Paper

Development of Driving Fatigue Strain Index Using Fuzzy Logic to Analyze Risk Levels of Driving Activity

Mohammad Firdaus Ani*[a] Non-member, Minoru Fukumi* Fellow, Seri RahayuKamat * Non-member, Mohamad Minhat** Non-member Kalthom Husain*** Non-member,

(Manuscript received Jan. 00, 20XX, revised May 00, 20XX)

The objective of this study is to develop a Driving Fatigue Strain Index using fuzzy logic to analyze the risk levels of driving activity among road users. Driving fatigue is always related to the driving activity and has been identified as one of the vital contributors to the road accidents and fatalities in Malaysia. Therefore, the present paper introduces the use of fuzzy logic for the development of strain index to provide the systematic analysis and propose an appropriate solution in minimizing the number of road accidents and fatalities. The development of 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 conditions. IF-THEN rules were used to define the input and output variables which correspond to physical measures. This index is a reliable advisory tool for providing analysis and solutions to driving fatigue problem, which constitutes the first effort toward the minimization of road accidents and fatalities.

Keywords : fatigue, strain index, fuzzy logic, risk levels, membership function.

1. Introduction

The ninth and tenth Malaysia Plan[1, 2] indicated that Malaysia aspires to be a developed country by 2020 and as the developed country, Malaysia had improvised the transportation, road, and highway systems. This improvisation had encouraged the infrastructures, facilities, and comfort-ability among the road users. Indirectly, the driving activity becomes important as this medium is being practical, cheaper, and faster in connecting human from one to another place. Driving is the controlled operation and movement of motorized vehicles with wheels such as a car by a human[3]. Driving is the complex activity, where the interaction between the driver, the vehicle, and the environment are continuous and numerous.

However, in some occurrences driving activity can give the negative effect to human. Driving activity can cause accidents and fatalities to a human in daily life as they get fatigued while driving. Driving fatigue is a feeling of drowsiness due to longer driving period, monotonous road condition, adverse climatologically environment or individual characteristics is direct or contributing factor in road accidents[4]. Previous study by[4], stated that the 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 environmental condition and the length of driving period as proved by the previous study[5]-[7].

Many countries around the world including Malaysia are facing a major problem with road accidents and fatalities. In fact, 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[8]. 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[8, 9]. The WHO’s data in Fig. 1

a) Correspondence to: Mohammad Firdaus Ani. E-mail: c501747001@tokushima-u.ac.jp

* Department of Information Science and Intelligent Systems, Tokushima University, 2-1 Minamijosanjima-cho 770-8506, Japan

** Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, 76100 Durian Tunggal, Melaka, Malaysia

*** Department of Methodology, International Islamic University College Selangor, Bandar Seri Putra, 43000 Kajang, Selangor, Malaysia

and Fig. 2 prove that Malaysia has a significant traffic and driving problem based on the high fatality rate.

Based on provisional data by the Royal Malaysian Police (RMP), Department of Statistic Malaysia, Malaysia Institute of Road Safety Research (MIROS), and Ministry of Transport, there were 7,152 road fatalities and 521,466 road accidents have been reported in 2016[(10)-(13)]. Besides, the research by[(14)] has made a prediction on fatalities in Malaysia and reported that there will be 10,716 fatalities during 2020. The in-depth crash investigation on some cases carried out by MIROS has found that driving fatigue is one of the top contributors to the road accidents in Malaysia from 2007 until 2013[(15)].

