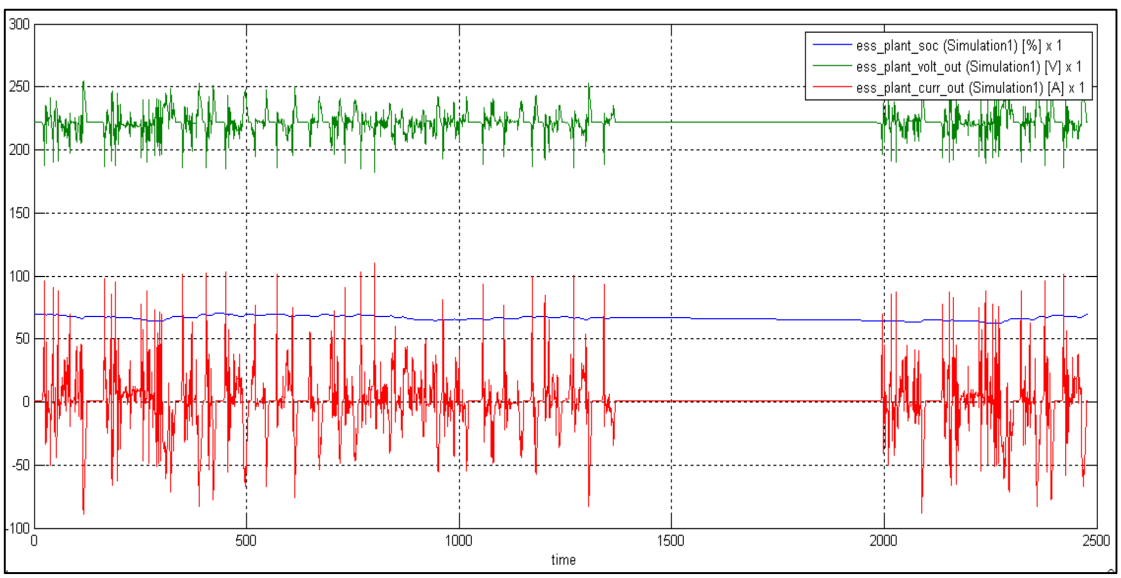

Figure 7.50: Autonomie Toyota Prius' FTP75 Results for Battery SOC, voltage and current

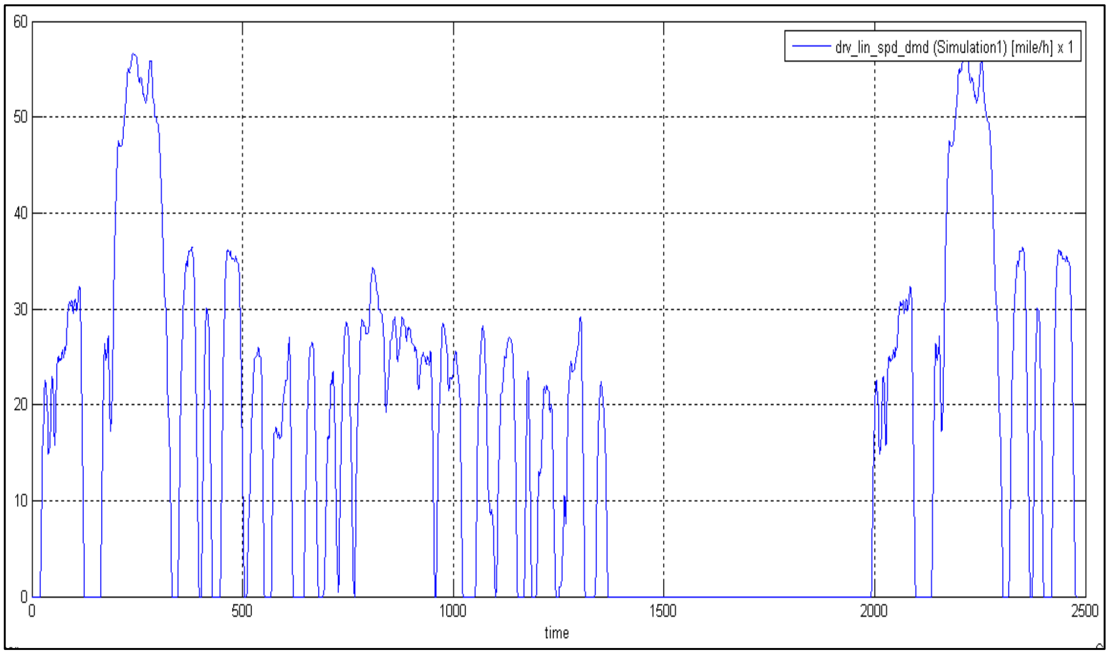

Figure 7.51: Autonomie Toyota Prius' FTP75 Results for Velocity Profile

US06:

