Statistical Analysis of Driver Behaviour and Eco-Driving model based on CAN bus Data

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Abstract

The objective of this thesis is to analyse driving behaviour and to characterize the effects of an efficient way of driving, termed eco-driving, that enables the driver to reduce fuel consumption and CO₂ emissions.

The approach used to assess driving style is a collection of data from a CAN bus of a car equipped with OBD-II (on-board diagnostic) system. The driving experiment was performed for nine drivers who drove in a normal way or regular driving style and one driver was an eco-driver who drove in an economical driving style. The driving route was approximately 18.7 kms (which took between 25 to 30 minutes) in Halmstad city, Sweden.

The drivers are compared based on driving parameters such as, speed, accelerator (gas pedal) and brake pressure, which are obtained from CAN bus data. Furthermore, a hierarchical clustering algorithm also used to classify the drivers based on the average value of the signals.

The results show the average speed for the eco-driver lower than the normal drivers and the gas pedal usage also indicates a direct relationship with the speed profile. However, the brake pressure result demonstrates the eco-driver and some normal drivers braked more frequently due to the traffic situations.

Keywords: Fuel consumption, Drivers’ behaviour, Eco-driving, Relevant driving parameters, Clustering
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Chapter 1

Introduction

Previous researches have described several factors influencing fuel consumptions. As discussed in some papers, factors such as: driving style, road type, traffic situation, vehicle choice, type of fuel, tyre pressure and use of electrical equipments such as air conditioner, heater and audio system while driving have an influence on fuel consumption [1] [2]. It was also explained that almost 82% of fuel wasted by heat lost by the engine and the remaining 18% consumed by mechanical energy out of motor such as rolling friction, rolling drag and powering acceleration. According to the report, the driver can reduce the influence caused by mechanical energy out of the motor [2]. On the other hand, several studies have proved that driving style has an impact on fuel consumption and CO$_2$ emissions [3] [4] [5]. According to [5] report, efficient drivers can save from 5 to 10% of fuel. The other related study has described that a driving style can affect fuel economy and CO$_2$ emissions based on an experiment results on diesel cars for different drivers [3]. One way to solve the problem is changing driving behaviour by following a smart and smooth way of driving called eco-driving, which is a fuel efficient driving style [6]. An eco-driver reduces 14% of fuel and CO$_2$ emissions and an aggressive driver increases the fuel consumption up to 40% [3].

Eco-driving was started in the United States [7], however, it originated in Finland, and was translated and adapted by the National Association of Swedish Driving Schools (STR) at the end of 1998 [8]. The main purpose of eco driving is to change driver behaviour by offering useful advice or tips for driving styles such as: shift up early, maintain steady speed, anticipate traffic flow, accelerate and decelerate smoothly [9] [7][10].

Although many other related works are done and ongoing about driving behaviour and eco-driving style, it is still interesting to do more analysis and investigation in this area to understand how to use fuel efficiently. In this thesis, the analysis of driving behaviour is based on relevant signals collected from CAN bus information of a vehicle. To gather data, driving experiments were done for nine normal drivers and one eco-driver. The main goal is to characterize the driving style in terms of relevant features of the CAN bus.

1.1 Problem Description

The following issues will be addressed in this study:

- Communication with a car

Since a car has a lot of sensors which generate data, we could access the data through a CAN bus, which is one of the protocols in an on-board diagnostics (OBD-II) system found in the car [10]. Thus, we need to have a device that communicates with the CAN bus in order to communicate with the car.

- Determine relevant signals from a CAN bus data that can be influenced by driving style. One of the objectives of this work is to find parameters related to driving behaviour and fuel consumption according to CAN bus information.

- Identify eco-driving behaviour compared to normal driving.
Chapter 1. Introduction

Eco-driving has been mentioned fuel efficient driving style in the former works. Since the main goal of this study is to characterize the driving behaviour in terms of fuel consumption, we will look into the driving style of an eco-driver compared to normal drivers based on the features of the CAN bus data.

1.2 Research questions

To describe the driver based on the data collected from a CAN bus of the car and to determine whether the driving is a fuel efficient driver or not, the following research questions will be raised:

• What are the parameters used to characterize driving behaviour in terms of fuel consumption in the previous studies?

• What are the relevant features from the CAN bus related to driving behaviour?

• Is there a difference between eco-driving style and normal driving in terms of the CAN bus features and fuel consumption?

1.3 Scope

Some limitations of this study have impacted on the result and the desired goal. Those limitations relate to the factors which may have influenced fuel consumption and driving behaviour. Those factors are:

• The data collection process did not use any device to measure the actual fuel consumption, so it was a bit difficult to determine the actual fuel consumption of the drivers.

• Vehicle choice (only one vehicle used in the experiments) including the tyre type.

• Air conditioner, heater and audio system (the same setup for all drivers except the radio in the car was switched off during one of the experiments).

• The car used for the experiment was a Volvo car S60 with an automatic gearbox, so it was impossible to test one of the eco-driving tips such as, shift up before 2,000-2,500 RPM (Revolutions per minute = engine speed) which works only in a car with a manual transmission.

1.4 Thesis Structure

The thesis is organized in the following manner: Section 2 describes the background knowledge of the thesis; related work is in section 3; Section 4 describes the methods which have been used in this thesis; the results and analysis are depicted in Section 5; Section 6 contains the conclusions and finally, Section 7 deals with possible future work.
Chapter 2

Background

2.1 Eco-driving

Eco-driving is a driving style to promote fuel efficiency and traffic safety as well as to keep the environment healthy by reducing CO\textsubscript{2} emissions. An engine speed from 1,200 to 2,500 revolutions per minute (RPM), saves 5 to 10 % of fuel on average [6].

Eco-driving is not a new rule to apply as a new way of driving rather it is a skill to be integrated into a normal way of driving [11]. Moreover, several works have described golden rules which are commonly used by an eco-driver[9] [6] [11].

**Look ahead and anticipate the traffic flow**

One of the golden rules of eco-driving is a technique of reading the road as far ahead as possible and anticipating the surrounding traffic flow to drive at a steady speed and to avoid unnecessary braking.

**Maintain a steady speed at low RPM (Revolutions per minute)**

This is a method of driving smoothly at low engine speed using the highest gear possible, because to drive at a high speed and use high RPM increase fuel consumption.

**Shift up as soon as possible**

Eco-driving rules recommend that a driver shifts into high gear around 2500 RPM in a petrol car and 2,000 RPM in a diesel car, without forgetting the traffic situations and vehicle specification.

