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 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 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.

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

Year	Total Number of Accidents	Casualities			
		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

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

This papers explained about Driving Fatigue Strain Index (DFSI) and Decision Support System (DSS) for driving fatigue. This work was supported in part by Tokushima University and Universiti Teknikal Malysia Melaka under the TMAC ER Unit 2017 (TMAC Edcuation and Research Unit) and Research Acculturation Grant Scheme (RAGS) (Research Acculturation Grant Scheme RAGS/1/2015/SG0/FKP/03/ B00107. This paper is submitted on 13th March 2018. Accepted on 21st May 2018.

Mohammad Firdaus Ani is with Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, 76100 Durian Tunggal, Melaka, Malaysia (e-mail: mohammad.firdaus.ani@gmail.com).

Seri Rahayu Kamat is with Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, 76100 Durian Tunggal, Melaka, Malaysia (e-mail: seri@utem.edu.my).

Minoru Fukumi is with Department of Information Science and Intelligent Systems, Tokushima University, 2-1 Minamijosanjima-cho, 770-8506 Japan (email: fukumi@is.tokushima-u.ac.jp).

Mohamad Minhat is with Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, 76100 Durian Tunggal, Melaka, Malaysia (e-mail: mohdm@utem.edu.my).

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 Acquistion

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 DSFI 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.

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

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

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)		

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

	Multiplier						
Risk of Driving	**MA**	**HR**	**HGF**	**WBV**	**SPD**	**DD**	**DFSI**
Safe	1	1	1	1	1	1	1
	1	1	1	2	1	1	2
Slightly						1	3[a]
Unsafe	3	3	3	3	1	1	80
Unsafe					1	1	81[b]
	81	81			81	81	>81

[a]If any factor is 3.
[b]If 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 performed [10]-[16]. Table VI presents the example data set available from the previous studies.

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

Risk Factors	Results
Muscle Activity (MA)	129.500 µV
Heart Rate (HR)	82.000 bpm
Hand Grip Force (HGF)	277.910 N
Whole-body Vibration (WBV)	2.607 m/s2
Seat Pressure Distribution (SPD)	13.875 kPa
Driving Duration (DD)	30.00 min

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

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					

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

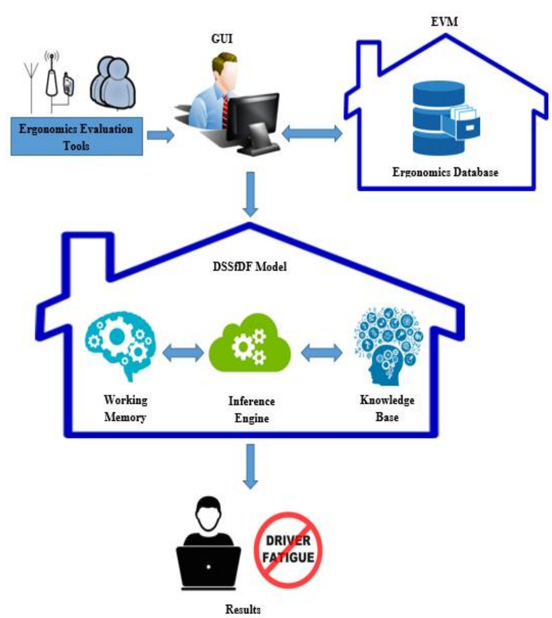

Fig. 1.The EVM and DSSfDF integrate together in DSS.

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

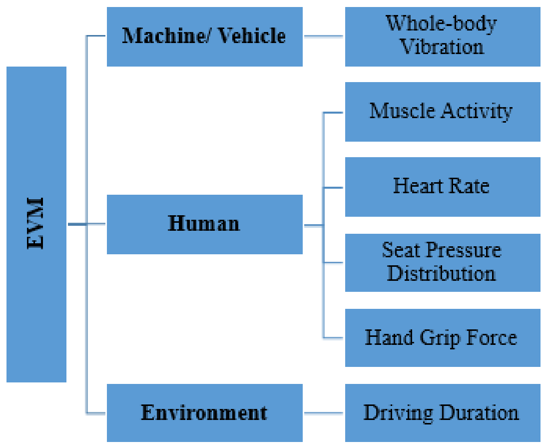

Fig. 2.The structure of EVM.