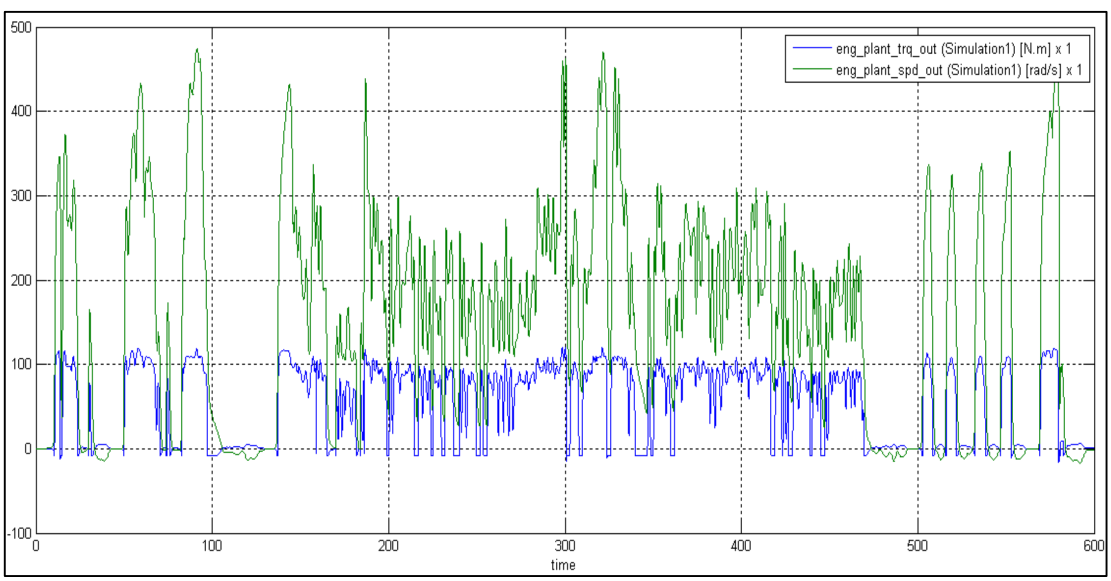

Figure 7.52: Autonomie Toyota Prius' US06 Results for Engine speed and torque

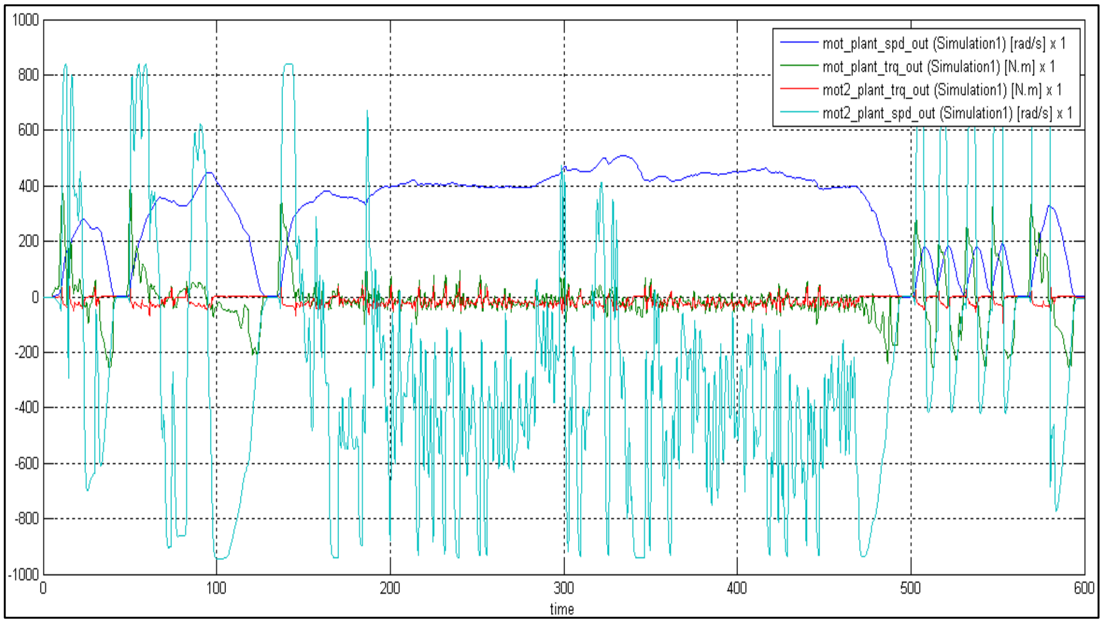

Figure 7.53: Autonomie Toyota Prius' US06 Results for

Motors' speed and torque

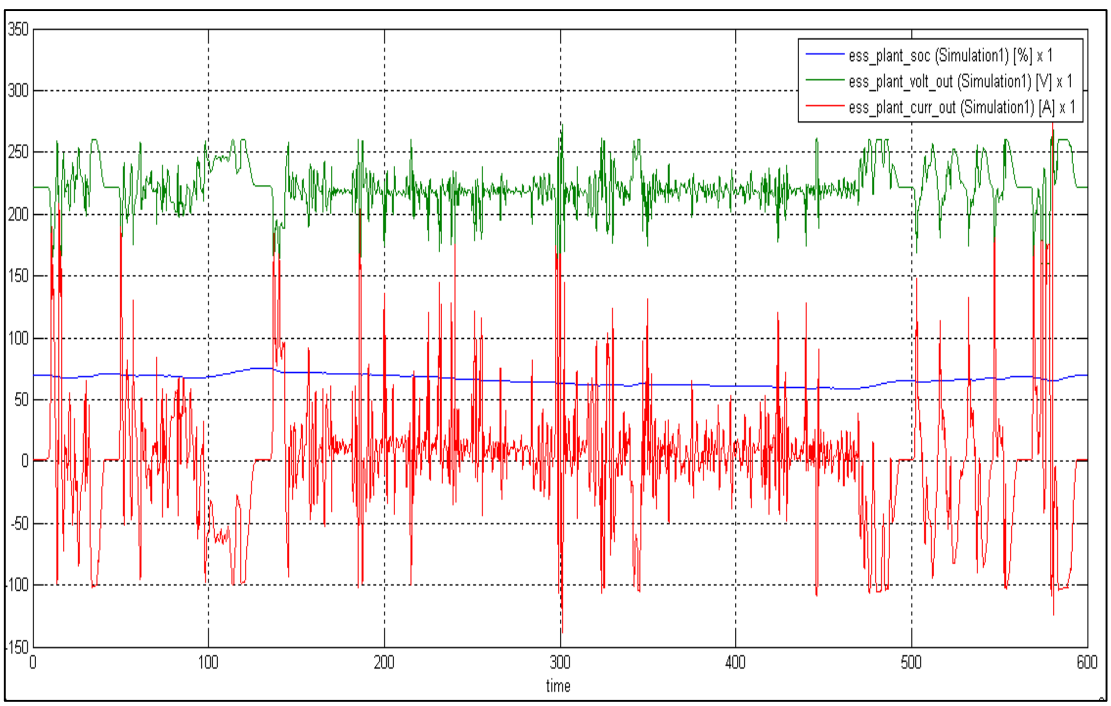

Figure 7.54: Autonomie Toyota Prius' US06 Results for Battery SOC, voltage and

current

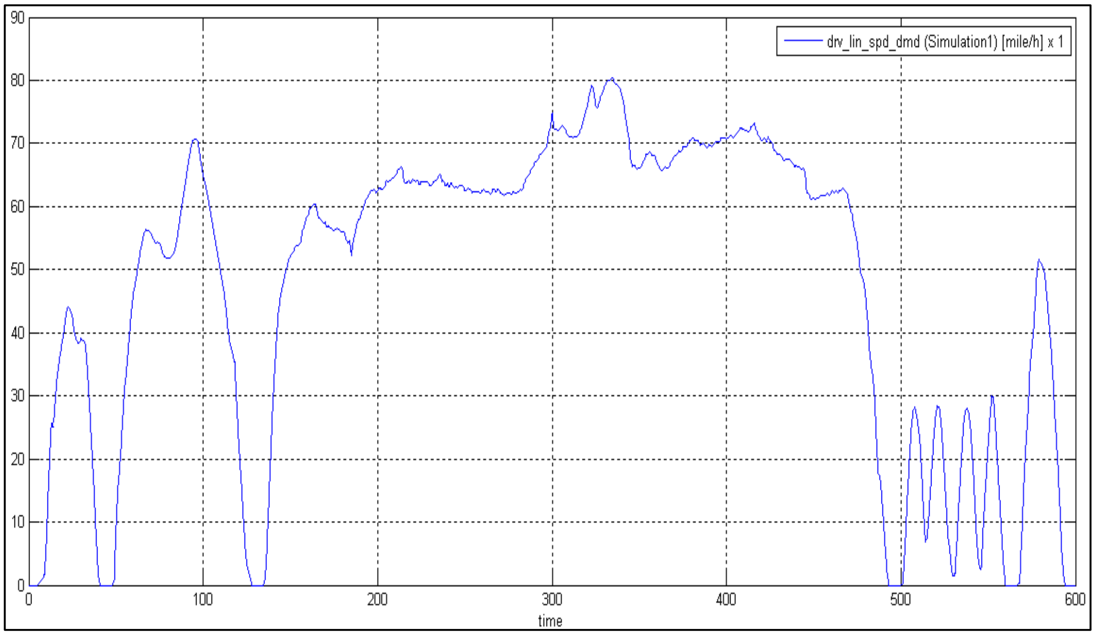

Figure 7.55: Autonomie Toyota Prius' US06 Results for Velocity Profile

Appendix D

This Appendix provides the true CAN data logger results for Toyota Prius

Time (s) Prius	Absolute Load Value[%]	Board Temperature [degC]	Engine_RPM [rpm]	GPS_Alt_Metres	GPS_Lat_Deg	GPS_Lon_Deg	GPS_Speed_Kph	HVBatt_Current[Amps]	HVBatt_SOC [%]	HVBatt_Voltage [Volts]
7.11	17.2549	11	1296	0	0.0000	0.0000	0	4	67.0588	224
75.12	16.4706	19	1302.25	81	43.2561	-79.9022	0	2	65.0980	214
143.94	16.4706	23	1292.75	77	43.2561	-79.9023	0	6	62.7451	204
