MODELLING AGGRESSIVE DRIVING BEHAVIOUR IMPACT ON VEHICLE FUEL CONSUMPTION AND TAILPIPE EMISSIONS

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DEDICATION

"Only Allah knows what is the unforeseen, and onto Him we should rely, so endure patiently with a beautiful patience, and therefore our life will be fine"

And this is also part of His divine plan for what I never seek and never ask,
I dedicated this thesis to those who were dear to my heart, prays, and loves me, day and night

Opah
Ayah
Umi
Dek Sanah
Dek Amer
Haziq
Ida
and Hamza Yusuf

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ABSTRACT

Vehicles, the environment, and drivers are important factors in driving behavioural studies. However, previous research related to vehicle's fuel consumption and tailpipe emissions were focused on driving behaviour while treating the driver's behaviour with a lack of consideration. Therefore, this study aims to model the impact of aggressive driving behaviour on vehicle fuel consumption and tailpipe emissions by considering characteristic of driver in real driving behaviour. Self-reported assessment tool was used to identify aggressive and non-aggressive drivers. Both types of drivers were then invited for on-road driving assessment (ODA) under different traffic conditions over five consecutive days. During the ODA, driver behaviour (anger expressions) were evaluated by an in-car observer, while driving behaviour and driving performances were observed and recorded using video camera and GPS Logger. The recorded anger expression during ODA were then validated with self-reported anger expression and triangulated with the actual driving behaviour and driving performance. Data recorded in the GPS Logger were then extracted in order to develop driving cycles for aggressive and non-aggressive drivers. The driving cycle was developed using micro trips by eliminating idling conditions. Aggressive drive cycle (AGDC) was compared with non-aggressive drive cycle (NGDC) and the findings from previous studies based on kinematic assessment parameters. AGDC and NGDC were then simulated using a chassis dynamometer in the laboratory to measure the vehicle's fuel consumption and tailpipe emissions. Tailpipe emissions obtained from the AGDC and NGDC were also compared based on speed variations, traffic conditions, and road sections. The results from the Driving Anger Expression Inventory (DAX) questionnaires revealed that 35 out of 330 respondents were aggressive drivers and the rest were non-aggressive drivers. Based on 10 aggressive drivers and 1 non-aggressive driver who agreed to participate in the ODA, the findings on anger expressions showed insignificant difference between recorded and self-reported anger expressions. Based on the validated data, more than 58% consistencies in vehicle and verbal aggressions were found between self rating and in-car observation. While, only 35% and 42 % of vehicle and verbal aggressions, respectively shown by aggressive drivers in the video camera observation. Aggressive drivers were found to tailgate other vehicles, performed dangerous overtaking, violated the lane-keeping and red-light signals. For driving performances, it showed that aggressive drivers had a shorter travel time, higher average speed, and higher maximum speed as compared to non-aggressive drivers. Strong negative correlations was found between aggressive drivers travel time and average speed indicating that higher choice of speed had shortened the travel time. The comparative characteristics of AGDC and NGDC showed that the AGDC had shorter driving time, higher average speed, higher positive acceleration, and lower negative acceleration and positive acceleration kinetic energy (PKE) compared to the NGDC. While the comparison of AGDC with previous studies indicated that AGDC has similar kinematic characteristics with drive cycles in China, Taiwan, Jakarta, Chennai, Hong Kong, Tehran, and Tianjin. Results for the simulated driving cycles showed that AGDC had lower fuel consumption compared to NGDC. It was found that more than 50% of CO_2 and less than 2% of CO emissions from AGDC and NGDC have been emitted. As speed increases, CO and CO_2 emissions have increased. CO and CO_2 emissions were found slightly higher during the afternoon traffic than other traffic conditions. For interrupted and non-interrupted road sections, AGDC illustrated increasing CO emissions in contrast to NGDC. While for CO_2, AGDC showed high CO_2 emissions at the interrupted section during the afternoon traffic and non-interrupted section during the morning traffic. The study concluded that modelling aggressive driving behaviour impact on vehicle fuel consumption and tailpipe emissions using new methods is capable of conveying realistic results. The application of new methods in the study can be used in other driver and driving behaviour studies that benefit for the environmental management.