**Accelerate and Decelerate smoothly by releasing the accelerator in time**

This technique of eco-driving style has a positive impact on both fuel consumption and CO\textsubscript{2} emissions.

**Check tyre pressure frequently**

It is important to check tyre pressures frequently, at least once per a month to avoid the risk of driving with low tyre pressure, which can cause accidents and consume more fuel.

**Check any extra energy requiring waste fuel**

Extra energy in the cars such as the air conditioner and different electrical equipment can cause unnecessary fuel consumption, so it is necessary to use these energy resources when it is required. In addition to the golden rules of eco-driving, silver rules are described in ECOWILL project[11]

- Choose a good vehicle which can save fuel and has a low emission rate
- Avoid using cars for short trips
- Switch off the engine at short stops
- Get rid of unnecessary weight
- Avoid roof racks and roof loads
- Use of low friction oils and low engine tyres
- Choose an alternative transport method

Eco-driving has enormous advantages [11], such as:

- Enhanced road safety and driving skill
• Reduced fuel consumption (5 to 10 %) and CO\textsubscript{2} emissions by 10 to 15%

• Improve traffic safety

• Reduce risk of accidents

• Reduce vehicle repairs and maintenance costs

• Minimize stress and increase comfort

Furthermore, the treatise project [6] mentioned that eco-driving helps to reduce:

• Noise nuisance

• Local air pollutants

• Accident rate and so on

2.2 The role of speed, accelerator pedal position and brake pressure for fuel consumption

In this study, driving behaviour refers to a characteristic of drivers in terms of parameters related to fuel consumption. Those behaviour include speeding, acceleration/deceleration and braking behaviour. Referring to previous studies and from the collected data, we have taken into account parameters which have influenced fuel consumption, such as speed, accelerator pedal position and brake pressure.

2.2.1 Vehicle speed

The pattern of speed in a trip is called the speed profile of a vehicle during that trip, which means a vehicle might be at rest, accelerating, cruising (constant speed) and decelerating in a certain journey [1]. Speed is more important in highway road than in urban according to [2]. One of the eco-driving tip is to drive at a steady speed along the trip [11][6]. Maintaining a constant speed helps to avoid hard acceleration and deceleration behaviour which waste fuel [2]. We have obtained the speed signal from the CAN bus data through the driving experiment to analyse the driving behaviour.

2.2.2 Brake pressure

Brake pressure is also another important signal which we have got from the CAN bus information. The recommendation of eco-driving instruction is to avoid hard braking and instead accelerate and decelerate slowly and smoothly. Moreover, aggressive driving, which is characterized by hard braking and speeding can increase the fuel consumption by 40% [3].

2.2.3 Accelerator Pedal Position

The third selected signal from the CAN bus information is the accelerator (gas pedal), which has also impact on fuel consumption. The previous works recommended that to avoid high usage of gas pedal to save fuel, which indicate that there is a strong relationship between pedal usage and fuel consumption. Accelerator pedal position is also another signal which was available in the CAN bus data and found through the driving experiment.
2.3 OBD-II System

OBD refers to an on-board diagnostics system, which provides vehicle diagnostic information [12]. The standard emerged to meet EPA (Environmental Protection Agency) emission standards, however, after a time, the standard came with different versions and different features such as ALDL, OBD-I, OBD 1.5 [10].

OBD-II is a new OBD standard, which originated in the 1990s to control the engine system, the standard can define the type of diagnostic connector and pin-out and also provide the appropriate vehicles’ parameters. The connector has pins that provide a power to scan tool from the vehicle battery or users can connect a scan tool to the power source directly. The OBD-II specification also provides the female 16-pin (2x8) J1962 connector for interface [12].

All cars that are built after January 1, 1996 have an OBD-II system. There are five basic OBD-II protocols that are commonly used, between the on-board diagnostic computer and the scanner console or tool. Most of the vehicles today use one of these protocols and it is possible to identify the protocol used based on which pins are present on the J1962 connector (figure 2.1). The below table 2.1 describes OBD-II Pin Layout of those connectors [13].

![Figure 2.1: OBD-II Connector](image)

<table>
<thead>
<tr>
<th>Pin</th>
<th>Signal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>J1850 Bus+</td>
<td>J1850 Bus+</td>
</tr>
<tr>
<td>4</td>
<td>CGND</td>
<td>GND</td>
</tr>
<tr>
<td>5</td>
<td>SGND</td>
<td>GND</td>
</tr>
<tr>
<td>6</td>
<td>CAN High</td>
<td>J-2284</td>
</tr>
<tr>
<td>7</td>
<td>ISO 9141-2 K-LINE</td>
<td>Tx/Rx</td>
</tr>
<tr>
<td>10</td>
<td>J1850 Bus-</td>
<td>J1850 Bus-</td>
</tr>
<tr>
<td>14</td>
<td>CAN Low</td>
<td>J-2284</td>
</tr>
<tr>
<td>15</td>
<td>ISO 9141-2 L-LINE</td>
<td>Tx/Rx</td>
</tr>
<tr>
<td>16</td>
<td>+12v</td>
<td>Battery Power</td>
</tr>
</tbody>
</table>

2.3.1 OBD-II PIDs (Parameter IDs) and OBD-II Modes

OBD-II parameter IDs are codes used to request data from a vehicle, and are used as a diagnostic tool. In addition to SAE standard J/1979 PID, many manufacturers have also defined their own PID for their vehicles. These codes are part of SAE standard J/1979, required to be implemented in all cars sold in North America since 1996 [14]. There are
ten modes of OBD-II regardless of the protocol used, as shown below in table 2.2, but it is not mandatory that all vehicles support all the codes [10].

<table>
<thead>
<tr>
<th>Modes(Hexadecimal)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x01</td>
<td>Show current data</td>
</tr>
<tr>
<td>0x02</td>
<td>Show freeze frame data</td>
</tr>
<tr>
<td>0x03</td>
<td>Show stored Diagnostic Trouble Codes</td>
</tr>
<tr>
<td>0x04</td>
<td>Clear Diagnostic Trouble Codes and stored values</td>
</tr>
<tr>
<td>0x05</td>
<td>Test results, oxygen sensor monitoring (non CAN only)</td>
</tr>
<tr>
<td>0x07</td>
<td>Show pending Diagnostic Trouble Codes</td>
</tr>
<tr>
<td>0x08</td>
<td>Control operation of on-board component system</td>
</tr>
<tr>
<td>0x09</td>
<td>Request vehicle information</td>
</tr>
<tr>
<td>0xA</td>
<td>Permanent Diagnostic Trouble codes(DTCs) (Cleared DTCs)</td>
</tr>
</tbody>
</table>

### 2.4 CAN bus

CAN bus is one of the most popular protocols in the automotive industry, which enables different components of vehicles to communicate with each other. It was established by Robert Bosch in 1983 and officially released in 1986. It is the newest protocol added to the OBD-II system[14] [10].