203.90	16.0784	25	1303.75	77	43.2558	-79.9019	0	4	60.3922	202
258.83	16.8627	27	1200.75	76	43.2574	-79.9015	0.57	-15	59.2157	228
307.84	15.6863	28	1307.75	72	43.2601	-79.8977	0.03	2	61.1765	220
354.95	16.4706	30	1130.25	73.81	43.2602	-79.8907	53.65	-7	61.5686	236
402.96	54.5098	31	1864	79.56	43.2589	-79.8847	22.28	1	63.1373	232
450.94	15.2941	32	1100.75	91.03	43.2574	-79.8775	43.18	-8	63.1373	242
498.97	15.6863	33	1002.25	85.3	43.2560	-79.8719	43.11	-7	64.7059	248
563.89	42.7451	34	1190.5	82.81	43.2549	-79.8672	21.05	1	65.4902	236
636.01	0.0000	35	0	66.97	43.2524	-79.8579	35.83	22	63.5294	204
703.05	56.8627	36	1684.25	66.09	43.2497	-79.8475	45.36	-5	60.0000	216
753.04	0.0000	36	0	64.38	43.2478	-79.8400	20.57	6	61.9608	228
812.24	0.0000	37	0	59.86	43.2514	-79.8412	30.73	-10	64.7059	256
863.03	38.0392	37	1187.5	60.28	43.2519	-79.8471	46.76	2	65.4902	240
930.96	47.4510	38	1213.25	66.23	43.2487	-79.8505	49.58	2	65.8824	236
