

Development of Driving Fatigue Strain Index for Reducing Accident Risk Among Drivers

Mohammad Firdaus Ani, Seri Rahayu Kamat, Minoru Fukumi, and Mohamad Minhat

Abstract—Driving has become more important as this medium being practically, faster and cheaper in connecting human from one to other places. However, in some occurrences driving activity can cause disaster or death to human in daily life as they get fatigued while driving. Driving fatigue is one of the top contributor to the road crashes. Therefore this study is to develop a driving fatigue strain index (DFSI), collaborate with Decision Support System (DSS), to quantify the risk levels caused by driving activity, and to propose an appropriate solution in minimizing the number of road accidents caused by the driving fatigue. The decision support system provide fast and systematic analysis, and solutions to minimize the risk and the number of accidents associated with driving fatigue. The development of DFSI is based on risk factors associated with driving activity such as muscle activity, heart rate, hand grip force, seat pressure distribution, whole-body vibration, and driving duration. All risk factors are assigned with multipliers, and the DFSI is the output or result of those multipliers. The development of DFSI is essential to analyze the risk factors that would contribute significantly to discomfort and fatigue associated with driving. Besides, in the future this index will have a capability to recommend alternative solutions to minimize fatigue while driving.

Index Terms—Decision support system, Fatigue, Hand grip force, Heart rate, Seat pressure, strain index, Whole-body vibration

I. INTRODUCTION

DRIVING 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

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injured in road accidents. Based on the previous research [1], fatigue can be dangerous as other road safety issues such as drink driving and there are no laws regulating drivers' fatigue. As a driver, fatigue can cause and bring many problems and effects, including slowing the driver reactions and decisions, decreasing the driver tolerance for other road users, poor lane tracking and maintenance of speed and decreasing driver alertness. Driving fatigue been defined as a feeling of drowsiness due to extended driving period, monotonous road condition, adverse climatologically environment or drivers' individual characteristics is direct or contributing factor in road accidents [1]. According to [1], subjective feeling of fatigue, which combined with negative effects on performance due to time spent on cognitively demanding tasks can

TABLE I
TOTAL CASUALTIES AND DAMAGES CAUSED BY ROAD ACCIDENTS IN
MALAYSIA

Year	Total Number of Accidents	Casualties			
		Death	Serius	Minor	Total
2007	363,319	6,282	9,273	18,444	33,999
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

somehow affected the driving performance due to sleepiness, monotonous driving environmental condition and the length of driving period as in previous studies [2]-[4]. The Royal Malaysian Police (RMP) is the agency responsible for collecting accident data. In Malaysia, all road accidents must be reported to the police. Based on provisional data by the RMP, there were 7,152 road fatalities and 521,466 road accidents has been reported in 2016 [5] as shown in Table I.

Moreover, Malaysian Institute of Road Safety Research (MIROS) has made a prediction of fatalities and it is reported that there will be 10,716 fatalities during 2020 [6]. The in-depth crash investigations on some crash cases carried out by

MIROS [7] found that risky driving, speeding and fatigue are the main causes of 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 are no data reported for 2014 until 2016. Due to the above mentioned points, much effort has been made to develop; advanced decision, adding methodologies, reliable decision making procedures, efficient optimization methods and algorithms as well as user-friendly computational tools for transportation. However, there is no study on development of strain index for driving fatigue. Many previous study developed the strain index for analyzing jobs in industry [8], [9].

