Develop Decision Support System Framework via Algorithm and Ergonomics Approach for Improving Driving Fatigue

Doctoral Dissertation

Submitted for the Dr. Degree

in the University of Tokushima

March 2020

Mohammad Firdaus Bin Ani

Information Science and Intelligent Systems

Systems Innovation Engineering

Graduate School of Advanced Technology and Science

The University of Tokushima

Acknowledgments

The research presented in this dissertation has been carried out at the University of Tokushima under the direction and guidance of Professor Minoru Fukumi with Associate Professor Dr. Seri Rahayu Binti Kamat.

First and foremost, I would like to take this opportunity to express my sincere acknowledgment to my supervisor Professor Minoru Fukumi for his essential supervision, support and encouragement towards the completion of this thesis.

I would also like to express my greatest gratitude to Associate Professor Dr. Seri Rahayu Binti Kamat from Universiti Teknikal Malaysia Melaka (UTeM) for her advice and suggestions through this journey in completion of this research.

Special thanks to Dr. Momoyo Ito, Dr. Shinichi Ito, and Dr. Teruaki Ito from the University of Tokushima, for their valuable comments and encouragement. They have supported me from various sides of my research.

I gratefully acknowledge the funding sources that made my research work possible. I was funded by the Tokushima-UTeM Academic Centre (TMAC) and B5 Laboratory for the financial support throughout this research.

A very special thank you also goes out to all the friends from the University of Tokushima and Universiti Teknikal Malaysia Melaka who have helped me with my research.

Lastly, I would like to thank my family for all their love and encouragement. They raised me with a love and supported me in all my pursuits. Besides that, special thanks to most of all for my loving, supportive, encouraging, and patient wife Athirah Mohd Ghazali whose faithful support during the final stages of this research is so appreciated.

Abstract

Nowadays, driving activity has become more important as this medium being practical, faster and cheaper in connecting humans from one to another place. However, driving activity can cause disaster or death to a human in daily life as they get fatigued while driving. Driver fatigue is a top contributor to road crashes. The primary objective of this research was to develop a decision support system framework for improving the driving fatigue problem. The decision support system aims to provide systematic analysis and solutions to minimize the risk and the number of accidents associated with driving fatigue.

Four major stages involved as the pillar in the development of decision support system; acquisition of knowledge, integration of knowledge, development of driving fatigue strain index using fuzzy logic membership function, and development of ergonomics vehicle model (EVM) and decision support system for driving fatigue (DSSfDF) model. The development of the strain index is based on the six risk factors associated with driving fatigue; muscle activity, heart rate, hand grip pressure force, seat pressure distribution, whole-body vibration, and driving duration. The data is collected for all the risk factors and consequently, the three conditions or risk levels are defined as “safe”, “slightly unsafe”, and “unsafe”.

A membership function is defined for each fuzzy condition. IF-THEN rules were used to define the input and output variables that correspond to physical measures. There are six main components for the development of EVM and DSSfDF model; ergonomics evaluation tools, graphical user interface (GUI), ergonomics database, working memory, inference engine, and knowledge base. Both models are essential systems and reliable advisory tools for providing analysis on risk factors that contribute significantly to driving fatigue and providing solutions and recommendations to the problem related to driving fatigue.

The graphical user interface was used to communicate the system with users. The decision support system is an essential system to analyze the risk factors that would contribute significantly to driving fatigue associated with the driving activity. Besides, the decision support system provides solutions and recommendations to the users in order to minimize the number of road accidents in Malaysia.

Contents

List of Tables

List of Figures

Chapter 1 Introduction

Malaysia, along with other countries are now in the exciting rate of urbanization level. The report by Transformasi Nasional 2050, also known as TN50, estimated that almost 60% of the world population will be staying in urban during 2025 (Land Public Transport Commission, 2006). As the urbanization level increases, the human population around the world has become more dependent on the transportation system. Indirectly, the growth of a number of vehicles on roads has made the current transportation system face several challenges and problems. One of the challenges and problems is road safety and accident. Speeding and risky driving are the major cause of accidents in road transportation. Many efforts have been made by the governments, researchers, road safety practitioners, and road safety society and organizations regarding these two causes. However, the number of road accidents still on the dangerous level. Hence, this study will focus on other causes of road accidents that are driving fatigue.

Based on report from the Royal Malaysian Police (RMP) and Department of Statistic Malaysia (DOS), 6,740 road fatalities and 548,598 road accidents have been reported in 2018 as shown in Table 1.1 (Malaysia Institute of Road Safety Research, 2015; Traffic Investigation and Enforcement Department, 2018; Department of Statistic Malaysia, 2019; Ministry of Transport, 2019). The data shows that the number of road accidents in Malaysia increased year by year since 2008. Besides, the total average number of vehicles involved in accidents from 2008 until 2018 is about 467,566. From this number of accidents, some of the crashes were caused by the factor of fatigue (MIROS, 2015). Driving fatigue causes the driver to be discomfort during driving, and reduction of motor control and strength capability, which leads to performance decrement and increased the risk of accidents and human error (Yung, 2016).

Table 1.1: Total casualties and damages caused by road accidents in Malaysia from 2008-2019

Year	Total Number of Accidents	Casualties			
		Death	Serious	Minor	Total
2008	373,071	6,527	8,868	16,879	32,274
2009	397,330	6,745	8,849	15,823	31,417
2010	414,421	6,872	7,781	13,616	28,269
2011	449,040	6,877	6,328	12,365	25,570
2012	462,423	6,917	5,868	11,654	24,439
2013	477,204	6,915	4,597	8,388	19,900
2014	476,196	6,674	4,432	8,598	19,704
2015	489,606	6,706	4,120	7,432	18,258
2016	521,466	7,152	4,506	7,415	19,073
2017	533,875	6,740	3,310	6,539	16,589
2018	548,598	6,284	Undisclosed	Undisclosed	Undisclosed
2019	133,912	1,483 (Jan-Mac)	Undisclosed	Undisclosed	Undisclosed

Figure 1.1 shows the accident's contributors according to MIROS (MIROS, 2015). Based on the MIROS report, 80.6% of road accidents are caused by human error, 13.2% caused by road conditions, and 6.2% are caused by the vehicle.

Figure 1.1: Accident's contributors (MIROS, 2015)

The in-depth crash investigations on some crash cases carried out by MIROS (2015), found that risky driving, speeding, and fatigue are main categories of human error. Table 1.2 and Table 1.3 list the crash contributing factors based on MIROS' in-depth crash investigation, which found that risky driving, speeding, and fatigue are the main causes of a traffic accident in Malaysia from 2007 to 2010. While from 2011 through 2013, it was found that fatigue was the fifth cause of road accidents. There is no data reported for 2014 until 2016.

Table 1.2: Crash contributing factors from 2007 through 2010 (MIROS, 2015)

Main crash contributing factors out of 439 cases	**Number**	**%**
Risky Driving	121	28
Speeding	93	21
Fatigue	70	16
Safety, Health, and Environment	38	9
Road Defects	36	8
Driving Under the Influence	24	5
Brake Defects	20	5
Conspicuousness	18	4
Tyre Defects	14	3
Overloading	11	3

Table 1.3: Crash contributing factors in Malaysia from 2011 to 2013 (MIROS, 2015)

Main crash contributing factors out of 439 cases	**Number**	**%**
Risky Driving	75	29
Speeding	68	26
Conspicuousness	55	21
Road Defects	27	10
Fatigue	17	7
Brake Defects	6	2

Tyre Defects	4	2
Driving Under the Influence	3	1
Safety, Health, and Environment	2	1
Overloading	2	1

Many countries around the world including Malaysia facing a major problem with road accidents and fatalities. The U.S. National Highway Traffic Safety Administration (NHTSA) reported that every year, around 100,000 traffic accidents and 71,000 injuries related to driver drowsiness, out of which more than 1,300 are fatal. NHTSA estimates that between 2% and 23% of all vehicle crashes can be attributed to driver fatigue (Sacco and Farrugia, 2012). Besides, the National Police Administration of France concludes that 20.6% of accidents causing death are fatigue-related (Bhardwaj et al., 2013). In fact, the World Health Organization (WHO) has reported that road accidents are the ninth most common cause of death and the prediction number of fatalities to be approximately 1.24 million (WHO, 2013). The data revealed by WHO shows that the fatality rate in Malaysia is the highest among the Association of Southeast Asian Nations (ASEAN) countries and developed countries in the world (WHO, 2013; Abdelfatah, 2016). The WHO's data in Figure 1.2 and Figure 1.3 prove that Malaysia has a significant traffic and driving problem based on the high fatality rate. Besides, the accident costing report shows that the road fatalities cost the nation roughly US Dollar 2.75 billion in 2011 based on a loss of MYR 1.2 million per fatality, which equivalent with almost 1% of the country's gross domestic product (GDP) (Yusoff et al., 2011).

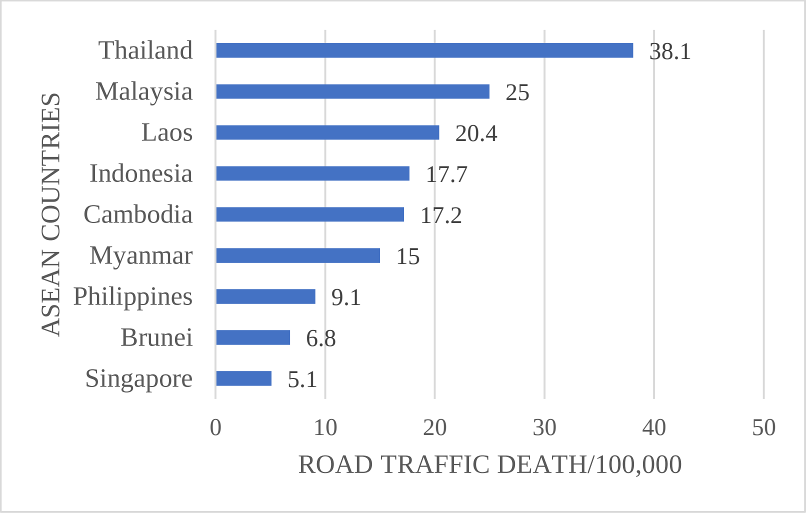


Figure 1.2: Road fatality rate among the ASEAN countries. Adapted from *Traffic Fatality Causes and Trends in Malaysia*, by Abdelfatah. A, 2016

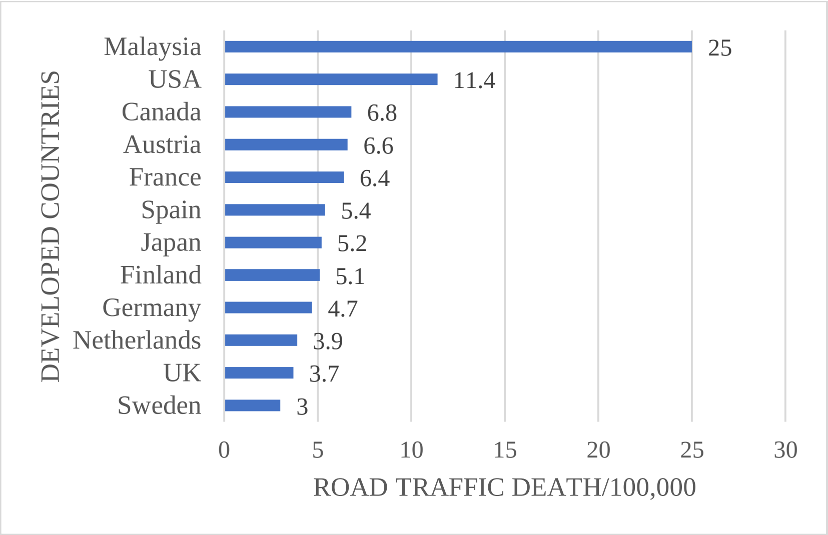


Figure 1.3: Road fatality rate among the developed countries. Adapted from *Traffic Fatality Causes and Trends in Malaysia*, by Abdelfatah. A, 2016

Driver fatigue is one of the key causes of road accidents for the driver in transportation (San et al., 2016; Desmond et al., 2012). Driver fatigue can be classified as one of the main areas of driver behavior that need to be addressed in order to reduce the number of people killed and seriously injured in road accidents. Based on the previous research, fatigue can be dangerous as other road safety issues such as drink driving and there are no laws regulating driver fatigue. As a driver, fatigue can cause and bring many problems and effects including slowing the driver reactions and decisions, decreasing driver tolerance for other road users, poor lane tracking, and maintenance of speed and decreasing driver alertness.

Driving fatigue has been defined as a feeling of drowsiness due to extended driving period, monotonous road condition, adverse climatologically environment or drivers' individual characteristics are direct or contributing factors to road accidents. It also can be defined as feeling tiredness and reduced alertness when driving which is associated with drowsiness, and which impairs capability and willingness to perform the driving task (San et al., 2016). According to Meletis and Baker (2004), subjective feeling of fatigue which combined with negative effects on performance due to time spent on cognitively demanding tasks can somehow affect the driving performance due to sleepiness, monotonous driving environment condition and the length of driving period as previous studies proved (Otmani et al., 2005; Papadelis et al., 2007; Seen et al., 2010). A study by Muhammad et al. (2008) pointed out that 37.7 percent of commercial bus drivers in Malaysia had encountered fatigue during driving where the long driving duration and awkward working hours had a synergistic effect in inducing the onset fatigue (Norlen et al., 2008).

There are some risk factors that play important roles in the occurrence of fatigued-traffic accidents. The previous work by Dobbie (2002) determined that prolonged driving without rest can increase the fatigue level and deteriorate the driving performance. The long duration of driving, inadequate sleep, and other cumulative factors caused the sleep-deprived drivers to make a higher number of right edge- line crossings and other errors

(Otmani et al., 2005; Philip et al., 2003). Besides, studies have also shown that working duration and sleep deprivation, as a result of disruption of an individual's routine sleep cycle (Philip et al., 2003; Philip, 2005; Tippayanate, 2006), clearly contributed to the deterioration of driving performance.

There are several important cognitive characteristics are common measures in the context of fatigue. According to Yung (2016), these characteristics include arousal, alertness or attention, cognitive control, motivation, and stress. Arousal has usually been used in transportation safety studies as its purpose to assess sleep deprivation which, the main root cause of trucking accidents, especially at night. Philip et al., (2005) study the sleep deprivation and they found that sleepiness combined with fatigue significantly affected the reaction time (RT) and reduce the performance of the drivers. The arousal can be measured based on the heart rate, electrodermal response, pupil dilation or eye blinking, and self-reported questionnaires.

The alertness and attention translate the sensory and work-related inputs into actionable items. The gaze direction and electroencephalography (EEG) are some of the examples of methods that can be used to measure alertness and attention. While cognitive control is the time taken to process information and can be evaluated or measured based on reaction time (RT). The fourth characteristic, motivation is the most difficult characteristic to measure and recognize as it cannot be assessed except via questionnaires and validated scales. The fifth characteristic, stress can be evaluated through several measures such as heart rate variability, blood pressure, and body postures (Yung, 2016).

The study by Yung (2016) quantified the mental fatigue by using the intrusive monitoring systems, intrusive monitoring system, and subjective measures. Besides, the study quantified the physical fatigue by detecting the chemical changes in the muscle.

These chemical changes can be evaluate using Electromyography (EMG). The recent study by Lu et al., (2017), quantified the fatigue by conducting the survey for the manufacturing workers. Through the survey, the study found that changes in work postures and sweating, and a slowing of work pace are the most common symptoms of fatigue among the workers. Table 1.4 shows the summarization of the commonly used indicators of fatigue development.

Table 1.4: The indicators of fatigue development

Measurement	**The direction of change with fatigue**
Heart Rate	Increases in physical fatigue
Heart rate variability (HRV)	a. Reduce in root mean square of the successive differences with mental fatigue b. Increase in low frequency or a high-frequency ratio
Electromyography (EMG)	a. Reduce in mean power frequency b. Increase in root mean square amplitude
Strength	Reduce in maximum exertion
Tremor	Increase in physiological and postural tremor
Pupil dilation	Increase in mental fatigue and drowsiness
Eyeblink rate	Increase in percentage eyelid closure over the pupil over time
Reaction time	Increase reaction time and lapses
Performance	Increase in errors and task completion time
Force variability	Increase in variability with physical fatigue
Subjective assessment	Increase in ratings of discomfort and fatigue

In recent years, the development of fatigue prediction model has received significant attention and focus from the researchers in the fields of aviation, driving, mining, and professional athletics. The growing demand for this type of model is a direct effect of the way modern humans live in the 21st century in industrialized societies. The main objective of the fatigue prediction model is to specify the underlying relationships between sleep regulation and circadian dynamics.

Dinges (2004) present the model that underlying relationships among sleep and circadian dynamics in the control of alertness and neurobehavioral performance capability. This model aims to estimate the behavioral capability and any relative risk of adverse events in a fatigued state. This study concluded that there is a need for the model to be closer to the goal of accurately predicting human behavioral capability across many days of changing sleep and wake schedules.

Wang et al., (2006) carried out a comprehensive survey of research on driver fatigue detection and provide structural categories for the methods which have been proposed. The study by Eriksson and Papanikolopoulos (1997) produce a system to locate and track the eyes of the drivers by using the symmetry-based approach. The continuity of this study proposes a non-intrusive vision-based system for the detection of driver fatigue (Singh and Papanikolopoulos, 1999). The system uses a color video camera and deals with skin color information and the driver's eye. The same pattern recognition techniques are used to determine the state of the eye. The system will draw the conclusion and issues a warning signal if the eyes remain closed for an abnormal period of time (5-6 sec). Smith et al., (2002, 2003) develop a model and system for analyzing human driver alertness. This system predicts a motion and color statistics to robustly track a driver's head and facial features detect eye or mouth occlusion, detect eye blinking and closure, and recovers the 3D gaze of the eyes.

The development of fatigue prediction model have potential in this recent years, but research must be carried out to clearly establish their basic scientific and ecological validity relative to laboratory data, and relative to different real-world scenarios is essential. The researchers have to ensure the models not to be used beyond their range of validity and capability. Previous studies done had limited information on driving fatigue and focused only on commercial bus drivers through questionnaires and salivary cortisol (Muhammad et al., 2008; Norlen et al., 2008). Besides, the study on the development of the regression models of psychophysical and biomechanical factors was lacking and more focused on one or other issues or problems.

Application of regression analysis in modeling and optimization has been proven in various fields, from food products to electronic technology as it is being practicality, economy and relative ease of use (Deshpande et al., 2008; Lotfy et al., 2007; and Axelevitch and Golan, 2007). Published work of regression modeling on driver fatigue and ergonomics study is lacking. A wide range of factors affecting fatigue is still not modeled (Dinges, 2004) and psychophysical and biomechanical factors are one of them.

However, the study by the author has developed the regression models of driver fatigue using response surface methodology by design expert software. (Ani, M.F, 2016). The regression models are used to estimate the value of risk factors that contribute to driver fatigue. In this study, six regression models in the form of polynomial equations were successfully formulated. The validation analysis was carried out by the author, and the results show that the models can be used and reliable for predicting the value of risk factors. All the validation run results fall within the 90% prediction interval (PI) of the developed models and their residual errors were less than 10%.

As this dissertation is the continuity from the author's Master's thesis (Ani, M.F, 2016), all these regression models will be used in the development of driving fatigue strain index (DFSI) and decision support system (DSS) for driving fatigue. However, there is no details discussion about the development of the regression model that will be found in this dissertation.

In terms of the development of a decision support system (DSS) for transportation, there are many previous studies that have been done. However, there is no study on the development of a decision support system that focuses only on the causes of road accidents especially driving fatigue. In the early stage, DSS was conceived as simple databases for storing and retrieving information deemed useful to decision-makers (Silver, 1991). This tool then has been improved and has become real support in complex human decision making processes that help decision-makers to identify a possible solution that can optimize choice (French, 2000; Dell'Acqua et al., 2011).

The recent study by Fancello et al. (2013) developed the decision support system for road safety analysis for supporting the public administration in planning safety intervention on the road network. Besides, the study by Dell'Acqua et al. (2011) developed the road safety knowledge-based decision support system. These DSS identify and rank hazardous sites on roadways in order to reduce the number of road accidents. Another recent study is the development of DSS for analysis of vulnerable road users' safety issues called SAFEBRAIN (Tripodi et al., 2012). This DSS developed to select safety measures to reduce the risk of accidents of vulnerable road users.

A tabulated in Table 1.5, the author summarized that the previous development of DSS in transportation is more focus on road safety, routing and scheduling, maintenance, material handling, and management. Hence, in realizing the need for solving the problem mentioned in Chapter 1, the author proposes a new decision support system that more focuses on driving fatigue as the contributing factor for road accidents.

Table 1.5: Selected DSS and application in transportation

Author / Developer	Objective and Application	Finding / Contribution
Suzuki (2009)	• DSS for dynamic optimization of fuel purchases. • The DSS as the fuel optimizer that defines optimal moments of refueling, corresponding to the concrete point of purchase (truck stop) and optimal quantities of fuel to be purchased for the truck.	The system can reduce fuel costs by 2%. The author proves the system out-performs standard fuel-optimizers by more than $100,000 and $1,000,000 in annual fuel cost savings for carriers with 500 and 10,000 trucks.
A. Caputo, L. Fratocchi, and P. Pelagagge (2006)	• DSS for optimal planning of road, long haul, freight transportation activities by minimizing the total transportation cost through the proper aggregation of customer orders in separate full truckload (FTL) and less than truckload (LTL) shipments.	The study found that the system can yield 35% higher savings than traditional or manual planning.
M. Zacharias, S.T. Mehdi, and M. Christos (2006)	• Assist the daily activities of Greek transportation firms during the special event. The system was known as XENIOS. • XENIOS helps the decision-maker to solved complex routing and scheduling problems such as economic aspect, customer service level, and driver working conditions faced during the Athens 2004 Olympic Games.	The system solved the problems and the final decision can be made based on total delivery time, cost of vehicle utilization and violation level of the customer's hard time.
J. Selih, A. Kne, A. Srdic, and M. Zura (2008)	• DSS for rational management and maintenance of the road transportation infrastructure by using the AHP method. • The DSS determines the set	After the DSS is tested on 27 MR&R projects for a highway section, the authors found that MR&R project indirect costs are significant in comparison with the MR&R project direct cost.

	of road maintenance, repair and rehabilitation (MR&R) project that produces maximized overall benefit subject to budget and compatibility constraints.	
M. Jakimavicius and M. Burinskiene (2007)	• DSS corporate with GIS facilities for accessibility based road or automobile transportation system analysis, which evaluates the different road transportation system. • The expert's knowledge was used to assign weight criteria and rank transportation based on their multiple criteria evaluation.	The DSS used as an advisor for decision-makers on allocating investment for the development and expansion of the road network and defining the boundaries of the road network. This system was applied in Lithuania for real-life analysis of transportation systems.
G. Zografos and N. Androutsopoulos (2005)	• DSS for hazardous materials transportation risk management such as hazardous materials distribution and emergency response decisions.	The DSS contributes to the provision of alternative efficient hazardous materials distribution with minimum cost and risk, identification of the emergency response unit's location that minimizes the incident response time, routing of the emergency response units, and optimize the evacuation plans.
V. Toretta, M. Raboni, S. Copelli, and G. Urbini (2013)	• This DSS which is also known as TrHaM quantified the total risks related to the transport of hazardous materials along with different type routes by using GIS.	This DSS helps the decision-maker to estimates the risk distribution and planning transportation activities.
A. Tripodi, L. Persia, and Paola Di Mascio (2012)	• DSS for analysis of vulnerable road user's safety. • This DSS is called as SaferBrain used GIS-based application. SaferBrain is developed to select safety measures to reduce the accidents risk on vulnerable road users.	SaferBrain can be used by the decision-maker for taking a decision in preventive or in a corrective phase. SaferBrain has been developed as a web application accessible for free.