ABSTRAK

Kenderaan, persekitaran, dan pemandu merupakan faktor-faktor penting dalam kajian tingkah laku pemanduan. Walau bagaimanapun, kajian terdahulu yang berkaitan penggunaan bahan api dan pelepasan ekzos kenderaan tertumpu pada tingkah laku pemanduan, manakala tingkah laku pemandu kurang dipertimbangkan. Oleh itu, kajian ini bertujuan untuk memodelkan kesan tingkah laku pemanduan yang agresif terhadap penggunaan bahan api dan pelepasan ekzos kenderaan dengan mengambil kira karakter pemandu dalam tingkah laku pemanduan sebenar. Alat penilaian lapor kendiri digunakan bagi mengenal pasti pemandu yang agresif dan bukan agresif. Kedua-dua jenis pemandu kemudian dipelawa menyertai penilaian pemanduan atas jalan (ODA) dalam keadaan lalu lintas yang berbeza selama lima hari berturut-turut. Semasa ODA, tingkah laku pemandu (ekspresi marah) dinilai oleh pemerhati dalam kenderaan, sementara tingkah laku pemanduan dan prestasi pemanduan diperhatikan dan direkodkan kamera video dan Pengelog GPS. Ekspresi marah yang direkodkan semasa ODA disahkan dengan ekspresi marah lapor kendiri dan diselaraskan dengan tingkah laku dan prestasi pemanduan. Data yang direkodkan dalam Pengelog GPS kemudian diekstrak untuk membina kitaran pemanduan untuk pemandu agresif dan bukan agresif. Kitaran pemanduan dibangunkan menggunakan perjalanan mikro dengan mengasingkan keadaan melahu. Kitaran pemanduan agresif (AGDC) dibandingkan dengan kitaran pemanduan bukan agresif (NGDC) dan dapatan kajian terdahulu berdasarkan parameter penilaian kinematik. AGDC dan NGDC kemudian disimulasikan menggunakan dinamometer casis di makmal bagi mengukur penggunaan bahan bakar kenderaan dan pelepasan ekzos. Pelepasan ekzos yang diperoleh daripada AGDC dan NGDC dibandingkan berdasarkan kelajuan yang pelbagai, keadaan lalu lintas, dan bahagian jalan raya. Hasil soal selidik Inventori Ekspresi Marah Pemanduan (DAX) menunjukkan bahawa 35 daripada 330 responden ialah pemandu agresif dan selebihnya pemandu bukan agresif. Berdasarkan 10 pemandu agresif dan 1 pemandu bukan agresif yang bersetuju menyertai ODA, dapatan ekspresi marah menunjukkan perbezaan yang tidak ketara antara ekspresi yang direkodkan dengan ekspresi marah lapor kendiri. Berdasarkan data yang disahkan, lebih dari 58% kekonsistenan dalam sifat agresif kenderaan dan lisan telah ditemui diantara penilaian lapor kendiri dan pemerhatian dalam kenderaan. Manakala, hanya 35% sifat agresif kenderaan dan 42% sifat agresif lisan yang telah ditunjukkan oleh pemandu agresif dalam pemerhatian kamera video. Pemandu agresif didapati mengekori rapat kenderaan lain, memotong kenderaan lain secara berbahaya, tidak kekal di lorong sendiri dan melanggar lampu isyarat merah. Bagi prestasi pemanduan, kajian menunjukkan pemandu agresif mempunyai masa perjalanan lebih singkat, kelajuan purata yang lebih tinggi, dan kelajuan maksimum yang lebih tinggi berbanding dengan pemandu bukan agresif. Korelasi negatif yang kuat telah ditemui diantara masa perjalanan pemandu agresif dan kelajuan purata menunjukkan bahawa pemilihan kelajuan yang lebih tinggi telah mengurangkan masa perjalanan. Ciri-ciri perbandingan AGDC dan NGDC menunjukkan bahawa AGDC mempunyai masa memandu yang lebih singkat, kelajuan purata lebih tinggi, pecutan positif lebih tinggi, dan pecutan negatif dan daya kinetik pecutan positif (PKE) yang lebih rendah berbanding dengan NGDC. Manakala perbandingan AGDC dengan kajian terdahulu menunjukkan bahawa AGDC mempunyai ciri-ciri kinematik yang serupa dengan kitaran pemanduan di China, Taiwan, Jakarta, Chennai, Hong Kong, Tehran, dan Tianjin. Keputusan simulasi kitaran pemanduan menunjukkan bahawa AGDC menggunakan bahan api lebih rendah berbanding dengan NGDC. Didapati bahawa lebih dari 50% pelepasan CO_2 dan kurang dari 2% pelepasan CO daripada AGDC dan NGDC dilepaskan. Apabila kelajuan meningkat, pelepasan CO dan CO_2 semakin tinggi. Pelepasan CO dan CO_2 didapati agak tinggi semasa lalu lintas tengah hari berbanding waktu lalu lintas lain. Pada bahagian jalan raya yang terganggu dan tidak terganggu, AGDC menunjukkan peningkatan pelepasan CO berbanding NGDC. Bagi CO_2 pula, AGDC menunjukkan pelepasan CO_2 yang tinggi dibahagian terganggu sewaktu lalu lintas tengah hari dan bahagian tidak terganggu semasa lalu lintas pagi. Kajian menyimpulkan pemodelan kesan tingkah laku pemanduan agresif terhadap penggunaan bahan api dan pelepasan ekzos kenderaan menggunakan kaedah baru mampu memberikan hasil yang realistik. Penggunaan kaedah baru dalam kajian ini dapat digunakan dalam kajian tingkah laku pemandu dan pemanduan lain yang bermanfaat untuk pengurusan alam sekitar.