Hence, this study is to counter these limitations by developing the DFSI to quantify risk levels, analyze, and propose a solution to minimizing the number of road accidents associated with driving fatigue as this index will warn and alert the drivers about the risk level and condition of the driving whether is safe or unsafe level. The strain index is a semi quantitative analysis that results in numerical score (SI score) that is believed to correlate with the risk levels of driving fatigue. The DFSI is based on multiplicative interaction among the risk factors. The DFSI represents the product of all multipliers that correspond to all risk factors. In this study, six risk factors; muscle activity, heart rate, hand grip force, seat pressure distribution, whole-body vibration, and driving duration, which related to driving fatigue [10]-[16] are considered as the main base to develop DFSI. All these risk factors, are related to three main domain; human, machine or vehicle, and environment while driving. Furthermore, all the risk factors are analyzed individual in order to determine the risk level, which then been assigned with multipliers to represent their severity for fatigue. From these multipliers, the strain index for driving fatigue is developed through the multiplicative interactions [8].

This paper is prepared to develop the driving fatigue strain index (DFSI) to quantify the risk levels of fatigue associated with driving activity and propose solution to minimize the risk of driving fatigue and indirectly reduces the number of road accidents in Malaysia.

II. METHODS

In developing the DFSI, there are eight steps that need to be passed through as the foundation of this development; data collection of each risk factors, data analysis of each risk factor, assigning a rating value of each risk factor, assigning the multiplier of each risk factor, calculating the DFSI value, defining the DFSI value, identifying the propose solution and recommendation, and development of decision support system (DSS). This section will give a brief explanation on the development of DFSI.

A. Knowledge Acquisition

Knowledge is a brain of to process the input data and information received by the system [17]. The knowledge can be acquired by extracting, structuring, and organizing knowledge from one to more sources [18]. In this study, the risk factors that contribute significantly to the driver fatigue is

determined by performing the knowledge acquisition. Besides, the ergonomics evaluation tools also had been 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. The pre-survey and the real road test experiment is conducted and performing among Malaysia's road users to examine and obtained information and data of 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 aged is between 20-25 years old.

There are seven main areas [8], [9], [19]-[23] that the author reviewed and referred as the guidelines in the development of DFSI. In this study, the author had referred the guidelines and standards from authorized organizations, societies 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, the expert opinion such as ergonomics practitioners, road safety practitioners, and academician gives a huge benefit in the development of the knowledge base of the DFSI especially for determining and assigning the risk levels and multipliers of each risk factor. All these risk factors, then can be classified into three areas or domains; human or driver (MA, HR, SPD), machine or vehicle (WBV), and environment (DD). In addition, each of the risk factors was provided with ergonomics evaluation tools to analyze and quantify the risk levels.

B. Integration of Knowledge

In the second stage, the risk factors and ergonomics evaluation tools are processed to integrate them. The risk factors of driving fatigue are matched with the ergonomics evaluation tools to quantify the risk levels and this is directly used to develop the DFSI. All these risk factors are selected based on the previous study that has proven all these factors will give a significant effect on fatigue associated with driving activity. Table II shows the previous studies that have been used as a guideline to quantify the risk criteria and risk levels of each risk factor.

Analysis of each risk factor produces a risk level (in rating form) which represents the effects of analyzed risk factors to the driver. The ratings are represented by numerical values from 1 to 5. The lowest rating indicates the comfort and non-fatigue, while the highest rating indicates the discomfort and fatigue. Table III summarizes the rating criteria for each factor

TABLE II
LIST OF THE PREVIOUS STUDIES USED AS GUIDELINES

Risk Factors	Previous Studies
Muscle Activity (MA)	[24], [25]
Heart Rate (HR)	[26], [27]
Hand Grip Force (HGF)	[28], [29]
Seat Pressure Distribution (SPD)	[30]
Whole-Body Vibration (WBV)	[31]
Driving Duration (DD)	[32]

to indicate risk levels due to driving fatigue.

