UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CLASSIFICATION OF AUTOMATED VEHICLE'S DRIVING STYLE BY ADAPTING MULTIDIMENSIONAL DRIVING STYLE INVENTORY FOR MALAYSIAN DRIVER

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MASTER OF SCIENCE IN MECHANICAL ENGINEERING

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Faculty of Mechanical Technology and Engineering

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A thesis submitted
in fulfillment of the requirements for the degree of
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2024

DECLARATION

I declare that this thesis entitled “Classification of Automated Vehicle’s driving style by adapting Mutidimensional Driving Style Inventory for Malaysian Driver“ is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : MUHAMMAD ZAINUL ABIDIN BIN KAMALUDIN

Date : 23 MARCH 2024

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering

Signature	:
Supervisor Name	: DR JUFFRIZAL BIN KARJANTO
Date	: 24 MARCH 2024

DEDICATION

To my beloved parents, Kamaluddin Md Dali and Azizah Binti Isnin and for my beloved family who encourages me by moral support, also do not forget to whom may involve either directly or indirectly for the success of our project.

Thank you.

ABSTRACT

The rapid advancements in automated vehicle technology have sparked questions about how these vehicles will behave on the road. To address this, must first understand the driving styles of human drivers and then predict the driving style of automated vehicles. The Multidimensional Driving Style Inventory (MDSI) is a commonly used tool to categorize human driving styles in different cultural contexts. This study's goal is to adapt the MDSI for use with Malaysian drivers and determine the specific driving profiles that exist among them. Additionally, the study examines the relationship between driving style and personality traits, as well as sociodemographic information. A total of 737 drivers, ranging in age from 17 to 49 years, completed the MDSI and a questionnaire on personality traits (trust, desire for control, and sensation seeking). Through Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA), the study found established a 5-factor structure for the MDSI, comprising risky, anxious, angry, careful, and dissociative driving styles. CFA confirmed that the model fit of the MDSI was acceptable. Further analysis revealed that some respondents exhibited only one driving profile, while others displayed multiple profiles. The study found that the MDSI factors had moderate correlations with "desire for control" but weaker associations with "trust" and "sensation seeking." Significant differences in driving styles were observed based on gender, age, experience, and the type of car driven. The study then proceeded to its second phase, which aimed to validate the five driving style factors (careful, risky, angry, anxious, and dissociative) among Malaysian drivers through on-road observational studies. Participants were asked to engage in driving experiments using instrumented vehicles on two designated routes, with 45 minutes of recorded driving tasks. The results indicated a modest correlation between the MDSI scores and the data obtained from on-road observations, particularly regarding acceleration in the x, y, and z directions. The findings from both phases of this study demonstrate that Malaysian drivers exhibit distinct driving profiles consisting of these five factors, and these profiles correlate with acceleration data. This data is essential for developing models of driving styles and accelerating the acceptance of user-driven automated vehicles in the near future.

KLASIFIKASI GAYA PEMANDUAN KENDERAAN AUTOMATIK DENGAN PENYESUAIAN INVENTORI GAYA PEMANDUAN PELBAGAI DIMENSI PEMANDU MALAYSIA