G. Fancello, M. Carta, and P. Fadda (2015)	• DSS for road safety analysis for supporting the public administration in planning safety interventions on the road network.	This system proposes a modeling tool that incorporates the different indicators to calculate the safety conditions.
G. Dell' Acqua, M. De Luca, and R. Mauro (2011)	• DSS for identifying and ranking the hazardous sites (Black Spot) on roadways.	The system able to detect more than 34 black spots on the network that authors studied, and the system has provided important support for decision making in order to reduce the danger level of the most hazardous black spot.
This study	• DSS for driving fatigue to provide systematic analysis and propose a solution to minimize the number of road accidents and fatalities associated with driving fatigue.	The system gives an early warning and detection of fatigue and gives better solutions and recommendations to the road users while driving, which consider two factors between human and road condition. Indirectly, it becomes one of the efforts in order to reduce the number of road accidents and fatalities.

Hence, due to above mentioned problem, this study counters this problem by investigating the ergonomic factors and psychophysical experience that contribute for driver fatigue among Malaysian while driving at the high risk accidental area, analyze the biomechanical factors for driving fatigue through an actual experiment felt and to formulate and validate the regression models using the ergonomic approach in solving the driver fatigue. In addition, this study reviews the application decision support system (DSS) on the vehicles related to driving fatigue. Furthermore, this study will develop the decision support system (DSS) to assess and systematic analyze, draw a new conclusion, and propose a solution and recommendation for reducing the number of road accidents in Malaysia.

However, for this dissertation the author will focus just on the development of Driving Fatigue Strain Index (DFSI), and development of Decision Support System for Driving Fatigue (DSSfDF) as this research is the continuation from the Master's research entitled "Developing Regression Models of Driver Fatigue Using an Ergonomics Approach" (Ani, 2016).

1.1 Significance of Research

The outcomes of this research are expecting on bringing a benefit towards:

1. **New findings/ New Knowledge**

    a. The industrial area and road safety practitioners can refer or use the outputs of this research to improve driving fatigue problems.

    b. Malaysian organizations such as the Road Transportation Department of Malaysia can use the data and models to improve existing guidelines and regulations for the Malaysian drive.

    c. This research can offer new references and methods for future research.

2. **Specific or Potential Applications / Contribution to Nation:**

    The outcomes of proposed study in example the database on Driving Fatigue Strain Index (DFSI) and Decision Support System for Driving Fatigue (DSSfDF) can be used by potential users such as road users, researchers, and general population as guidelines and references when driving as driving becoming importance medium in connecting human from one to another place in daily life. This study will be providing a database to the potential users regarding the muscle activity, heart rate, whole-body vibration, hand grip pressure force, seat pressure distribution, driving duration and as well as the risk level for the driving condition during the driving activity. The road user or researchers in solving the problem regarding driver fatigue can use the DSSfDF mode as they can obtain the information through a system. Indirectly, helps the government or nation to reduce the number of road accident and fatalities especially in Malaysia.

1.2 Structure of the Dissertation

The author has organized this dissertation into six main chapters, which consists of four stages as the pillars for the development of a decision support system as shown in Figure 1.4. The first chapter summarizes the background of the study which encompasses the introduction of the study, problem statement, objectives of study, the significant of research, and structure of the dissertation. In Chapter 2, the author explains the first stage for the development of a decision support system (DSS) that is the acquisition of knowledge. Chapter 3 describes the integration of knowledge by identifying the risk factors which contribute to driving fatigue. This is the second stage for the development of DSS. Chapter 4 presents and discussed the main findings of this study that is the development of driving fatigue strain index (DFSI) using the fuzzy logic. Meanwhile, Chapter 5 focused on the development of a decision support system for driving fatigue (DSSfDF). This development is the final stage of this study. This chapter will explain the method used for the system. Finally, Chapter 6 concludes the findings of this research based on the objectives of this research. Besides, the author proposes some suggestions or recommendations for future work in order to improve the driving fatigue strain index and decision support system for driving fatigue.

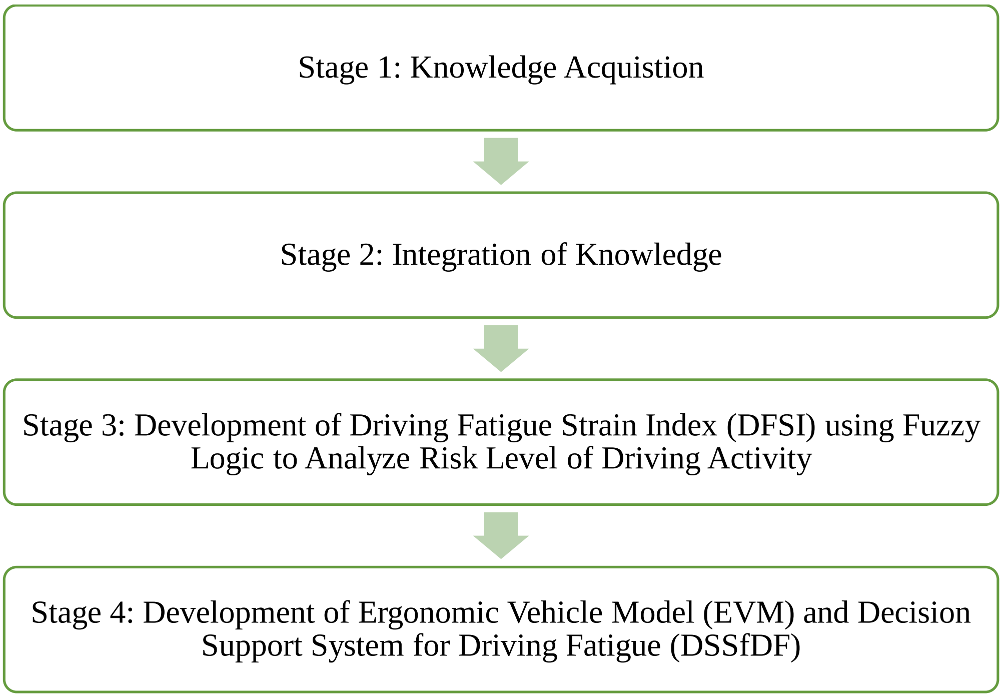


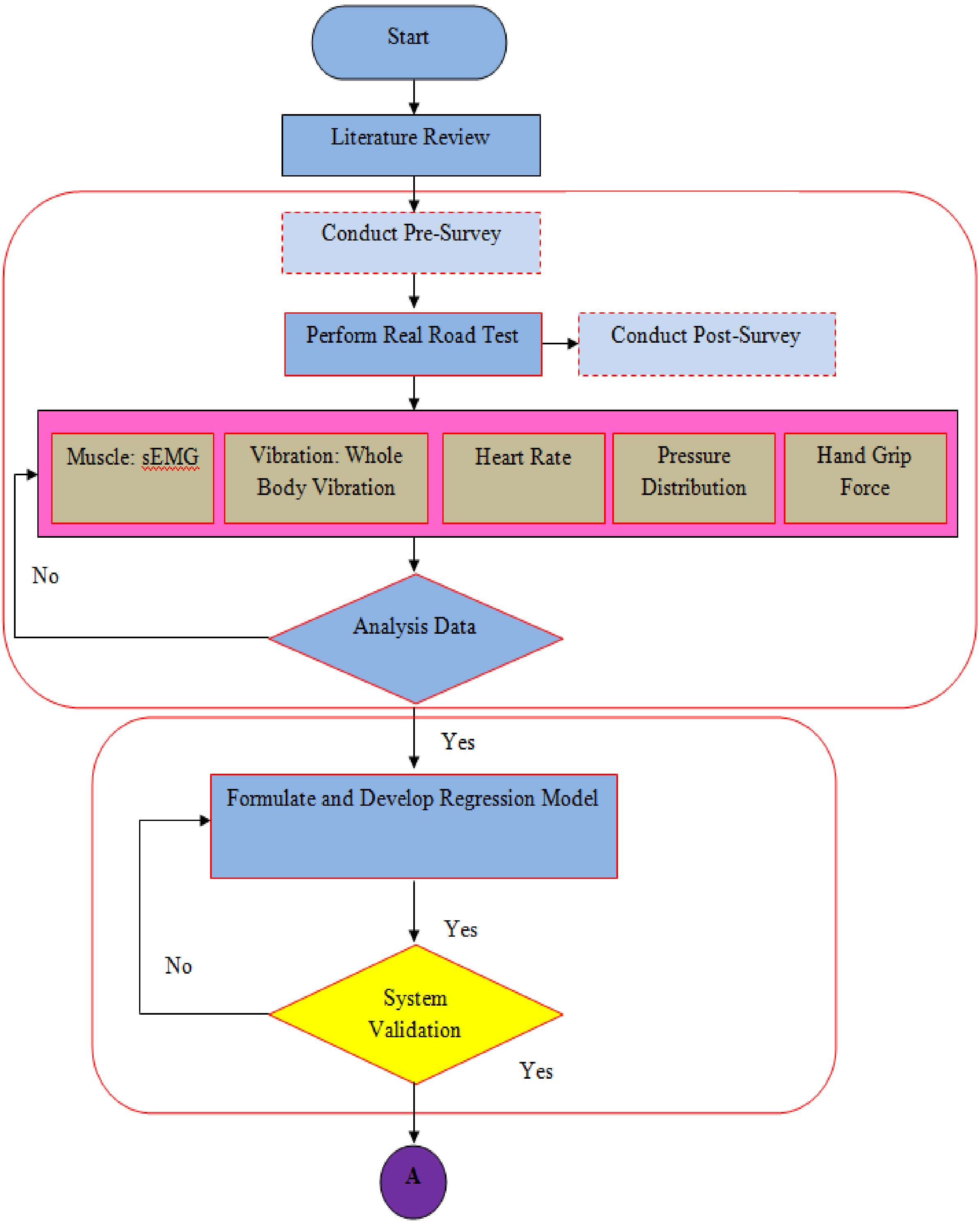
Figure 1.4: The flow for the development of a decision support system

Chapter 2 Acquisition of Knowledge

This chapter introduces the first stage for the development of a decision support system for driving fatigue (DSSfDF).

2.1 Stage 1: Knowledge Acquisition

Knowledge is a brain to process the input data and information received by the system (Halim et al., 2014; Turban, 1990). The knowledge can be acquired by extracting, structuring, and organizing knowledge from one to more sources (Edwards, 1996). In this study, the risk factors that contribute significantly to driver fatigue are determined by performing the knowledge acquisition. Besides, the ergonomics evaluation tools also are determined at this stage. This knowledge acquisition is achieved by gathering the information from reliable sources such as conducting the pre-survey, performing the real road test, reviewing the previous research and articles, referring the guidelines and international standards from authorized organizations or bodies, and getting opinions from the ergonomics expert to develop the knowledge base of the DFSI. In order to achieve knowledge acquisition, the process flow of the research was constructed first. The process flow is based on every objective in this research. Figure 2.1 shows the flow of the research from the beginning until the end of the research.


Start
Literature Review
Conduct Pre-Survey
Perform Real Road Test
Conduct Post-Survey
Muscle: sEMG
Vibration: Whole Body Vibration
Heart Rate
Pressure Distribution
Hand Grip Force
No
Analysis Data
Yes
Formulate and Develop Regression Model
Yes
No
System Validation
Yes
A

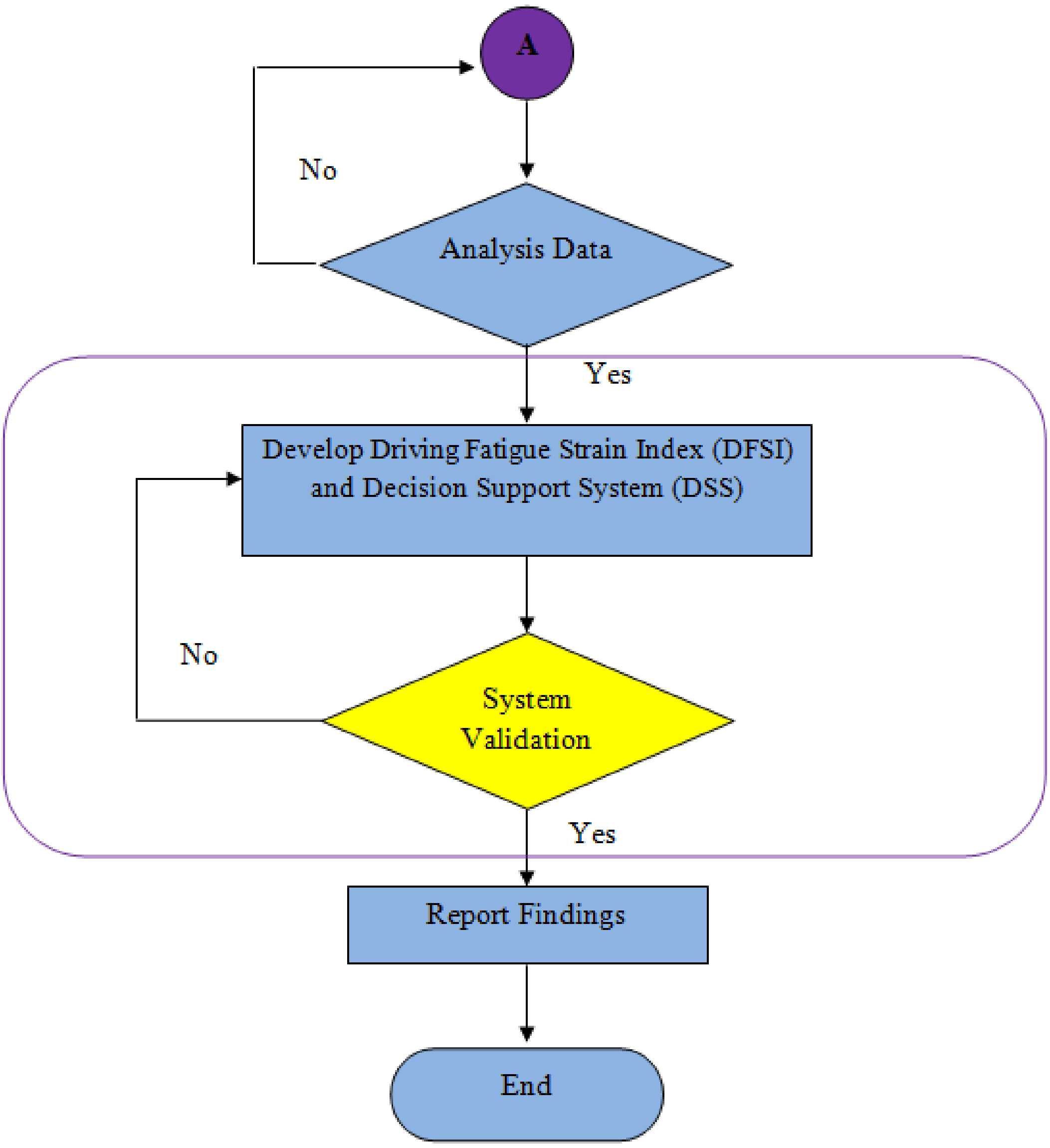


Figure 2.1: Process flow of the research

The pre-survey and the real road test experiment is conducted and performing among Malaysia's road users to examine and obtain information and data on each risk factor; muscle activity (MA), heart rate (HR), hand grip force (HGF), whole-body vibration (WBV), seat pressure distribution (SPD), and driving duration (DD). Besides, the previous research, articles or journals, magazines, and online databases regarding the risk factors that affected the fatigue associated with driving are reviewed. In this study, the subjects are consist of drivers that have at least two years of driving experiences and the subject's age is between 20-25 years old. The subjects are normal and have healthy bodies. Besides that, all the subjects told that they are refrained from drinking coffee, tea or alcohol, smoking, and free from taking any medicine. The health evaluation has been done 24 hours before the experiment to ensure they have enough habitual amount of sleep at night before the experiment in order to avoid sleep deprivation (Wickens et al., 2003). The subjects were given a brief interview and explanation, and blood pressure measurement was performed to ensure that the subjects were fit and ready for the experiment. The systolic blood pressure (SBP) and diastolic blood pressure (DBP) of all participants should not exceed 120/80mmHg during the experiments (Zuraida et al., 2019).

Continue by that, this research involves the analysis of experimental results and implementing the cognitive research to propose the regression model and table database. The regression model and table database also will be validated to prove the usability of the data and the degree of the applicability of this function.

The research continues with the analysis of data from the regression model in order to develop the driver fatigue strain index (DFSI) by using the fuzzy membership function (fuzzy logic). After that, this study will develop DSS for solving the fatigue problem among Malaysian's drivers. The graphical user interface (GUI) of this system is developed by the Django framework based on Python programming language. Finally, report any findings from this research.

However, this dissertation will focus just on the development of Driving Fatigue Strain Index (DFSI) and Decision Support System for Driving Fatigue (DSSfDF) (refer purple's box in Figure 2.1) as this research is the continuation from the Master's research entitled "Developing Regression Models of Driver Fatigue Using an Ergonomics Approach" (Ani, 2016). Hence, there is no details discussion on red boxes in Figure 2.1, and only the final results of the red box will be used in this research.

There are seven main areas (Angehrn and Luthi, 1990; Moore and Garg, 1995;; Liao, 2005; Karwowski et al., 2006; Lee et al., 2008; Zak, 2010; Halim and Omar, 2012) that the author reviewed and referring to the guidelines in the development of decision support system. In this study, the author has referred the guidelines and standard from authorized organization, society or bodies such as International Standard Organization (ISO), Royal Malaysia Police (RMP), Perusahaan Otomobil Nasional (PROTON), and Malaysian Institute of Road Safety Research (MIROS) to obtain information and data on number of road accidents and fatigue associated with driving.

Furthermore, expert opinion such as ergonomics practitioners, road safety practitioners, and academician gives a huge benefit in the development of the knowledge base of the system. All these risk factors, then are classified into three areas or domains; human or driver (MA, HR, SPD), machine or vehicle (WBV), and environment (DD).

Chapter 3 Integration of Knowledge

This chapter introduces the second stage for the development of a decision support system for driving fatigue (DSSfDF).

3.1 Stage 2: Knowledge Integration

In this stage, the risk factors and ergonomics evaluation tools are processed to integrate them. The risk factors of driving fatigue and the evaluation tools are matched together to quantify the risk levels and directly developed the DFSI. The six risk factors are identified as the vital factor contributing to the driving fatigue and have been assigned to the human-machine-environment domain as shown in Figure 3.1.

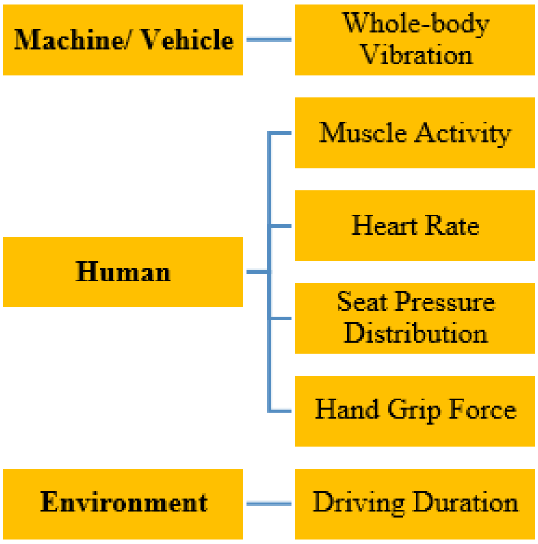


Figure 3.1: Human-machine-environment domain

The risk factors are selected based on the real road test experiment (as shown in Figure 3.2) and a previous study that has proven all these factors give a significant effect on fatigue while driving (Rahayu et al., 2015; Rahayu et al., 2015; Rahayu et al., 2016; Ani, 2016; Firdaus et al., 2017; Firdaus et al., 2017; Ani et al., 2017; Ani et al., 2017; Ani et al., 2017; Ani et al., 2018). Besides, some of the previous studies have been used as the guideline to quantify the risk levels of each risk factor as reflected in Table 3.1.

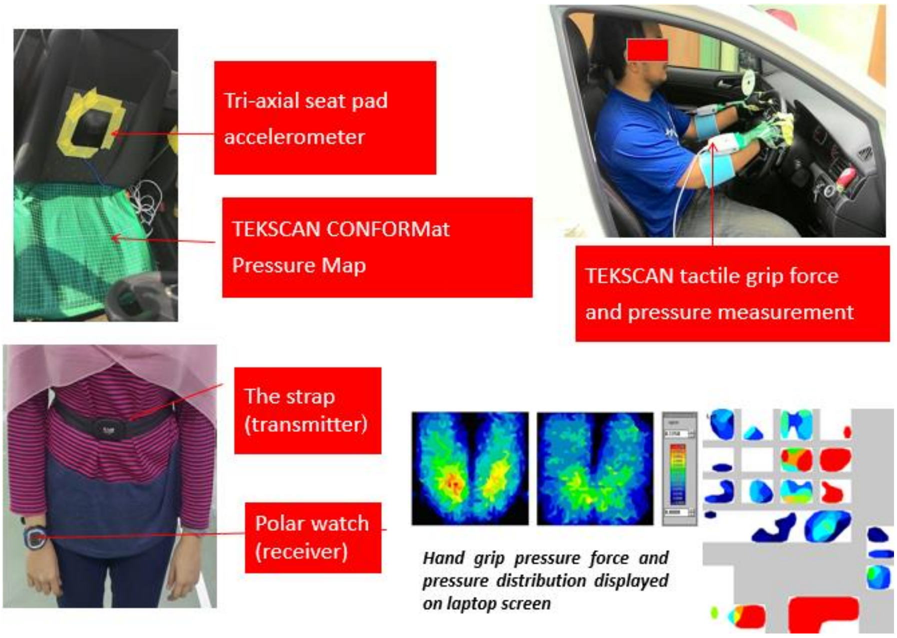


Figure 3.2: The experimental apparatus and setup

Table 3.1**:** The previous studies and standard used as guidelines

Risk Factors	Previous Studies
Muscle Activity (MA)	De Luca (1997); Rodgers (1992)
Heart Rate (HR)	NLM (2015); Jasiulewics-Kaczmarek and Drozyner (2013)
Hand Grip Force (HGF)	Chieh et al. (2003); Eksioglu and Kizilaslan (2008)
Seat Pressure Distribution (SPD)	De Looze et al. (2003)
Whole-Body Vibration (WBV)	ISO 2631-1 (1997)
Driving Duration (DD)	Mansfield et al. (2015)

Analysis of each risk factor produces a risk level which represents the effects of analyzed risk factors to the driver. Table 3.2 summarizes the risk criteria for each factor to indicate risk levels due to driving fatigue. These rating criteria and risk levels are based on the previous studies and standard mentioned in Table 2. The risk criteria and risk level will be used in stage 3 of development for DSSfDF.