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LIST OF ABBREVIATIONS

AASHO	-	American Association of State Highway Officials
AG	-	Aggressive Driver
AGDC	-	Aggressive Drive Cycle
AISS	-	Arnett Inventory Of Sensation Seeking
ANOVA	-	Analysis Of Variance
ARQ	-	Adolescent Risk-Taking Questionnaire
ARTEMIS	-	Assessment and Reliability of Transport Emission Models and Inventory Systems
AWSC	-	All Way Stop Controlled
BIS-11	-	Barratt Impulsiveness Scale Version
CE	-	Constructive/Adaptive Expressions
CH_4	-	Methane
CI	-	Confidence Interval
CMEM	-	Comprehensive Modal Emissions Model
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
COPERT	-	Computer Programme To Calculate Emissions From Road Transport
CPI	-	California Personality Inventory
CS	-	Control Sample
CUEDC	-	Composite Urban Emission Drive Cycle
DABQ	-	Driver Attitude and Behaviour Questionnaire
DAS	-	Driver Anger Scale
DAX	-	Driving Anger Expression Inventory
DBQ	-	Driver Behavioural Questionnaire
DC	-	Drive Cycle
DSQ	-	Driving Style Questionnaire
ECE	-	Urban Drive Cycle
EDAR	-	Emission Detection And Reporting
EPA	-	Environmental Protection Agency

EPHC	-	Environmental Protection And Heritage Council
EV	-	Electric Vehicle
FTP	-	Federal Test Procedure
GPS	-	Global Positioning System
GPX	-	GPS Exchange Format
GTSC	-	Governor's Traffic Safety Committee
HC	-	Hydrocarbons
IM	-	Inspection And Maintenance
INRET	-	French National Institute For Transport And Safety Research
IR	-	Infrared
IT	-	Information Technology
IVE	-	Impulsiveness, Venturesomeness, And Empathy
IVEM	-	International Vehicle Emissions Model
KML	-	Keyhole Markup Language
LDV	-	Light Duty Vehicle
MIROS	-	Malaysia Institute of Road Safety Research
MOBILE	-	Mobile Source Emission Model
MOVES	-	EPA's Motor Vehicle *Emission* Simulator
MSD	-	Mild Social Deviance
NGDC	-	Non Aggressive Drive Cycle
NO_2	-	Nitrous Oxide
NO_x	-	Nitrogen Oxides
OBM	-	On Board Measurement System
ODA		On-road Driving Assessment
PADS	-	Personal Driving Anger Situations
PAE	-	Physical Aggressive Expressions
PKE	-	Positive Acceleration Kinetic Energy
PM	-	Particulate Matter
RMQ	-	Risk Motivation Questionnaire – Risk Motivation
ROQ	-	Rohrmann’s Risk Orientation Questionnaire – Risk Aversion
SAPM	-	Speed Acceleration Probability Matrix
SD	-	Standard Deviation
SFTP	-	Supplemental Federal Test Procedure