ABSTRAK

Kemajuan pesat dalam teknologi kenderaan automatik telah menimbulkan soalan tentang bagaimana kenderaan ini akan berlaku di jalan raya. Untuk mengatasi ini, kita perlu memahami gaya pemanduan pemandu manusia terlebih dahulu, dan kemudian meramal gaya pemanduan kenderaan automatik. Instrumen Multidimensional Driving Style Inventory (MDSI) adalah alat yang kerap digunakan untuk mengkategorikan gaya pemanduan manusia dalam pelbagai konteks budaya. Tujuan kajian ini adalah untuk menyesuaikan MDSI untuk digunakan dengan pemandu Malaysia dan menentukan profil pemanduan yang khusus yang wujud di kalangan mereka. Selain itu, kajian ini mengkaji hubungan antara gaya pemanduan dan ciri-ciri personaliti, serta maklumat sosiodemografi. Sejumlah 737 pemandu, dengan rentang umur antara 17 hingga 49 tahun, telah menjalani MDSI dan menjawab soal selidik tentang ciri-ciri personaliti (kepercayaan, keinginan untuk mengawal, dan pencarian sensasi). Melalui Analisis Faktor Eksploratori (EFA) dan Analisis Faktor Pengesahan (CFA), kajian mendapati struktur 5 faktor telah ditubuhkan untuk MDSI, yang terdiri daripada gaya pemanduan berisiko, cemas, marah, berhati-hati, dan disosiatif. CFA mengesahkan bahawa model kesesuaian MDSI adalah diterima. Analisis lanjut mendedahkan bahawa beberapa responden hanya memaparkan satu profil pemanduan, manakala yang lain memaparkan beberapa profil. Kajian mendapati bahawa faktor-faktor MDSI mempunyai korelasi sederhana dengan "keinginan untuk mengawal" tetapi hubungan yang lebih lemah dengan "kepercayaan" dan "pencarian sensasi". Perbezaan yang signifikan dalam gaya pemanduan diperhatikan berdasarkan jantina, umur, pengalaman, dan jenis kereta yang digunakan. Kajian kemudiannya berjalan ke fasa kedua, yang bertujuan untuk mengesahkan lima faktor gaya pemanduan (berhati-hati, berisiko, marah, cemas, dan disosiatif) di kalangan pemandu Malaysia melalui kajian observasi di jalan raya. Peserta diminta untuk menjalani eksperimen pemanduan menggunakan kenderaan berinstrumen di dua laluan yang ditetapkan, dengan catatan tugas pemanduan selama 45 minit. Hasil kajian menunjukkan korelasi sederhana antara skor MDSI dan data yang diperoleh dari pemerhatian di jalan raya, terutamanya dalam hal percepatan dalam arah x, y, dan z. Hasil kajian dari kedua-dua fasa ini menunjukkan bahawa pemandu Malaysia mempunyai profil pemanduan yang berbeza yang terdiri daripada lima faktor ini, dan profil ini berkaitan dengan data percepatan. Data ini adalah penting untuk membangunkan model-model gaya pemanduan dan mempercepat penerimaan kenderaan automatik yang dikendalikan oleh pengguna dalam masa dekat.

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LIST OF ABBREVIATIONS

SAE	-	Society of Automotive Engineers
$AUTOAccD$	-	Automatic Acceleration and Data Controller
PSD	-	Power Spectral Density
$MIROS$	-	Malaysian Institute of Road Safety Research
DBQ	-	Driving Behaviour Questionnaires
$MDSI$	-	Multidimensional Driving Style Inventory
CFA	-	Confirmatory Factor Analysis
EFA	-	Exploratory Factor Analysis
$ANOVA$	-	Analysis of Variance
AI	-	Artificial Intelligence
$NDRT$	-	Non-Driving Related Task
DBI	-	Driving Behaviour Inventory
DSQ	-	Driving Style Questionnaire
$ADVS$	-	Attitude to driving Violation
DVQ	-	Driving Vengeance Questionnaire
$ADAS$	-	Advance Driver Assistance Systems
ABS	-	Anti-lock Braking System
CEO	-	Chief Executive Officer
CAN		Controller Area Network

LIST OF APPENDICES

LIST OF PUBLICATIONS

The followings are the list of publications related to the work on this thesis:

Kamaludin, M. Z. A., Karjanto, J., Muhammad, N., Yusof, N., Hassan, M. Z., Zulkifli, A. F. H., and Rashid, A. A. A, "Exploration of Automated Vehicle's Driving Style by Adapting Multidimensional Driving Styles Inventory for Malaysian Drivers, *Advance in Transportation Stusies vol. LVIII, 2022*, atsinternationaljournal.com/index.php/2022-issues/lviii-november-2022/1343.

Kamaludin, M. Z. A., Karjanto, J., Muhammad, N., Yusof, N. M., Hassan, M. Z., Zulkifli, A. F. H., and Ab Rashid, A. A. 2023. Validation of Malaysian Driving Style Self-Assessment with Observational Road Study. *International Journal of Automotive and Mechanical Engineering*, 20(2), 10502-10511.