Table 3.2: The risk criteria and risk level for the driving condition

Risk Factor					
MA (µV)	**HR (bpm)**	**HGF (N)**	**WBV (m/s²)**	**SPD (kPa)**	**DD (min)**
Little fatigue: $52 \geq 129$	Very fit: <84	Non-fatigue: ≥ 189.60	Comfort: < 0.315	Comfort: ≤ 5.80	Non-fatigue: < 40
Moderate fatigue: $130 \geq 300$	Fit: 84 – 105	Mild Fatigue: $57.80 > 189.60$	Little comfort: $0.315 > 0.63$	Discomfort: > 5.80	Fatigue: ≥ 40
Fatigue: $301 \geq 600$	Average: 106 – 122	Fatigue: < 57.80	Fairly comfort: $0.50 > 1.0$		
Very fatigue: $601 \geq 1100$	Unfit: >122		Discomfort: $0.8 > 1.6$		
			Very discomfort: 1.25- 2.5		

3.2 Integration of DSSfDF's Components

Figure 3.3 shows the structure of the Decision Support System for Driving Fatigue (DSSfDF) model which consists of three main components; working memory, knowledge base, and inference engine (Ani et al., 2018). These three components have to be integrated into DSS to provide the systematic and rapid analysis of risk factors associated with driving fatigue. In this system, the ergonomics database (refer Chapter 5) was created for the Ergonomics Vehicle Model (EVM) and the working memory for the DSSfDF model. The system will obtain the data and information on the user and vehicle profile, and risk factors, which entered by the users through the Graphical User Interface (GUI) (refer

Chapter 5) and stores them into the ergonomics database. This data and information have then been retrieved by the inference engine before it will send to the working memory. Then, the inference engine will examine and matches the data in the working memory with the available rule sets in the knowledge base to generate results and draw a new conclusion and solution. This section will be discussed how these components integrated together in DSSfDF.

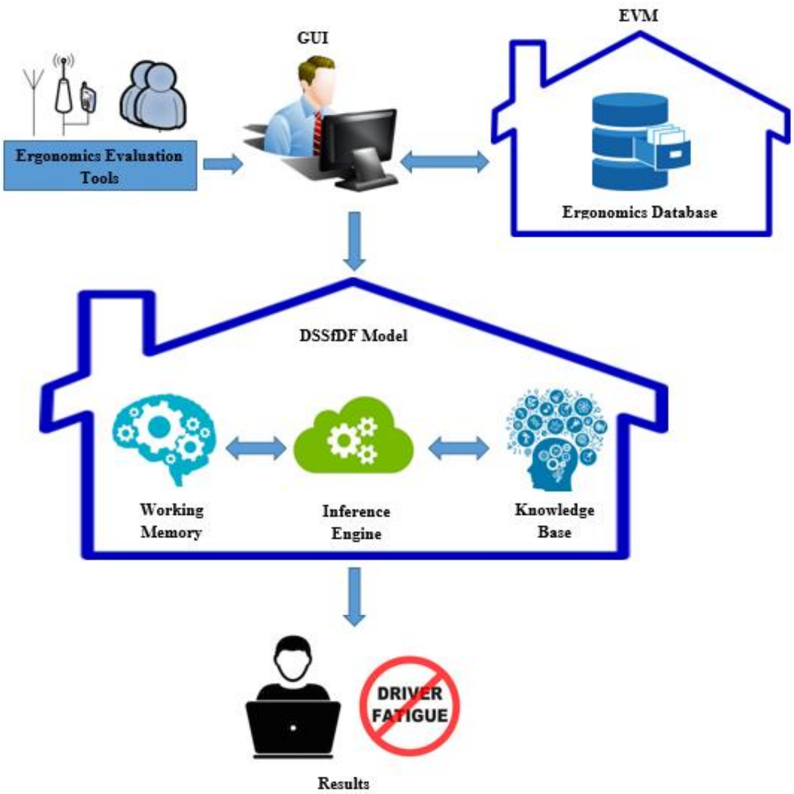


Figure 3.3: The structure of DSS

3.2.1 Working Memory

Working memory temporarily stores the data and the results of the analysis. The DSSfDF is provided with eight working memories for each of the risk factors and a driving fatigue strain index (DFSI). DFSI was developed using the fuzzy inference system (FIS) by

MATLAB software capability. The FIS consist of the membership function of inputs, fuzzy linguistic rules, and output membership function, which will be discussed in detail in Chapter 4. Figure 3.4 shows the structure of the working memories of the DSSfDF model.

All the working memories consist of the following classes:

1. Driver Memory: Collects data and information on driver's profile; type of vehicle, vehicle category, vehicle model, model year, driver name, age, gender, weight and height, health status, driving experience, and frequency of driving per day.

2. Muscle Activity (MA) Memory: Save data and information, and results of muscle activity analysis

3. Whole-body vibration (WBV) Memory: Save data and information, and results of whole-body vibration analysis.

4. Hand Grip Force (HGF) Memory: Save data and information, and results of hand grip pressure force analysis.

5. Heart Rate (HR) Memory: Save data and information, and results of heart rate analysis.

6. Seat Pressure Distribution (SPD) Memory: Save data and information, and results of seat pressure distribution analysis.

7. Driving Duration (DD) Memory: Save data and information, and results of driving duration analysis.

8. Driving Fatigue Strain Index (DFSI) Memory: Save results of DFSI and solutions.

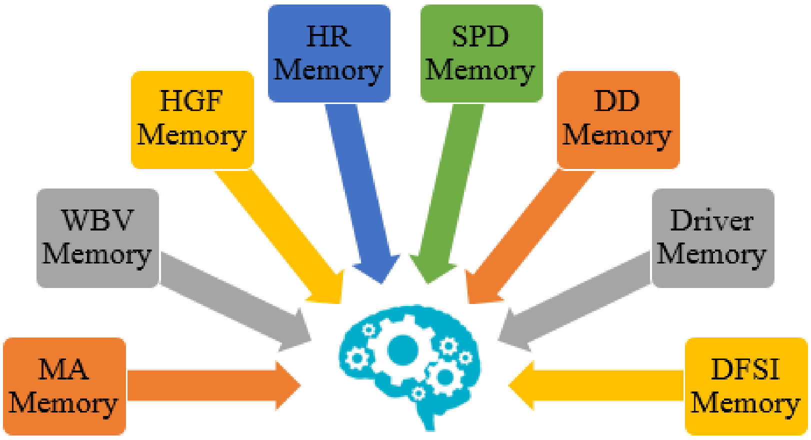


Figure 3.4: The structure of working memories of the DSSfDF model

3.2.2 Knowledge Base

The knowledge base contains the rule sets for the analysis such as muscle activity rule, hand grip force rule, whole-body vibration rule, heart rate rule, seat pressure rule, driving duration rule and driving fatigue strain index rule as shown in Figure 3.5. This is done using fuzzy logic.

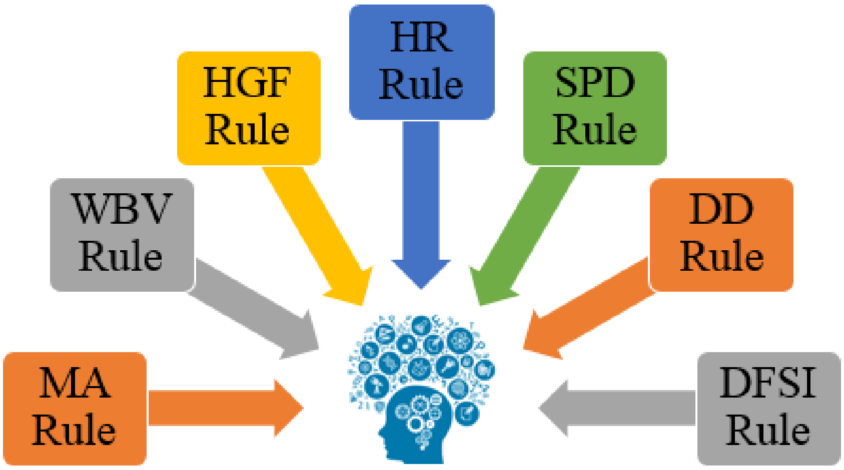


Figure 3.5: The rule sets contained in the knowledge base of the DSSfDF model

In this study, the Mamdani-type model (Tadic et al., 2014; Azadeh et al., 2008; Gentile et al., 2003; Aluclu et al., 2007) is used as the inference method, which uses the IF-THEN rules. The rule sets consist of a list of IF statements and a list of THEN conditions to process any input data and provide a set of alternative solutions and conclusions. The FIS by MATLAB is used to create the rule sets as explained by the author in Chapter 4.

3.2.3 Inference Engine

The inference engine is used to obtain the results and draw the new conclusion by matching the rule sets in the knowledge base and the data available in the working memory. The working process is done using fuzzy logic by applying the forward chaining method. The forward-chaining works by processing the data first and continuously using the rules in the knowledge base to draws new conclusions given by those data (Abraham, 2005; Lee et al., 2008).

The forward-chaining operates through a top-down approach which takes data available in the working memory before the results being generating based on satisfying conditions of rules in the knowledge base. The values of each linguistic variables are entered into the FIS's rule viewer to get the defuzzification value that shows a measure of the degree of DFSI. The results obtained will be saved in the working memory or directly displayed to the users through GUI.

Chapter 4 Development of Driving Fatigue Strain Index

This chapter introduces the third stage for the development of a decision support system for driving fatigue (DSSfDF) that is the development of driving fatigue strain index (DFSI).

4.1 Stage 3: Development of DFSI using Fuzzy Logic

Fuzzy logic is based on the concept of partial membership function (MF) in a set described by the MF(μA), which is a curve that defines how each point in the input space is mapped to a membership value described by real values $0 \leq [\mu A(x)] \leq 1$. Fuzzy logic is highly demanded in an industrial application to model nonlinear input-output relations as fuzzy provides a constructive way of turning qualities into mathematics (Klir and Yuan, 1996; Aluclu et al., 2008). Besides, the fuzzy logic for pattern recognition and approximate information processing and artificial neural networks have been used in a variety of areas, including process control, engineering management, business, medical diagnosis, biomechanics, human factors, and cognitive simulations (Karwowski and Ayoub, 1984; Karwowski et al., 1984; Karwowski, 1985; Karwowski et al., 1987; Karwowski et al., 1999; Karwowski et al., 2006; Karwowski and Mital, 2014).

However, based on reviewing the previous study, fuzzy logic has limited applications on the ergonomics aspect and approach such as analyzing the risk level of driving activity. The previous study and reported references should be consulted for additional information, guidelines, and examples on fuzzy logic (Baas and Kwakemaak, 1977; Karwowski and Ayoub, 1984; Karwowski et al., 1984; Karwowski, 1985;

Karwowski et al., 1987; Mayne, 1990; Klir and Yuan, 1995; Klir and Yuan, 1996; Berkan and Trubatch, 1997; Jang et al., 1997; Tanaka, 1997; Yen and Langri, 1998; Karwowski et al., 1999; Gentile et al., 2003; Tadic et al., 2003; Karwowski et al., 2006; Aluclu et al., 2008; Azadeh et al., 2008; Lee at al., 2008; Zimmermann, 2011; Lootsma, 2013; Karwowski and Mital, 2014). This chapter has presented the development of the DFSI using fuzzy logic to quantify the risk levels of fatigue associated with driving activity and propose a solution to minimize the risk of driving fatigue to reduce the number of road accidents and fatalities in Malaysia.

4.2 Build a Fuzzy Inference System

The DFSI was developed based on the fuzzy logic, which based on the concept of partial membership in a set described by the membership function (MF). MF is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. In this stage, the fuzzy inference system (FIS) was built. FIS is the process of formulating the mapping from a given input to an output using fuzzy logic. In order to build the FIS, the fuzzy logic toolbox graphical user interface (GUI) by the MATLAB software was used. There are five primary GUI tools for building, editing, and observing the FIS in the toolbox; FIS editor, MF editor, rule editor, rule editor, and surface viewer.

FIS editor displays information about an FIS such as input and output, and FIS type as shown in Figure 4.1.

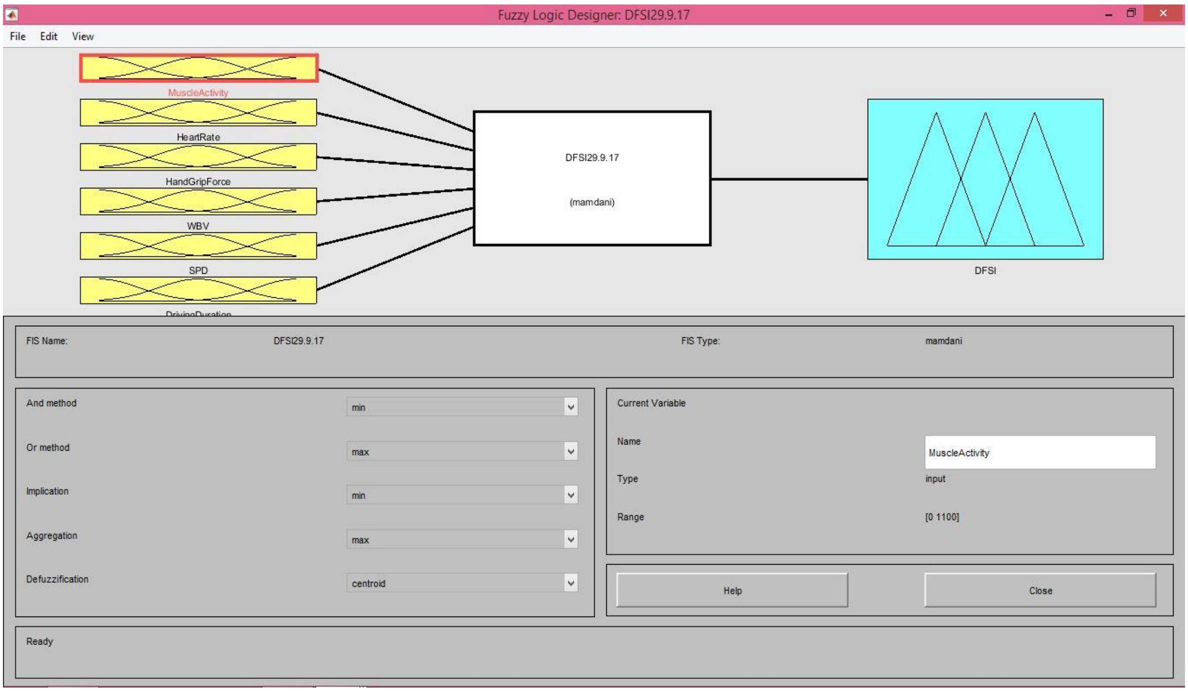


Figure 4.1: Fuzzy Inference System (FIS) editor

This section will discuss in detail the structure of the fuzzy logic system as shown in Figure 4.2.

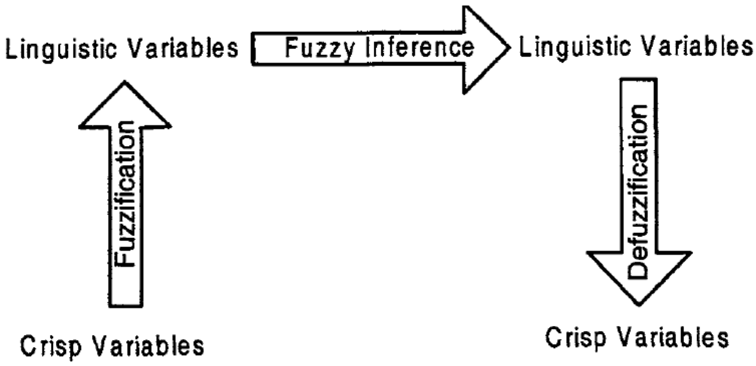


Figure 4.2: The structure of a fuzzy logic system (Wang, 2001)

4.2.1 Fuzzification

The inputs or also known as the linguistic variable of this study consists of the six risk factors; MA, HR, WBV, HGF, SPD, and DD. While the linguistic variable DFSI is the output variables of this study. The linguistic variables and its universe of discourse (i.e. range) are divided into fuzzy sets defined by the MF, which indicates the degree of membership in that set as shown in Figure 4.3 and Figure 4.4.

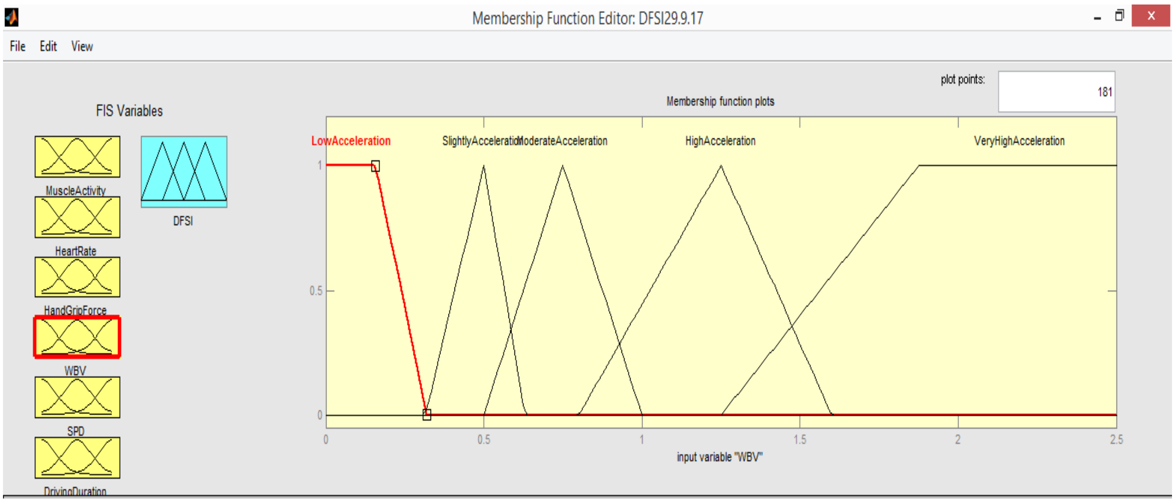


Figure 4.3: MF editor displaying the example of linguistic variable 'WBV' in term of fuzzy sets

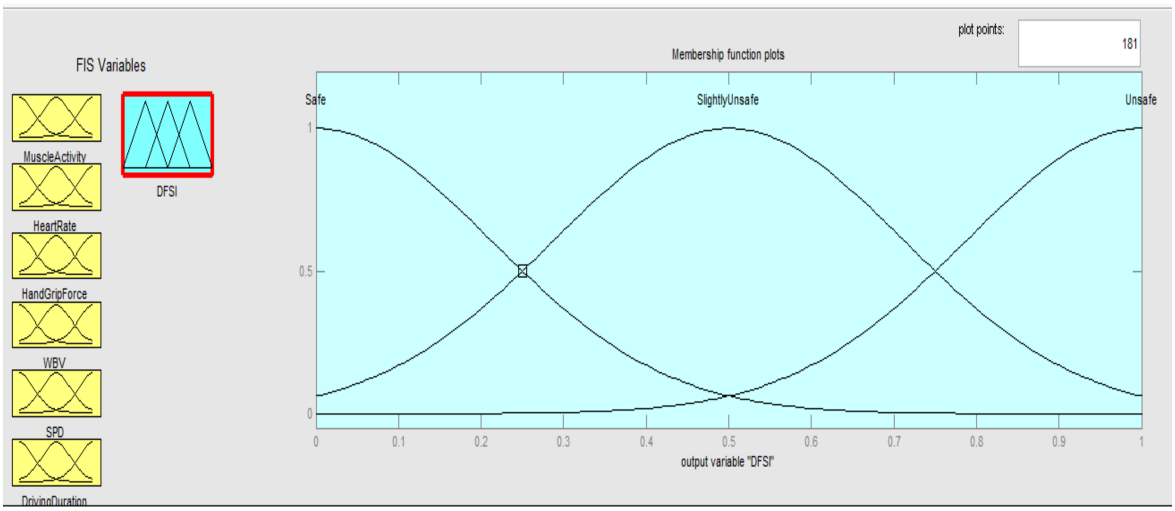


Figure 4.4: MF editor displaying the example of linguistic variable 'DFSI' as the output variable

The fuzzy sets represent the linguistic value of the linguistic variables for a specific input value x. For example, the variable ‘WBV’ is divided into five fuzzy sets; ‘low acceleration’, ‘slightly acceleration’, ‘moderate acceleration’, ‘high acceleration’, and ‘very high acceleration’. The input value of each fuzzy set is based on the risk criteria and risk levels of the risk factor as discussed in the previous chapter and reflected in Table 3.2. For example, the input WBV of x = < 0.315 m/s^2 belongs partially to the fuzzy set ‘low acceleration’. The input value of fuzzy sets is real numbers. The author uses the typical and simplest membership function that is triangular, trapezoidal and Gaussian membership function.

A simple membership function allows the author to graphically represent a fuzzy set. Besides, using more complex functions does not add more precision. The triangular function was defined by a lower limit a, an upper limit b, and value m, where a < m < b as shown in Figure 4.5. While the trapezoidal function was defined by a lower limit a, an upper limit d, a lower support limit b, and an upper support limit c, where a < b < c < d as shown in Figure 4.6.

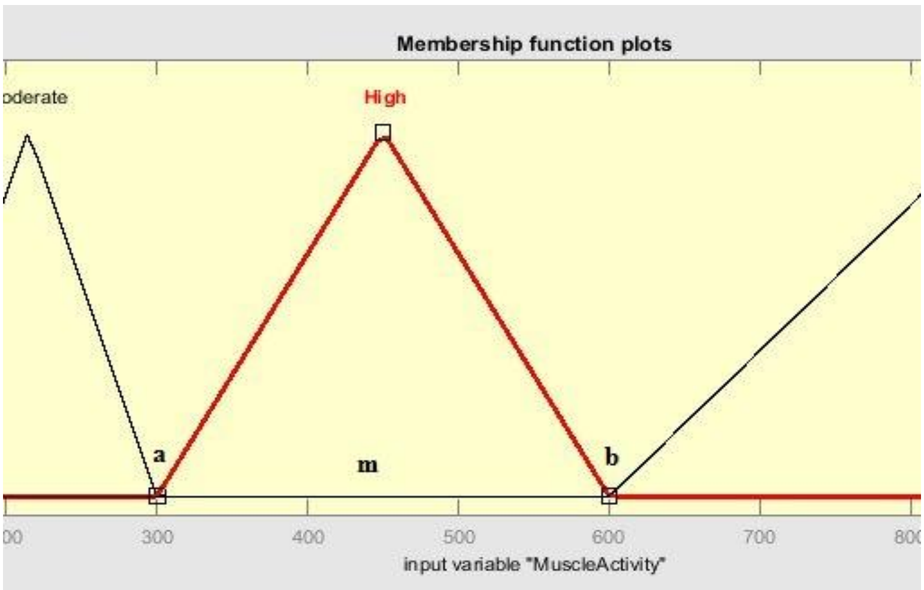


Figure 4.5: Triangular function

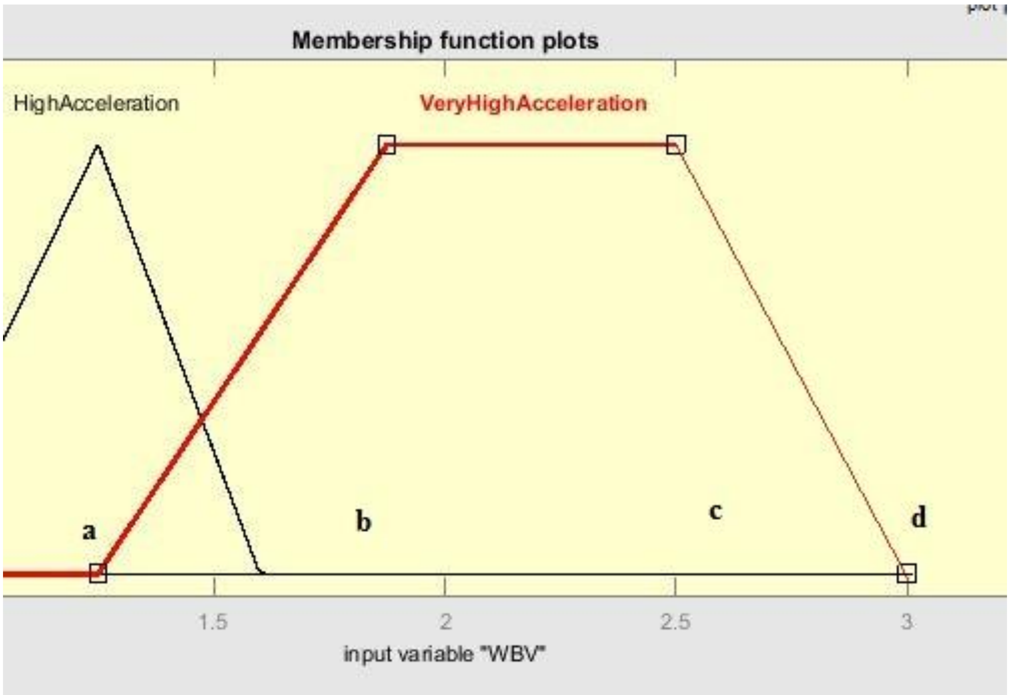


Figure 4.6: Trapezoidal function

Another function used in this study is Gaussian function, which defined as central value m and standard deviation k > 0. The smaller the k is, the narrower the "bell" is as shown in Figure 4.7.