983.97	56.8627	38	2207.75	80.11	43.2452	-79.8531	48.16	-14	65.4902	246
1067.29	34.9020	38	1153.75	86.8	43.2462	-79.8584	50.33	0	66.6667	234
1115.99	49.4118	38	1571	116.56	43.2448	-79.8560	57.92	6	65.8824	230
1167.12	51.3725	39	1941.25	133.48	43.2415	-79.8465	65.39	3	65.0980	228
1224.09	0.0000	39	0	167.53	43.2367	-79.8436	43.97	-16	65.4902	246
1315.02	40.3922	39	1132	159.03	43.2351	-79.8369	24.86	33	63.9216	196
1383.09	40.7843	39	2407.75	158.66	43.2282	-79.8391	15.63	42	60.3922	182
1429.34	0.0000	40	0	165.91	43.2297	-79.8460	55.78	-36	61.5686	250
1515.11	47.8431	40	1278.75	177.83	43.2316	-79.8537	59.52	0	61.9608	224
1577.13	47.8431	40	1578.75	172.45	43.2339	-79.8628	7	2	63.5294	224
1657.38	56.0784	40	1923.25	168.63	43.2352	-79.8680	29.87	0	63.9216	232
1761.10	0.0000	40	0	172.55	43.2376	-79.8775	0.03	55	63.5294	192
1841.41	38.8235	40	1187.5	175.59	43.2387	-79.8819	9.49	1	63.9216	226
1917.20	0.0000	41	0	167.89	43.2393	-79.8888	18.53	0	63.1373	224