Kamaludin, M. Z. A., Karjanto, J., Muhammad, N., Yusof, N., Hassan, M. Z., Zulkifli, A. F. H., and Rashid, A. A. A, The Validation of Malaysian Driving Style Through Self-Assessment Multidimensional Driving Style Inventory in On-Road Study *Automotive Experiences.* (In publishing process)

CHAPTER 1

INTRODUCTION

1.1 Research Background

As the technological reality of automated vehicles nears, the focus is shifting from the development of the technology to the question of how to design a good preference driving style for the future user. Ideally, driving style is a judgment expressed by the driver according to their driving character based on specific traits such as skill (e.g., speeding and taking the corner), behaviour (e.g., following distance), and personality traits (e.g., sensation seeking, desire for control, and trust). However, for the automated vehicle driving style, the vehicle is operated from various logic sensors by utilising many sensors throughout the vehicle. The automated vehicle is operated by mapping its surroundings through radar sensors that detect the adjacent positions of the road environment and condition. Since there is a mismatched preference between automated and human execution driving tasks, this would make the user unaware of the vehicle's intention concerning its navigation inside the automated vehicle. The difference between automated vehicle driving style and human while manoeuvring the vehicle would lead to physical and mental discomfort for the user. Hence, a study to investigate and validate the preferred automated vehicle's driving style by human users is crucial. The preferred driving style is expected to increase the comfort and preference of future automated vehicle users. Hence, the research should begin by investigating and characterising human driving style with a self-assessment database. Then, an actual driving activity in the road experiment scenario could be done to validate the driving behaviour of the human driving style. The objective of the validation driving style was to focus on the rating scales from self-assessment and vehicle record data through tri-axial (longitudinal,

lateral, and vertical) accelerations. The study contributes to developing a taxonomy/classification for future automated vehicle databases that intends to accelerate the acceptable preference users' by imitating the driving preference of future automated vehicle users. Results would benefit academicians and automakers by providing fundamental data from future users using road studies.

1.2 Problem Statement

At the national level, the Malaysian Institute of Road Safety Research (MIROS), in its effort to reduce the number of road fatalities, has pushed the employment of automated vehicles in Malaysia by the year 2030 (Sarani et al., 2016). As illustrated in Figure 1.1, the data from 2017 revealed that Malaysia ranked third globally for the highest number of road fatalities, after Thailand and South Africa. This data emphasizes the critical need to explore alternative measures to decrease this alarming statistic. Such efforts should not rely solely on the government; instead, it demands a collective commitment from the public and the automotive industry to pave the way for a safer future. Furthermore, based on the previous literature, human error was one of the primary factors contributing to the highest number of road accidents (Dokic et al., 2015). However, the number of road accidents could be reduced by as high as 90% when the driving task was taken over by human drivers when the technology was shifted to the automated vehicle (Arbib and Seba, 2017). In fully automated driving, human drivers will no longer constitute driving activities when the system inside the technology can control the vehicle by itself. According to Michon's definition level of driving actions within the vehicle will no longer constitute the control of the vehicle at the physical driving "operational level" but instead only at the giving instruction "strategic level" (Michon, 1985). Investigating the acceptability related to human driving preference must be specified first to produce the best experience and accelerate the adoption rate of a passenger

inside the automated vehicle (Basu et al., 2017). Hence, studying how automated vehicles operate should be done regarding human preferences is crucial. Automated vehicles' driving behaviour needs to be humanised to avoid the dismissal of the technology and not inducing any health-related issues in the user (Hilgarter and Granig, 2020). However, until now, how automated vehicles should operate or drive on the road is still being researched (Dillen et al., 2020; Meder et al., 2018).