SO_x	-	Sulphur Oxides
SPSS	-	Statistical Package For Social Science Software
SSS	-	Sensation Seeking Scale
TRL	-	Transport Research Laboratory
TXT	-	TeXT
UK	-	United Kingdom
USA	-	United States Of America
USEPA	-	United States Environmental Protection Agency
UTM	-	Universiti Teknologi Malaysia
UV	-	Ultraviolet
VAE	-	Verbal Aggressive Expressions
VHAE	-	Vehicle Aggressive Expressions
VOC	-	Volatile Organic Compound
WGS 84	-	World Geodetic System 1984

LIST OF SYMBOLS

n	-	Sample
p	-	Significant value
$\bar{X}$	-	Mean value
F	-	Fisher-test value
df	-	Degree of freedom
r	-	Correlation coefficient
T	-	Sum of rank value
U	-	Mann-Whitney U value
W	-	Lowest sum of rank value
z	-	Standardized z test statistic value

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The transportation sector is primarily a fossil fuel consuming sector which accounts for 14% of global greenhouse gas (GHG) emissions in comparison to other fields (UNEP, 2015). According to the International Environmental Agency (IEA, 2015), the transportation sector consumed half of the total demand for fossil fuel in Southeast Asia in the year 2015 since it is the primary source of energy for vehicles. Due to high fossil fuel consumption in the road transport field, approximately 28% of carbon dioxide (CO_2) emissions were attributed to road vehicles in Southeast Asia (IEA, 2015), whereas 89% of total transport-related emissions were reported from road transport in the ASEAN region (IEA, 2017).

With that said, the increasing population and urbanisation in Malaysia contributed to the rapid increase in the number of road vehicles. Similar to ASEAN countries, the transport sector in Malaysia also relies on petroleum-based fuels. More than 90% of vehicles are still running on petroleum-based fuels. Therefore, the growing vehicle population has considerably increased fossil fuel consumption and CO_2 emissions. According to a 2017 report by the Economic Research Institute for ASEAN and Asia (ERIA), Malaysia's transportation sector accounts for approximately 45% of energy consumption, largely from road transportation (Kondo, 2018). A recent report revealed that from 90%, around 67% of total emissions have been attributed to vehicles from the transportation sector (National Transport Policy Report, 2019).

The interaction between people and transport, which affects fuel consumption and tailpipe emission, is called travel behaviour (Anable, 2005; Yang et al., 2017). Recently, researchers have coined a new term in the travel behaviour field called driver behaviour, which has an effect on fuel consumption and tailpipe emission. Research on driver behaviour involves three major components: the driver, the vehicle and the environment (Wang et al., 2010). Driver behaviour refers to what the driver does and chooses to do with their knowledge, skills, perceptions and cognitive abilities (Evans, 2004). Moosavi et al. (2017) defined driver behaviour as meaningful driving patterns which can be intrinsic due to the personality of the driver. Personality is also addressed in the components of driver behaviour studies to determine driving behaviour (Chen et al. 2013). This indicates that a driver's behaviour has an influence on their driving behaviour. Driving behaviour is defined as the real-time actions of the driver on the road (Evans, 1991). This includes a form of regulated motions such as steering, lane keeping, accelerating and braking. These regulated motions are influenced by the types of vehicles as well as the variability of the drivers, thus implying that different drivers and vehicles will possess different driving behaviours (Kang, 2013).