CAN allows communication through Electric Circuit Unit (ECU), which is also decreased in cost and weight since it provides one CAN interface rather than analogue input to every device [15]. The table below 2.3, summarizes a short history of CAN [16].

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>Start of Bosch internal project to develop in vehicle network</td>
</tr>
<tr>
<td>1986</td>
<td>Official introduction of the CAN protocol</td>
</tr>
<tr>
<td>1987</td>
<td>First CAN controller chips by Intel and Phillips</td>
</tr>
<tr>
<td>1991</td>
<td>Bosch publishes CAN specification 2.0</td>
</tr>
<tr>
<td>1992</td>
<td>CAN Application Layer(CAL) protocol by CiA</td>
</tr>
<tr>
<td>1992</td>
<td>CAN Application Layer(CAL) protocol by CiA</td>
</tr>
<tr>
<td>1993</td>
<td>ISO 11898 standard published</td>
</tr>
<tr>
<td>1994</td>
<td>First international CAN Conference (iCC)</td>
</tr>
<tr>
<td>1994</td>
<td>Allen Bradley introduces Device Net</td>
</tr>
<tr>
<td>1995</td>
<td>ISO 11898 amendment (extended frame format)</td>
</tr>
<tr>
<td>2000</td>
<td>Development of time-triggered CAN</td>
</tr>
</tbody>
</table>

### 2.4.1 CAN messages

It is necessary to retrieve the real time information from the car to know the dynamic behaviour of the vehicle, communication between the equipment in the car is transmitted through CAN bus messages.

CAN bus is a broadcast type of message, the entire node in the network can hear the transmitted message, and there is no means that a message sends to a specific node. However, the CAN hardware enables a node to filter the message if it is not relevant.
CAN uses a short message, maximum of 94 bits and the messages are content address messages [17].

The CAN bus data is collected through OBD-II (On Board Diagnosis) which is an important standard for vehicle diagnosis information and reporting. As we mentioned above, CAN bus is one of the five protocols used in OBD-II vehicle diagnostic standard and is a popular protocol in the vehicle industry today.

CAN devices send data across the CAN network in packets called frames. A CAN frame is an entire CAN transmission also known as a CAN message. The basic CAN frame is described in the table below [18].

<table>
<thead>
<tr>
<th>Field</th>
<th>SOF</th>
<th>Arbitration</th>
<th>Control</th>
<th>Data</th>
<th>CRC</th>
<th>ACK</th>
<th>EOF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>11</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>0.64</td>
<td>0</td>
</tr>
<tr>
<td>Value</td>
<td>0</td>
<td>0...2031</td>
<td>0</td>
<td>0</td>
<td>0..8</td>
<td>x</td>
<td>X</td>
</tr>
</tbody>
</table>

Each frame field has the following descriptions:

- **SOF (start of frame) bit:** is the beginning of the frame with length 1 bit and its value is always zero (dominant bit).

- **Arbitration ID:** consists of two fields which are the IDENTIFIER field (11 bits) and RTR (Remote transmission frame) contains only 1 bit. The IDENTIFIER field identifies the message and indicates priority and the RTR field also determines which type of service shall be used and its value is always zero.

- **IDE (Identifier extension) bit:** It has one length field which allows differentiation between Standard and Extended CAN frame.

- **R0:** is a reservation bit for future development. The value can be either dominant or recessive.

- **DLC (Data Length Code):** determines the length of the data in bytes. It has four bits in length and its values in the range of 0 to 8.

- **Data:** is a field which consists of the main data. It contains between 0 to 8 bytes.

- **CRC (Cyclic redundancy check):** It contains 15 bits cyclic redundancy code and contains information related to data security.

- **ACK (Acknowledgement):** is a field used to check if any other nodes except for the transmitter have received an error free message. AS is the Acknowledgement slot which allows the transmitter and the receiver to communicate with each other and realizes if the message is error free or not. AD is also called ACK-Delimiter which determines the end of acknowledgement field by sending a recessive bit.

- **EOF (End of Frame):** consists of seven recessive bits.

In addition, a CAN bus has the following features as described in the manual [15]:
• It is a multi-master protocol
• Is based on OSI layer protocol
• Event triggered protocol, that is messages are transmitted based on certain events.
• The data frame is from 0 to 8 bytes.
• It is up to 1 Mbits/sec at cable length 40m
• Maximum data rate is 40 KBytes/sec
• Excellent error detection capability

There are two specifications of CAN [15]

• CAN 2.0A is also called Basic or Standard and has 11 bit message identifiers which was operated at a frequency of 250Kbit/sec-ISO11519.

• CAN 2.0B is an extension of CAN 2.0A or also known as Extended CAN, contains 29 bits message identifier and used up to 1Mbit/sec-ISO 11898.
Chapter 3

Related Works

Previous studies have investigated the relationship between driving behaviour and fuel consumption. They have also mentioned, eco-driving is one of the techniques used to save fuel and reduce CO\textsubscript{2} emissions.

In this literature review, we have concentrated on papers related to classification of eco-driver and normal drivers. Although most of the papers have discussed the classification of normal drivers in terms of fuel use and driving parameters, a few papers have also compared drivers before and after following eco-driving rules or where drivers were trained in the eco-driving style. We have searched related works using keywords and words such as: classification of eco-driver and normal driver, analysis of eco-driver and normal driver, driver behaviour and fuel consumption etc. The literature search was done using search engines such as Google, IEEE databases, ACE digital library and Science Direct.