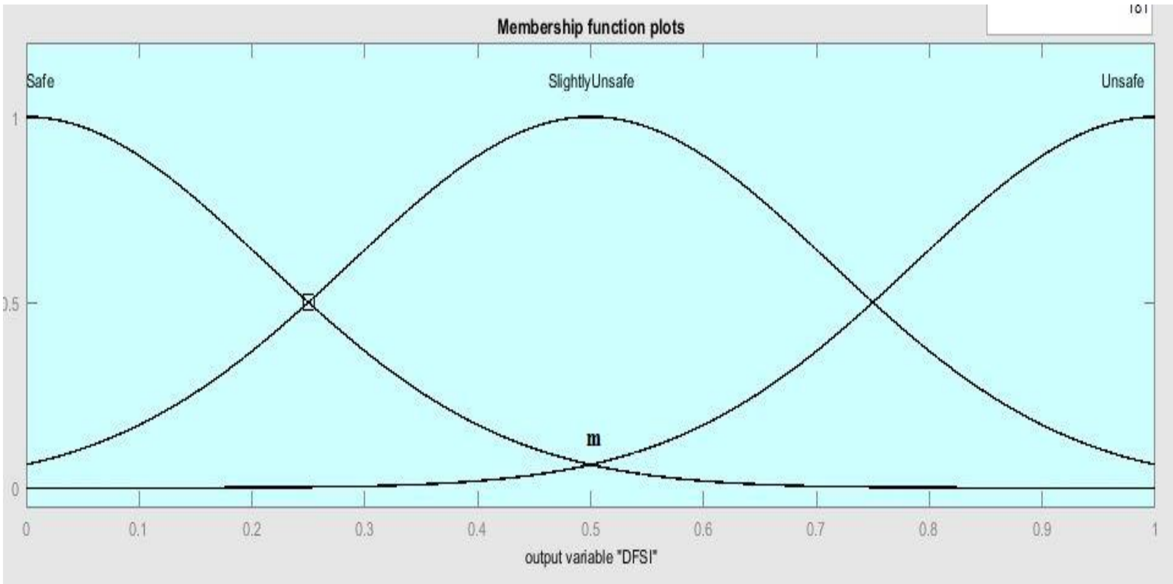


Figure 4.7: Gaussian function

4.2.2 Fuzzy Inference

In the FIS, the fuzzy inferences rules are required for fuzzy reasoning that determines the outputs corresponding to fuzzified inputs. The IF-THEN rules statement format is used to express the inference rule. IF-THEN rules are used to define the relationships between variables based on defined logic and membership functions. An IF-THEN rule is written in the form:

If x is A then y is B.

A and B are linguistic values defined by fuzzy sets on the ranges (universes of discourse) X and Y, respectively. The IF-part of the rule is called the antecedent (or premise), whereas the THEN-part of the rule (y is B) is called the consequent (or conclusion). In order to create the final consequent function or set, the implication method was used. In some cases, the IF-THEN rule is often not appropriate enough and more rules may be necessary to create a satisfying result. This can be done by considering an extension to this rule, which written in the form:

If x is A OR y is B then z is C

This extension IF-THEN statement now has two rules involved that are controlled by the logical operation in Boolean known as AND, OR, and NOT. Implication becomes the means by which the consequent is created from this rule, which is the "z is C" part.

The Mamdani-type, which is based on a simple structure of max and min operation, was used as the inference method. This method is usually used for inferencing, which truncating the consequent membership function of each discarded rule (at the minimum membership value of all the antecedents) and determining the final aggregated membership function. The rule editor GUI was used to edit the list of inference rules that define the behavior of the system as shown in Figure 4.8.

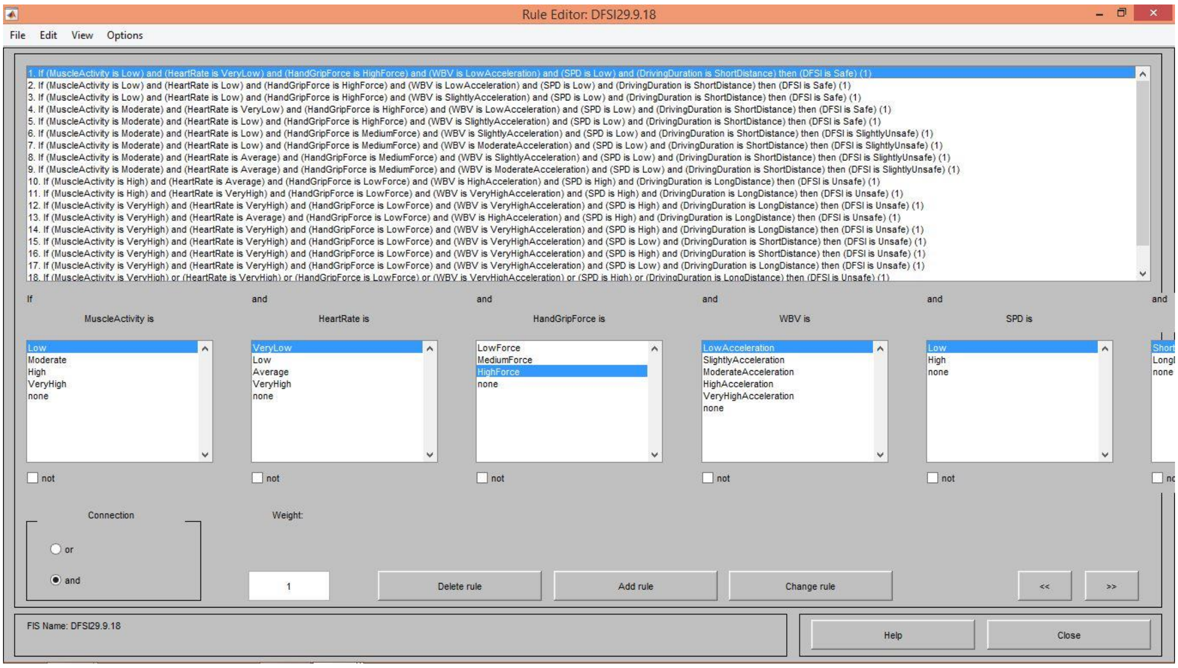


Figure 4.8: The rule editor for constructing and editing the rule statement

The rule editor allows the authors to construct the rule statement automatically. The example of the Mamdani-type model uses IF-THEN rules:

Rule 1 IF *MA* is Low AND *HR* is Very Low AND *HGF* is High Force AND *WBV* is Low Acceleration AND *SPD* is Low AND *DD* is Short THEN *DFSI* is Safe

Rule 2 IF *MA* is High AND *HR* is Average AND *HGF* is Low Force AND *WBV* is High Acceleration AND *SPD* is High AND *DD* is Long THEN *DFSI* is Unsafe

Where 'Very Low', 'Low', 'Average', 'High', 'Very High', 'Safe', and 'Unsafe' are fuzzy sets; MA, HR, HGF, WBV, SPD, DD, and DFSI are linguistic variables. The linguistic variables MA, HR, HGF, WBV, SPD, and DD are the input variables, while the linguistic variable DFSI is the output. In the rules, the connector AND can be replaced by OR and they are evaluated respectively by the operation of intersection and union. There are 20 rules stated in this study were constructed by the author as shown in Table 4.1.

Table 4.1: The rules set

No. of Rules	Rules Set
Rule 1	If (MA is Low) and (HR is Very Low) and (HGF is High Force) and (WBV is Low Acceleration) and (SPD is Low) and (Driving Duration is Short Distance) then (DFSI is Safe)
Rule 2	If (MA is Low) and (HR is Low) and (HGF is High Force) and (WBV is Low Acceleration) and (SPD is Low) and (DD is Short Distance) then (DFSI is Safe)
Rule 3	If (MA is Low) and (HR is Low) and (HGF is High Force) and (WBV is Slightly Acceleration) and (SPD is Low) and (DD is Short Distance) then (DFSI is Safe)
Rule 4	If (MA is Moderate) and (HR is Very Low) and (HGF is High Force) and (WBV is Low Acceleration) and (SPD is Low) and (DD is Short Distance) then (DFSI is Safe)
Rule 5	If (MA is Moderate) and (HR is Low) and (HGF is High Force) and (WBV is Slightly Acceleration) and (SPD is Low) and (DD is Short Distance) then (DFSI is Safe)
Rule 6	If (MA is Moderate) and (HR is Low) and (HGF is Medium Force) and (WBV is Slightly Acceleration) and (SPD is Low) and (DD is Short Distance) then (DFSI is Slightly Unsafe)

Rule 7	If (MA is Moderate) and (HR is Low) and (HGF is Medium Force) and (WBV is Moderate Acceleration) and (SPD is Low) and (DD is Short Distance) then (DFSI is Slightly Unsafe)
Rule 8	If (MA is Moderate) and (HR is Average) and (HGF is Medium Force) and (WBV is Slightly Acceleration) and (SPD is Low) and (DD is Short Distance) then (DFSI is Slightly Unsafe)
Rule 9	If (MA is Moderate) and (HR is Average) and (HGF is Medium Force) and (WBV is Moderate Acceleration) and (SPD is Low) and (DD is Short Distance) then (DFSI is Slightly Unsafe)
Rule 10	If (MA is High) and (HR is Average) and (HGF is Low Force) and (WBV is High Acceleration) and (SPD is High) and (DD is Long Distance) then (DFSI is Unsafe)
Rule 11	If (MA is High) and (HR is Very High) and (HGF is Low Force) and (WBV is Very High Acceleration) and (SPD is High) and (DD is Long Distance) then (DFSI is Unsafe)
Rule 12	If (MA is Very High) and (HR is Very High) and (HGF is Low Force) and (WBV is Very High Acceleration) and (SPD is High) and (DD is Long Distance) then (DFSI is Unsafe)
Rule 13	If (MA is Very High) and (HR is Average) and (HGF is Low Force) and (WBV is High Acceleration) and (SPD is High) and (DD is Long Distance) then (DFSI is Unsafe)
Rule 14	If (MA is Very High) and (HR is Very High) and (HGF is Low Force) and (WBV is Very High Acceleration) and (SPD is High) and (DD is Long Distance) then (DFSI is Unsafe)
Rule 15	If (MA is Very High) and (HR is Very High) and (HGF is Low Force) and (WBV is Very High Acceleration) and (SPD is Low) and (DD is Short Distance) then (DFSI is Unsafe)
Rule 16	If (MA is Very High) and (HR is Very High) and (HGF is Low Force) and (WBV is Very High Acceleration) and (SPD is High) and (DD is Short Distance) then (DFSI is Unsafe)

Rule 17	If (MA is Very High) and (HR is Very High) and (HGF is Low Force) and (WBV is Very High Acceleration) and (SPD is Low) and (DD is Long Distance) then (DFSI is Unsafe)
Rule 18	If (MA is Very High) or (HR is Very High) or (HGF is Low Force) or (WBV is Very High Acceleration) or (SPD is High) or (DD is Long Distance) then (DFSI is Unsafe)
Rule 19	If (MA is High) or (HR is Very High) or (HGF is Low Force) or (WBV is Very High Acceleration) or (SPD is High) or (DD is Long Distance) then (DFSI is Unsafe)
Rule 20	If (MA is High) or (HR is Average) or (HGF is Low Force) or (WBV is High Acceleration) or (SPD is High) or (DD is Long Distance) then (DFSI is Unsafe)

After constructing the rule statement, a road map of the whole fuzzy inference system for a system formed by six linguistic variables, 'MA', 'HR', 'HGF', 'WBV', 'SPD', and 'DD', each described by respective fuzzy was displayed on the rule viewer as shown in Figure 4.9. The output is represented by the linguistic variable 'DFSI' described by three fuzzy sets; 'safe', 'slightly unsafe', and 'unsafe'. The rule viewer interpreted the entire fuzzy inference process and shows how the shape of certain membership function influences the overall result.

The knowledge available on the DFSI produced by the interaction of six variables is described by 20 fuzzy rules. The color regions represent the fuzzy set obtained by the evaluation of each rule for the six inputs. The final aggregated output is obtained by combining the color regions, and the defuzzification value represents a measure of the degree of DFSI derived from the combination of the input values.

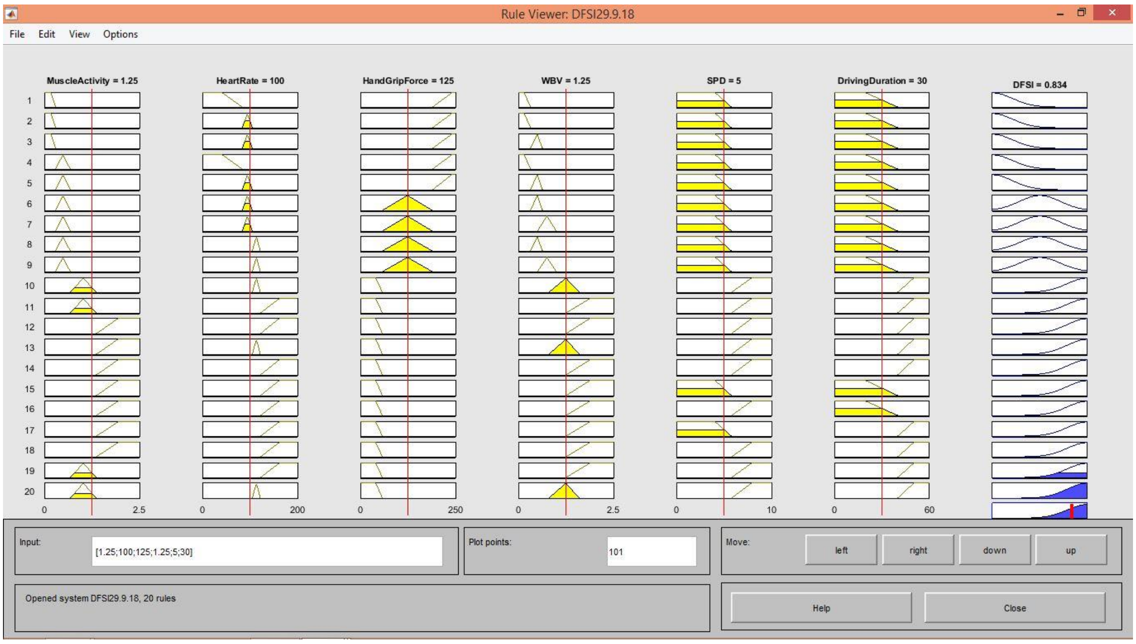


Figure 4.9: The example of the road map for the whole fuzzy inference display on the rule viewer.

4.2.3 Defuzzification

For data defuzzification which is the process of making a quantifiable result in fuzzy logic, this study uses a centroid average (CA) method. Defuzzification is the process of obtaining a single number from the output of the fuzzy set, which transfers the fuzzy inference results into a crisp output. In simple words, this process is realized by a decision making algorithm that chooses the best crisp value based on a fuzzy set (Wang, 2001; Masoum et al., 2002). Figure 4.2 shows the structure of a fuzzy system. Instead of the CA method, other methods that can be used for the defuzzification process are the center of gravity (COG) and the mean of maximum (MOM). However, for this research, the CA method was used as these approaches provide a better solution than other methods (Azadeh et al., 2008). The CA method decides the center of the area of the fuzzy set and returns the corresponding crisp value.

4.3 Results and Discussion: Testing and Demonstrating the DFSI

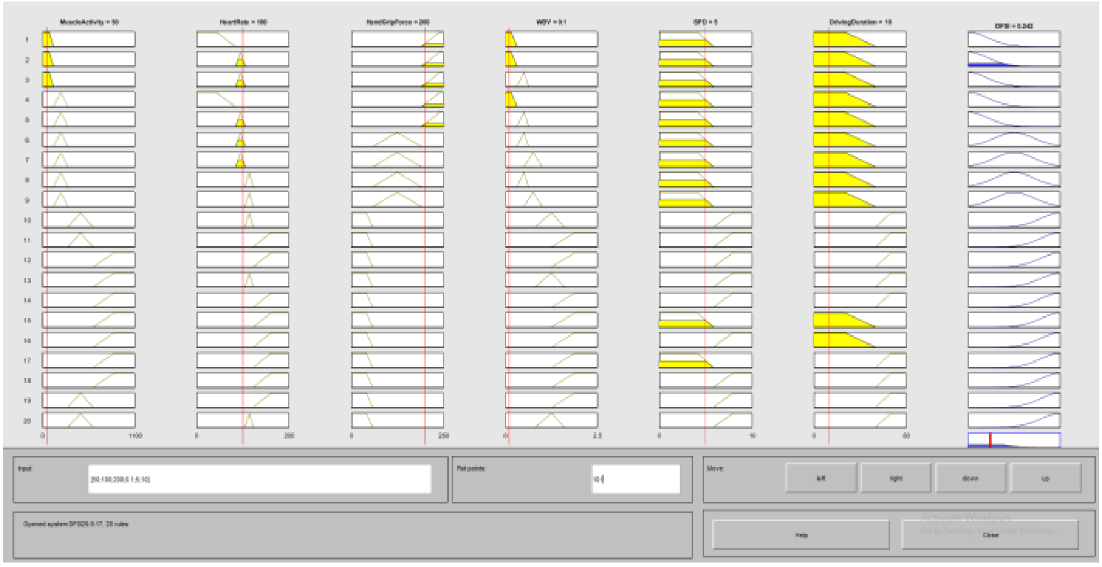
The DFSI methodology is tested and demonstrated by the authors using a data set available from the previously performed (Rahayu et al., 2015; Rahayu et al., 2015; Rahayu et al., 2016; Ani, 2016; Firdaus et al., 2017; Firdaus et al., 2017; Ani et al., 2017; Ani et al., 2018). Table 4.2 presents the example data set available from the previous studies. The author presented three examples, which represented three driving conditions; safe, slightly unsafe, and unsafe.

Table 4.2: The example of data sets

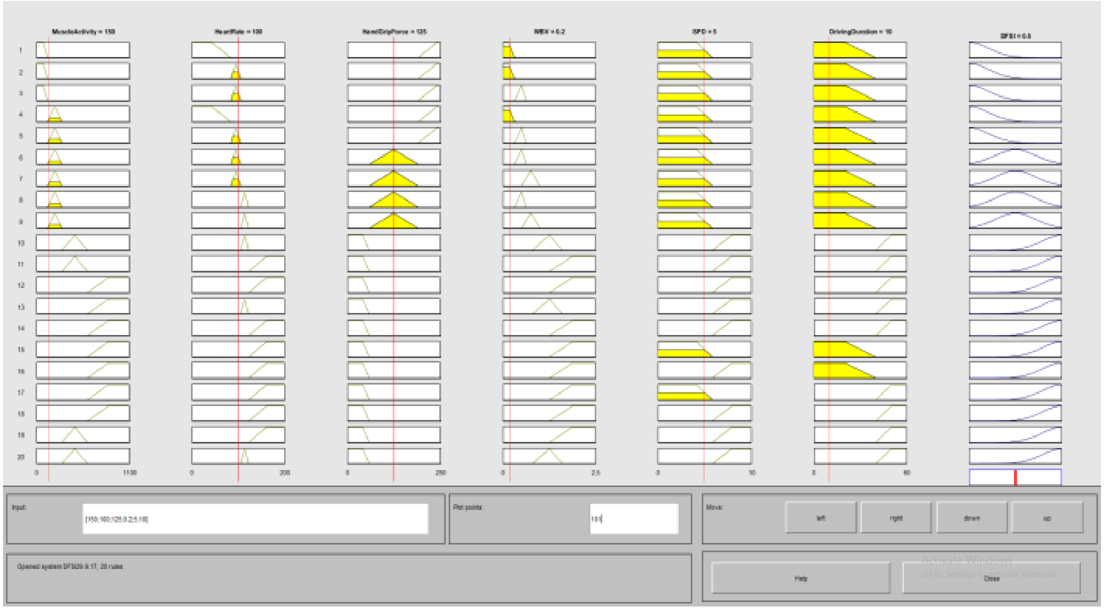
Risk Factors	Set 1	Set 2	Set 3
MA	50.0000 µV	150.0000 µV	50.0000 µV
HR	100.0000 bpm	100.0000 bpm	70.0000 bpm
HGF	200.0000 N	125.0000 N	50.0000 N
WBV	0.2000 m/s2	0.2000 m/s2	0.3987 m/s2
SPD	5.0000 kPa	5.0000 kPa	5.0000 kPa
DD	10.0000 min	10.0000 min	30.0000 min

By using the FIS, the values of each linguistic variable are entered into the rule viewer to get the defuzzification value represents a measure of the degree of DFSI. Figure 4.10 (a), Figure 4.10 (b), and Figure 4.10 (c) shows the rule viewer, which reflected the results of the analysis.