C. Development of DFSI

The DFSI was developed based on multiplicative interactions among risk levels of risk factors. The DFSI is the product of six factors that corresponded to six multipliers. The multipliers of each risk factors were developed based on professional judgements [8], [33] and based on the calculations, which will be discussed further in Section D. All risk factors can be described as a linear relationship as shown in (1). Table III shows the rating criteria representing the risk levels for each risk factor.

$$DFSI = MA \times HR \times HGF \times SPD \times WBV \times DD \quad (1)$$

TABLE III
RATING CRITERIA AND RISK LEVELS OF EACH RISK FACTORS

Risk Factor					
MA (μV)	HR (bpm)	HGF (N)	WBV (m/s ²)	SPD (kPa)	DD (min)
Rating: 1					
Little fatigue (1): 52 ≥ 129	Very fit (1): <84	Non-fatigue (1): ≥ 189.60	Comfort (1): < 0.315	Comfort (1): ≤ 5.80	Non-fatigue (1): < 40
Rating: 2					
Moderate fatigue (3): 130 ≥ 300	Fit (3): 84 – 105	Mild Fatigue (3): 57.80 > 189.60	Little comfort (2): 0.315 > 0.63	Discomfort (81): > 5.80	Fatigue (81): ≥ 40
Rating: 3					
Fatigue (81): 301 ≥ 600	Average (81): 106 – 122	Fatigue (81): < 57.80	Fairly comfort (3): 0.50 > 1.0		
Rating: 4					
Very fatigue (81): 601 ≥ 1100	Unfit (81): >122		Discomfort (81): 0.8 > 1.6		
Rating: 5					
			Very discomfort (81): 1.25- 2.5		

D. Determination of Multipliers

In determine the multipliers, the professional judgement [8],

[33] was used in this study. However, there are some calculation to be make in order to determine the multipliers of the risk factors. In this study, the positive criteria such as non-fatigue, little fatigue, very fit, comfort, moderate, and fairly has been assigned with the multipliers from the values of 1 to 3 as shown in Table IV. Meanwhile, for the negative criteria such as fatigue, very fatigue, discomfort, and unfit has been

TABLE IV
THE MULTIPLIERS OF RISK FACTOR

Risk Factor (Multiplier)					
MA (μV)	HR (bpm)	HGF (N)	WBV (m/s ²)	SPD (kPa)	DD (min)
Little fatigue (1)	Very fit (1)	Non-fatigue (1)	Comfort (1)	Comfort (1)	Non-fatigue (1)
Moderate fatigue (3)	Fit (3)	Mild Fatigue (3)	Little comfort (2)	Discomfort (81)	Fatigue (81)
Fatigue (81)	Average (81)	Fatigue (81)	Fairly comfort (3)		
Very fatigue (81)	Unfit (81)		Discomfort (81)		
			Very discomfort (81)		

assigned with the value of 81 as shown in Table IV.

The values is based on calculation. By referring to Table V and Section E, there are three risk level of driving; safe, slightly unsafe, and unsafe. The slightly unsafe level is the limit of the drivers before the condition of the driving become unsafe. In this study, the negative criteria can be categorize as the unsafe condition. From the Table V, the DFSI values is calculated using the (1) and the result for the slightly unsafe level is 3-80. Any values that exceed the values of 80 is consider as unsafe level. Hence, the values of 81 is assigned as the multipliers for the negative criteria.

E. Definition of the DFSI

There are three risk levels or categories that are assigned to indicate the effects of driving fatigue to drivers; safe, slightly unsafe, and unsafe. This level is defined based on the DFSI values. Table V represents the risk level of driving corresponding to the multipliers of each risk factors and the

TABLE V
RISK LEVELS OF DRIVING ACTIVITY

Risk of	Multiplier						DFSI
	MA	HR	HGF	WBV	SPD	DD	
Driving							
<i>Safe</i>	1	1	1	1	1	1	1
	1	1	1	2	1	1	2
<i>Slightly Unsafe</i>	3	3	3	3	1	1	80
<i>Unsafe</i>					1	1	81 ^b
	81	81			81	81	>81

^aIf any factor is 3.

^bIf any factor is 81

DFSI.