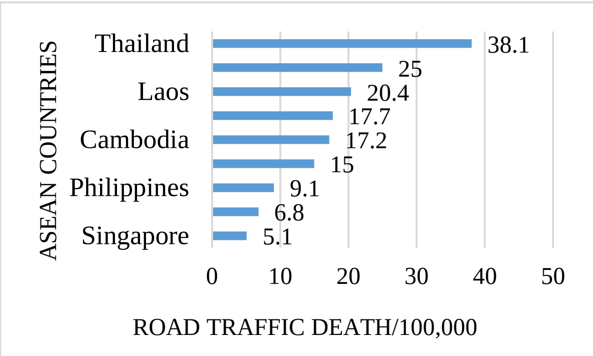

Fig.1. Road fatality rate of Malaysia versus ASEAN[(8)]

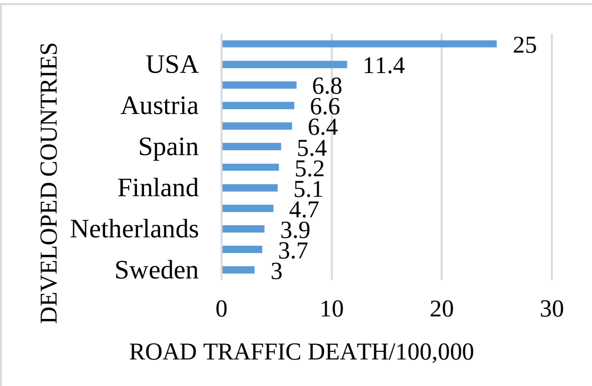

Fig.2. Road fatality rate of Malaysia versus developed countries[(8)]

Hence, this study is to counter these problems and issues by developing the Driving Fatigue Strain Index (DFSI) to quantify the risk level, analyze, and propose a solution to reduce the number of road accidents associated with driving fatigue. This index will give a warning or reminder, and alert to the road users about the risk level and condition of the driving whether is safe or unsafe conditions level. The strain index is a semi-quantitative analysis that results on the numerical score (SI score) that is believed to correlate with the risk levels of driving fatigue. This study is the extensionand improvement from the author's previous study entitled "Development of Driving Fatigue Strain Index to Analyze Risk Levels of Driving Activity"[(16)]. In the previous study by the authors, the strain index was developed using the multiplicative interaction among the risk factors by representing the product of all multipliers that correspond to all risk factors[(16)]. However, the proposed relationship between the risk rating criteria and the multipliers are the subject to criticism as the ratings and multipliers are based on the author's professional judgment. In previous study, the positive criteria such as non-fatigue, little fatigue, very fit, comfort, moderate, and fairly has been assigned with the multipliers from the value of 1 to 3, while the negative criteria such as fatigue, very fatigue, discomfort, and unfit has been assigned with the value of 81. These values are based on the simple calculation and professional judgement. The multiplier's value is used to get the DFSI values and the level of driving conditions. However, the main problem is the value of multipliers are not flexible as the values give the big different between the criteria. For example, the rating criteria of muscle activity is moderate fatigue with risk level between 130.00 μV to 300.00 μV, is assigned with multiplier of 3. Meanwhile, if the rating criteria is fatigue with risk level between 301.00 μV to 600.00 μV is assigned with multiplier of 81.Hence, this study improves the DFSI by developing the strain index using fuzzy logic. Fuzzy logic is based on the concept of partial membership function in a set described by the membership function (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 in order to model non-linear input-output relations as fuzzy provides a constructive way of turning qualities into mathematics[(17)-(18)]. Besides, the fuzzy logic for pattern recognition and approximate information processing and artificial neural networks (ANN) have been used in a variety of areas, including process control, engineering management, business, medical diagnosis, bio-mechanics, human factors and cognitive simulations[(19)-(25)]. 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[(17)-(38)]. This paper has presented the development of the driving fatigue strain index (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 in order to reduce the number of road accidents and fatalities in Malaysia.

2. Methodology

This paper focused on the development of driving fatigue strain index (DFSI), which consist several steps that need to be passed through as the foundation for this development. Some of the steps are similar to the previous study by the authors[(16)]. This section will give a brief explanation of the development of DFSI.