Set 1



Set 2



Set 3

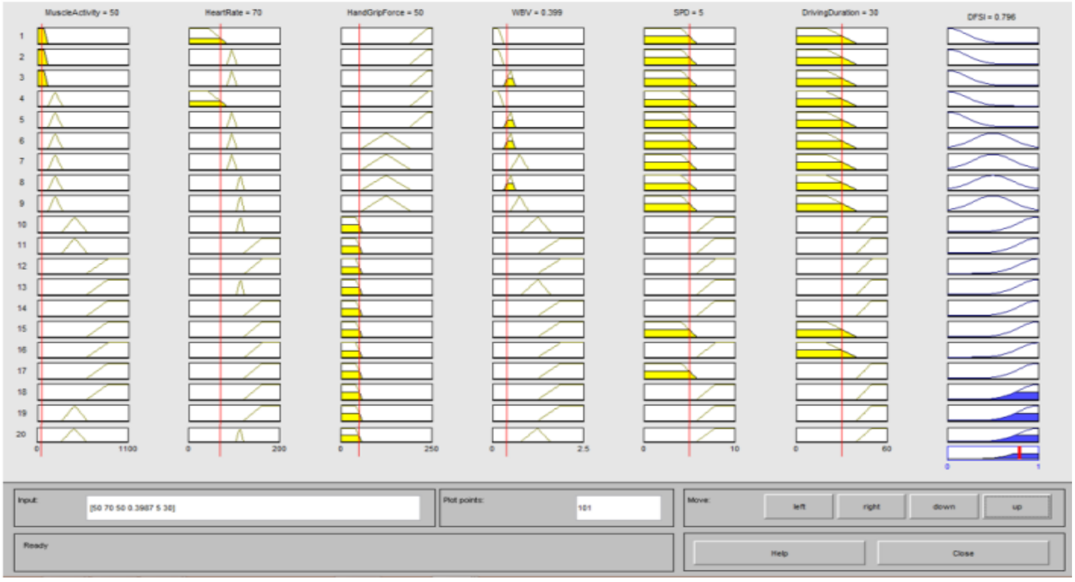
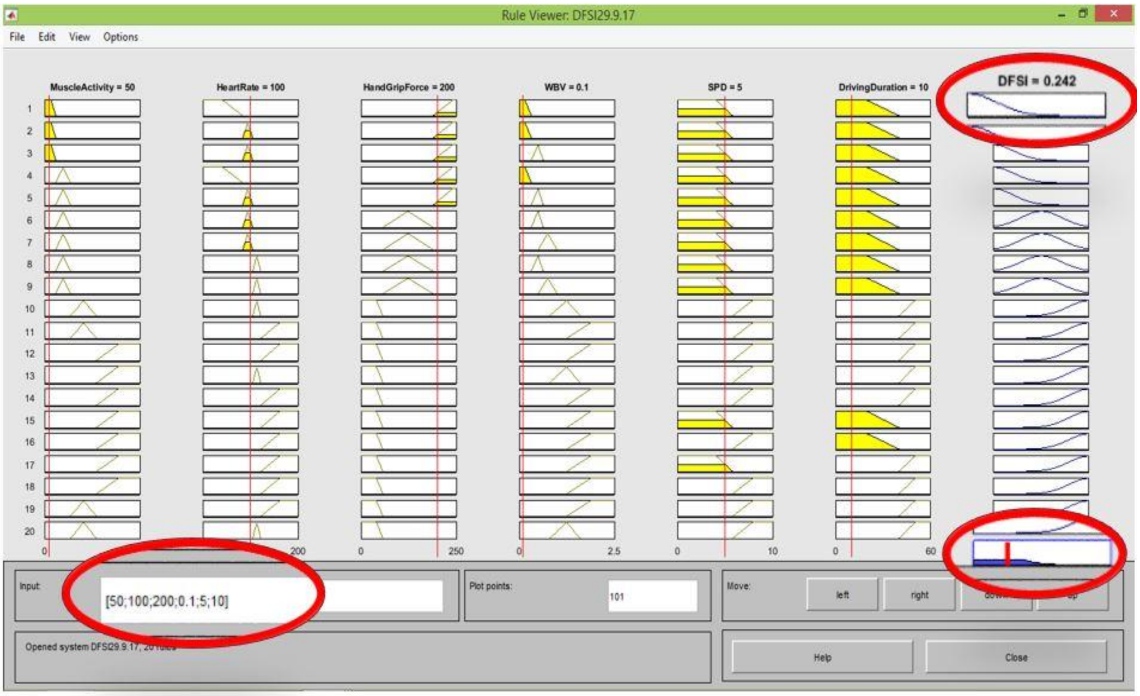


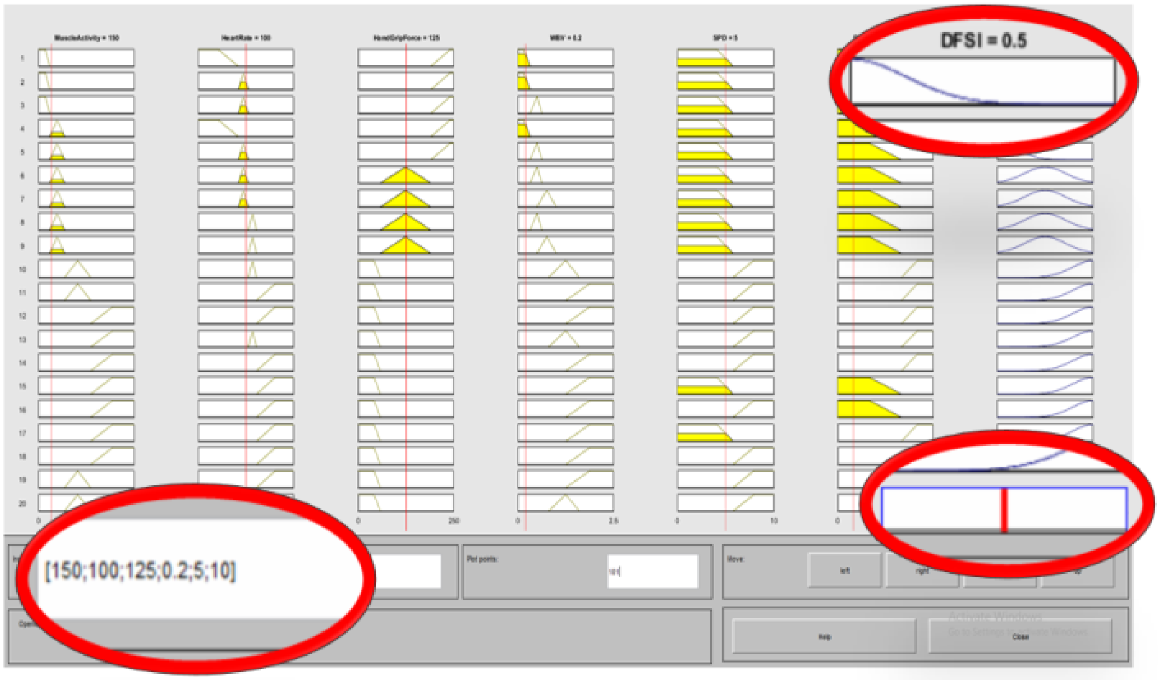
Figure 4.10: The value of linguistic variables are entered into the rule viewer; (a) Set 1; (b) Set 2; (c) Set 3

A zoomed version of the rule viewer for the fuzzy inference process based on the Mamdani-type is shown in Figure 4.11 (a), Figure 4.11 (b), and Figure 4.11 (c). As the input value entered into the system, the rule viewer will show the value of DFSI that is 0.242, 0.5, and 0.796.

Set 1


Rule Viewer: DFSI29.9.17
File Edit View Options
MuscleActivity = 50
HeartRate = 100
HandGripForce = 200
WBV = 0.1
SPD = 5
DrivingDuration = 10
DFSI = 0.242
Input:
[50;100;200;0.1;5;10]
Plot points:
101
Move:
left
right
Help
Close

Set 2


DFSI = 0.5
[150;100;125;0.2;5;10]
left
right
Help
Close

Set 3

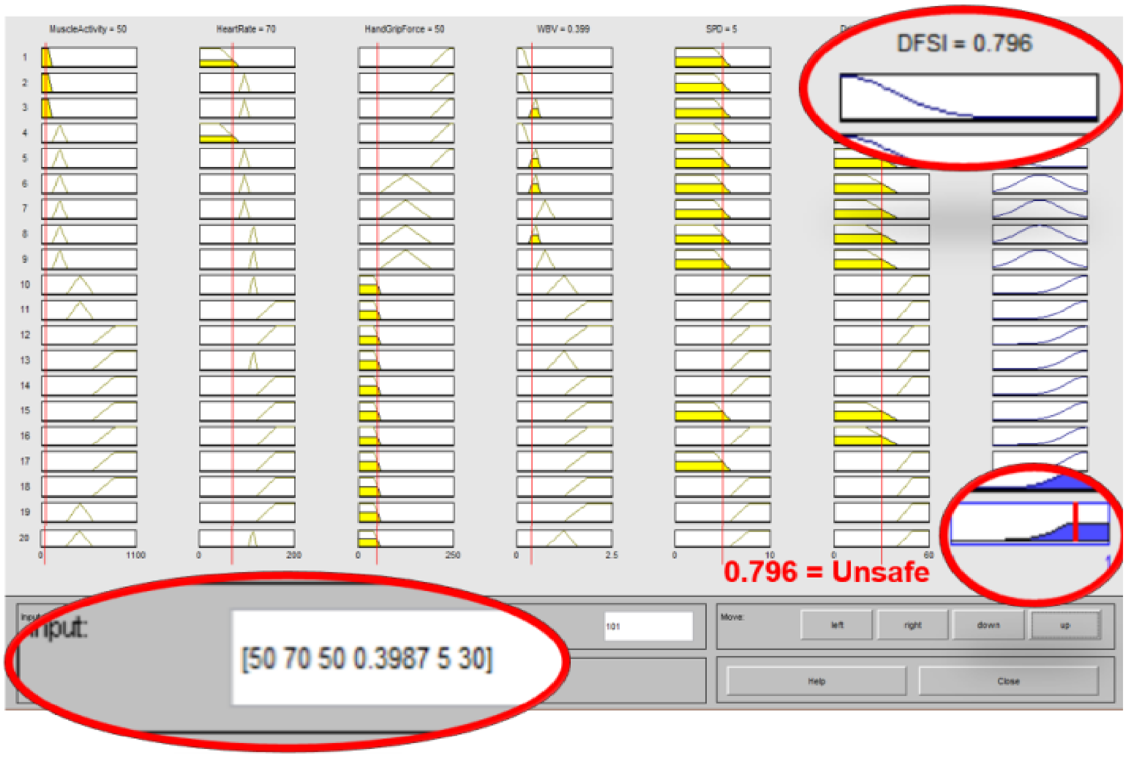


Figure 4.11: The zoomed version of the rule viewer of FIS for; (a) Set 1; (b) Set 2; (c) Set 3

The final DFSI's output is obtained by combining the color regions fuzzy sets, and the defuzzification value that is 0.242, 0.5, and 0.796, represents a measure of the degree of DFSI derived from the combination of the input values of linguistic variables. Figure 4.12 (a), Figure 4.12 (b), and Figure 4.12 (c) show the membership function plot for the linguistic variable 'DFSI', which gives a clear picture of getting the safe, slightly unsafe, and unsafe condition. As explained earlier, the DFSI has three fuzzy sets; safe, slightly unsafe, and unsafe. Table 4.3 summarizes the results of the demonstration.

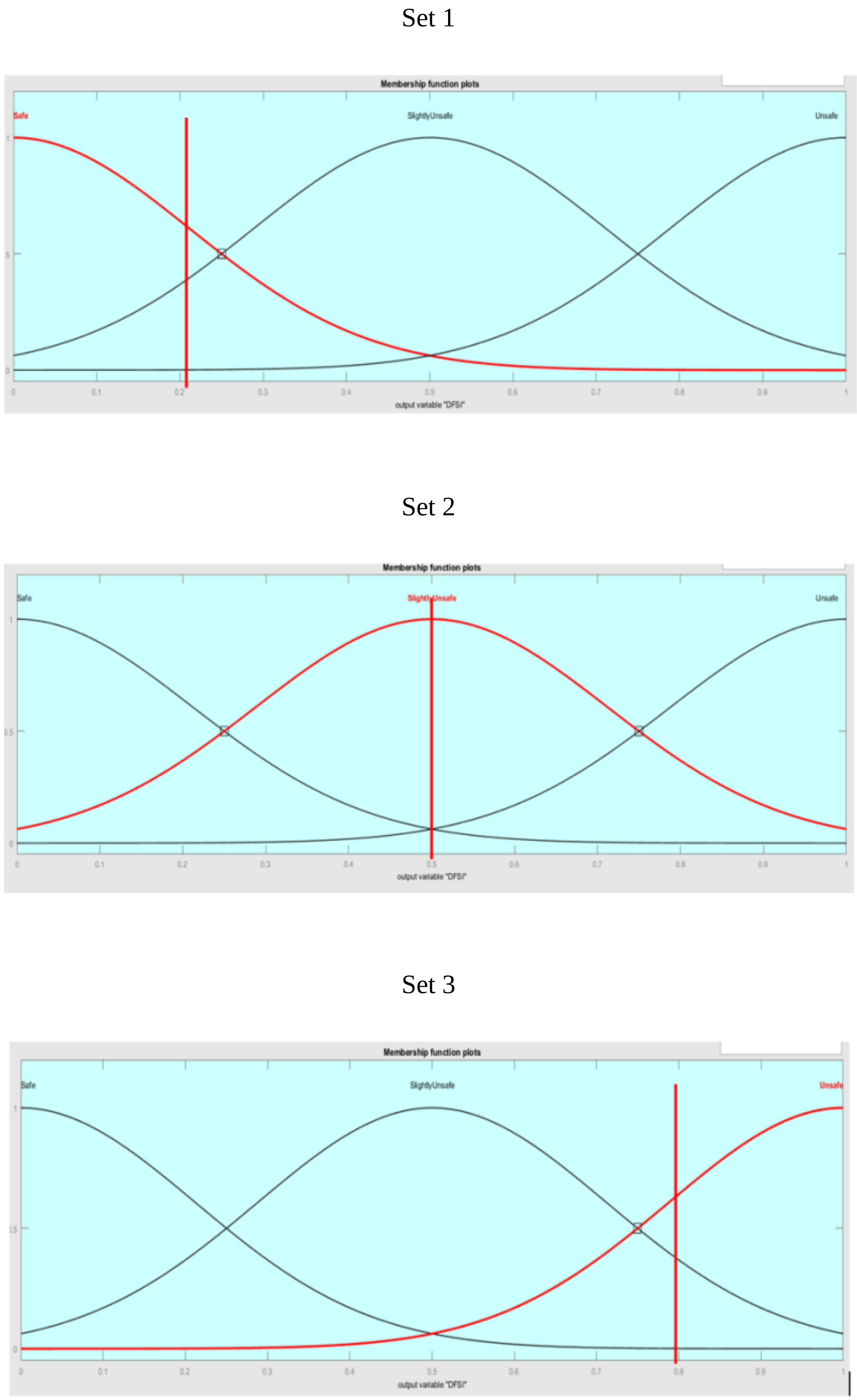


Figure 4.12: Membership function plots for the DFSI of; (a) Set 1; (b) Set 2; (c) Set 3

Table 4.3: Result summarization

Set	DFSI	Driving Condition
1	0.242	The driving conditions are considered safe and these conditions are the best and need to be maintained to ensure a driver is comfortable and safe
2	0.5	The driving conditions are considered slightly unsafe and that condition can harm the driver and the possibility to involve in accidents.
3	0.796	The driving conditions are considered unsafe and the driver is not allowed to drive the car as the condition can lead to road accidents

4.4 Summary

The present chapter introduces a novel approach based on fuzzy logic for the development of DFSI. The use of fuzzy set theory and fuzzy set inference system presents advantages over a traditional mathematical approach due to its ability to model uncertainty derived from fuzziness and subjectivity. Besides, fuzzy logic is capable to combine quantitative data with qualitative information in a systematic way by using fuzzy IF-THEN rules.

In the development of DFSI for the driving condition evaluation, the most significant variables that affect the driving fatigue are identified, their relation is analyzed, and the linguistic variables, fuzzy sets, and fuzzy IF-THEN rules are determined to describe the behavior of the factors. The DFSI is expected to be useful for the risk assessment methodology to quantify the driving condition level associated with the driving activity. The DFSI based on fuzzy logic introduced here is just the first step, and additional work is required, which will be discussed in the next chapter of this dissertation.

Chapter 5 Development of Decision Support System

This chapter introduces the fourth stage for the development of a decision support system for driving fatigue (DSSfDF). The chapter presents the continuity study from the previous work, which designing the graphical user interface (GUI) for a decision support system (DSS) of driving fatigue. As driving fatigue has been recognized as one of the significant contributory factors to road accidents and fatalities in Malaysia, the author developed the decision support system that providing analysis, and proving solutions and recommendations to the road users. In other words, the decision support system acts as the advisory and decision-maker tool. In designing the GUI for a DSS, the Django based on Python programming language was used by the authors. There are five main GUI has been designed in this study; Admin GUI User Profile and Driving Information GUI, Regression Model GUI, Risk Factor Analysis GUI, and Superuser GUI

5.1 Stage 4: Development of Decision Support System for Driving Fatigue (DSSfDF)

Due to Chapter 1-mentioned points, much work has been made to develop advanced decision aiding methodologies that offer reliable decision-making procedures, efficient optimization, and algorithms as well as user-friendly computer tools for transportation. Besides, computer technology nowadays becomes increasingly being used to support the development process of decision support system (DSS). The decision support system (DSS) has expanded over the past four decades from theoretical concepts into real-world computerized applications.

A DSS can be defined as the ability to make the right decision and the reliable advisory tool using the computer-based system, which helps the decision-maker in solving complex and unstructured transportation decision problems and provides the systematic analysis and solution in the shortest time. In terms of the development of a decision support system (DSS) for transportation, there are many previous studies that have been done. However, there is no study on the development of a decision support system that focuses only on the causes of road accidents especially driving fatigue. The previous development of DSS in transportation is more focus on road safety (Fancello et al., 2015), routing and scheduling (Toretta et al., 2013), maintenance and management (Selih et al., 2008), and material handling (Dell'Acqua et al., 2011).

This study presents the continuity of the author's previous study (Ani et al., 2019; Ani et al., 2018; Firdaus et al. 2018). The previous study by Ani et al. (2018), discussed the components for developing the ergonomic vehicle mode (EVM) and decision support system for driving fatigue (DSSfDF). While the previous study by Ani et al. (2019) discussed the development of the Driving Fatigue Strain Index (DFSI). All these studies are much related to this chapter. One of the components is a graphical user interface (GUI). Hence, this study will discuss the component of DSS that is a user interface or GUI. The designing of the GUI is essential in the development of DSS as the interface is used to gather the important data and risk factors in the real situation of driving by separately them into more systematic modules that are easy to understand for further analysis

This chapter is prepared to design the graphical user interface (GUI) for a decision support system of driving fatigue that assists the road users to make a decision on the driving condition in order to minimize the risk of driving fatigue and directly reduced the number of road accidents in Malaysia.

5.2 Designing and Developing the Graphical User Interface using Django

The Django framework based on Python programming language is used to develop the GUI for the web-based system of decision support system. The Django is a full-stack Python web framework, which promotes rapid development and clean, pragmatic design (Dauzon et al., 2016). Django is based on Python, which is a very popular programming language and offers powerful support for integration with other languages and tools and comes with wide standard libraries. Besides, the author used Django as it provides a high-level framework that enables the author to build a web application that is DSS with relatively few lines of codes. In addition, using Python in this framework allows the author to have benefited from all Python libraries and assures very good readability. Instead of Django, other web application frameworks are Ruby on Rails and CakePHP. The previous study by Plekhanova (2009) claimed that Django received the highest weighted score of 4.05, Ruby on Rails is second with 3.85, and CakePHP got 2.95 based on her study on evaluating the web development frameworks. Table 5.1 summarized the results of the study.

Table 5.1: Evaluation of web application frameworks

		Django		Ruby on Rails		CakePHP	
Evaluation Criteria	Weight	Rating	Weighted Score	Rat-ing	Weighted Score	Rating	Weighted Score
User interface development	0.2	4	0.8	3	0.6	3	0.6
Maintainability	0.15	4	0.6	3	0.45	3	0.45
Data management and migration	0.2	4	0.8	5	1	2	0.4
Testability	0.15	3	0.45	4	0.6	2	0.3
Popularity	0.1	5	0.5	3	0.3	5	0.5
Community and Maturity	0.1	5	0.5	5	0.5	3	0.3
Marketability	0.1	4	0.4	4	0.4	4	0.4
Total:	1		4.05		3.85		2.95

As the DSS provides the user interfaces (UI), the Movie-View-Controller (MVC) pattern and Model-View-Template (MVT) pattern were normally used. Basically, the MVC pattern is based on three components; model, view, and controller.

- Model: Model represents data organization in a database. Each model defines a table in the database and the relations between other models.
- View: The view handle generating what the user will see. In the web application world, this usually means generating HTML.
- Controllers: The controller check whether the user is authenticated or can generate the HTML code from the template. In other words, the controller handles a user's interaction with the author's web application by deciding which single view and set of models to use to satisfy the request.

The Django will take care of the controller part which acts as code that controls the interaction between the model and view. As the user requests for a resource, Django acts as a controller and check if it is available. The Django uses the user-defined URL paths for picking which view to be used. The view wills decide which models are needed and pass them off to the template, which the template is an HTML file mixed with Django Template Language (DTL). The template function is to create the pages HTML. The generated HTML is passed back to the user's browser. Figure 5.1 visualized the data flow through Django at a high level.

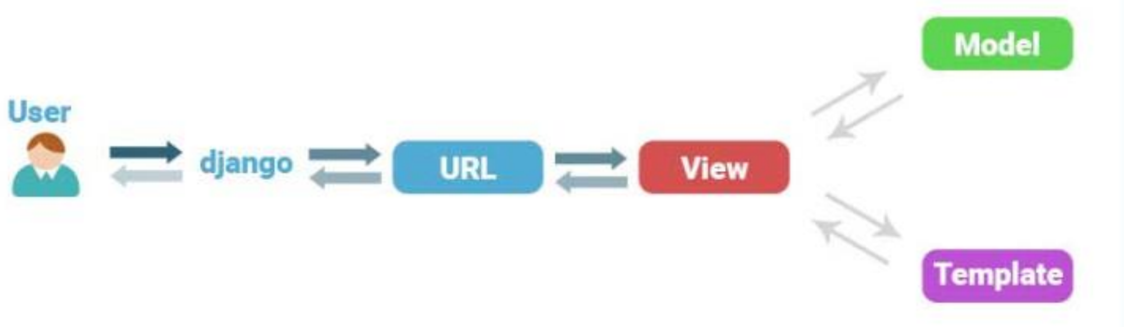


Figure 5.1: Data flow through Django

5.2.1 Running the Server

The system starts by running the server using the command prompt (cmd.exe). The command will be called the system to search the python programming file from the saving folder. The command python manage.py run server will start the server and performing the system checks. This system check is required for validating the Django projects as it detects common problems or errors regarding the programming. Serious errors will prevent Django commands from running the server. Figure 5.2 shows the command prompt for performing the system checks. Command prompt also is used to monitor any activities in the system.

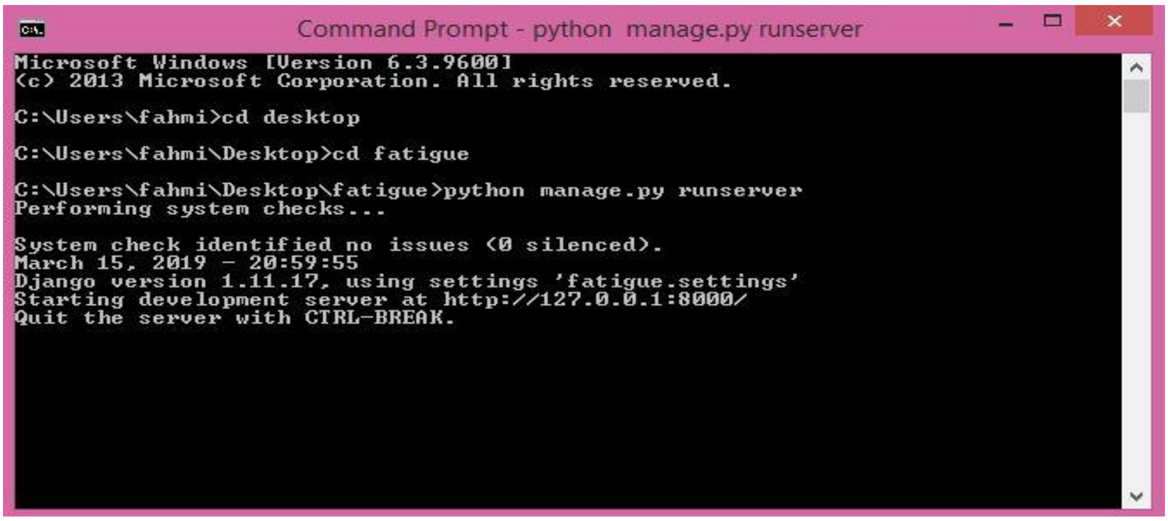


Figure 5.2: Performing system checks for server

The commands are written as follows:

1st command	: *cd desktop*	- the location of programming file
2nd command	: *cd fatigue*	- name of programming file
3rd command	: *python manage.py runserver* or *python manage.py runserver 0.0.0.0:80*	- to perform the system check and start the server.