Based on the table, the drivers are considered safe during driving when they obtain a multiplier of 1 for each factor or a multiplier of 2 for WBV. Generally, to obtain a safe level the DFSI should be 1–2. These conditions are the best and need to be maintained to ensure a driver is comfortable and safe. The level is slightly unsafe if the DFSI is 3–80. The risk factors associated with driving fatigue indicate that the condition can harm the driver and possibility to involve in accidents. While, driving are considered unsafe if the DFSI equals or exceeds 81. The drivers are not allowed to drive the car. Therefore, immediate investigation and improvement are required.

F. Development of Ergonomic Vehicle Model and Decision Support System for Driving Fatigue

Two model were developed in the final stage of this study namely as Ergonomic Vehicle Model (EVM) and Decision Support System for Driving Fatigue (DSSfDF). . Each models have different purpose and function. EVM is used to captures and gathers the information on vehicles, drivers, and the data about the risk factors related to driving fatigue; muscle activity, heart rate, hand grip pressure force, whole-body vibration, seat pressure distribution, and driving duration.

While, the DSSfDF performed analysis based on information and data captured by the EVM. The purpose of this model is to quantify the risk levels of each risk factors and draw a new conclusion based on DFSI value. Both models then transformed into a computer program to enable a user's to perform analysis with minimal data manipulation and time spent.

III. RESULTS AND DISCUSSION

The DFSI methodology is tested and demonstrated by the authors using a data set available from the previous studies

TABLE VI
THE EXAMPLE OF DATA SET [10]-[16]

Risk Factors	Results
Muscle Activity (MA)	129.500 μ V
Heart Rate (HR)	82.000 bpm
Hand Grip Force (HGF)	277.910 N
Whole-body Vibration (WBV)	2.607 m/s ²
Seat Pressure Distribution (SPD)	13.875 kPa
Driving Duration (DD)	30.00 min

performed [10]-[16]. Table VI presents the example data set available from the previous studies.

The rating criteria and multipliers are determined from Table II as follows:

- MA obtained a “Little Fatigue” level, thus rating is 1, and multiplier of 1
- HR obtained a “Very Fit” level, thus rating is 1, and multiplier of 1
- HGF obtained a “Non-Fatigue” level, thus rating is 1, and multiplier of 1

- WBV obtained a “Very Discomfort” level, thus rating is 5, and multiplier of 81
- SPD obtained a “Discomfort” level, thus rating is 2, and multiplier of 81
- DD obtained a “Non-Fatigue” level, thus rating is 1, and multiplier of 1

By using the (1), the total value of DFSI is 6561. Then, the DFSI values are compared to Table IV. Table VII summarizes the results of analysis of risk factors, the value of the DFSI, and the risk of driving. The value indicates that the driving is considered unsafe and the driver is not allowed to drive the car. Therefore, immediate investigation and improvement are required. The MA, HR, HGF, and DD shall be maintained as

TABLE VII
SUMMARIZATION OF THE RESULT

Risk Factor	MA	HR	HGF	WBV	SPD	DD
Rating	Little Fatigue	Very Fit	Non-fatigue	Very discomfort	Discomfort	Non-fatigue
Multiplier	1	1	1	81	81	1
DFSI				6561		
Risk of Driving				Unsafe		

they contribute to lower values of DFSI. While, WBV and SPD need improvements as they contribute to the higher value of DFSI.

There is no comparative analysis with other similar work, which has already been published is performed as there is no study regarding the development of strain index for driving fatigue. However, this study is based on the previous study [8], [9] which focused on the development of strain index for standing jobs.