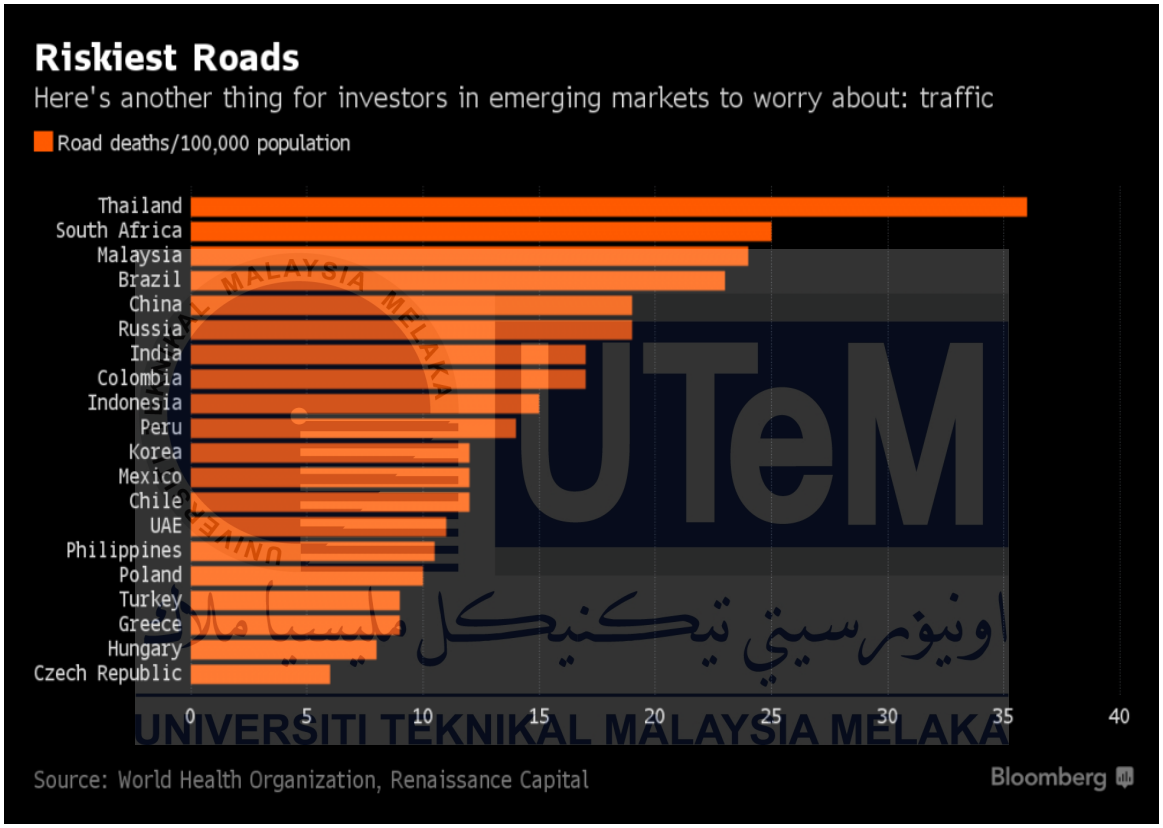

Figure 1.1: The statistic for the riskiest driver on the road for 2017 (Tan, 2017)

There are methods or measurements to formulate the previous researcher's human driving style, such as collecting the data using a survey or questionnaire (Dillen et al., 2020). A self-report has been established to measure driver behaviour and driving style in the last decade, such as the Driving Behaviour Inventory (DBI) (Glendon et al., 1993), Driving Style Questionnaire (DSQ) (French et al., 1993), Attitudes to Driving Violations (ADVS) (West and Hall, 1997) and Driver Behaviour Questionnaire (DBQ) (Martinussen et al., 2013).

Later, Taubman from Israel (Taubman-Ben-Ari et al., 2004) created the Multidimensional Driving Style Inventory (MDSI) to conclude all the driving styles into one questionnaire. Since then, MDSI has been widely translated in various countries and found various driving styles based on their countries. For example, in Romania, the researcher found seven (7) driving styles (Holman and Havârneanu, 2015), while in China, Spain, and the Netherlands, found six (6) driving styles (Long and Ruosong, 2019; Padilla et al., 2020; van Huysduynen et al., 2015) and in Malaysia only discovered four (4) factors (Karjanto et al., 2016). The different outcome of driving styles raises the question of whether a questionnaire is a proper means to identify a person's driving style or whether there is a difference because of bias from the respondents. The possibility of bias came from the respondent being unaware of the questionnaire's objective (Beiker, 2012; Shanker et al., 2013; Sümer et al., 2006). The reason was that the respondent completed without performing the actual task, causing of possibility that the respondent just answered the questionnaire based on their point of view during that time. Therefore, their predicted performance evaluations may still have a hazy reference point problem since the drivers lack objective feedback directly linked to their driving activities (Van Huysduynen et al., 2018; WÅhlberg, 2017). In addition, the focus on how a driving style is validated has been shifted recently, such as in the works of Huysduynen et al. (2018) validated the driving style found in Netherlands and Belgium drivers using the driving simulator studies. Nonetheless, studies on a real road with human users, especially the driving behaviour of Malaysian drivers, are relatively new.

1.3 Research Objectives

The main objectives of this study are:

i) To classify the Malaysian automated vehicle driving style using Multidimensional Driving Style Inventory (MDSI) and its relation to personality traits (Desire for Control, Sensation Seeking and Trust) with inference statistics.

ii) To validate the Malaysian automated vehicle driving style through gathered acceleration data and direct evaluation recorded from the on-road experiment.