- The *runserver* parameter starts the development server.
- *0.0.0.0:80* is the internal IP address to the network adapter, which means this server will listen and respond only to the computer on which it is launched (server). If the system in a local network and wanted to make this web-based system available on other computers, just enter the local IP address of the server instead of *0.0.0.0:80.* For example, by entering the local IP address *10.132.7.153* as shown in Figure 5.3, this web-based system can be connected to other computers or mobile phones as shown in Figure 5.4.

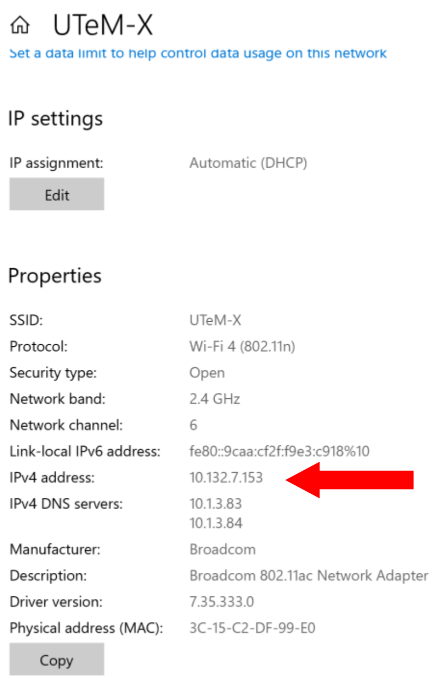


Figure 5.3: Local IP address of the server

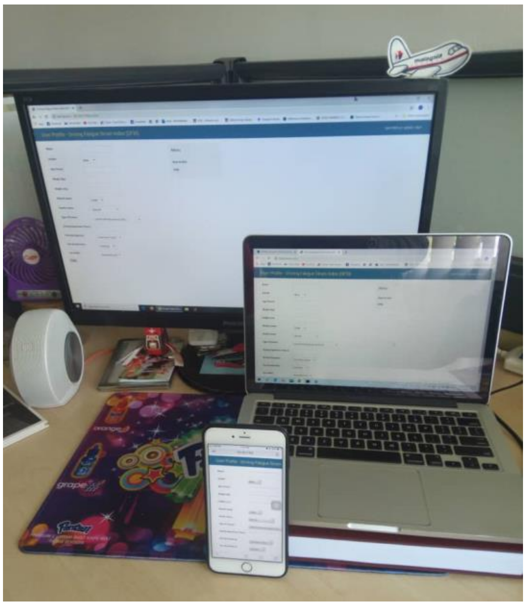


Figure 5.4: The web-based system for DSS available on other computers or mobile phones

- If the command executed correctly, the window should show the message, *system checked identified no issue* as shown in Figure 5.2.

To prove the result, just open the browser and enter the following URL:

http://localhost:8000.

Django confirms that the system already run by displaying the system interface as shown in Figure 5.5.

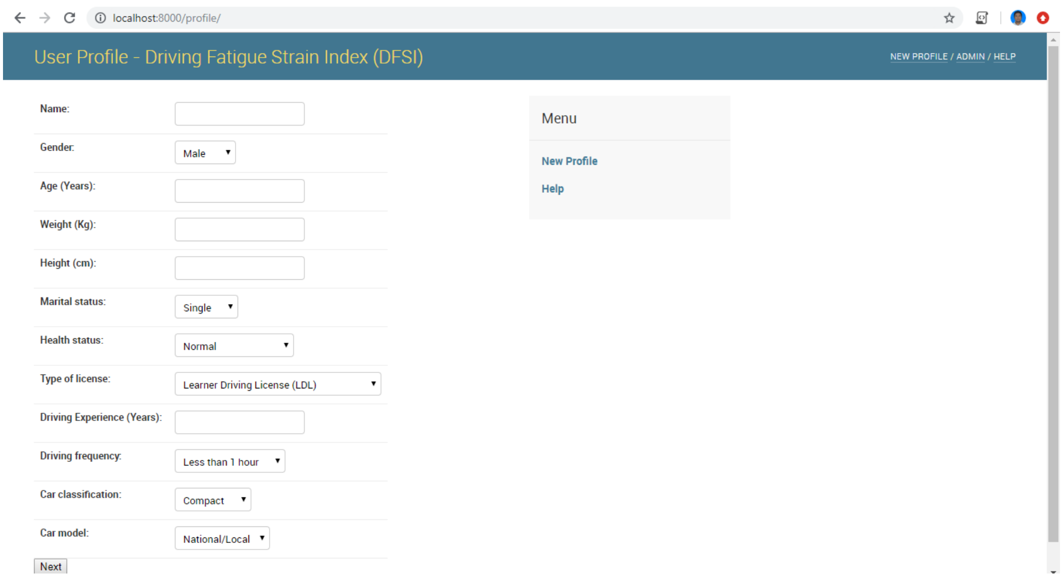


Figure 5.5: The first system interface

5.2.2 Database and Server Setup

For the database, the author used the SQLite database. The system has the db.sqlite3 database file and has the extension .sqlite3. The SQLite database was choose by the author for this system as it implements a small, fast, self-contained, high-reliability, and full-featured. Besides, the SQLite database is a commonly used database engine. Instead of the SQLite database, Django also supports several major database engines such as MySQL, PostgreSQL, Oracle, MongoDB, and GoogleAppEngine Datastore. The selection of the server database is important as this server will store all the data on the website.

For the web server, the Django has its own web server. The Django itself is equipped with a lightweight web server for developing and testing applications. The advantage of using the web server is the server can be restarted whenever there is a modification on the code.

5.3 Type and Function of GUI's

Five main GUIs have been designed in this study to perform various functions; the admin interface, superuser GUI, the user profile and driving information GUI, regression model GUI, and risk factor analysis GUI. This section will discuss the result form the development of GUI for DSS.

5.3.1 Admin Interface

The first GUI for the DSS is an admin interface that can perform CRUD (Create, Read, Update, and Delete) operations on the system. The admin interface is a ready-to-use user interface for administrative activities provided by the Django. Figure 5.6 shows the Django admin interface for administrative activities.

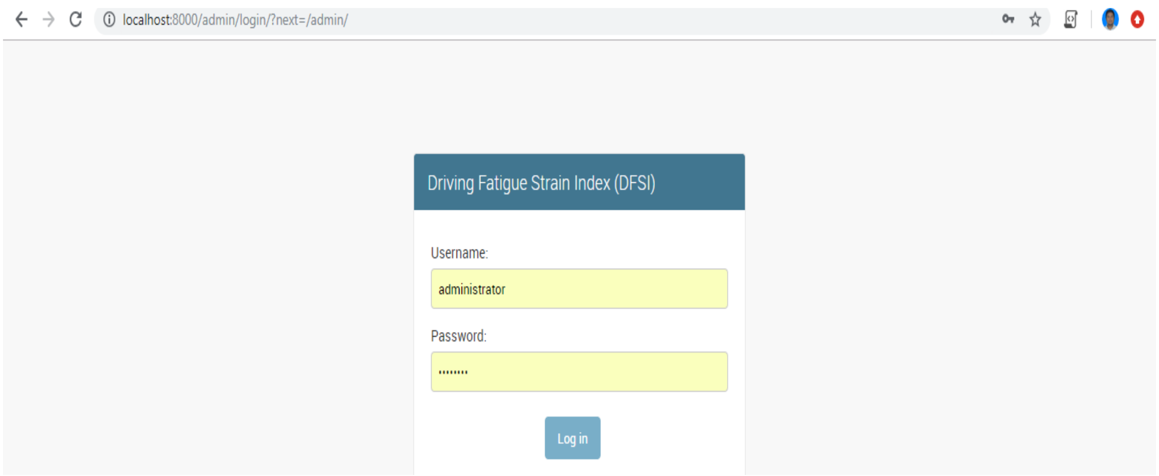


Figure 5.6: Django admin interface

This interface depends on the django.countrib module. In order to enable it, ensure that some modules are imported in the INSTALLED_APPS and MIDDLEWARE_CLASSES tuples of the myproject/settings.py file. For INSTALLED_APPS should have:

```
INSTALLED_APPS = (
    'django.contrib.admin',
    'django.contrib.auth',
    'django.contrib.contenttypes',
    'django.contrib.sessions',
    'django.contrib.messages',
    'django.contrib.staticfiles',
    'myapp',
)
```

While for MIDDLEWARE_CLASSES should have:

```
MIDDLEWARE_CLASSES = (
    'django.contrib.sessions.middleware.SessionMiddleware',
    'django.middleware.common.CommonMiddleware',
    'django.middleware.csrf.CsrfViewMiddleware',
    'django.contrib.auth.middleware.AuthenticationMiddleware',
    'django.contrib.messages.middleware.MessageMiddleware',
    'django.middleware.clickjacking.XFrameOptionsMiddleware',
)
```

Then, search this interface by typing the localhost:8000/admin/ at the search toolbar of the web browser or click on the "Admin" button on the toolbar of the interface as shown in Figure 5.7 in order to access the admin interface as represented in Figure 5.6.

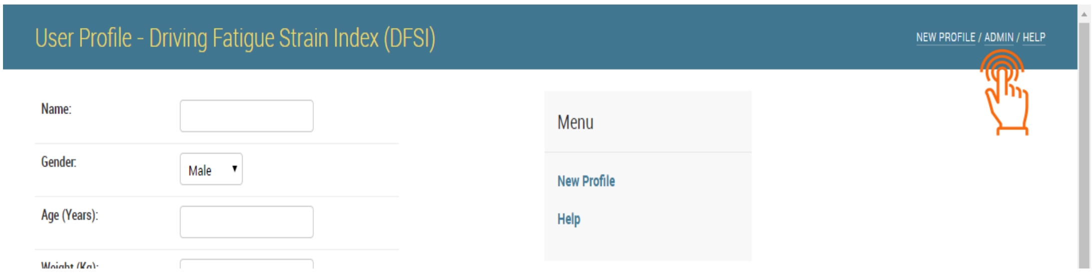


Figure 5.7: Entering the admin interface by clicking the "Admin" button

5.3.2 Superuser GUI

Once the admin has logged in into the system, the superuser GUI was displayed as shown in Figure 5.8. This superuser GUI enables the admin to perform the CRUD (Create, Read, Update, Delete) operations.

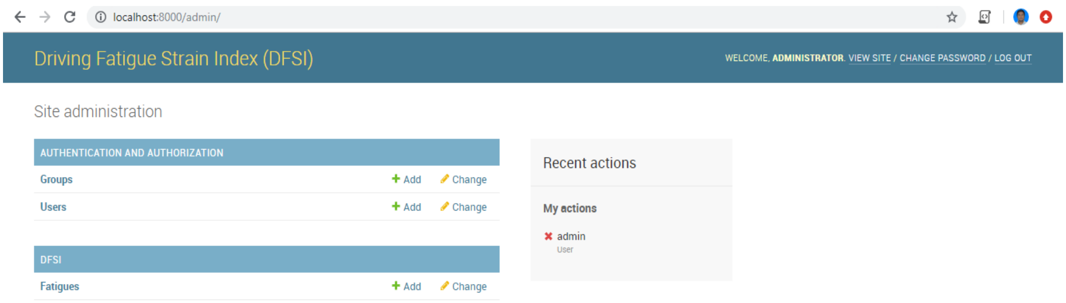


Figure 5.8: Superuser GUI of DSS

The admin can monitor any activities in the system such as create, read, update, and delete the information and input entered by the user by clicking on "Fatigues" option button in the superuser GUI of DSS. The new interface will display on the screen as shown in Figure 5.9, which shows the database of the users.

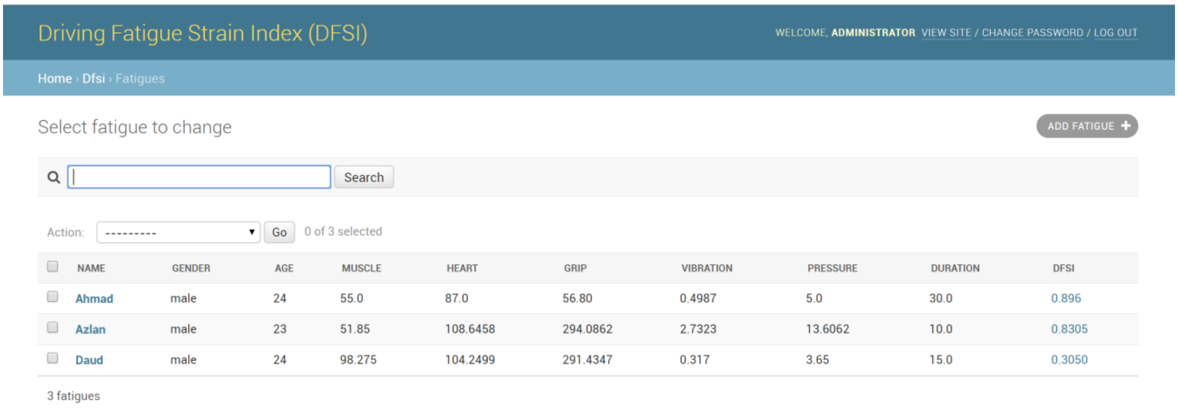


Figure 5.9: Database of the DSS

Apart from that, the admin can update or delete the data of the users, which is no longer needed as shown in Figure 5.10

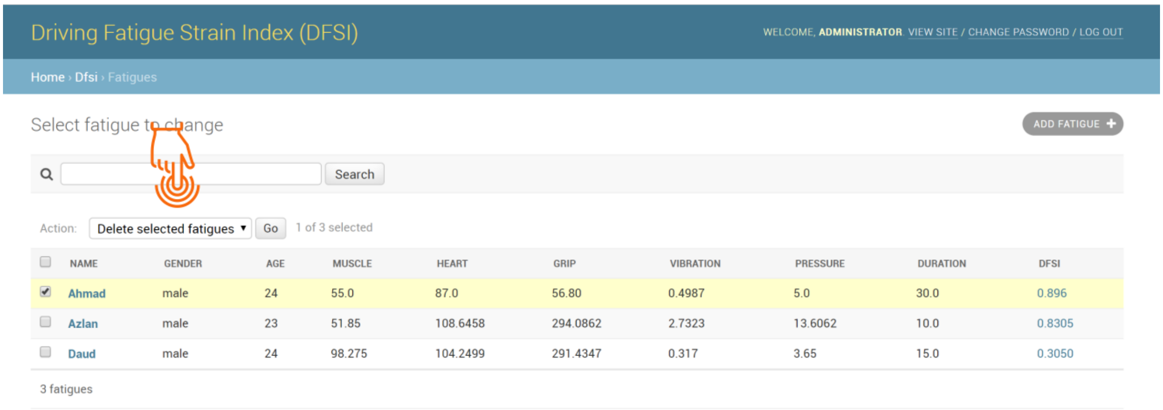


Figure 5.10: Deleting the user data

By selecting *Delete selected fatigues* on the "Action" option button, the interface of confirmation for deleting the data will be displayed on the screen as shown in Figure 5.11. The superuser GUI only can be accessed by the admin of this system as the username and password are needed.

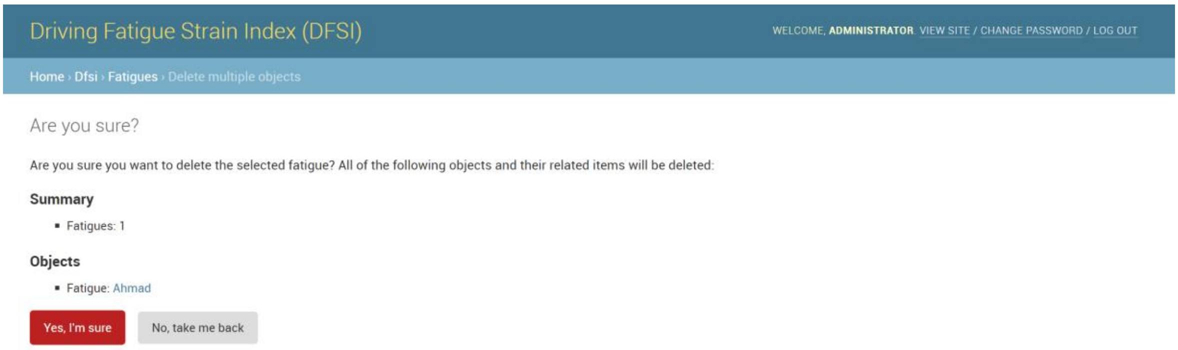


Figure 5.11: Confirmation for deleting the user's data

5.3.3 User Profile and Driving Information GUI

The main GUI for users consists of two classes; user's profile, and driving information. The user profile and driving information GUI is designed and used to enable the user to record the details of the user and driving such as name, gender, age, weight, height, marital status, health status, type of license, driving experience, driving frequency, car classification, and car model as shown in Figure 5.12.

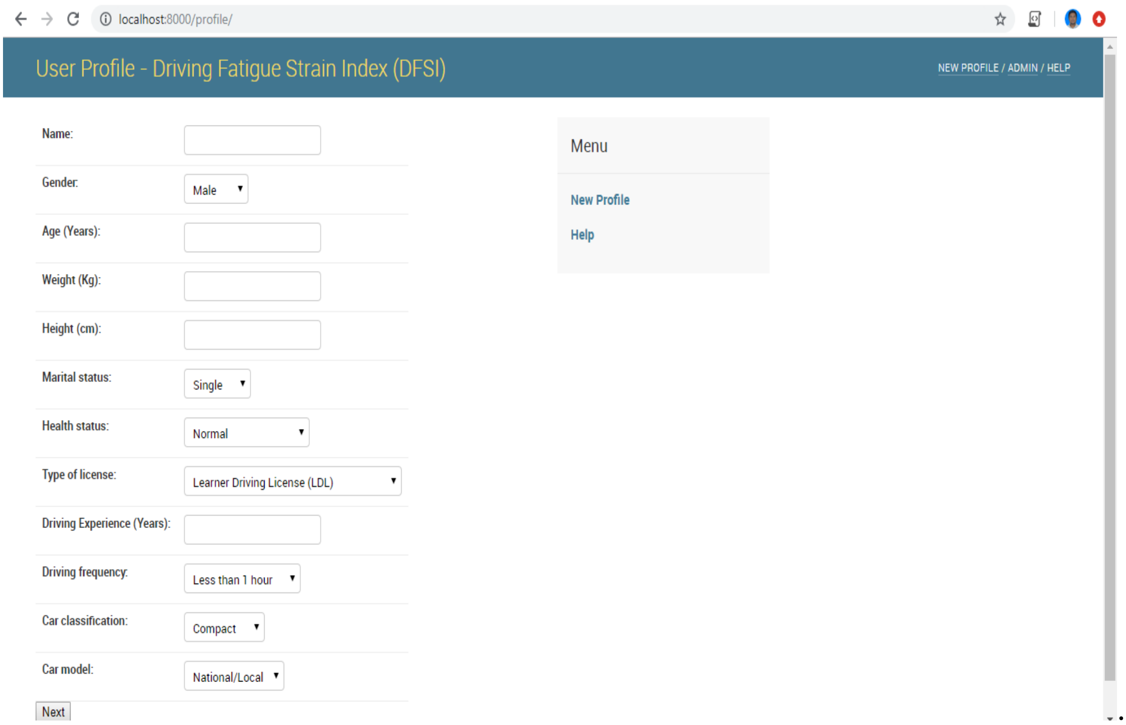


Figure 5.12: User profile and driving information GUI of DSS

The entry box was equipped with the name, age, weight, height, and driving experience's class for the user to enter the information and data. For gender, marital status, health status, type of license, driving frequency, car classification, and car model was equipped with a combo box for each class to assist the user to select appropriate information and data. Table 5.2 summarized the character of the main GUI of DSS.

Table 5.2: Characteristic of user profile and driving information GUI of DSS

Classes	Type of Box	Listed Item/Selection	Methods
Name	Entry	-	Enter / key in
Gender	Combo	• Male • Female	Selection
Age	Entry	-	Enter / key in
Weight	Entry	-	Enter / key in
Height	Entry	-	Enter / key in
Marital Status	Combo	• Single • Married	Selection
Health Status	Combo	• Normal • Obesity • Low back pain • Asthma • High blood pressure • Chronic pain • Depression • Arthritis • Others	Selection
Type of Licence	Combo	• Learner Driving Licence (LDL) • Probationary Driving Licence (PDL) • Competent Driving Licence (CDL) • Vocational/Commercial Driving Licence • International Driving Permit (IDP)	Selection
Driving Experience	Entry	-	Enter / key in
Driving Frequency	Combo	• Less than 1 hour • 1 hour • 2 hours • More than 2 hours	Selection
Car Classification	Combo	• Compact • Sedan • MPV • Van • SUV • City / Kei • Hatchback • Crossover • Coupe • Others	Selection
Car Model	Combo	• National / Local • Import	Selection

After the information and data required in the interface have been entered and selected, the user should click the "Next" button in GUI for saving the information into the database of the DSS and continue for the next GUI as shown in Figure 5.13. All the information entered and given by the user will be saved in the SQLite database as has been explained earlier.

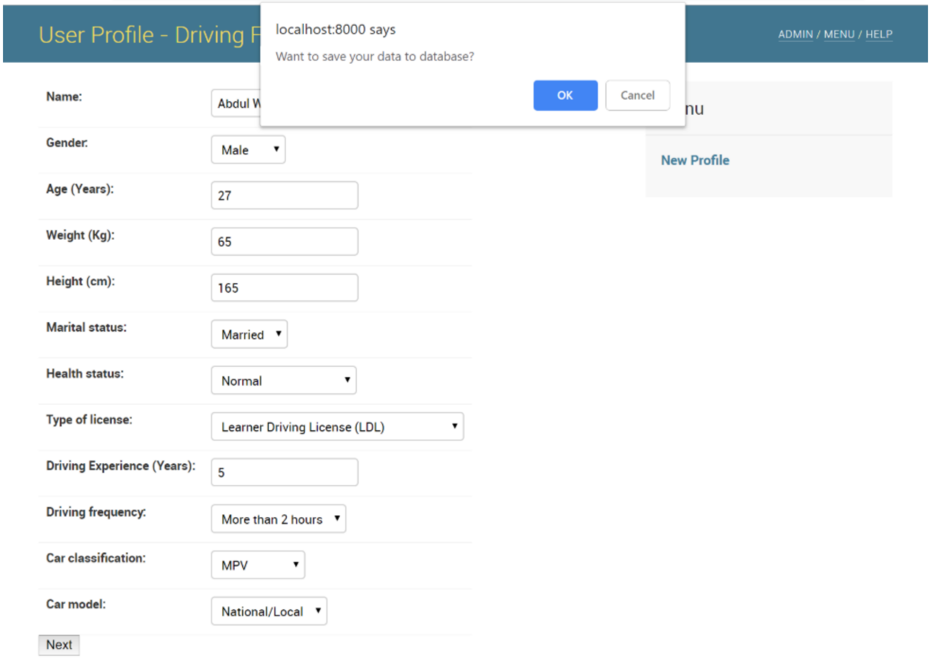


Figure 5.13: Confirmation of saving user data into database

Besides, the "Help" button also provided for the user in the user profile and driving information GUI as shown in Figure 5.14. This "Help" button gives the guidelines to the users on how to use this system properly. The system will give a step by steps on how to use this system as shown in Figure 5.15.