The first related paper is a literature review of "Using on-board logging devices to study the longer-term impact of an eco-driving course", which describes the impact of driver behaviour on fuel consumption before and after eco-driving course. They have collected data from the CAN bus of different vehicles using the on-board logging device. The collected data has relevant parameters related to fuel consumption and eco-driving rules such as mileage, number of revolutions per minute, the position of the accelerator pedal and instantaneous fuel consumption. However, they mentioned that CAN bus data can differ from different vehicles manufacturer and model [19]. To prove the effect of eco-driving style on fuel efficiency, an experiment was performed for ten drivers for ten months. By using some statistical analysis methods such as three-way ANOVA and t-test, they compared the drivers before and after the eco-driving course. The result showed that the mean value of fuel reduced by 5.8% for all drivers after the eco-driving course. On the other hand, the experiment also showed that 40% of the drivers can save fuel without taking any eco-driving course.

The paper titled "Using statistical models to characterize an eco-driving style with an aggregated indicator" [20], aims at building aggregated indicators for the purpose of characterizing eco-driver. Thus, an experiment was also performed by permitting the driver to drive twice on the same route, for the first time, in a normal driving method and for the second time by following the golden principles of eco-driving. Like the first paper, an on-board logging device was used to gather data and the device was connected with CAN bus of the vehicle. In addition, the vehicle contains GPS, camera and a fuel meter called DFL1x-5bar for validation of fuel consumption in the experiment. The impact of eco-driving on fuel consumption was indicated by the t-test method. According to the result, the average fuel consumption is reduced by 12.5% to 25% after eco-driving instructions. The final result of the paper provides two statistical models or logistic regression models, the first model is based on the main rules of eco-driving which provides some feedback to drivers to improve their driving style. The second model is based on positive kinetic energy(PKE) which is assumed to be used for nomadic device implementation.

The third related work is "Impact of eco-driving on emissions and fuel consumption" [8], which deals about the economical driving style effects compared with normal driving.
in-terms of reducing emissions and fuel consumption. In order to get the driving information of drivers, experiments were done on 16 students by allowing them to drive on the same routes of three different places. The routes used were about the same distance and the used vehicle was petrol-driven 1998 VW Golf 1.6. The total driving distance for the 32 journeys was 375 km. All drivers drove twice before and after eco-driving instructions since the purpose is to realize the effects of eco-driving. As the results, the average speed for all drivers was the same before and after eco-driving instruction (36.9 km/h before and 36.7 km/h after instruction). Similarly, the average acceleration (0.67 m/s\(^2\) before and 0.69 m/s\(^2\) after). However, the average retardation change from –0.49 m/s\(^2\) before instruction to –0.41 m/s\(^2\) after. The average fuel consumption and the emission of carbon dioxide were reduced by 10.9% as a result of the instructions.

"Data driven analysis of usage and driving parameters that affect fuel consumption of heavy traffic" is a master thesis in statistics and data mining [21]. The thesis has built a model using data mining techniques such as random forests and gradient boosting to classify a vehicle’s parameters that affect the fuel consumption in heavy traffic. The analysis was performed by splitting the data into train and trial sample to avoid a high dimensionality problem. According to the results, random forests performance was better than gradient boosting, which are 0.808 and 0.698 respectively. The random forests method has also provided important variables such as speed, distance with trailer, distance with cruise control activities, maximum speed and coasting to predict the target variable fuel consumption.

From the result, they have concluded that, taking into account the relevant parameters could help to determine the fuel consumption rate in heavy traffic. Moreover, they have calculated the mean square error rate of the models to check the performance of the constructed model. The mean square error of the random forests method was low, which showed that the prediction model is good.

Another related paper in this literature review is "Driving Style Analysis Using Data Mining Techniques" [22]. The purpose of the paper is to alert drivers to their driving style in order to obviate the danger of accidents. To gather data from the vehicle, they have used a Gipix-102B tracking device, which is a GPS based device and give information to the user about the position of the vehicle and other significant signals such as time and speed. The device was installed on the monitored vehicle. The experiment was done on twenty five different drivers by allowing them to drive on the same route using nine tracks. They have done a statistical analysis of relevant parameters such as speed, acceleration and braking. Moreover, they have used data mining techniques such as Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA). The HCA method is used to group the drivers according to the relevant driving parameters and the PCA is also used to identify significant variables by linearly transforms the original variable and compose a new set of variables.

The final related work in this chapter is a master thesis titled as "Characterization of drivers’ energetic efficiency" [23] which aims at qualifying efficient driving and driving behaviour. That was done by identifying parameters related to fuel consumption. For the driving analysis, five sections representing 64 km of driving were considered: each of them clarifies a certain type of driving conditions (e.g. highway) where all drivers can be compared. The 11 drivers used the same truck, a Volvo FL. The first two approaches were single criterion analysis and multi-criteria analysis for computation of correlation of the data to identify relevant parameters. The second approaches are system based on simple logistics equation and system based on single criterion analysis, used for ranking the
drivers based on relevant parameters. As a result, speed and kinetic energy were found as an important parameters for driving efficiency on different types of the road such as altitude change, roundabouts and curves. Moreover, maintaining constant speed and variation of angle on both throttle and brake pedals are found important behaviour for driving efficiency. The system also helped to rank the drivers based on those parameters.

In this study, we have focused on analysis of driver behaviour based on CAN bus data and comparison of eco-driver with normal drivers based on relevant signals/parameters to driving behaviour and fuel consumption. We have done an experiment for drivers (eco-driver and normal drivers) and we have provided some descriptive statistical analysis similar to [19] [20] works.
Chapter 4

Methods

4.1 Data Collection

4.1.1 Data loggers

A Data Acquisition System (DAQ) is a process of collecting electrical signals that measure real world physical conditions (for example: vehicles) and transmit the signals to devices such as computers or mobiles for further processing [24]. The data from a vehicle enables us to know its dynamic behaviour and to describe driver behaviour based on the obtained information.

In this thesis, we have performed a data collection process from a CAN bus of a car through OBD-II interface using a data logger. A Data logger is a device which is used to perform a data acquisition system either within its built-in instrument or with external devices. Most data loggers are small and battery powered, and they normally have internal memory for data storage. Furthermore, data loggers usually interface with a computer, and they have a software for activation and to view the recorded data. One of the main advantages of a data logger is that it can automatically record data on a 24 hour basis. The price ranges from $25 to $1000. The difference between these data loggers is the manner of recording and storing data [24].

As mentioned above, it was required to use a data logger for this study, which has a CAN bus interface and able to read CAN bus messages. Although plenty of tools were available to read the diagnostic information of a car, we have spent some time by looking for an appropriate tool for the car Volvo S60 with a reasonable cost. After some research and suggestions from an experienced user (Volvo car group), we have tried two logging devices, such as Lawicel CANUSB and ICP CON, although we have succeeded on one of them (ICP CON) finally.