Various research conducted on fuel consumption and tailpipe emissions were according to driving behaviour. The determination of fuel consumption and vehicle emissions is important for policy makers so that driving conditions on roads can be managed. Among the factors that influence vehicle fuel consumption and tailpipe emissions are highway traffic operations (Grote et al., 2016; Papakostopoulos et al., 2017), pavement conditions (Sandberg, 2011), highway designs (Barth & Boriboonsomsin, 2009; Al-Ghandour, 2014), types of vehicles (Alessandrini et al., 2009; Tietge et al., 2015), number of highway vehicles (Schrank et al., 2012) and the mileage covered by vehicles (El-Shawarby et al., 2005; Treiber et al., 2008). Driving behaviour may be generally categorised as smooth, experienced or aggressive driving.

Aggressive driving, sometimes referred to as 'dynamic driving', consists of high accelerations and decelerations, high maximum vehicle speeds, and high engine speed operations which consequently influence fuel consumption and emissions. Dynamic driving is typically stimulated by impatience, frustration or anger and manifests itself through unsafe driving behaviours such as running red lights, traffic weaving or tailgating. According to Deffenbacher et al. (2002), aggressive driving behaviour is defined as a type of emitted behaviour intended to hurt other road users, either physically or psychologically, while driving angrily. An aggressive driver is defined as one who drives too closely, at excessive speeds, weaves through traffic, runs stop lights and signs, and other dangerous acts (NTHSA, 2000). As a result, aggressive driving is not the result of simple lapses or errors while driving. It is an intentional behaviour by the driver and their target is another road user (Lajunen et al., 1998). Aggressive driving behaviour is related to a driver's personality traits, feelings of fatigue and stress (Alonso et al., 2019), individual characteristics and environmental factors (Dula and Geller, 2003; Neuman et al., 2003; Tasca, 2000). Thus, aggressive driving behaviour can vary depending on different regions within a state (Beck et al., 2006).

The relationship between aggressive driver and aggressive reactions while driving depends on the amount of anger that the driver is feeling. This is usually determined by the severity of the behavioural response, the personality of the driver (verbal, physical, general anger, impulsiveness) and demographics (age and milage) which all have a direct effect on aggressive driving behaviour (Lajunen and Parker, 2001). However, a systematic literature review conducted by Muslim et al. (2018) had revealed that driving style, which simply describes the type of drivers on the road, has not been sufficiently examined. The study also found that aggressive driving interferes with the association between fuel consumption, emission and the driver's personality. Thus, there is a knowledge gap between driver behaviour and vehicle emission and fuel consumption.

1.2 Problem Statement

It has been known for decades that the way people drive strongly affects the fuel consumption and vehicle emission. Many research works have been conducted on vehicle fuel consumption and tailpipe emissions in relation to driving behaviour, with a few focusing on aggressive driving behaviour. For example, several studies focused on calm driving (Alessandrini et al., 2009), normal driving (Leaners, 2009; Fonseca et al., 2010; Tang et al., 2014), quiet driving (Meseguer et al., 2015), neutral driving (Tang et al., 2014), eco driving (Johansson et al., 2003; Leaners, 2009; Fonseca et al., 2010; Mierlo et al., 2004; Heijne et al., 2017), sportive driving (Mierlo et al., 2004), defensive driving (Tzirakis et al., 2007; Hobeika et al., 2014; Dia & Panwai, 2015), passive driving (Felstead et al., 2009) and aggressive driving (Tzirakis et al., 2007; Gao & Checkel, 2007; Dia & Panwai, 2015; Meseguer et al., 2015; Faria et al., 2019). These studies were conducted in different driving environments such as road location, traffic condition, road geometry, and weather conditions. Most researchers have reported that aggressive driving consumes more fuel and produces more emissions, but their outcomes widely vary. The divergence may be attributed to the different estimation methods used and the variety of vehicles, drivers and environments.