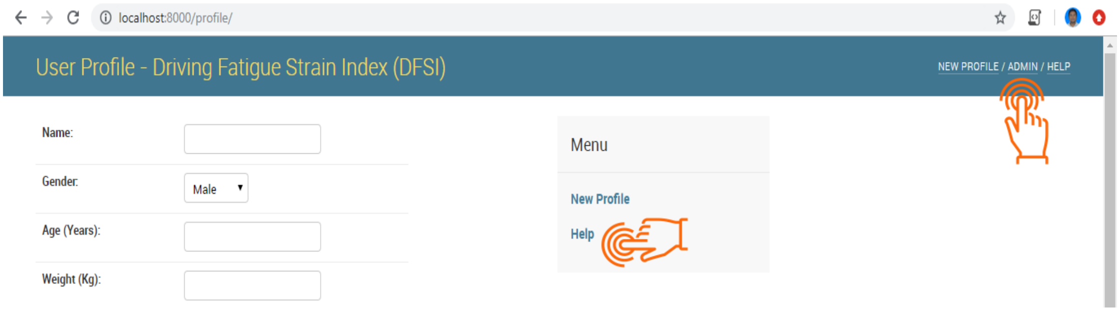


Figure 5.14: "Help" button for users

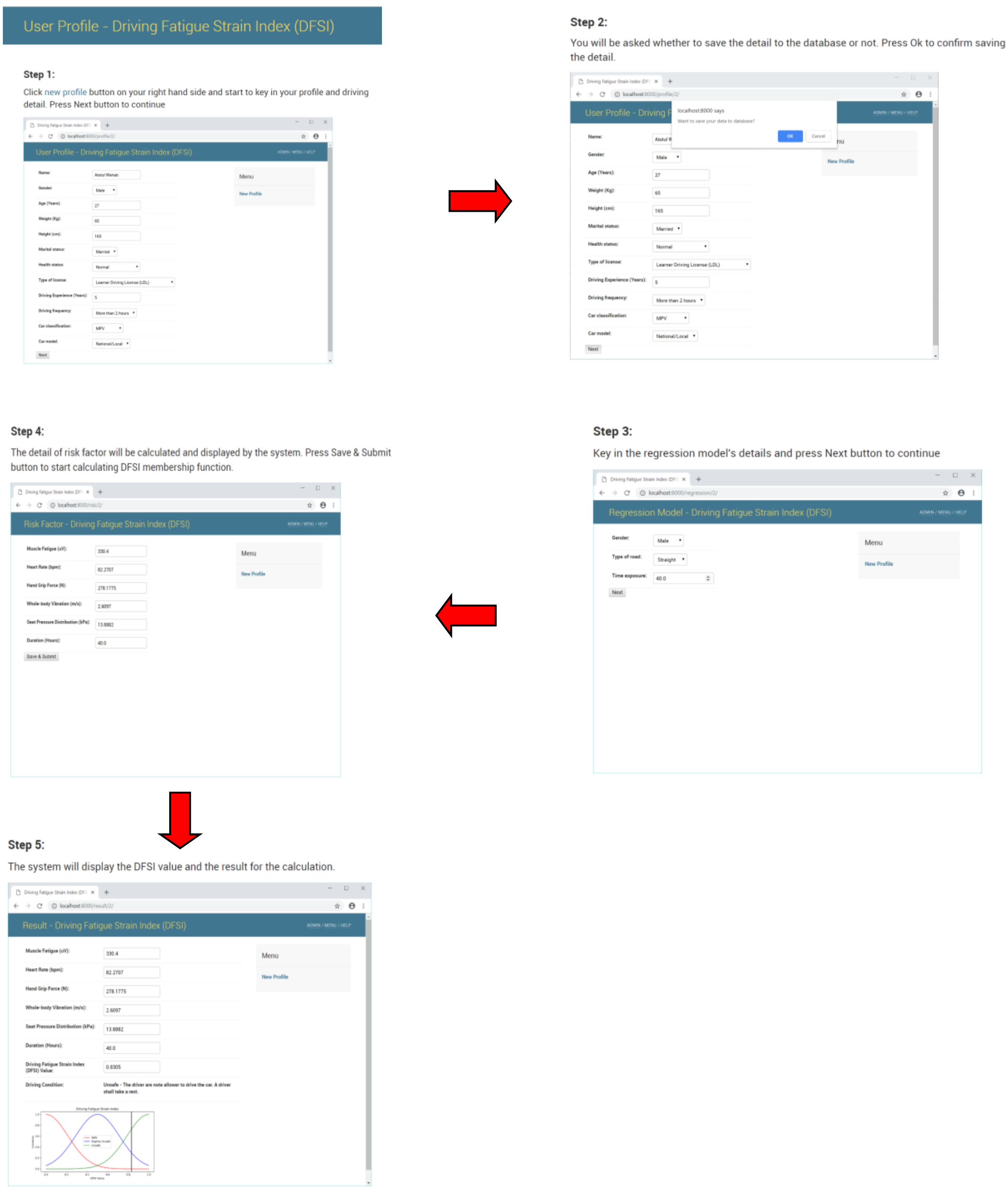


Figure 5.15: Step by steps guidelines for users

5.3.4 Regression Model GUI

The next interfaces are for the regression model as shown in Figure 5.16. The purposes of this interface to get the user's result and data on the risk factors without doing the real road test experiment. The regression model in the form of a polynomial equation is used in defining the relationship between the input parameters and output responses. This is done by substituting the real experiment with the regression model. The six groups of the regression model, which represented six risk factor of driving fatigue; muscle fatigue, heart rate, hand grip force, whole-body vibration, seat pressure distribution, and duration were developed in the author's previous studies (Ani, 2016; Ani et al., 2017; Ani et al., 2017; Firdaus et al., 2017; Firdaus et al., 2017; Ani et al., 2018). The development of regression models is not been discussed in this dissertation. However, the author provides all regression models as shown in Table 5.3 until Table 5.7.

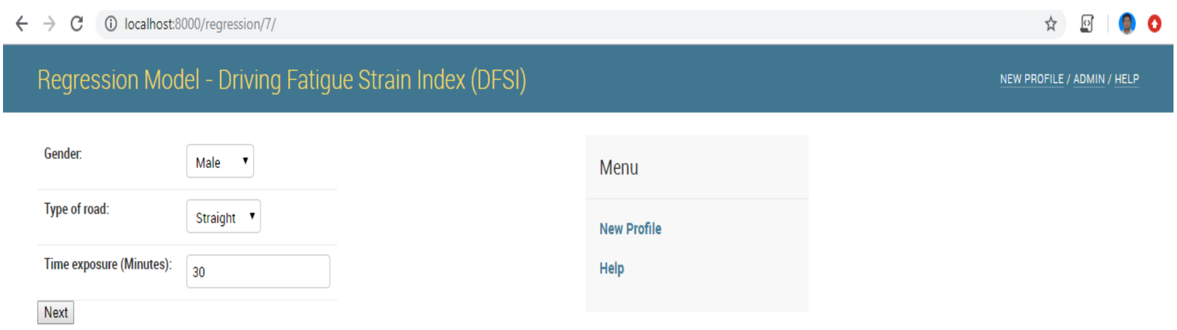


Figure 5.16: Regression model GUI of DSS

Table 5.3: The regression model for muscle activity (MA)

Type of Road	**Straight**
Gender	Female
Muscle Fatigue = -16.15000+4.64500* Time Exposure	
Type of Road	Straight
Gender	Male
Muscle Fatigue = -41.00000+9.28500* Time Exposure	
Type of Road	Winding
Gender	Female
Muscle Fatigue = +102.65000+14.94000* Time Exposure	
Type of Road	Winding
Gender	Male
Muscle Fatigue = +845.85000+6.66167* Time Exposure	
Type of Road	Uphill
Gender	Female
Muscle Fatigue = -104.15000 +14.01167* Time Exposure	
Type of Road	Uphill
Gender	Male
Muscle Fatigue = +24.22500+19.43417* Time Exposure	
Type of Road	Downhill
Gender	Female
Muscle Fatigue = +213.35000+4.75833* Time Exposure	
Type of Road	Downhill
Gender	Male
Muscle Fatigue = +533.07500+3.39583* Time Exposure	

Table 5.4: The regression model for heart rate (HR)

Type of Road	**Straight**
Gender	Female
Heart Rate = +120.62500 - 0.87917 * Time Exposure	
Type of Road	Straight
Gender	Male
Heart Rate = +117.43750 - 0.87917 * Time Exposure	
Type of Road	Winding
Gender	Female
Heart Rate = +146.12500 - 0.87917 * Time Exposure	
Type of Road	Winding
Gender	Male
Heart Rate = +142.93750 - 0.87917 * Time Exposure	
Type of Road	Uphill
Gender	Female
Heart Rate = +139.12500 - 0.87917 * Time Exposure	
Type of Road	Uphill
Gender	Male
Heart Rate = +135.93750 - 0.87917 * Time Exposure	

Type of Road	Downhill
Gender	Female
Heart Rate = +131.50000 - 0.87917 * Time Exposure	
Type of Road	Downhill
Gender	Male
Heart Rate = +128.31250 - 0.87917 * Time Exposure	

Table 5.5: The regression model for hand grip force (HGF)

Type of Road	**Straight**
Gender	Female
Hand Grip Force = +98.47094 - 0.89138 * Time Exposure	
Type of Road	Straight
Gender	Male
Hand Grip Force = +299.38906 - 0.53029 * Time Exposure	
Type of Road	Winding
Gender	Female
Hand Grip Force = +46.84844 + 2.33129 * Time Exposure	
Type of Road	Winding
Gender	Male
Hand Grip Force = +298.62656 + 2.69237 * Time Exposure	
Type of Road	Uphill
Gender	Female
Hand Grip Force = +90.08844 - 0.59304 * Time Exposure	
Type of Road	Uphill
Gender	Male
Hand Grip Force = +348.12156 - 0.23196 * Time Exposure	
Type of Road	Downhill
Gender	Female
Hand Grip Force = +60.99719 + 0.79146 * Time Exposure	
Type of Road	Downhill
Gender	Male
Hand Grip Force = +292.50781 + 1.15254 * Time Exposure	

Table 5.6: The regression model for a seat pressure distribution (SPD)

Type of Road	**Straight**
Gender	Female
Pressure Distribution = +11.19875 + 0.026533 * Time Exposure	
Type of Road	Straight
Gender	Male
Pressure Distribution = +13.51225 + 9.40000E-003 * Time Exposure	
Type of Road	Winding
Gender	Female
Pressure Distribution = +11.31325 + 0.032400 * Time Exposure	

Type of Road	Winding
Gender	Male
Pressure Distribution = +13.97275 + 0.015267 * Time Exposure	
Type of Road	Uphill
Gender	Female
Pressure Distribution = +11.99900 + 0.023000 * Time Exposure	
Type of Road	Uphill
Gender	Male
Pressure Distribution = +13.43450 + 5.86667E-003 * Time Exposure	
Type of Road	Downhill
Gender	Female
Pressure Distribution = +11.94450 + 0.025800 * Time Exposure	
Type of Road	Downhill
Gender	Male
Pressure Distribution = +14.10500 + 8.66667E-003 * Time Exposure	

Table 5.7: The regression model for whole-body vibration (WBV)

Type of Road	**Straight**
Gender	Female
Vibration (R.M.S) = +2.77078 - 0.010513 * Time Exposure	
Type of Road	Straight
Gender	Male
Vibration (R.M.S) = +2.77322 - 4.08750E-003 * Time Exposure	
Type of Road	Winding
Gender	Female
Vibration (R.M.S) = +3.15853 + 3.42083E-003 * Time Exposure	
Type of Road	Winding
Gender	Male
Vibration (R.M.S) = +3.17247 + 9.84583E-003 * Time Exposure	
Type of Road	Uphill
Gender	Female
Vibration (R.M.S) = +2.91703 - 9.71250E-003 * Time Exposure	
Type of Road	Uphill
Gender	Male
Vibration (R.M.S) = +2.84547 - 3.28750E-003 * Time Exposure	
Type of Road	Downhill
Gender	Female
Vibration (R.M.S) = +3.05716 - 6.79583E-003 * Time Exposure	
Type of Road	Downhill
Gender	Male
Vibration (R.M.S) = +2.98834 - 3.70833E-004 * Time Exposure	

All these regressions then will program or writing in Django. For this interface, the user required to select and enter the gender, type of road, and time exposure of driving. The system will calculate the results based on the appropriate regression models. Figure 5.17 shows the interface for the result from the regression model. The interface will display the results for each risk factors; muscle fatigue, heart rate, hand grip force, whole-body vibration, and seat pressure distribution. These results then will save and submitted to a fuzzy inference system (FIS).

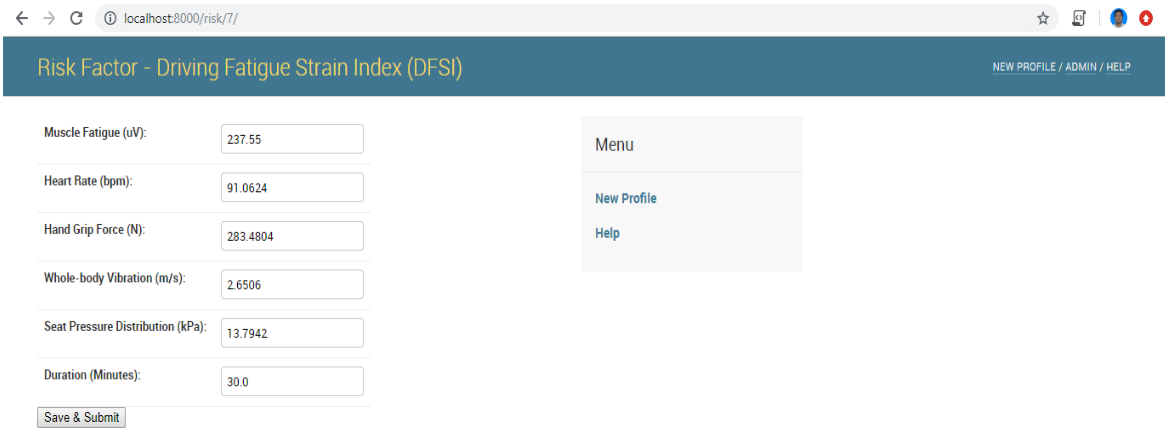


Figure 5.17: Result's interface from the regression model GUI of DSS

5.3.5 Risk Factor GUI

The final GUI for the DSS is risk factor analysis GUI. This interface consists of driving fatigue strain index (DFSI), which has been developed using the fuzzy inference system by MATLAB software and SciKit-Fuzzy by Python. SciKit-Fuzzy is a fuzzy logic toolbox for python that implements many useful tools and functions for computation and projects involving fuzzy logic. The development of DFSI has been discussed in a previous study (Ani et al., 2018; Ani et al., 2019).

From the result of the regression model, the system will analyze the result through SciKit-Fuzzy. The system will calculate the value of DFSI. The driving condition of the user is identified based on the DFSI's value, which has three fuzzy sets; safe, slightly unsafe, and unsafe. Figure 5.18 shows the risk factor analysis GUI.

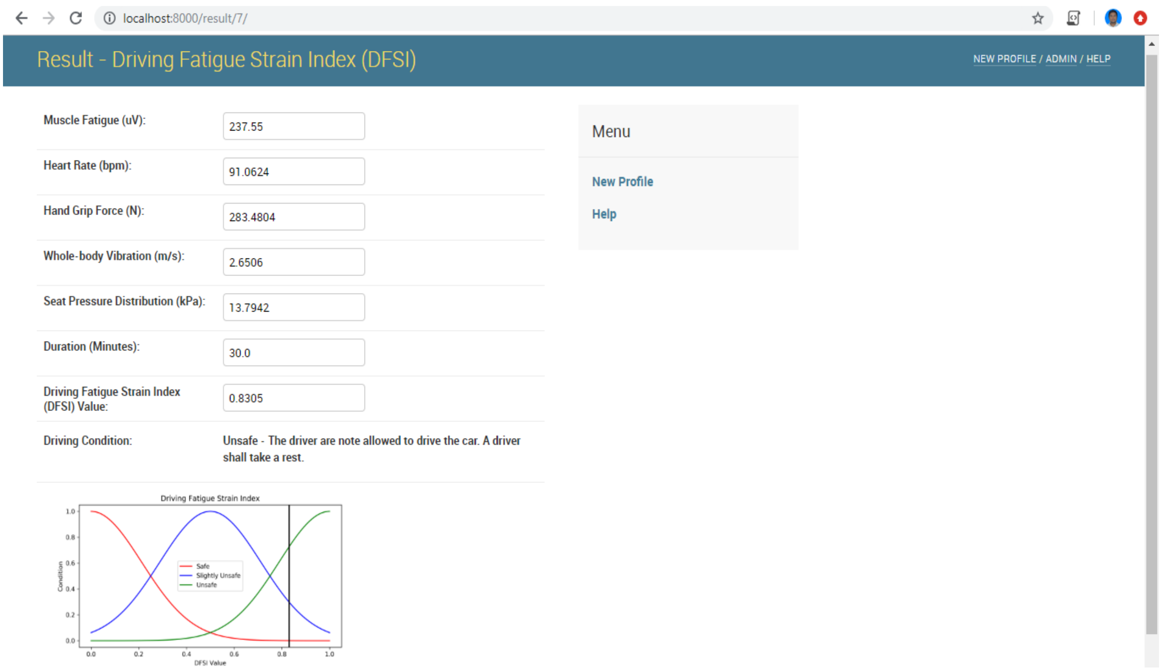


Figure 5.18: Risk factor analysis GUI shows the DFSI's value and driving condition of the user

5.4 Summary

Through this study, the decision support system for driving fatigue (DSSfDF) was successfully designed and developed by the author. There are five main GUIs; admin interface, superuser GUI, user profile and driving information GUI, regression model GUI, and risk factor analysis GUI have been successfully developed using Django. These entire GUI can perform various tasks and analysis for the user. The author believes that the development of DSS for driving fatigue using the Python programming language is a new contribution to the body of knowledge and novelty of this study. Besides, this system will successfully provide the driving condition’s risk level for road users. Indirectly, give an early warning and detection of fatigue while driving.

Chapter 6 Conclusion and Future Plan

This study successfully developed the decision support system for driving fatigue, also known as DSSfDF, which is very important system to provide systematic and rapid analysis of the risk factors that contribute significantly to driving fatigue. Besides, this system will successfully provide the driving condition's risk level, give initially warning and detection of fatigue, and give a better solution and recommendation to the users while driving. Indirectly, it becomes one of the efforts in order to reduce the number of road accidents and fatalities, especially in Malaysia.

In Chapter 1, the author explained the background of the study which covered the introduction of the study, problem statement, objectives of study, the significant of research, and structure of the dissertation. In this chapter, an increase in the number of road accidents especially in Malaysia becomes the main reason for the author interested in conducting this study. In order to reduce the number of road accidents, the author comes up with the solution by developed a Decision Support System for Driving Fatigue namely as DSSfDF.

In Chapter 2 and 3, the first and second stages for the development of DSS were successfully executed by the author. Both stages are very essential to this development as these stages explained how the knowledge been acquired and integrated into this DSS. Both stages explained the important methodology, guidelines, and components in the DSSfDF model that will be used in the next stage.

Chapter 4 is the most important part of this dissertation, and of course a main finding and stage in the development of DSS. In Chapter 4, the driving fatigue strain index

(DFSI) was successfully created by the author. The DFSI was developed using a fuzzy inference system by MATLAB software and SciKit-Fuzzy by Python. This development is expected to be useful for the risk assessment methodology to quantify the driving condition level associated with the driving activity.

Chapter 5 discussed the continuity study from the previous chapter. In this chapter, the graphical user interface (GUI) for a Decision Support System for Driving Fatigue (DSSfDF) was successfully designed. Five main GUIs; Admin GUI User Profile and Driving Information GUI, Regression Model GUI, Risk Factor Analysis GUI, and Superuser GUI has been designed by using Django based on Python programming language.

In Chapter 6, the author concludes this study as the main objectives are successfully achieved. The author believes that the development of DSSfDF is a new contribution to the body of knowledge and novelty of this study as this system will successfully provide the driving condition's risk level for road users. Some recommendations have also been suggested by the author through this chapter.

6.1 Future Plan

Currently, the DSSfDF will be an inactive driving system as the system built and conduct using the web-based system. The users or researchers have to enter the data of the drivers before getting the driving risk levels and driving conditions. Hence, in the future, the author plans to develop the system as an active driving safety system that will be placed in the vehicle for real-time fatigue detection. Figure 6.1 shows an illustration of how the system works.

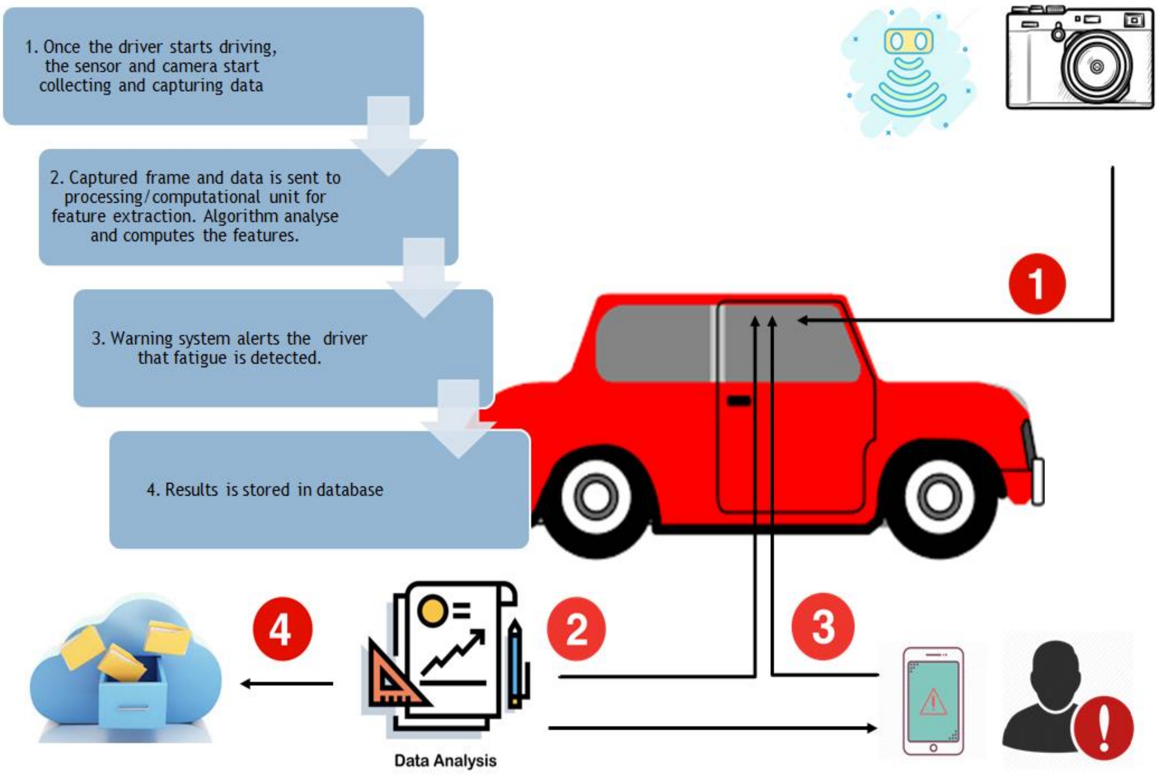


Figure 6.1: Illustration diagram of future driver fatigue alert system

The system consists of driver fatigue detection. It starts right away when the driver starts driving, and the sensor and camera start collecting and capturing data. The captured frame and data is sent to the processing or computational unit for feature extraction. The algorithm analyzes and computes the features. Once the feature is analyzed, warning sound in the form of an audible sound will be triggered to alert the drivers. The detection result will be stored in the database for future usage.