ICP CON

The ICP CON I-7540D from ICP DAS is a CAN Ethernet gateway and able to convert CAN messages to Ethernet messages [25]. The CAN-Ethernet gateway provides Internet communication via TCP/IP protocol by making the CAN network joined together over Internet/Ethernet so that remote monitoring is possible. In addition, the CAN-Ethernet gateway monitors networked communication and enables transparent CAN based application to the user. It also supports a lot of applications including protocol independent transfer of the CAN messages. The CAN-Ethernet gateway also works with some higher CAN protocols such as CANopen, DeviceNet or other proprietary protocols. Furthermore, it has the following applications [26]

- Control System
- Building Automation
- Factory Automation
- Home Automation
- Monitor System
4.1. Data Collection

• Vehicle Automation

Moreover, the manual [26] has described various features of CAN-Ethernet gateway includes the following:

• 80186-80 Embedded CPU, or compatible
• Support a variety of TCP/IP features, including TCP, IP, ICMP, ARP
• 10/100 BASE-TX Ethernet Controller
• Reloadable Operating Software
• Message transmitted by using TCP/IP protocol
• Diagnostics
• COM driver support interrupt, 1K QUEUE Input and Output buffer
• Support one RS-232 port, one RS-485 port and one CAN port
• 2500Vrms photo-isolation protection on CAN side.
• Jumper select 120 Ohm terminator resistor for CAN channel
• Phillip 82C 250/251CAN Transceiver
• Support both CAN specification 2.0A and 2.0B

How to connect to the CAN bus?

The I-7540D provides one CAN port with two CAN bus connector interfaces to have a CAN bus wiring. The connectors and its pin assignment are shown in the figure and table below, respectively [26].

![Figure 4.1: CAN bus Connector](image)

<table>
<thead>
<tr>
<th>Pin No</th>
<th>Signal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N/A</td>
<td>Not connected</td>
</tr>
<tr>
<td>2</td>
<td>CAN-L</td>
<td>CAN-L bus line(dominant low)</td>
</tr>
<tr>
<td>3</td>
<td>N/A</td>
<td>Not connected</td>
</tr>
<tr>
<td>4</td>
<td>CAN-H</td>
<td>CAN-H bus line(dominant high)</td>
</tr>
<tr>
<td>5</td>
<td>N/A</td>
<td>Not connected</td>
</tr>
</tbody>
</table>
**Ethernet Connector**

The signals from the Ethernet (10/100 Base-TX) expelled to an RJ45 socket using a standard CAT 3 and CAT 5 network cable to establish connection. The network speed and connection negotiated by the power on I-7540D. Figure and table 4.2 are the Ethernet connector and it’s pin assignment respectively [26].

![Ethernet Connector](image)

**Figure 4.2: Ethernet Connector**

<table>
<thead>
<tr>
<th>Pin No</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TX+</td>
<td>Transmit Data +</td>
</tr>
<tr>
<td>2</td>
<td>TX-</td>
<td>Transmit Data -</td>
</tr>
<tr>
<td>3</td>
<td>RX+</td>
<td>Receive Data +</td>
</tr>
<tr>
<td>4</td>
<td>N.C.</td>
<td>Not Connected</td>
</tr>
<tr>
<td>5</td>
<td>N.C.</td>
<td>Not connected</td>
</tr>
<tr>
<td>6</td>
<td>RX-</td>
<td>Receive Data -</td>
</tr>
<tr>
<td>7</td>
<td>N.C.</td>
<td>Not connected</td>
</tr>
<tr>
<td>8</td>
<td>N.C.</td>
<td>Not connected</td>
</tr>
</tbody>
</table>

**Lawicel CANUSB**

The LAWICEL CANUSB is a small CAN to USB dongle which is 60mm long, 35mm wide and 15mm, can be used with windows and Linux operating system. It has two drivers, such as, virtual COM port driver (VCP) and Direct driver (D2XX). The first driver can be used as standard RS232 COM port and the second driver uses a DLL to communicate with the CANUSB. However, it is not possible to use both drivers on the same PC. The CANUSB handles both the 11bit and 29bit ID format. In addition, it has the following specifications [27]

- Blue Transparent Case, 1 meter shielded USB cable.
- Industrial temp range -40C to +85C.
- USB 2.0 Full Speed, uses FTDI FT245RL.
- Philips SJA1000 CAN Controller running at 16Mhz.
- Philips 82C251 CAN Transceiver (Fully Compatible with ISO 11898-24V).
- Free Interface DLL and ActiveX controller or low level Ascii Commands via USB driver.
4.1. Data Collection

Lawicel CANUSB was compatible with the car and could log the CAN bus data from the car using its software and an application program written in C#. Nevertheless, the obtained CAN bus IDs was not easy to decrypt and to get the exact representation of those IDs. The picture and comparisons of the logging tools are described in the figure and table 4.3.

4.1.2 Linksys Router

The router used for the data collection process is a simple Linksys router (figure 4.4). The purpose of the router is to disseminate data (signals) along a network. It is usually required to be configured in order to communicate with any network components.

4.1.3 Vehicle

All the cars after January 1, 1996 are equipped with OBD-II system. The vehicle (figure 4.5) used during the experiment was a Volvo car S60 model which is built in 2010. In addition, some of the specifications that described in the technical characteristics [29] are the following:
4.1.4 Driving Route

The route used for the experiment was about 18.7 km (which took from 25 to 30 minutes) in Halmstad city. The route was suggested by the eco-driving teacher, which includes all kinds of events such as intersections, roundabouts, turns, highway and traffic lights. Figure 4.6 is the driving test route shown in Google map, which obtained by coordinates of GPS (Global Positioning System).

4.2 Clustering algorithm: Hierarchical Clustering

Cluster analysis is a method of grouping similar individual items. It is not a specific algorithm itself, rather achieved by various algorithms for clustering [30]. There are different kinds of cluster model given by researchers to build clustering algorithms. For example: hierarchical clustering used a connectivity model which considers the distance connectivity and K-means clustering also included in the centroid model which used a single mean vector to represent each cluster [30].

