REGRESSION ANALYSIS OF OXYGEN SATURATION LEVEL FOR CRITICAL DRIVING FATIGUE FACTORS USING BOX-BEHNKEN DESIGN

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ABSTRACT: Driving fatigue research is becoming more popular as the number of fatigue-related road incidents rises. However, there are limited studies examining the role of physiological factors and the significant variables influencing them to determine driving fatigue. Hence, the purpose of this study was to perform a regression analysis to evaluate whether variables such as driving duration, driving speed, body mass index (BMI), gender and types of roads are relevant in influencing oxygen saturation levels and how these variables interact to suggest driving fatigue. A regression analysis was carried out utilizing the Box-Behnken design. The results showed that the values of Prob > F for all variables were less than 0.01%, showing that all variables significantly impacted the oxygen saturation levels. The oxygen saturation levels declined as driving duration, speed, and BMI rose. The same pattern emerged between female and male drivers. Furthermore, the oxygen saturation levels were lower on straight roads than on rather difficult uphill/downhill roads. The regression model was evaluated to determine its accuracy by comparing output data from software prediction and actual driving experiments. First, the output data prediction interval obtained by both approaches was within a 95% confidence interval, satisfying the minimum quantitative limitation of a 90% predictive interval. Residual errors were also less than 10%. The findings may be helpful to researchers and decision-makers involved in the field of road safety in an effort to lower the number of traffic accidents brought on by driver fatigue.

KEYWORDS: *Oxygen Saturation Level; Driving Fatigue; Box-Behnken design; Regression Analysis*

1.0 INTRODUCTION

Malaysia is currently one of Southeast Asia's most urbanised countries, with one of the fastest rates of urbanisation [1]. In 2020, 77% of the country's population had already moved to towns and cities, a 70% increase from 2010 and predicted to exceed 80% by 2030 [2]. As a result of urban sprawl and an increase in urban population demand, the transport sector has also experienced rapid growth. Unfortunately, the increasing growth of urban transportation has resulted in significant economic losses in road safety as Malaysian road accidents climbed significantly from 414,421 in 2010 to 567,516 in 2019 [3].

Driving fatigue is one of the major causes of automobile accidents [4]. Fatigue is a feeling of exhaustion caused by mental and physical activities, which reduces reaction time and other critical cognitive qualities required for driving, such as concentration and decision-making. To prevent fatigue-related road crashes, the indicators and factors influencing driving fatigue must be identified.

A survey of the existing literature found that only a few attempts have been undertaken to examine the influence of human physiological systems such as oxygen saturation levels in influencing driving fatigue [5]. The oxygen content of the Earth's atmosphere is 21% with a normal oxygen saturation level is 95% or greater [6]. Driving fatigue will occur when the oxygen intake is below 95% when driving due to the invigoration of the physiological activities where the supply of oxygen is insufficient in comparison to the quantity needed. The level of oxygen saturation levels will drop at the onset of fatigue and impair crucial brain functions such as decision-making [7]. As a result, it is fair to consider oxygen saturation level a reliable indicator for driving fatigue.

Regression analysis has recently been widely used in a range of industries to solve road safety issues because of its simplicity and accessibility. To the best of our knowledge, there has been no research that uses regression analysis to investigate the use of physiological factors like oxygen saturation level as a metric for diagnosing driving fatigue. Therefore, the objective of this study was to perform regression analysis using Box-Behnken design to determine which factors, such as driving duration, driving speed, body mass index (BMI), gender and types of roads, are significant in influencing oxygen saturation level and how these factors affect each other in indicating driving fatigue.

2.0 METHODS

2.1 Demographics Data

This study consisted of six male and six female participants. All participants aged between 20 and 25 with at least two years of car driving experience. Young drivers in this age range had a higher rate of being involved in fatal and non-fatal crashes than drivers in the middle-age range [8]. The participants were then divided into three weight status categories: healthy, overweight and obese, with BMIs ranging from 18.5-24.9 kg/m², 25.0-29.9 kg/m² and 30 kg/m² and above, respectively. Regardless of BMI, each participant was declared healthy and had no daily pharmaceutical regimen.

2.2 Experimental Design

First, anthropometry measurements and a health examination were taken. To guarantee that the baseline fatigue in all participants was comparable, the participants were instructed to have at least seven to nine hours of sleep the night before the driving test. Insufficient night sleep duration can cause sleep deprivation and can lead to hypertension, which will negatively impair vital cognitive skills required when driving [9]. Before the experiment, participants' blood pressure was taken using an Omron Evolv to ensure that they had normal blood pressure, less than 80 mm Hg for diastolic and less than 120 mm Hg for systolic, respectively. For six hours before the trial, the participants were not allowed to smoke or drink liquids containing caffeine or alcohol, such as coffee or tea.