6.2 Contributions to Knowledge and Science

Science advances in small steps. Every piece added to knowledge helps to progress the understanding of the area bit by bit. This project and the resulting thesis and publications have made a small contribution to the general understanding of the decision support system and driving fatigue problem which, though essential to everyone's life, is taken for granted.

Although there has been published work by other researchers in the general area of decision support system, most publications of necessity have addressed one or the other issues such as decision support system for transportation which is focused on material handling, scheduling, and transportation maintenance. These publications are scattered far and wide and the circumstances in which these studies were done are as diverse as the researchers themselves.

None of the publications provide either a comprehensive or critical perspective on this field. The previous study regarding this research was very limited and the scope of the study was narrowed and focuses on a certain area. Besides, the majority of previous research was performed in the simulator (simulation study) and model. The author believes that the development of a decision support system for the driving fatigue problem among Malaysian is a new contribution to the body of knowledge.

Bibliography

Abdelfatah, A., 2016. Traffic Fatality Causes and Trends in Malaysia. Massachusetts Institute of Technology. American University of Sharjah.

Angehrn, A.A. and Lüthi, H.J., 1990. Intelligent decision support systems: a visual interactive approach. Interfaces, 20(6), pp.17-28

Aluclu, I., Dalgic, A. and Toprak, Z.F., 2008. A fuzzy logic-based model for noise control at industrial workplaces. Applied Ergonomics, 39(3), pp.368-378.

Ani, M.F., 2016. Developing Regression Models of Driver Fatigue Using an Ergonomics Approach. Master's thesis, Universiti Teknikal Malaysia Melaka. http://eprints.utem.edu.my/id/eprint/18595

Ani, M.F., Kamat, S.R.B. and Husin, K., 2017. A Study of Psychophysical Factor for Driver Fatigue Using Mathematical Model. Journal of Mechanical Engineering, Vol SI 3 (2), 109-122.

Ani, M.F, Kamat, S.R. And Ghazali, A., 2017 Development of A Regression Model for Relationship between Psychophysical and Biomechanics Factors Of Push Activities. Malaysia Journal of Public Health Medicine.

Ani, M.F., Minhat, M., Mahmood, W.H.W., Kamat, S.R. and Fukumi, M., 2017, November. Development of driving fatigue strain index to analyze risk levels of driving activity. In 2017 International Conference on Electrical, Electronics and System Engineering (ICEESE) (pp. 95-99). IEEE.

Ani, M. F., Kamat, S. R., Hambali, R. H. and Mahmood, W. H. W.., 2017. A Study of Psychophysical Factor (Heart Rate) For Driver Fatigue Using Regression Model. Malaysia Journal of Public Health Medicine. pp. 38, 9.

Ani, M.F., Fukumi, M., Kamat, S.R., and Minhat, M. 2018. Development of regression model for driving fatigue detection based on seat pressure distribution force of the drivers The Turkish Online Journal of Design, Art and Communication Special Edition, p.2677-2684.

Ani, M. F., Kamat, S. R., Fukumi, M., Ito, M., Minhat, M., & Rayme, N. S. 2018. Development of Ergonomic Vehicle Model and Decision Support System for Driving Fatigue. In Intelligent Manufacturing & Mechatronics: Proceedings of Symposium, 29 January 2018, Pekan, Pahang, Malaysia (pp. 355-369). Springer Singapore.

Ani, M.F., Fukumi, M., Rahayu Kamat, S., Minhat, M. and Husain, K., 2019. Development of driving fatigue strain index using fuzzy logic to analyze risk levels of driving activity. IEEJ Transactions on Electrical and Electronic Engineering.

Axelevitch, A. and Golan, G., 2007. Modeling and Optimization of Film Deposition by Magnetron Sputtering. Journal of Uncertain Systems, 1(4), pp.277-290.

Azadeh, A., Fam, I.M., Khoshnoud, M. and Nikafrouz, M., 2008. Design and implementation of a fuzzy expert system for performance assessment of an integrated health, safety, environment (HSE) and ergonomics system: The case of a gas refinery. Information Sciences, 178(22), pp.4280-4300.

Berkan, R.C. and Trubatch, S., 1997. *Fuzzy system design principles*. Wiley-IEEE Press.

Bhardwaj, A., Aggarwal, P., Kumar, R. & Chandra, N. 2013. Image Filtering Techniques Used for Monitoring Driver Fatigue: A Survey. Citeseer.

Caputo, A.C., Fratocchi, L. and Pelagagge, P.M., 2006. A genetic approach for freight transportation planning. Industrial Management & Data Systems, 106(5), pp.719-738.

Chieh, T.C., Mustafa, M.M., Hussain, A., Zahedi, E. and Majlis, B.Y., 2003, August. Driver fatigue detection using steering grip force. In Research and Development, 2003. SCORED 2003. Proceedings. Student Conference on (pp. 45-48). IEEE.

Dauzon, S., Bendoraitis, A. and Ravindran, A., 2016. Django: Web Development with Python. Packt Publishing Ltd.

Department of Statistic Malaysia., 2019. Social Statistic Bulletin, Malaysia 2016, (Online), Available at: <https://www.dosm.gov.my/v1/index.php> (Accessed: August 15, 2019).

Dell'Acqua, G., De Luca, M. and Mauro, R., 2011. Road safety knowledge-based decision support system. Procedia-Social and Behavioral Sciences, 20, pp.973-983.

Deshpande, R., Chinnan, M. & McWatters, K. 2008. Optimization of a chocolate-flavored, peanut–soy beverage using response surface methodology (RSM) as applied to consumer acceptability data. LWT-Food Science and Technology, 41**,** 1485-1492.

Desmond, P.A., Neubauer, M.C., Matthews, G. and Hancock, P.A. eds., 2012. The Handbook of Operator Fatigue. Ashgate Publishing, Ltd.

De Luca, C.J., 1997. The use of surface electromyography in biomechanics. Journal of applied biomechanics, 13(2), pp.135-163.

De Looze, M.P., Kuijt-Evers, L.F. and Van Dieen, J.A.A.P., 2003. Sitting comfort and discomfort and the relationships with objective measures. Ergonomics, 46(10), pp.985-997.

Dinges, D.F., 2004. Critical research issues in development of biomathematical models of fatigue and performance. Aviation, space, and environmental medicine, 75(3), pp.A181-A191.

Dobbie, K., 2002. Fatigue-related crashes: An analysis of fatigue-related crashes on Australian roads using an operational definition of fatigue (No. OR 23).

Edwards, J.S., 1996. Decision Support and Expert Systems: Management Support Systems. Journal of the Operational Research Society, 47(5), pp.717-718.

Eksioglu, M. and Kızılaslan, K., 2008. Steering-wheel grip force characteristics of drivers as a function of gender, speed, and road condition. International journal of industrial ergonomics, 38(3-4), pp.354-361.

Eriksson, M. and Papanikotopoulos, N.P., 1997, November. Eye-tracking for detection of driver fatigue. In Intelligent Transportation System, 1997. ITSC'97., IEEE Conference on (pp. 314-319). IEEE.

Fancello, G., Carta, M. and Fadda, P., 2015. A decision support system for road safety analysis. Transportation Research Procedia, 5, pp.201-210.

Firdaus, M., Rahayu, S., Minhat, M., Fukumi, M. and Ito, T., 2017. A study of biomechanical factor for driver fatigue using regression model. Safety, Health, and Environment, 38, p.9.

Firdaus, M., Rahayu, S., Minhat, M., Fukumi, M. and Ito, T., 2017. Effect of vibration towards driving fatigue and development of regression model based on vibration. In The Proceedings of Design & Systems Conference 2017.27 . The Japan Society of Mechanical Engineers. pp. 2506.

Gentile, M., Rogers, W.J. and Mannan, M.S., 2003. Development of a fuzzy logic-based inherent safety index. Process Safety and Environmental Protection, 81(6), pp.444-456.

Halim, I. and Rahman Omar, A., 2012. Development of prolonged standing strain index to quantify risk levels of standing jobs. International Journal of Occupational Safety and Ergonomics, 18(1), pp.85-96.

Halim, I., Arep, H., Kamat, S.R., Abdullah, R., Omar, A.R. and Ismail, A.R., 2014. Development of a decision support system for analysis and solutions of prolonged standing in the workplace. Safety and health at work, 5(2), pp.97-105.

International Organization for Standardization, 1997. Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 1: General requirements. The Organization.

Jasiulewicz-Kaczmarek, M. and Drożyner, P., 2013. The role of maintenance in reducing the negative impact of a business on the environment. In Sustainability Appraisal: Quantitative Methods and Mathematical Techniques for Environmental Performance Evaluation (pp. 141-166). Springer, Berlin, Heidelberg.

Jakimavičius, M. and Burinskiene, M., 2007. Automobile transport system analysis and ranking in Lithuanian administrative regions. Transport, 22(3), pp.214-220.

Jang, J.S.R., Sun, C.T. and Mizutani, E., 1997. Neuro-fuzzy and soft computing-a computational approach to learning and machine intelligence [Book Review]. IEEE Transactions on automatic control, 42(10), pp.1482-1484.

Karwowski, W., Gaweda, A., Marras, W.S., Davis, K., Zurada, J.M. and Rodrick, D., 2006. A fuzzy relational rule network modeling of electromyographical activity of trunk muscles in manual lifting based on trunk angels, moments, pelvic tilt and rotation angles. International Journal of Industrial Ergonomics, 36(10), pp.847-859.

Karwowski, W., 1999. Application of fuzzy systems in human factors. Handbook of fuzzy sets and possibility theory, pp.589-620.

Karwowski, W., Mulholland, N.O., Ward, T.L. and Jagannathan, V., 1987. A fuzzy knowledge base of an expert system for analysis of manual lifting tasks. Fuzzy sets and Systems, 21(3), pp.363-374.

Karwowski, W., Ayoub, M.M., Alley, L.R. and Smith, J.L., 1984. Fuzzy approach in psychophysical modeling of human operator-manual lifting system. Fuzzy Sets and Systems, 14(1), pp.65-76.

Karwowski, W. and Mital, A. eds., 2014. Applications of fuzzy set theory in human factors (Vol. 6). Elsevier.

Karwowski, W. and Ayoub, M.M., 1984. Fuzzy modelling of stresses in manual lifting tasks. Ergonomics, 27(6), pp.641-649.

Karwowski, W., 1985. Why do ergonomists need fuzzy sets. In Ergonomics International 85. Proceedings of the Ninth Congress of the International Ergonomics Association, Bernemouth, England. Taylor & Francis, London .pp. 409-411.

Klir, G.J. and Yuan, B., 1996. Fuzzy sets, fuzzy logic, and fuzzy systems: selected papers by Lotfi A. Zadeh. World Scientific Publishing Co., Inc..

Klir, G.J. and Yuan, B., 1995. Fuzzy sets and fuzzy logic: theory and applications. Upper Saddle River, pp. 563.

Land Public Transport Commission, 2006. Pengangkutan Menuju Ke Era 2050 Sebuah Koleksi Aspirasi Rakyat. Transformasi Nasional 50. 2017. 7: 1-60.

Lee, T.Z., Wu, C.H. and Wei, H.H., 2008. KBSLUA: A knowledge-based system applied in river land use assessment. Expert Systems with Applications, 34(2), pp.889-899.

Lootsma, F.A., 2013. Fuzzy logic for planning and decision making (Vol. 8). Springer Science & Business Media.

Lu, L., Megahed, F.M., Sesek, R.F. and Cavuoto, L.A., 2017. A survey of the prevalence of fatigue, its precursors and individual coping mechanisms among US manufacturing workers. Applied ergonomics, 65, pp.139-151.

Malaysia Institute of Road Safety Research, 2015. General road accident statistic in Malaysia 2019, (Online), Available at: <https://www.miros.gov.my/1/page.php?id=364> (Accessed: August 29, 2019).

Mayne, A.J., 1990. Fuzzy sets, uncertainty, and information. *Journal of the Operational Research Society*, *41*(9), pp.884-886.

Mansfield, N., Sammonds, G. and Nguyen, L., 2015. Driver discomfort in vehicle seats–Effect of changing road conditions and seat foam composition. Applied ergonomics, 50, pp.153-159.

Masoum, M.A.S., Ladjevardi, M., Fuchs, E.F. and Grady, E.M., 2002, July. Optimal placement and sizing of fixed and switched capacitor banks under nonsinusoidal operating conditions. In IEEE Power Engineering Society Summer Meeting, (Vol. 2, pp. 807-813). IEEE.

Meletis, C.D. and Barker, J.E., 2004. Herbs and nutrients for the mind: A guide to natural brain enhancers (Vol. 1). Greenwood Publishing Group.

Mohamed, N., Fadhli, M.M., Othman, H., Sarani, R. and Voon, W.S., 2008. Fatigue among commercial bus drivers in Malaysia: role of driving hours and single versus two driver approach (No. MRR 07/2008).

National Library of Medicine (NLM), 2015. Heart Rate, Available at: https://www.nlm.nih.gov/news/2011.html. (Accessed: May 14, 2015).

Otmani, S., Pebayle, T., Roge, J. and Muzet, A., 2005. Effect of driving duration and partial sleep deprivation on subsequent alertness and performance of car drivers. Physiology & behavior, 84(5), 715-724.

Papadelis, C., Chen, Z., Kourtidou-Papadeli, C., Bamidis, P.D., Chouvarda, I., Bekiaris, E. and Maglaveras, N., 2007. Monitoring sleepiness with on-board electrophysiological recordings for preventing sleep-deprived traffic accidents. Clinical Neurophysiology, 118(9), pp.1906-1922.

Philip, P., Sagaspe, P., Moore, N., Taillard, J., Charles, A., Guilleminault, C. and Bioulac, B., 2005. Fatigue, sleep restriction and driving performance. Accident Analysis & Prevention, 37(3), pp.473-478.

Philip, P., Sagaspe, P., Taillard, J., Moore, N., Guilleminault, C., Sanchez-Ortuno, M., Åkerstedt, T.B. and Bioulac, B., 2003. Fatigue, sleep restriction, and performance in automobile drivers: a controlled study in a natural environment. Sleep, 26(3), pp.277-280.

Plekhanova, J., 2009. Evaluating web development frameworks: Django, Ruby on Rails and CakePHP. Institute for Business and Information Technology.

Rahayu, S., Firdaus, M. and Husain, K., 2015. A Comparison Study between Right Hand and Left Hand Grip Pressure Force While Driving. Australian Journal of Basic and Applied Science, 9(19), pp.50-58.

Rahayu, S. and Firdaus, M., 2015. A comparison study between the road condition with pressure distribution on the seat and car vibration, International Journal of Emerging Technology and Advanced Engineering Vol. 5.

Rahayu, S., Firdaus, M. and Fa'iz, M. 2016. A comparison study for the road condition with hand grip force and muscle fatigue. Malaysia Journal of Public Health Medicine Special vol. 1, pp.7-13.

Sacco, M. and Farrugia, R.A., 2012, May. Driver fatigue monitoring system using support vector machines. In 2012 5th International Symposium on Communications, Control and Signal Processing (pp. 1-5). IEEE.

San, P.P., Ling, S.H., Chai, R., Tran, Y., Craig, A. and Nguyen, H., 2016, August. EEG-based driver fatigue detection using hybrid deep generic model. In Engineering in Medicine and Biology Society (EMBC), 2016 IEEE 38th Annual International Conference of the (pp. 800-803). IEEE.

Šelih, J., Kne, A., Srdić, A. and Žura, M., 2008. Multiple-criteria decision support system in highway infrastructure management. Transport, 23(4), pp.299-305.

Seen, K.S., Tamrin, S.B.M. and Meng, G.Y., 2010. Driving fatigue and performance among occupational drivers in simulated prolonged driving. Global Journal of Health Science, 2(1), p.167.

Singh, S. and Papanikolopoulos, N.P., 1999. Monitoring driver fatigue using facial analysis techniques. In Intelligent Transportation Systems, 1999. Proceedings. 1999 IEEE/IEEJ/JSAI International Conference on (pp. 314-318). IEEE.

Smith, P., Shah, M. and da Vitoria Lobo, N., 2003. Determining driver visual attention with one camera. IEEE transactions on intelligent transportation systems, 4(4), pp.205-218.

Smith, P., Shah, M. and da Vitoria Lobo, N., 2000. Monitoring head/eye motion for driver alertness with one camera. In Pattern Recognition, 2000. Proceedings. 15th International Conference on (Vol. 4, pp. 636-642). IEEE.

Suzuki, Y., 2009. A decision support system of dynamic vehicle refueling. Decision Support Systems, 46(2), pp.522-531.

Tanaka K., 1997. An Introduction to Fuzzy Logic for Practical Applications. Springer: USA

Tadic, D., Savovic, I., Misita, M., Arsovski, S. and Milanovic, D.D., 2014. Development of a fuzzy logic-based inherent safety index for food industries. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 228(1), pp.3-13.

Tippayanate, N., 2006. The impact of sleep deprivation on driving performance. Khon Kaen Hospital Medical Journal, 30(3), 320-325.

Traffic Investigation and Enforcement Department, 2018. Transport Statistic Malaysia 2017, Ministry of Transport Malaysia.

Tripodi, A., Persia, L., Di Mascio, P., Corazza, M.V. and Musso, A., 2012. A decision support system for analysis of vulnerable road users safety issues: results of the Saferbrain project. Procedia-Social and Behavioral Sciences, 53, pp.841-850.

Torretta, V., Raboni, M., Copelli, S. and Urbini, G., 2013. Application of a decision support system to the transport of hazardous materials. Environmental Engineering & Management Journal (EEMJ), 12(10).

Turban, E. 1990. Decision support and expert systems: management support systems. Prentice Hall PTR.

Wang, Q., Yang, J., Ren, M. and Zheng, Y., 2006, June. Driver fatigue detection: a survey. In Intelligent Control and Automation, 2006. WCICA 2006. The Sixth World Congress on (Vol. 2, pp. 8587-8591). IEEE.

Wang, K., 2001. Computational intelligence in agile manufacturing engineering. Agile Manufacturing The 21st Century Competitive Strategy, Oxford, UK: Elsevier Science Ltd, pp.297-315.

Wickens, C. D., Lee, J., Liu, Y. D. and Gordon-Becker, S. 2003. Introduction to Human Factors Engineering.

World Health Organization, 2013. Violence, Injury Prevention, World Health Organization. Global status report on road safety 2013: supporting a decade of action. World Health Organization.

Yung, M., 2016. Fatigue at the Workplace: Measurement and Temporal Development. UWSpace. http://hdl.handle.net/10012/10119

Yen J, Langari R. 1998. Fuzzy Logic: Intelligence, Control, and Information. Prentice-Hall, Inc: USA

Yung, M., 2016. Fatigue at the workplace: Measurement and temporal development.

Yusoff, M.F.M., Mohamad, N.A. and Nor, N.G.M., 2011. Malaysian Value of Fatal and Non Fatal Injury due to Road Accident: The Willingness to Pay Using Conjoint Analysis Study. In Proceedings of the Eastern Asia Society for Transportation Studies The 9th International Conference of Eastern Asia Society for Transportation Studies, 2011 (pp. 33-33). Eastern Asia Society for Transportation Studies.

Zacharias, M., Mehdi, S.T. and Christos, M., 2006. Practical aspects of DSS design for commodities transportation during special events. *ACM SIGSOFT Software Engineering Notes*, *31*(1), pp.1-6.

Zak, J., 2010. Decision support systems in transportation. In Handbook on Decision Making (pp. 249-294). Springer, Berlin, Heidelberg.

Zimmermann, H.J., 2011. Fuzzy set theory—and its applications. Springer Science & Business Media.

Zografos, K.G. and Androutsopoulos, K.N., 2005, January. A decision support system for hazardous materials transportation and emergency response management. In 84th Annual Meeting of the Transportation Research Board, Washington, DC.

Zuraida, R., Iridiastadi, H., Sutalaksana, I.Z. and Suprijanto, S., 2019. An Analysis of EEG Changes during Prolonged Simulated Driving for the Assessment of Driver Fatigue. Journal of Engineering and Technological Sciences, 51(2), pp.290-302.

List of Publications

Main Paper

[1] Mohammad Firdaus Ani, Minoru Fukumi, Seri Rahayu Kamat, Mohamad Minhat, Kalthom Husain, “Development of Driving Fatigue Strain Index using Fuzzy Logic to Analyze Risk Levels of Driving Activity”, IEEJ Transactions on Electrical and Electronic Engineering, 2019, Published

Sub Paper

[1] Mohammad Firdaus Ani, Seri Rahayu Kamat, Mohamad Minhat, Minoru Fukumi, Teruaki Ito, “A Study of Biomechanical Factor for Driver Fatigue using Regression Model”, International Design and Concurrent Engineering and Manufacturing Systems Conference, Osaka, Paper No.9, September, 2017, Published

[2] Mohammad Firdaus Ani, Seri Rahayu Kamat, Mohamad Minhat, Minoru Fukumi, Teruaki Ito, “Effect of Vibration Towards Driving Fatigue and Development of Regression Model based on Vibration”, Proc. of Design and System Conference 2017, 27(p.2506), The Japan Society of Mechanical Engineers, 2017, Published

[3] Mohammad Firdaus Ani, Seri Rahayu Kamat, Kalthom Husin, "A Study of Psychophysical Factor for Driver Fatigue using Mathematical Model", Journal of Mechanical Engineering, Vol. SI 3(2) pp.109-122, 2017, Published

[4] Mohammad Firdaus Ani, Minoru Fukumi, Seri Rahayu Kamat, Mohamad Minhat, "Development of Driving Fatigue Strain Index for Reducing Accident Risk Among Drivers", International Conference on Electrical, Electronics and System Engineering (ICEESE) pp.95-99, 2017, Published

[5] Mohammad Firdaus Ani, Seri Rahayu Kamat, Mohamad Minhat,Ruzy Haryati Hambali, Kalthom Husain, "A Study of Psychophysical Factor (Heart Rate) for Driver Fatigue using Regression Model", Malaysian Journal of Public Health Medicine, Vol. 2 pp.1-9, 2018, Published

[6] Mohammad Firdaus Ani, Minoru Fukumi, Seri Rahayu Kamat, Mohamad Minhat, "Development of Regression Model for Driving Fatigue Detection based on Seat Pressure Distribution Force of the Drivers", The Turkish Online Journal of Design, Art and Communication Special Edition, pp.2677-2684, 2018, Published

[7] Mohammad Firdaus Ani, Seri Rahayu Kamat, Minoru Fukumi,Momoyo Ito, Mohamad Minhat, Nur Syafiqah Rayme “Development of Ergonomic Vehicle Model and Decision Support System for Driving Fatigue”, Intelligent Manufacturing & Mechatronics, Springer, Singapore, pp.355-369, 2018, Published

[8] Mohammad Firdaus Ani, Minoru Fukumi, Seri Rahayu Kamat, Mohamad Minhat,Teruaki Ito, “A Construction Framework of Decision Support System for Improving Driving Fatigue”, Proceedings of Manufacturing System Division Conference 2018, pp.307, The Japan Society of Mechanical Engineers, 2018, Published