In this dissertation, we applied a hierarchical clustering algorithm, which is used to cluster items by creating a tree or dendrogram. It calculates the distance between objects to classify them. Hierarchical clustering has two approaches for clustering such as divisive and agglomerative methods. The divisive method is a top down approach which starts with taking the whole items as one cluster and then splits into different clusters by considering the distance between them. On the other hand, the agglomerative method uses
4.3 KML Polygon

KML stands for keyhole Markup Language, which is a file format utilized to present geographic information on earth browsers such as Google Earth and Google maps [32]. In MATLAB, we can generate a polygon in KML format, based on the given information. For this study, since we need to observe the driving style of each driver, we need to use the KML polygon to plot the signals that are obtained from the CAN bus. To generate a polygon, we need to give a signal ID and GPS data (latitude and longitude). In addition, it is possible to plot the polygon in different colors.

The advantage of hierarchical clustering is, it is easier to understand the clustering method from a tree or dendrogram. The disadvantage is the time complexity of the algorithm is $O(N^2)$, which is very slow in a large dataset [31].

Figure 4.6: Driving route in Halmstad city, Sweden

a bottom up approach, which starts with a single item and then aggregates into different clusters [30] [31].
### Table 4.3: Comparison of Logging Tools

<table>
<thead>
<tr>
<th>Description</th>
<th>Lawicel CANUSB</th>
<th>ICP CON I7540D</th>
</tr>
</thead>
</table>
| **Description** | 1. Small dongle that plugs into any PC USB Port and gives an instant CAN connectivity.  
2. Can be treated by software as a standard COM Port.  
3. No need for any extra drivers or by installing a direct driver DLL for faster communications and higher CAN Bus loads.  
4. Sending and receiving can be done in standard ASCII format [28]. | 1. The CAN Ethernet Gateway from ICP DAS.  
2. Enables CAN networks to be coupled together over the Internet or Ethernet.  
3. Message transmitted by the TCP/IP protocol  
4. Diagnostics [25] |
| **Advantage** | 1. Small  
2. Inexpensive  
3. USB 2.0 connection  
4. Works on Win, Linux, Mac  
5. Compliant to CAN 2.0A and 2.0B  
6. TimeStamp  
7. Powered by the USB [28]. | 1. Easy to use data logger for the diagnosis of the CAN networks and recording of the received data.  
2. Support both CAN specification 2.0A and 2.0B.  
3. Easy to transmit and receive CAN messages. [25]. |
| **Disadvantage** | 1. In order to work, we need to connect 2 additional resistors.  
2. It is not easier to use.  
3. It requires some additional software to analyse the data. | 1. It is more expensive than Lawicel CANUSB. |
| **Price** | 1. 1045 SEK | 1. 3900 SEK |
Chapter 5

Results and Analysis

5.1 Experiment

5.1.1 Setup of the experiment

For the data collection process, the ICP CON I-7540D is used to read out all the signals from CAN bus through OBD-II system. The default configuration of the ICP CON provides an Ethernet output IP address of 192.168.255.1. In order to connect OBD-II output (table 2.1) with the ICP CON, a female sub-D cable is used. The ICP CON has CAN-L and CAN-H which can connect with pin out 2 and pin out 7 of sub-D cable, respectively. However, the linksys router is configured to give a static IP address of 192.168.255.1 to the ICP CON using DHCP (Dynamic Host Configuration Protocol). Moreover, an Ethernet RJ45 cable also used to connect the router with the ICP-CON through its Ethernet interface.

In general, while driving, the ICP CON gets all the signals from the OBD-II system using the CAN network and forwards them to the router. Then, the router also disseminates the signals to the android device through a wireless network. The application installed on the android device enables us to log all the CAN bus data and is saved in a text file. Both are powered through the 12V power plug from the car. The experimental setup depicted in figure 5.1.

![Experimental Setup Diagram]

Figure 5.1: Experimental Setup

5.1.2 Driving experiment

Participants in the experiment were ten drivers, nine of them were normal drivers and one driver was an eco-driver who trained in eco-driving style. The drivers drove on the same route twice, the experiments long for one week. Through the experiments, we have logged 40 CAN bus signals, however, some of the signals’ values were apparently zero. The reason could be, either the information is not available on the CAN bus or not found in the data stream [19]. In addition, we have obtained the location stamps (Latitude and Longitude) from GPS information of the android device.
5.2 Preprocessing Data

During the experiment, we have logged 40 CAN bus signals, time stamp and location stamp (latitude and longitude) as shown in table 5.1, which is the example of a test file with 15335 observations. The first column is the signal ID and the second column contains the corresponding value. The time and location stamp (latitude and longitude) are logged respectively.

<table>
<thead>
<tr>
<th>Signal ID</th>
<th>Value</th>
<th>Time</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>09:12:00</td>
<td>56.677338</td>
<td>12.879498</td>
</tr>
<tr>
<td>1</td>
<td>0.0</td>
<td>09:12:00</td>
<td>56.677338</td>
<td>12.879498</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>09:12:00</td>
<td>56.677338</td>
<td>12.879498</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>09:12:00</td>
<td>56.677338</td>
<td>12.879498</td>
</tr>
<tr>
<td>4</td>
<td>0.0</td>
<td>09:12:00</td>
<td>56.677338</td>
<td>12.879498</td>
</tr>
<tr>
<td>5</td>
<td>68.0</td>
<td>09:12:00</td>
<td>56.677338</td>
<td>12.879498</td>
</tr>
</tbody>
</table>

Table 5.2: Arranged test file

<table>
<thead>
<tr>
<th>VehSpeed</th>
<th>ABSWarning</th>
<th>ACCompDisp</th>
<th>ACCPedalposition</th>
<th>Airflow</th>
<th>AmbientTemp</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>68</td>
<td>24.75</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>68</td>
<td>24.75</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>68</td>
<td>24.75</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>68</td>
<td>24.75</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>68</td>
<td>24.75</td>
</tr>
</tbody>
</table>

For further analysis, we were required to arrange the obtained data to make compatible with a statistical tool (Matlab) so, we rearrange it in the following way:

- The obtained CAN bus signals, time stamp and location stamps are placed on the same row to easily access the desired signals.

- All signal IDs are given their right name to be distinguished by name instead of number. Table 5.2 is a sample example new test file which contains 15335 observations.

5.3 Descriptive statistics of relevant signals related to driving behaviour and fuel consumption

5.3.1 Vehicle speed

To compare the driving behaviour based on the relevant signals, a descriptive statistical analysis is done to describe the data of the relevant features.