2.1 Acquisition of Knowledge The first step in developing the DFSI was the acquisition of knowledge. The knowledge, which acts as the brain to process the input data and information received by the system, can be acquired by extracting, structuring, and organizing knowledge from one or more sources[(16), (39), (40)]. In this study, the knowledge is acquired and achieved by conducting the pre-survey, performing the real road test, reviewing the previous journals and articles, referring the guidelines and international standards from authorized organizations and bodies, and getting an expert opinion from ergonomist and engineer. The data and information about the risk factors; muscle activity (MA), heart rate (HR), hand grip pressure force (HGF), whole-body vibration (WBV), seat pressure distribution (SPD), and driving duration (DD) that significantly contributed to the driving fatigue are examined and obtained by conducting and performing the pre-survey and the real road test experiment. This survey and real road test experiment are participated by Malaysia's road users, using the national car and Malaysia's road system, and driving through Malaysia's road environment.

Besides, the authors gathered the knowledge by reviewing the previous research, articles or journals, and online database. There are seven main journals[(41)-(47)] have been reviewed and referred as the guidelines for the development of DFSI. Instead of that, the authors has referred the authorized organization, and society or bodies such as International Standard Organization (ISO), Royal Malaysia Police (RMP), *Perusahaan OtomobilNasional*(PROTON), and Malaysian Institute of Road Safety Research (MIROS) to obtained information and data regarding the standard, laws and regulations, and the statistics data on the number of road accidents and fatalities in Malaysia. In addition, the expert opinion such as ergonomics practitioners, road safety practitioners, and academician gives a huge contribution to this study.

2.2 Integration of Knowledge 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 has been assigned to the human-machine-environment domain as shown in Fig. 3.

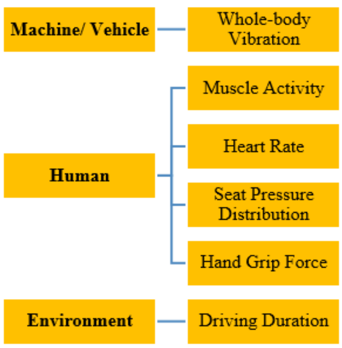

Fig.3. Human-machine-environment domain

The risk factors are selected based on the real road test experiment and a previous study that has proven all these factors give a significant effect on fatigue while driving[(41)-(47)]. Besides, some of the previous studies has been used as the guideline to quantify the risk levels of each risk factors as reflected in Table 1.

Table 1. List of the previous study used as guidelines.

Risk Factors	Previous Studies
Muscle Activity (MA)	(48), (49)
Heart Rate (HR)	(50), (51)
Hand Grip Force (HGF)	(52), (53)
Seat Pressure Distribution (SPD)	(54)
Whole-Body Vibration (WBV)	(55)
Driving Duration (DD)	(56)

2.3 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 a FIS such as input and output, and FIS type as shown in Fig. 4. 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 variable of this study. This study using the Mamdani-type as the inference method, which is based on a simple structure of max and min operations. For data defuzzification, this study uses centroid average (CA) method. This is because the approaches provide a better solution than other methods[(36)]. Defuzzification is the process of producing a quantifiable result in fuzzy logic.

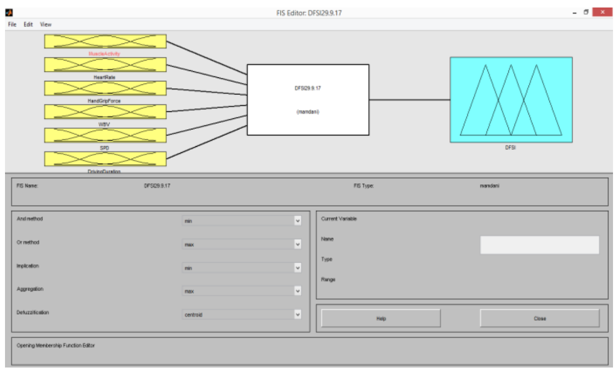

Fig. 4. FIS editor.

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 Fig. 5 and Fig. 6. 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'.