There are numerous factors that influence fuel consumption and emissions, among which are the timing of stops, speed changes, and high acceleration driving and high engine speed (Brundell-Freij and Ericsson, 2005). These factors are definitely related to the type of vehicle, characteristics of the driver, and road environment. To accurately represent aggressive driving behaviour in fuel consumption and emission research, some researchers provided specific driving instructions to induce aggressive driving behaviour among selected participants (Tzirakis et al. 2007; Felstead et al. 2009; Fonseca et al., 2010; Berry, 2010). This approach is questionable since the outcomes were obtained from participants forced to drive aggressively in a non-natural way. Moreover, several studies have used different vehicles, for example, Tzirakis et al. (2007), Fonseca et al. (2010) and Berry (2010). It can be argued that vehicle type is one of the important factors that influences emissions and fuel consumption.

The type of driver also has an influence on vehicle fuel consumption and tailpipe emission since their behaviour will vary. Many previous studies classified driver behaviour by assessing volunteers or random participants as moderate or aggressive based on vehicle speed and acceleration intensity in real driving conditions (Gao & Checkel, 2007; Berry, 2010; Meseguer et al., 2015; Faria et al., 2017; Faria et al., 2019) or simulated driving conditions (Hobeika et al., 2014; Mudgal et al. 2014; Tang et al., 2014; Dia & Panwai, 2015; Boubaker et al., 2016). Even though these methods are applicable, it can be argued that the classification of the driver is based on driving behaviour through the regulated motion of a vehicle, not the characteristics of a driver. A driver's characteristic is closely related to their behaviour, which then affects his or her driving behaviour. This is because different drivers exhibit their own driver behaviour characteristics, which is affected by the driver's self-attributes, such as gender, age, ethnicity, driving experience, emotion, cultural background, etc. Even for the same driver, driving behaviour may alter from situation to situation, which can be attributed to the driver's behaviour characteristics. It is also believed that there are differences in the driver characteristics of each driver due to the way their subconscious mind works and responds. The conversion between subconscious to conscious mind will also generate unique responses in brains function. Therefore, in driving behaviour studies, it is important to consider the driver's behaviour in relation to the driver's characteristics as it reflects on vehicle fuel consumption and tailpipe emission.

To date, these issues have not been addressed in the available research on the relationship between aggressive driving behaviour and vehicle fuel consumption and tailpipe emissions. The aforementioned issues bring up the need to empirically model the impact of aggressive driving behaviour on fuel consumption and emission by considering the characteristics of the driver, thus motivating this research.

1.3 Aim and Objective of the Research

The study aims to empirically model the impact of aggressive driving behaviour on vehicle fuel consumption and tailpipe emissions by considering the characteristics of the driver. The specific objectives of this study are as follows:

i. To identify aggressive drivers using a self-reported assessment tool
ii. To observe anger expression and measure driving performance
iii. To relate aggressive driver with actual driving performance
iv. To develop drive cycles for simulation of vehicle fuel consumption and tailpipe emission
v. To measure the vehicle fuel consumption and tailpipe emissions resulted from actual aggressive driving behaviour

1.4 Research Goal

The scopes of this study are presented as follows:

(a) The identification of an aggressive driver is only limited to their expressions of anger. The observed expressions of anger include physical, verbal and the use of a vehicle on road. Anger expressions that are considered as aggressive are rated as "often aggressive" and "almost always aggressive", while the non-aggressive are rated as "rarely aggressive" and "sometimes aggressive". This study does not include the driver's personality, attitude, social factor, cognitive, emotions and lifestyle.

(b) On-road assessment is conducted using the same vehicle, time, and route. However, the assessment does not include night driving and different weather conditions. In addition, on-road measurements are conducted within five consecutive working days during different traffic hours (7.30 - 8.00 a.m.), (12.30 - 1.00 p.m.) and (5.00 - 5.30 p.m.) along a 13 km stretch road composed of multiple road categories and traffic management schemes.

(c) Driving patterns were simulated based on the speed data to derive vehicle fuel consumption and tailpipe emissions without imitating the action of vehicle tailgating, dangerous overtaking and lane-keeping due to the limitation of the equipment. The simulated driving patterns do not include non driving phase.