Time (s) Prius	Input Voltage [mV]	LongTermFuelTrim_B1	MAF[g/s]	Motor1 Speed[RPM]	Motor1Torque[Nm]	Motor2Speed[RPM]	Motor2Torque[Nm]	Outside_Air_Temp[degC]	ShortTermFuelTrim_B1	Veh_Speed[kph]
7.11	14175	-4.6875	3.39	4641	0	-3	0	-2	-12.5	0
75.12	14132	-4.6875	3.09	4678	0	0	0	-2	1.5625	0
143.94	14075	-4.6875	3.1	4934	0	-106	-46.875	-1	1.5625	2
203.90	14075	-4.6875	3.07	4641	0	3	0	-1	0.78125	0
258.83	14075	-4.6875	3.04	443	0	1490	-53.125	-2	-10.9375	44
307.84	14132	-4.6875	3.04	4685	0	-2	1.625	-2	-2.34375	0
354.95	14132	-4.6875	2.7	-113	0	1595	-26	-2	-7.03125	43
402.96	14132	-1.5625	15.68	3722	-22.125	1255	57.25	-2	1.5625	34
450.94	14132	-5.46875	2.32	-325	0	1552	-26	-2	-3.90625	42
498.97	14132	-5.46875	2.37	-169	0	1481	-26	-2	-5.46875	39
563.89	14075	-3.90625	7.67	1071	-16.75	1235	14.875	-1	0	31
636.01	14175	-5.46875	0.09	-3454	0	1331	57.625	-2	0	36
703.05	14175	-2.34375	14.15	1682	-24	1765	7.25	-2	-0.78125	50
753.04	14132	-5.46875	0.1	-1883	0	727	31.75	-2	0	20
812.24	14075	-5.46875	0.09	-1126	0	435	-123.625	-2	0	23
863.03	14132	-4.6875	6.56	-447	-14.625	1744	-2.875	-2	0	48
930.96	14075	-4.6875	8.57	-214	-20	1758	-2.625	-2	0.78125	48
983.97	14132	-1.5625	18.65	2537	-35.5	1908	-13	-2	-3.125	51
1067.29	14075	-4.6875	6.01	-828	-13.5	1918	-10.375	-2	-3.125	54
1115.99	14132	-2.34375	11.54	278	-19.375	2107	9.25	-2	0.78125	57
1167.12	14075	-1.5625	14.84	787	-22.875	2427	7.75	-3	-0.78125	66
1224.09	14075	-5.46875	0.75	-3903	0	1507	-68.75	-3	0	42
1315.02	14175	-2.34375	7	3073	-3.25	797	145.625	-3	0.78125	18
1383.09	13989	0	8.21	3965	-5.5	762	174.25	-3	3.125	17
1429.34	14032	-5.46875	0.2	-4126	0	1592	-119.125	-3	0	48
1515.11	14075	-3.90625	10.76	-350	-20.25	2235	-6.875	-3	-1.5625	60
1577.13	14075	-3.125	10.18	3399	-20.5	728	90.625	-3	0.78125	15
1657.38	14075	-1.5625	16.12	2319	-24.5	1802	20.875	-3	-2.34375	47
1761.10	14132	-3.90625	0.09	1464	24.875	409	256.125	-3	0	4
1841.41	14032	-4.6875	7.03	485	-15.5	1466	2.125	-3	-1.5625	39
1917.20	14075	-5.46875	0.15	-1640	0	622	-11.125	-3	0	17

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