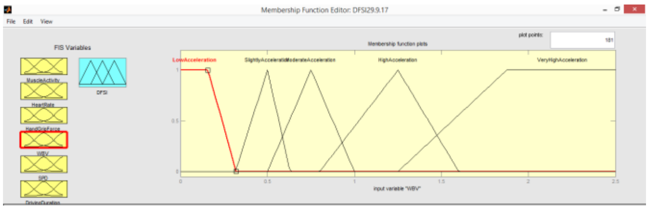

Fig. 5. MF editor displaying the example of linguistic variable 'WBV' in term of fuzzy sets.

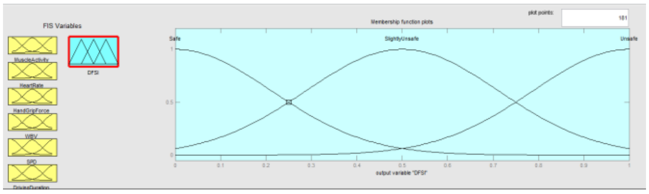

Fig. 6. MF editor displaying the example of linguistic variable 'DFSI' as the output variable.

The input value of each fuzzy sets is based on the risk criteria and risk levels of the risk factor as discussed in the previous study by the authors[16]. For example, the input WBV of x = <0.315 m/s2 belongs to partially to the fuzzy set 'low acceleration' as shown in Table 2.

Table 2. Rating criteria and risk levels [16].

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

The input value of fuzzy sets is real numbers. The authors use the typical and simplest membership function that is triangular, trapezoidal and Gaussian membership function. Simple membership function allow the author to graphically represent a fuzzy set. Besides, using the 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 Fig.7. 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 Fig. 8

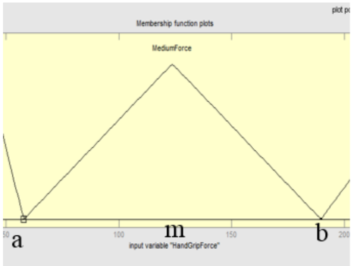

Fig. 7. Triangular function.

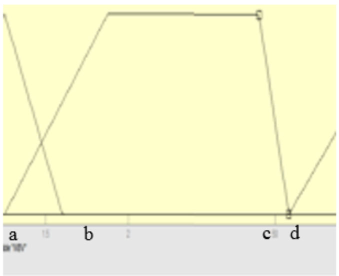

Fig. 8. Trapezoidal function.

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 Fig. 9.

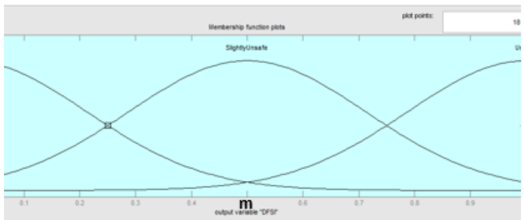

Fig. 9. Gaussian function.

In the FIS, the inferences rules are required for fuzzy reasoning. The IF-RULE statement format is used to express the inference rule. As mentioned earlier, the Mamdani-type, which is based on a simple structure of max and min operation was used as the inference method. The rule editor GUI was used to edit the list of inference rules that define the behavior of the system as shown in Fig. 10.

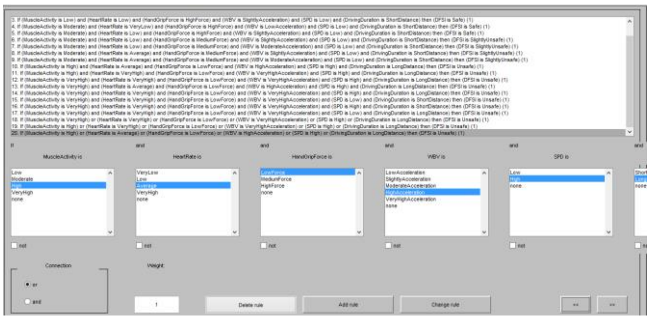

Fig. 10. The rule editor for constructing and editing the rule statement.

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 is 20 rules statement in this study was constructed by the authors as shown in Fig. 10.