(d) The research only measured emissions of carbon monoxide (CO) and CO_2 resulting from aggressive driver behaviour using an integrated gas analyzer and chassis dynamometer equipment in the UTHM Pagoh Automotive laboratory.

(e) The research randomly selected a non-aggressive driver from a group of non-aggressive samples to represent a control sample for an On-Road Driving Assessment (ODA).

(f) The vehicle used in on-road measurement and laboratory had a similar vehicle specification. The RON 95 petrol was used for on-road measurement and laboratory work. RON 95 is selected in the study because it is the most commonly used and serves as the cheaper and value for money offering in the market.

1.5 Significance of Research

The main contributions of this research are as follows:

(a) Combination of assessment methods

The research is expected to empirically model aggressive driving behaviour impact on vehicle fuel consumption and tailpipe emissions by considering the characteristics of the driver. Aggressive drivers are screened through self-reported assessment tool on the driving anger expression. These drivers were then invited for On Road Driving Assessment (ODA) to evaluate real expression of driving anger, driving behaviour, and driving performances. The combination of these two assessment methods has not been applied in previous studies related to fuel consumption and tailpipe emissions based aggressive driving behaviour. Therefore, this study can significantly depict the results of vehicle fuel consumption and tailpipe emissions based on actual aggressive behaviour. Furthermore, the combination of these two methods can be applied to other types of driving behaviour studies.

(b) Drive cycle development

The research aims to develop a new non-legislative drive cycle based on real aggressive driving behaviour, which can be used to measure vehicle fuel consumption and tailpipe emissions. This driving cycle is different from previous driving cycles as these were mostly built based on different road types, vehicles, and geographical conditions without considering the driver as an influencing factor. Besides that, the development of the driving cycle incorporated all aggressive driving patterns obtained from aggressive drivers.

This step is in contrast with the common practise of drive cycle development, whereby previous literature only selected the best driving pattern in vehicle fuel consumption and emission studies as a representative drive cycle. Therefore, this developed driving cycle can also be used as a reference in other aggressive driving behaviour studies concerning similar demographic, road network, and engine requirements.

1.6 Thesis Outline

Chapter 1 discusses the background of aggressive driving behaviour, factors that contribute to aggressive driving, common methods to evaluate aggressive drivers along with its implication on vehicle fuel consumption and tailpipe emissions with a brief overview of previous studies and problem statement. This chapter also provides the research objectives, scope and limitations of the study, significance of the study and the general research framework.

Chapter 2 reviews extends of the literature relevant to the study topic by including research works from previous studies. The literature review discusses causal factors of aggressive driving behaviour, expressions of anger in aggressive driving behaviour, common types of aggressive driving behaviour, methods and tools to measure driving behaviour, implications of aggressive driving behaviour to the environment, types of instruments or measurements for fuel consumption and tailpipe emissions of vehicles, drive cycle, and research gap.

Chapter 3 documents the methodology used in this research. There are four phases involved starting from identification of aggressive driver, on-road driving assessment, driving cycle construction, and measurement of vehicle fuel consumptions and tailpipe emissions. Details methodology for each phases are discussed in this chapter.

Chapter 4 presents the results of four different phases in the study. In Phase I, the chapter describes findings on identification of aggressive drivers using DAX questionnaires which includes the descriptive and inferential analysis for participants, DAX Subscales, and DAX items. In Phase II, the chapter describes findings of ODA which covers the analysis for in-car observation, video camera observation, and driving performance observation. This also includes the descriptive and inferential analysis, comparisons, and triangulation of findings based on all observations. In Phase III, the chapter presents the findings on developed drive cycles and comparisons of kinematic characteristics among these drive cycles, including drive cycles differences from previous studies. Lastly, in Phase IV, the study presents the results of vehicle fuel consumptions and tailpipe emissions based on the simulated drive cycles.

Finally, Chapter 5 summarises and concludes the research. Several constructive recommendations for further improvements in similar or related research is also suggested for future work.

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