The speed profile of the drivers is drawn in the histograms which compare the eco-driver and the normal drivers. The comparison is in two laps of the driving experiment to see if there is any difference while repeating the same experiment.
5.3. Descriptive statistics of relevant signals related to driving behaviour and fuel consumption

Figure 5.2: Speed profile of drivers when comparing eco-driver (EcoD) and normal drivers (D1 to D9) in lap 1

Figure 5.3: Speed profile of drivers when comparing eco-driver (EcoD) and normal drivers (D1 to D9) in lap 2

Figure 5.2 and Figure 5.3 describe the frequency distribution of speed for all drivers in total number of samples approximately from 13200 to 16500. The range distribution of data for the eco-driver is lower than the normal drivers in both laps. In other words, all normal drivers drove at a speed above 80 km/h but the eco-driver drove below 80 km/h. The highest frequent value occurred around 60 km/h for the eco-driver and 60 to 64 km/h for the normal drivers. The lap time of the experiments is between 22 and 28 minutes.
Likewise, on average, the eco-driver (EcoD) scored lower when it’s compared with the other normal drivers, which are 43.1 km/h and 41.9 km/h in lap 1 and lap 2, respectively, while the normal drivers have an average range between 43 and 48.

The above results consider all road types such as straight roads, curves, roundabouts and also traffic lights. Though all drivers drove on the same route, we could notice that traffic jams during the experiment have an impact on the driving behaviour. Thus, we have filtered out those events by dividing the data. Thanks to GPS (geographical information system) coordinates, where we can draw a KML polygon on a Google map. For example: figure 5.4 is the speed profile of a driver using a polygon, which shows the speed variation (high, low or constant) on different events. In this case, the polygon has three dimensions (x, y and z axis, which are the latitude, longitude and signal ID respectively).

Figure 5.4: KML polygon of speed during events such as curves, roundabouts and traffic lights

Figure 5.5: KML polygon of speed on events such as curves, roundabouts and traffic lights based on a threshold value
The generated KML polygon result in figure 5.4 shows, the speed profile of one driver on events such as curves, roundabouts and traffic lights. Those events exist during all driving experiments. As it’s described in the figure, the altitude of speed is low when there are events such as red lights at traffic roads, roundabouts and curves, but, the speed is somehow constant on straight roads. Consequently, we have generated the polygon again by giving a threshold value to divide the data for different roads. For example: the assumption was the driver might drive above 20 km/h of speed along straight roads (without any obstacles such as turns and traffic lights).

As the result of figure 5.5, the generated KML polygon is smooth for the described events and normal when there are no events such as roundabouts, curves and traffic lights. Thus, the average result of the selected data shown in the box plots of the next figure.

![Box plots of speed in curves, roundabouts and at traffic lights](image)

**Figure 5.6: Box plots of speed in curves, roundabouts and at traffic lights**

The box plots in figure 5.6, the speed profiles on events indicates there is a difference between the eco-driver and the normal drivers; mainly the average (median) marked value of speed for the eco-driver is lower than the normal drivers. The lap time of the drivers shows, the eco-driver has finished in 26 minutes, whereas the normal drivers took about from 22 to 28 minutes but traffic conditions during the driving experiment also obstructs comparisons between the drivers. Furthermore, we have compared the drivers based on the average value of speed. To categorize the drivers based on the average speed, we have used an agglomerative method of a hierarchical clustering algorithm from the data mining tools.
Chapter 5. Results and Analysis

Figure 5.7: Hierarchical cluster of the drivers based on the average speed on straight roads

In figure 5.7, the clustering algorithm groups the drivers according to the average speed value. At the first level (D1, D8), (EcoD, D3), (D2, D7) and (D4, D5) are clustered. In the next step (D1, D8, EcoD, D3) and (D2, D7, D4, D5) are clustered, and in the final step D9 is added to the first group and D6 is also added to the second group. From the result, we can identify two main groups such as (D1, D8, EcoD, D3, D9) and (D2, D7, D4, D5, D6) where the eco-driver (EcoD) is categorized with some of the normal drivers, which indicates the

Figure 5.8: Hierarchical cluster of the drivers based on the average speed in curves, traffic lights and roundabouts
eco-driver doesn’t have a big difference with normal drivers on straight roads. On the other hand, the clustering result of figure 5.8, the drivers are categorized in two groups as with the first figure, where (D1, D8, D6, D7, D5, D4, D9) and EcoD are in one group and (D2, D3) are in another group. Since the drivers drove on the same route throughout the experiment, the effect of curves and roundabouts are the same for all drivers. However, the cause of the clustering result for EcoD, D2 and D3 were heavy traffic lights during the experiments (as we observed in the KML polygon result) and also they completed the lap in a little bit longer time than the other normal drivers (26, 25 and 28 minutes, respectively).

5.3.2 Brake pressure

The logged data of brake pressure for all drivers is apparently zero most of the time, which shows there was no many brakes. Thus, we have filtered the data by considering values larger than zero to get the actual braking of the drivers.

![Brake Pressure Profile](image)

Figure 5.9: Comparison of eco-driver (EcoD) and normal drivers (D1 to D9) by Brake Pressure in lap 1

The distribution of brake pressure shown in figure 5.9 and figure 5.10, which compare the eco-driver (EcoD) and the normal drivers (D1 to D9) in lap 1 and lap 2. The results show the profile of drivers are about the same in both laps, the highest frequent brake occurred around 5 for the eco-driver and for the normal drivers from 8 to 10. Moreover, it shows the eco-driver distribution of brake pressure is higher than the normal drivers. On average, the eco-driver has high brake pressure than the normal drivers.
Figure 5.10: Comparison of eco-driver (EcoD) and normal drivers (D1 to D9) by Brake Pressure in lap 2

Figure 5.11: Hierarchical cluster of drivers when comparing eco-driver (EcoD) and normal drivers (D1 to D9) at brake pressure > 0

Likewise, the hierarchical cluster analysis in figure 5.11 group the driver based on the average value of the brake pressure. The two main groups of the results are (D6, D9, D7, D5, D1, D8) and (EcoD, D2, D3, D4). The second group in the categorization result
5.3. Descriptive statistics of relevant signals related to driving behaviour and fuel consumption

has some similarity with the categorization of the drivers’ speed profile in curves, roundabouts and at traffic lights in figure 5.8, where D2 and D3 are clustered in one group. In a general view, although the clustering result does not show more difference between the eco-driver and the normal drivers, from the histogram, we could see that the eco-driver brakes frequently but gently, more often than the normal drivers due to the traffic situations.

5.3.3 Accelerator Pedal Position

The distribution of the accelerator pedal position signal shown in figures below 5.12 and 5.13, which compare the eco-driver (EcoD) and the normal drivers (D1 to D9).