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 Fig. 11. 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 show 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 defuzzificated value represents a measure of the degree of DFSI derived from the combination of the input values.

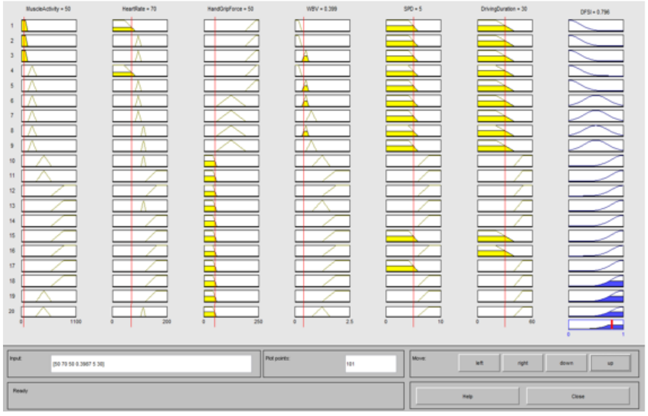

Fig. 11. The example of the road map for the whole fuzzy inference display on rule viewer.

3. Results and Discussion

The DFSI methodology is tested and demonstrated by the authors using a data set available from the previously performed[41]-[47]. Table 3 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 3. The example of data sets [41]-[47].

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 variables are entered into the rule viewer to get the defuzzification value represents a measure of the degree of DFSI. Fig. 12(a), Fig. 12(b), and Fig. 12(c) shows the rule viewer, which reflected the results of the analysis.

A zoomed version of the rule viewer for the fuzzy inference process based on the Mamdani-type is shown in Fig. 13(a), Fig. 13(b), and Fig. 13(c). As the input value in entered into the system, the rule viewer will show the value of DFSI that are 0.242, 0.5, and 0.796.

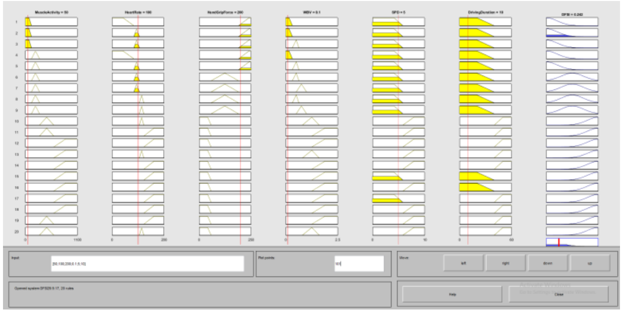

Fig. 12(a). The value of linguistic variables (Set 1) are entered into the rule viewer

Fig. 12(b). The value of linguistic variables (Set 2) are entered into the rule viewer

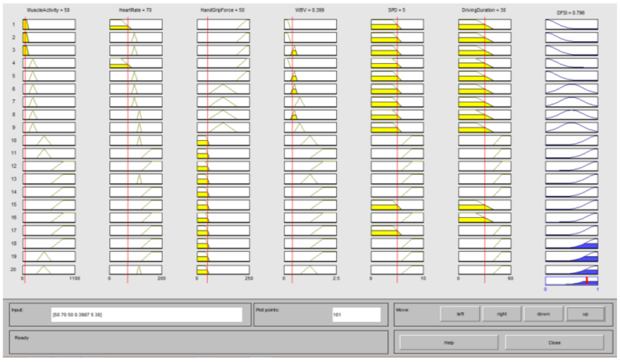

Fig. 12(c). The value of linguistic variables (Set 3) are entered into the rule viewer