1.4 Scope of Work

The scopes of this study are as follows:

i) The translated questionnaire included Multidimensional Driving Style Inventory (MDSI) (Taubman-Ben-Ari et al., 2004), Desirability for Control (Burger and Cooper, 1979), Sensation-Seeking (Zuckerman and Aluja, 2015) and Trust (Merritt et al., 2013) to explore the driving style and personality trait relationship. **(Scope objective 1)**

ii) Two (2) types of data collection during an on-road experiment: 1) designated observer will evaluate the driving behaviour of the participant. 2) The acceleration data from driver behaviour using an accelerometer installed inside the vehicle. **(Scope objective 2)**

1.5 Structure of Thesis

This thesis organisation is comprised of five further chapters, as summarised below.

- **Chapter 2**: A review of the recent literature on relevant information on developments and attempted approaches to formulate the taxonomy of

driving style for an automated vehicle. Further information about the validation of driving style using self-assessment is summarised in this chapter.

- **Chapter 3**: Provides detailed information on the methodology and workflow of the present research; these include the formulation and validation of the taxonomy of driving style. The chapter clarifies the experiment procedure, the instrumented vehicle's development, and the statistical analysis method during the progression of this thesis.
- **Chapter 4**: The chapter presents the result and discussion of the study. The subchapter was divided into two major parts. First, it explains the formulation of the taxonomy of driving style via statistical method analysis from the Multidimensional Driving Style Inventory (MDSI) questionnaire. Followed by a second part, validation of MDSI through observation, self-assessment, and vehicle recorded data. Through the validation method, the study illustrated the classification of Malaysian drivers.
- **Chapter 5**: Presents the conclusion of the study. The conclusions are based on the research objectives, followed by a recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The recent literature has generated a considerable volume of theories to formulate the driving style for an automated vehicle. The study about the recognition type of driving style is the starting point for researchers and the automaker in the field of the human factor to set up new policies and milestone plans for the user of an automated vehicle. To date, Rozhkova and Olentsova (2020) predicted that the future of human civilisation has been shaped in many ways with more development of technology and more sophisticated life will continue. The same goes for the vehicle that will be changed to the automated vehicle where no driver is needed to drive the vehicle. Hence, to make the realisation of the future users of an automated vehicle acceptable for humans' preference, the driving style must be recognised before the human user fully utilises the technology. The literature was split into specific main subtopics, as shown in Figure 2.1.

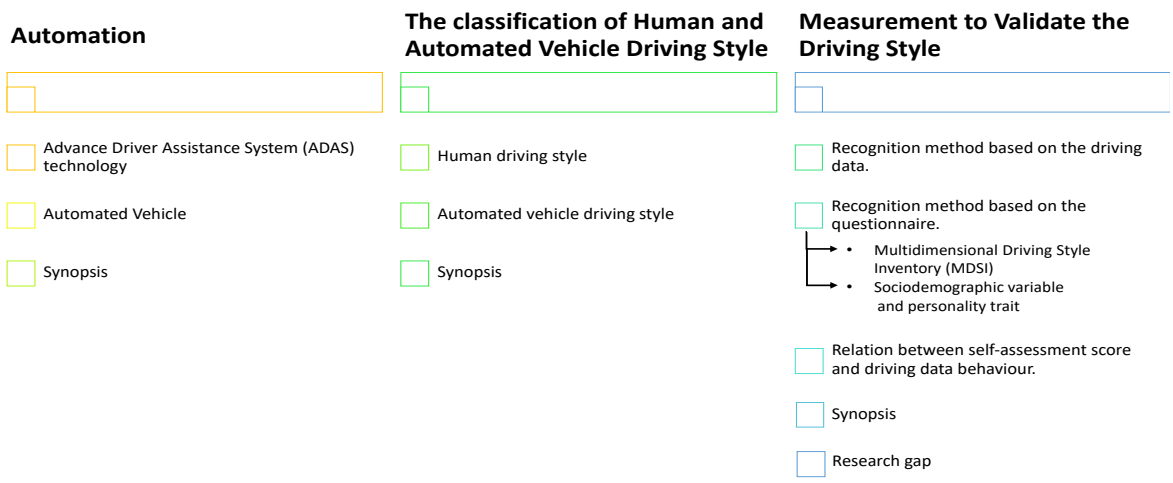

Figure 2.4.11: Structural outline for modelling of automated vehicle driving style