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

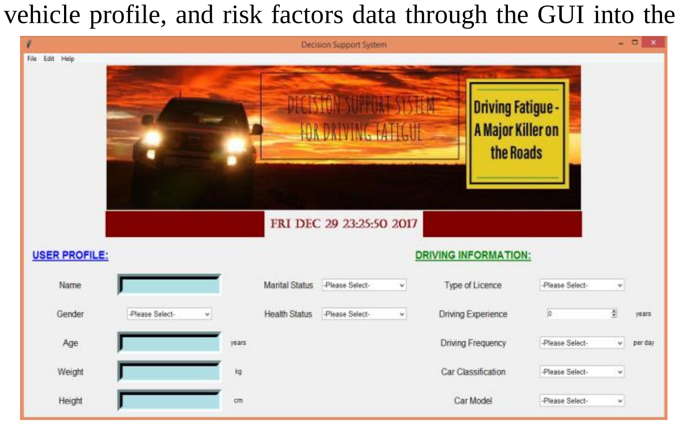

Fig. 3.The graphical user interface (GUI) for DSS

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.

ACKNOWLEDGMENT

The authors would like to acknowledge the Ministry of Higher Education (MOHE) for funding this research under Research Acculturation Grant Scheme (RAGS) (Research Acculturation Grant Scheme RAGS/1/2015/SG0/FKP/03/ B00107, Centre for Research and Innovation Management (CRIM) and TMAC ER Unit 2017 (TMAC Education and Research Unit) for providing facilities, laboratories, respondents and assistance throughout this study.

REFERENCES

[1] C.D. Meletis and J.E. Barker, "Herbs and nutrients for the mind: A guide to natural brain enhancers," Greenwood Publishing Group, 2004, pp.117-122.

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

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

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

[5] Department of Statistics. (2017, September). Department of Statistics Malaysia: the official website of Malaysia statistics agency – Statistics of Malaysia. Social Statistic Bulletin, Malaysia. [Online]. Available:http://www.statistics.gov.my