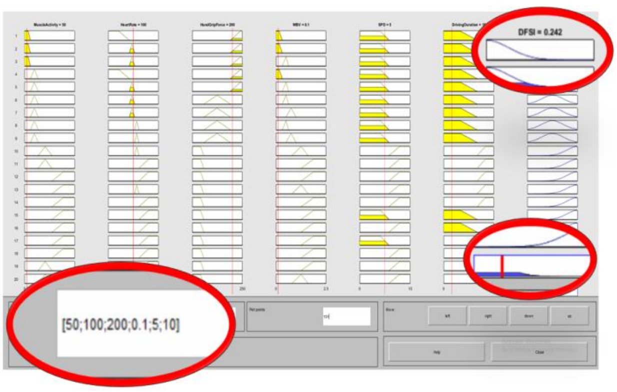

Fig. 13(a). The zoomed version of the rule viewer of FIS for set 1

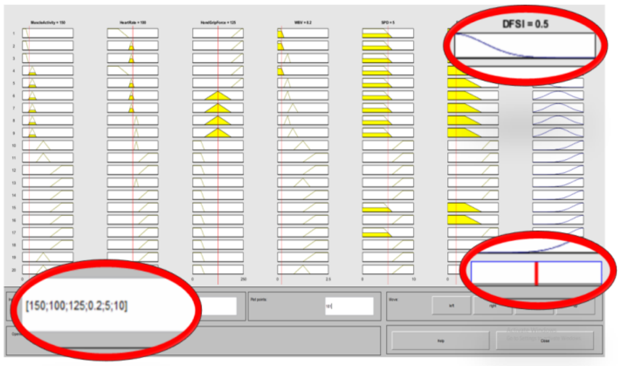

Fig. 13(b). The zoomed version of the rule viewer of FIS for set 2

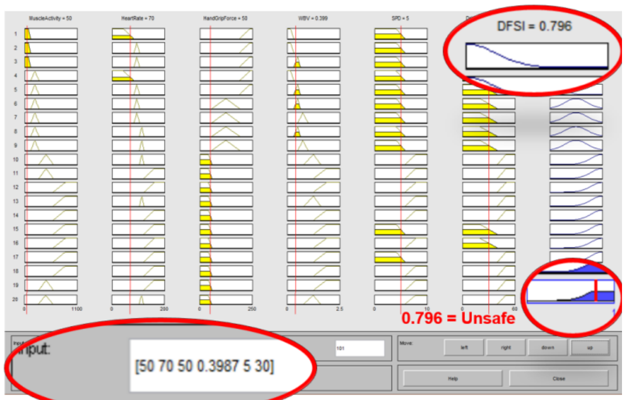

Fig. 13(c). The zoomed version of the rule viewer of FIS for set 3

The final DFSI's output is obtained by combining the color regions fuzzy sets, and the defuzzificated value that are 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. Fig. 14(a), Fig. 14(b), and Fig. 14(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 summarizes the results from the demonstration.

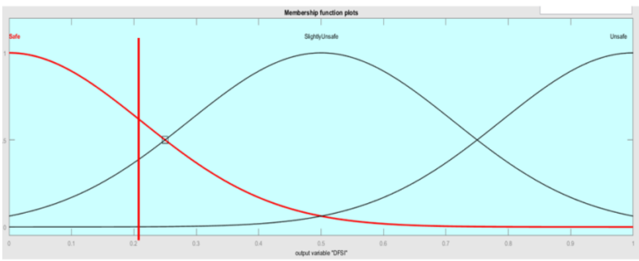

Fig. 14(a). Membership function plots for the DFSI of set 1.

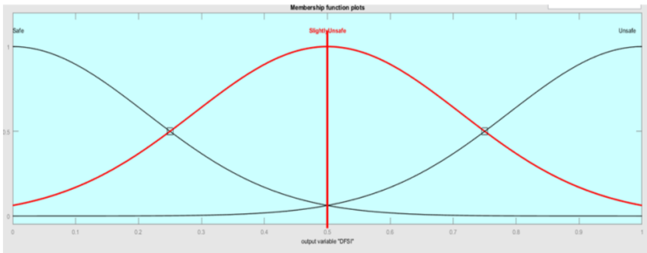

Fig. 14(b). Membership function plots for the DFSI of set 2.