Fig. 1 shows decision support system for driving fatigue which, consist of EVM and DSSfDF model. Both models have

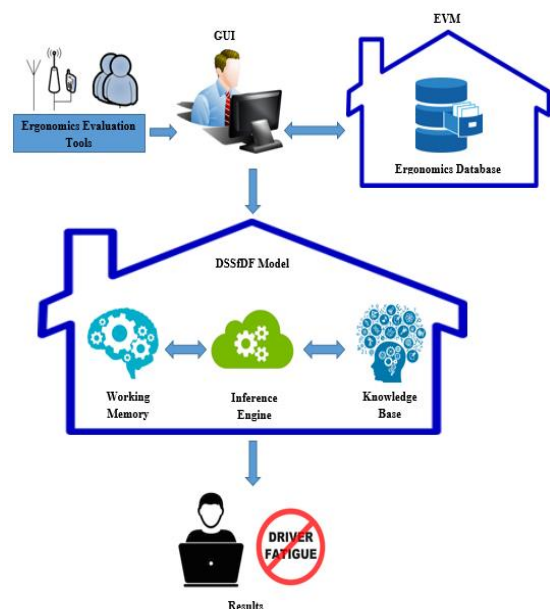


Fig. 1. The EVM and DSSfDF integrate together in DSS.

to worked and integrated together into the DSS to provide systematic analysis of risk factors associated with driving fatigue with minimal data manipulation and time spent.

In DSS, the ergonomic database was created for the EVM, and the working memory, inference engine, and knowledge base for the DSSfDF model. All the risk factors have been identified and divided into three main domain namely as vehicle or machine, human, and environment as shown in Fig. 2. All the information and data captured by EVM then been

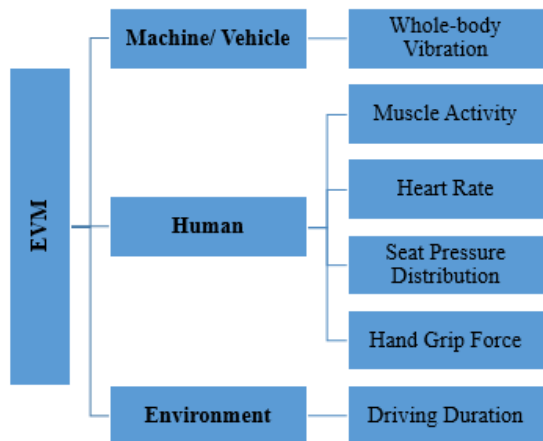


Fig. 2.The structure of EVM.

analysed using by DSSfDF model. The detailed explanation on the ergonomic database, working memory, inference engine, and knowledge base can be find in the other author’s study [34].

The graphical user interface (GUI) was developed and used as a medium for users to communicate with the system. The users entered the data and information such as user and vehicle profile, and risk factors data through the GUI into the



Fig. 3.The graphical user interface (GUI) for DSS

system as shown in Fig. 3. The ergonomics database in EVM stored the data and information before been retrieved by the inference engine and sent to the working memory in DSSfDF model.

The inference engine will check and matches the data in the

working memory with the available rule sets [34] in the knowledge base to generate results and draw a new conclusion and solution. The results and conclusion obtained will saved in the working memory of DSSfDF model or can be directly displayed through the GUI.

IV. CONCLUSION

The Driving Fatigue Strain Index is one of the risk assessment methodology based on multiplicative interaction among six risk factors to quantify the risk levels associated with driving activity. All risk factors have been reported as potential or generic risk factors for driving fatigue problem among Malaysian’s drivers. The risk factors are chosen by considering psychophysical, biomechanical, and ergonomic factors and principles. In order to test the effectiveness, the DFSI is tested and to be demonstrated using the previous study data set. The proposed relationship between the risk ratings criteria and the multipliers are subject to criticism. To a significant extent, the proposed ratings criteria and multipliers are based on the author’s professional judgments. However, the DFSI is at an early stage of development. Therefore, there are still have a room of improvements for this development. Besides, the detailed explanation about the DSS are not discussed in depth in this study as it is a part of the author’s full research. The readers can find the detailed discussion on DSS in [34]. In future, the author wants to developed and determine the multipliers using the fuzzy membership function in order to get the accurate and flexible value of multipliers. Furthermore, the proposed recommendation should be validated to determine their effectiveness.

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