[6] S. Rohayu, S.M. Sharifah Allyana, M.M. Jamilah, and S.V. Wong, "Predicting Malaysian road fatalities for year 2020," *Transportation Research Board*, 2012.
[7] Road Facts. (2015, November). Statistic Accident, Malaysian Institute of Road Safety Research, Malaysia. [Online]. Available: http://www.miros.gov.my/1/page.php?id=17&k=StatisticAccident.
[8] J. Steven Moore, and A. Garg, "The strain index: a proposed method to analyze jobs for risk of distal upper extremity disorders." *American Industrial Hygiene Association Journal* 56(5), 1995, pp. 443-458.
[9] I. Halim, and A. Rahman Omar, "Development of prolonged standing strain index to quantify risk levels of standing jobs." *International Journal of Occupational Safety and Ergonomics* 18(1), 2012, pp. 85-96.
[10] S. Rahayu, M. Firdaus, and K. Husain, "A Comparison Study between Right Hand and Left Hand Grip Pressure Force While Driving." *Australian Journal of Basic and Applied Science*, 9(19), 2015, pp.50-58.
[11] S. Rahayu, M. Firdaus, and M. Fa'iz. "A comparison study for the road condition with hand grip force and muscle fatigue." *Malaysia Journal of Public Health Medicine Special vol. 1*, 2016, pp. 7-13.
[12] S. Rahayu, and M. Firdaus, "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, 2015.
[13] M. Firdaus, and S. Rahayu. "A mathematical modeling of psychophysical factor for driver fatigue." *Journal of Current Research in Science.*, in press.
[14] M. Firdaus, S. Rahayu, M. Minhat, M. Fukumi, and T. Ito, "A study of biomechanical factor for driver fatigue using regression model." *Safety, Health, and Environment* 38(9).
[15] M.F. Ani, S.R.B. Kamat, and K. Husin, "A Study of Psychophysical Factor for Driver Fatigue Using Mathematical Model." *Journal of Mechanical Engineering,* Vol SI 3 (2), 2017, pp. 109-122.
[16] M. Firdaus, S. Rahayu, M. Fukumi,.M. Minhat and T. Ito, "Effect of Vibration towards Driving Fatigue and Development of Regression Model Based on Vibration." *Risk* 1000, 2017.
[17] I. Halim, H. Arep, S.R. Kamat, R. Abdullah, A.R. Omar, and A.R. Ismail, "Development of a decision support system for analysis and solutions of prolonged standing in the workplace." *Safety and health at work* 5(2), 2014, pp. 97-105.
[18] J.S. Edwards, "Decision support and expert systems: management support systems," *Journal of the Operational Research Society* 47(5), 1996, pp. 717-718.
[19] A.A. Angehrn, and H.J. Lüthi, "Intelligent decision support systems: a visual interactive approach." *Interfaces* 20(6), 1990, pp. 17-28.
[20] S.H. Liao, "Expert system methodologies and applications—a decade review from 1995 to 2004." *Expert systems with applications* 28(1), 2005, pp. 93-103.
[21] W. Karwowski, A. Gaweda, W.S. Marras, K. Davis, J.M. Zurada, and D. Rodrick, "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), 2006, pp. 847-859.
[22] T.Z. Lee, C.H. Wu, and H.H Wei, "KBSLUA: A knowledge-based system applied in river land use assessment." *Expert Systems with Applications* 34(2), 2008, pp. 889-899.
[23] J. Zak, "Decision support systems in transportation." *Handbook on Decision Making*. Springer, Berlin, Heidelberg, 2010, pp. 249-294.
[24] C.J. De Luca, "The use of surface electromyography in biomechanics." *Journal of Applied Biomechanics* 13(2), 1997, pp. 135-163.
[25] S.H. Rodgers, "A functional job analysis technique." *Occupational Medicine (Philadelphia, Pa.*) 7(4), 1992, pp. 679-711.
[26] National Library of Medicine. (2015, May). Heart Rate. U.S National Library of Medicine, U.S [Online]. Available at: https://www.nlm.nih.gov/news/2011.html
[27] M. Jasiulewicz-Kaczmarek, and P. Drożyner, "The role of maintenance in reducing the negative impact of a business on the environment." Sustainability Appraisal: *Quantitative Methods and Mathematical Techniques for Environmental Performance Evaluation*. Springer, Berlin, Heidelberg, 2013, pp. 141-166.
[28] T.C. Chieh, M.M. Mustafa, A. Hussain, E. Zahedi, and B.Y. Majlis, "Driver fatigue detection using steering grip force." Research and Development, 2003. *SCORED 2003. Proceedings. Student Conference on. IEEE*, 2003.
[29] M. Eksioglu, and K. Kızılaslan, "Steering-wheel grip force characteristics of drivers as a function of gender, speed, and road condition." *International journal of industrial ergonomics* 38(3-4), 2008, pp. 354-361.
[30] M.P. De Looze, L.F. Kuijt-Evers, and J.A.A.P. Van Dieen, "Sitting comfort and discomfort and the relationships with objective measures." *Ergonomics* 46(10), 2003, pp. 985-997.
[31] International Organization for Standardization. Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 1: General requirements. The Organization, 1997.
[32] N. Mansfield, G. Sammonds, and L. Nguyen, "Driver discomfort in vehicle seats–Effect of changing road conditions and seat foam composition." *Applied ergonomics* 50, 2015, pp. 153-159.
[33] B.V. Koen, "Professional Judgement in Engineering." Perspectives on the Professions 11(2), 1992.
[34] M.F. Ani, M. Fukumi, S.R. Kamat, M. Ito, M. Minhat, and N.S. Rayme, "Development of Ergonomic Vehicle Model and Decision Support System for Driving Fatigue," *Lecture Note in Mechanical Engineering. Springer.* Paper ID:3