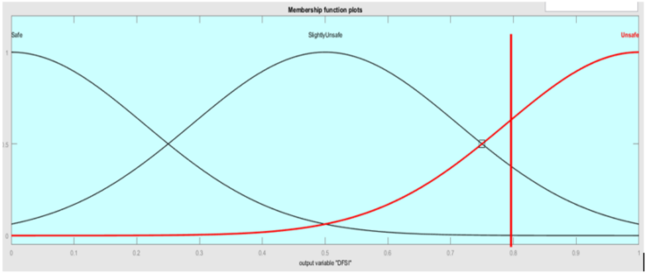

Fig. 14(c). Membership function plots for the DFSI of set 3.

Table 4. Result summarization

Set	DFSI	Driving Condition
1	0.242	The driving conditions are considered safe and the 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 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. Conclusion

The present paper 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.

Conflict of Interest

There is no conflict of interest.

Acknowledgement

The authors would like to acknowledge the Universiti Teknikal Malaysia Melaka (UTeM) and Tokushima University for technical, educational, and financial support through the Tokushima U-UTeM Academic Center (TMAC) and Human Sensing Laboratory.

References

(1) The Economic Planning Unit :"Ninth Malaysia Plan (2006-2010)", Prime Minister's Department,(2006).

(2) The Economic Planning Unit :"Tenth Malaysia Plan (2011-2015)", Prime Minister's Department,(2010).

(3) Dictionary.com : "Driving", Collins English Dictionary-Complete & Unabridged 10th Edition, Harper Collins Publishers. Available at: http://www.dictionary.com/. (Accessed: October 3, 2017).

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

(5) 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), pp.715-724 (2005).

(6) C. Papdelis, Z. Chen and C. Kourtidou-Papedeli : "Monitoring sleepiness with on-board electrophysiological recordings for preventing sleep-deprived traffic accidents", Clinical Neurophysiology, 118(9), pp.1906-1922 (2007).

(7) 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), pp. 167 (2010).

(8) World Health Organization : "Global status report on road safety 2013", Geneva, Switzerland (2013).

(9) A. Abdelfatah : "Traffic fatality causes and trends in Malaysia", Massachusetts Institute of Technology (2016).

(10) OECD/ITF : "Malaysia in road safety annual report 2015", OECD Publishing, Paris. (Online), Available at : <http://dx.doi.org/10.1787/irtad-2015-29-en> (Accessed: June 15, 2015).

(11) Department of Statistic Malaysia : "Social statistic bulletin, malaysia 2016", (Online), Available at: <https://www.dosm.gov.my/v1/index.php> (Accessed: December 15, 2016).

(12) Malaysia Institute of Road Safety Research : "General road accident statistic in Malaysia 2016", (Online), Available at: <https://www.miros.gov.my/1/page.php?id=364> (Accessed: September 29, 2017).

(13) Ministry of Transport : "Transport statistic Malaysia 2016", Ministry of Transport Malaysia, (2016).

(14) S. Rohayu, S. M. SharifahAllyana, M. M. Jamilah, and S. V. Wong : "Predicting Malaysian road fatalities for year 2020", Proc 14th International Conference on Road Safety and Simulation, (2012).

(15) Road Facts : "Statistic accident", Available at: http://www.miros.gov.my/1/ (Accessed: November 14, 2015).

(16) M. F Ani, S. R. Kamat, M. Fukumi, M. Minhat, W. H. W. Mahmood :

"Development of Driving Fatigue Strain Index to Analyze Risk Levels of Driving Activity", International Journal of Electrical and Electronic Systems Research, Vol. 12. (2018).

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

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

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

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

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

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

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

(24) W. Karwowski, J. Grobelny, Y. Yang and W. G. Lee "Applications of fuzzy systems in human factors", Handbook of fuzzy sets and possibility theory, pp.589-620 (1999).

(25) 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), pp.847-859 (2006).

(26) R. C. Berkan and S. L. Trubatch : "Fuzzy Systems Design Principles: Building Fuzzy IF-THEN Rule Bases", The Institute of Electrical and Electronics Engineers. Inc., New York, pp. 496 (1997).