Figure 5.12: Histograms of accelerator pedal position when comparing eco-driver (EcoD) with normal drivers (D1 to D9) in lap 1

Figure 5.13: Histograms of accelerator pedal position when comparing eco-driver (EcoD) with normal drivers (D1 to D9) in lap 2
The spread of accelerator pedal position is shown in the figures, the values fall in the range of 0 to 25 for most drivers (both eco-driver and normal drivers). On average, the eco-driver used less gas pedal than the normal drivers in both laps, (the eco-driver has 5.8 and 5.75 in lap 1 and lap 2 respectively, whereas the normal drivers scored between 6.6 and 7).

Figure 5.14: Hierarchical cluster drivers based on the average accelerator Pedal Position in lap 1

Figure 5.15: Hierarchical cluster drivers based on the average accelerator Pedal Position in lap 2

As the figures 5.14 and 5.15 show, the clustering result has several levels and a small difference is found between the normal drivers, but we could see a big difference with the eco-driver. In addition, both figures indicate EcoD is added finally with some distance difference in the categorizations. Thus, the clustering result described the average pedal
value related to the speed profile of the drivers where it also showed lower mean value for the eco-driver than the normal drivers.

### 5.3.4 Stops/idling

Although there are various factors of fuel consumption, frequent stop/idling is one of them. In the experiment, the traffic jam was one of the cause to have stops/idles. Thus, we considered stops of each driver at traffic lights in both laps. The below table compare the number of stops at traffic lights during the trips.

Table 5.3: Number of stops when comparing Eco-driver (EcoD) and Normal Drivers (D1 to D9)

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Number of Stops in lap 1</th>
<th>Number of stops in lap 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>EcoD</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>D1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>D2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>D3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>D4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>D5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>D6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>D7</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>D8</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>D9</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 5.3 describes the drivers have in the range between 3 to 5 stops or idles at traffic lights, some drivers have equal number of stops in both laps. On the other hand, the technology in the Volvo car helped the engine to automatically switch off when the car was stationary, which protect from fuel wastage during stops/idles.

### 5.3.5 Fuel Consumption

Although we did not use any device to read the actual fuel consumption of the drivers, we tried to find information from the CAN bus signal. FuelLevelIndicated was one of the signals found from the CAN bus, which is related to fuel consumption. Thus, the fuel consumption of the drivers computed from the relative change of fuel from the start to the end of the lap by taking a difference.

\[
\text{Fuel consumption} = \text{FuelLevelValueAtStartOflap} - \text{FuelLevelValueAtEndOflap}
\]

The relative change of the fuel for all drivers is shown in the below table (table 5.4), which compares the eco-driver (EcoD) and the normal drivers (D1 to D9).

As the results indicate the average fuel consumption is in the range of 0.6 and 1.4. On average, D2 and D8 used less fuel than the other drivers. However, it also showed there is more than 80% of fuel difference between drivers, which is beyond expectation. As the previous studies report, there could be a maximum of 30 to 40% difference of fuel usage between good and bad drivers. The possible cause of errors in our study could be:

- Since the fuel consumption is computed from the car sensor, it is sensitive to be affected by the angle position of the car at starting and stopping.
Table 5.4: Fuel Consumption when comparing Eco-driver (EcoD) and Normal Drivers (D1 to D9)

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Average fuel in litres</th>
</tr>
</thead>
<tbody>
<tr>
<td>EcoD</td>
<td>1.1 l</td>
</tr>
<tr>
<td>D1</td>
<td>1.1 l</td>
</tr>
<tr>
<td>D2</td>
<td>0.6 l</td>
</tr>
<tr>
<td>D3</td>
<td>1.2 l</td>
</tr>
<tr>
<td>D4</td>
<td>1.2 l</td>
</tr>
<tr>
<td>D5</td>
<td>1.4 l</td>
</tr>
<tr>
<td>D6</td>
<td>1.4 l</td>
</tr>
<tr>
<td>D7</td>
<td>1.4 l</td>
</tr>
<tr>
<td>D8</td>
<td>0.9 l</td>
</tr>
<tr>
<td>D9</td>
<td>1.3 l</td>
</tr>
</tbody>
</table>

- Although we tried to keep the same setup during the driving experiment, external factors such as temperature can affect the fuel consumption.
- A numerous amount of stops/idles is also one of the factors for fuel consumption, but the result does not show an increasing value of fuel with the number of stops (table 5.3 and 5.4), which indicate the results do not influenced more by driving behaviour.

### 5.4 Relationship of the relevant signals

In order to see the relationship of the above relevant signals, we have taken a sample data over time on different roads such as straight, curves and at traffic light.

![Figure 5.16: Relationship of relevant signals](image)

The gas pedal has shown a direct relationship with the speed (both have ascending and descending behaviour at the same time) in figure 5.16. On the other hand, the value of speed falls when there is brake pressure. That means the effect of the gas pedal and brake pressure over time can be seen on speed which is already measured as a separate signal.
Chapter 6

Conclusion

In this thesis, we have tried to analyse the driving behaviour in terms relevant features related to driving behaviour and fuel consumption.

The CAN bus data provide information related to driving behaviour, such as speed, brake pressure, pedal position and others. Thus, we have done a statistical analysis of relevant signals to compare the driving style of the drivers.

The average speed of the eco-driver is lower than the normal drivers (41.9 km/h and 43.1 km/h in lap 1 and lap 2 respectively, whereas for the normal drivers between 43 and 48 km/h). Similarly, the gas pedal usage by the drivers has a direct relationship with the speed profile. On the other hand, the results show the eco-driver used more brakes due to the traffic jams which also hindered a strictly accurate comparison of all the drivers’ performance.

Furthermore, we identified some behaviour of the eco-driver that make different from the normal drivers such as, avoiding high speed and less usage of the accelerator (gas pedal), however, brakes frequently because of the traffic lights.
Chapter 7

Future Work

As a future work, we can see additional things can be performed to analyse driving behaviour, especially to compare drivers according to their driving style.

1. Use a good device to record the real fuel consumption of the drivers.
2. Perform many tests using different vehicles to see the consequences of driving behaviour and fuel consumption.
3. Perform the tests among many eco-drivers and normal drivers to have a better comparison.
4. Normalize the data to get more information from the statistical analysis and include other driving parameters which might be related to fuel consumption and driving behaviour.
Bibliography


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