Mohammad Firdaus Ani is a first-year Ph.D student at Tokushima University, Japan. He received a bachelor's degree in manufacturing management engineering from Universiti Teknikal Malaysia Melaka (UTeM) and a master's degree in manufacturing engineering from Universiti Teknikal Malaysia Melaka (UTeM), Malaysia. He currently doing Ph.D degree in information science and intelligent system. He interested in research field of manufacturing, system intelligent, fuzzy logic, and ergonomics. More details about him can be find at ResearchGate:researchgate.net/profile/Mohammad_Firdaus_Ani.

Seri Rahayu Kamat received the Ph.D in Mechanical Engineering in 2010 from Sheffield Hallam University, Sheffield, United Kingdom. She specializes in Industrial Ergonomic, Biomechanics, Work System Design and Industrial Engineering. Dr Seri was attached as lecture at Department in Mechanical Engineering in Polytechnic Port Dickson in 1995 until 2001. She has experienced teaching on Industrial Engineering, Economy Engineering, Quality Control, Manufacturing Process and System Engineering. After finish her master on 2003 at Universiti Teknologi Malaysia, she attached as a lecture in University Technical Malaysia Malacca (UTeM) at Faculty of Manufacturing Engineering from 2003 until 2007. She is currently in UTeM as a Senior Lecture. She has authored 70 articles and conference paper in Malaysia and other countries. She has received gold medal award in Ergonomic Design Competition Malaysia 2016, gold medal award in UTeM Expo 2015 (UTeMEX 2015), bronze medal award in Malaysian Technology Expo 2012 in PWTC Kuala Lumpur, Malaysia and gold medal award in UTeMEX 2012 in UTeM, Malacca. She led project MOA with industrial project grant (worth700,000) at Composites Technology Research Malaysia, CTRM and AMIC and PROTON Holdings Berhad. She is a member of the Institution of Engineers Malaysia (IEM) and Board of Engineers Malaysia (BEM).

Minoru Fukumi received the B.E. and M.E. degrees from the University of Tokushima, in 1984 and 1987, respectively, and the doctor degree from Kyoto University in 1996. Since 1987, he has been with the Department of Information Science and Intelligent Systems, University of Tokushima. In 2005, he became a Professor in the same department. He received the best paper awards from the SICE in 1995 and Research Institute of Signal Processing in 2011 in Japan, and best paper awards from some international conferences. His research interests include neural networks, evolutionary algorithms, image processing and human sensing. He is a member of the IEEE, RISP, JSAI and IEICE.

Mohamad Minhat received a Ph.D in Mechanical Engineering at University of Auckland (UoA), NZ in 2010 and Master of Science in Engineering and Manufacturing Management from Coventry University of England, UK in 2003 as well as Bachelor (Hons) in Mechanical and Manufacturing Engineering from the University of Wales, College of Cardiff, UWCC, Wales, UK in 1994. He is attached as a Teaching Engineer & Lecturer of Universiti Teknikal Malaysia Melaka (UTeM) since 2001. He has both experiences in the academic field as well as in the industries. He was with Aero-Composites Technologies (CTRM) Malaysia in 2000 before starting his career in UTeM and worked as the Facilities Engineer with Samsung Display International (SDI) Malaysia from 1995 to 2000. He was a Malaysian Government scholar fully sponsored by the Ministry of Higher Education (MoHE) to pursue his first degree up to post-graduate studies.