(27) J. S. R. Jang, C. T. Sun, and E. Mizutani : "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 (1997).

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

(29) G Klir and B. Yuan : "Fuzzy sets and fuzzy logic", New Jersey: Prentice hall, Vol. 4 (1995).

(30) F. A Lootsma : "Fuzzy logic for planning and decision making", Springer Science & Business Media, Vol. 4 (2013).

(31) K. Tanaka : "An introduction to fuzzy logic for practical applications", Springer (1997).

(32) J. Yen and R. Langari, : "Fuzzy logic: intelligence, control, and information", Prentice-Hall, Inc. (1998).

(33) H. J. Zimmermann : "Fuzzy set theory—and its applications", Springer Science & Business Media (2011).

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

(35) D. Tadic, I. Savovic, M. Misita, S. Arsovski and D. D. Milanovic : "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 (2003).

(36) A. Azadeh, I. M. Fam, M. Khoshnoud and M. Nikafrouz : "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 (2008).

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

(38) S. M. Baas and H. Kwakernaak : "Rating and ranking of multiple-aspect alternatives using fuzzy sets", Automatica, 13(1), pp.47-58 (1977).

(39) 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), 97-105 (2014).

(40) E. Turban : "Decision support and expert systems: management support systems. Prentice Hall PTR (1990).

(41) S. R. Kamat, 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) Special (2015): pp. 50-58 (2015).

(42) 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, pp.7-13 (2016).

(43) 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).

(44) 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 (2017).

(45) M. F. Ani, S. R. Kamat, R. H. Hambali and W. H. W. Mahmood : "A Study of Psychophysical Factor (Heart Rate) For Driver Fatigue Using Regression Model.", Safety, Health and Environment, 38, 9 (2017).

(46) 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, s2 (2017).

(47) M.F. Ani : "Developing Regression Models of Driver Fatigue Using An Ergonomics Approach", Master's Thesis, Universiti Teknikal Malaysia Melaka. (2016).

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

(49) S. H. Rodgers : "A functional job analysis technique", Occupational medicine (Philadelphia, Pa.), 7(4), pp. 679-711 (1992).

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

(51) M. Jasiulewicz-Kaczmarek and P. Drozyner : "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, pp.141-166 (2013).

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

(53) M. Eksioglu and K. Kizilaslan : "Steering-wheel grip force characteristics of drivers as a function of gender, speed, and road condition.", International journal of industrial ergonomics 38.3, pp. 354-361 (2008).

(54) M. P. De Looze, L. F. M. Kuijt-Evers and J. Van Dieen : "Sitting comfort and discomfort and the relationships with objective measures.", Ergonomics 46, no. 10, pp.985-997 (2003).

(55) International Organization for Standardization (ISO). "Mechanical vibration and shock-evaluation of human exposure to whole-body vibration-part 1: general requirements." Standard No. ISO 2631-1:1997. Geneva: ISO, (1997).

(56) N. Mansfield, G. Sammonds and L. Nguyen : "Driver discomfort in vehicle seats–Effect of changing road conditions and seat foam composition.",

Applied ergonomics, 50, pp.153-159 (2015).

Mohammad Firdaus (Non-member) 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

Minoru Fukumi (Fellow) 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.

Seri RahayuKamat (Non-member) She completed her 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).

Mohamad Minhat (Non-member) He 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.

Kalthom Husain (Non-member)Kalthom Husain, Ph.D is an Associate Professor at Department of Methodology at International Islamic University College Selangor, Malaysia. Involved and engaged in multi-displinary research like Engineering and Social Science, ICT and Social Science. Passionate in research encompassing TESL Education and New Media Communication. Earned her Ph.D from University of Brighton, United Kingdom. Vast experience as an academics in higher Institutions in Malaysia. Actively conduct joint-research across universities in Malaysia and Australia (Charles Stuart University, Sydney, Australia