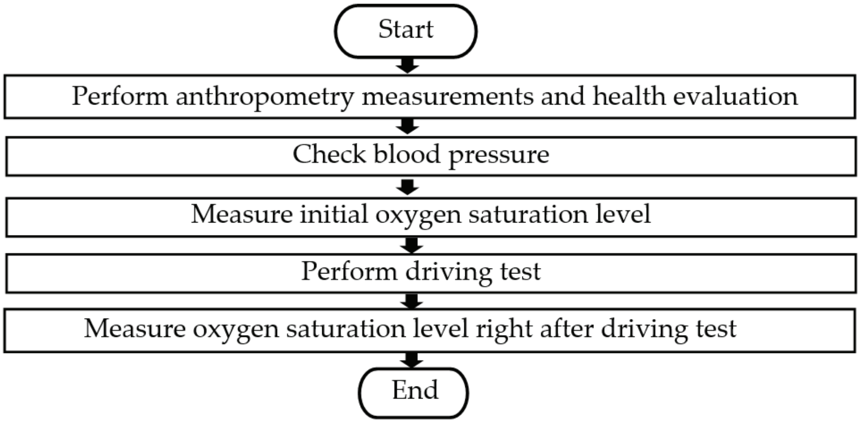

Figure 1: Experimental flow

Throughout the trial, a Perodua Bezza GA T with an automatic gearbox was used. The trial was carried out between 8:30 a.m. and 10:30 a.m. when there were fewer reports of fatigue-related traffic collisions [10]. The entire experiment was carried out on sunny days, and radio and cell phone use while driving were restricted. The oxygen saturation levels were measured by placing a wireless pulse oximeter on the driver's fingertip. The measurement was obtained both before and after the driving was completed.

2.3 Regression Analysis

This study employed regression analysis for five factors, namely (i) driving duration, (ii) driving speed, (iii) body mass index (BMI), (iv) gender and (v) types of roads on the oxygen saturation levels to indicate driving fatigue. The combination of these five variables has not been investigated in previous studies.

A well-known Box-Behnken design was utilised since it is proven to be effective in determining potential interactions between variables. The experimental design layout was created initially based on the minimum and maximum of independent variables, as shown in Table 1. A total of sixty-eight experimental runs were carried out in this study. The data of the oxygen saturation levels from actual driving experiments were then fed into the layout. The model was examined using an Analysis of Variance (ANOVA) tool to identify the most significant independent variables that affected the oxygen saturation levels, as well as how the independent variables and output response influence each other in indicating driving fatigue. Finally, a polynomial equation to predict the value of the oxygen saturation levels was created.

Table 1: Experimental design (independent variable)

Independent Variable	Minimum	Maximum	Unit
Numeric Variable			
Driving Speed	80.00	100.00	km/h
Driving Duration	15.00	30.00	minute
BMI	18.5	35.00	kg/m^2
Categorical Variable			
Gender	Female	Male	-
Type of Road	Straight	Uphill/Downhill	-

3.0 RESULTS AND DISCUSSION

3.1 ANOVA

The statistical model's stability was confirmed using ANOVA to identify the most significant independent variables and evaluate how driving duration, driving speed, BMI, gender and types of roads affected oxygen saturation levels in indicating driving fatigue.

Table 2: ANOVA analysis for response surface quadratic model

Source	Sum of Squares	DF	Mean Square	F-Value	Prob > F	Remark
Model	130.00	18	7.22	6.366E+007	< 0.0001	significant
A	28.22	1	28.22	6.366E+007	< 0.0001	significant
B	28.22	1	28.22	6.366E+007	< 0.0001	significant
C	32.00	1	32.00	6.366E+007	< 0.0001	significant
D	14.67	1	14.67	6.366E+007	< 0.0001	significant
E	14.67	1	14.67	6.366E+007	< 0.0001	significant
A^2	0.000	1	0.000	-	-	not significant
B^2	0.000	1	0.000	-	-	not significant
C^2	4.49	1	4.49	6.366E+007	< 0.0001	significant
AB	0.000	1	0.000	-	-	not significant
AC	0.000	1	0.000	-	-	not significant
AD	0.000	1	0.000	-	-	not significant
AE	0.000	1	0.000	-	-	not significant
BD	0.000	1	0.000	-	-	not significant
BE	0.000	1	0.000	-	-	not significant
CD	0.000	1	0.000	-	-	not significant
CE	0.000	1	0.000	-	-	not significant
DE	0.000	1	0.000	-	-	not significant
Residual	0.000	49	0.000	-	-	-
Lack of Fit	0.000	33	0.000	-	-	-

Pure Error	0.000	16	0.000	-	-	-
Cor Total	130.00	67		-	-	-
Std. Dev.	0.000	R-Squared	1.0000	-	-	-
Mean	97.00	Adj R-Squared	1.0000	-	-	-
C.V.	0.000	Pred R-Squared	1.0000	-	-	-
PRESS	0.000	Adeq Precision	1.0000	-	-	-

The values of Prob>F less than 0.01% indicate that the independent variables have significant impacts on the output response. The A= Driving Duration, B= Driving Speed, C= BMI, D= Gender, E= Types of Roads, and C^2= BMI^2 were less than 0.01%, showing that the independent variables were significant in determining the oxygen saturation levels.

The following part describes the behaviour of the oxygen saturation levels in response to the significant variables determined by software prediction and actual driving experiments. The polynomial regression equations (1), (2), (3) and (4) developed by ANOVA were used to predict the oxygen saturation levels.

i. Road: Straight, Gender: Female

$$99.68384-(0.13333\times \text{Driving Duration})-(0.10000\times \text{Driving Speed})+(1.00875\times \text{BMI})-(0.024385\times \text{BMI}^2) \quad (1)$$

ii. Road: Uphill/downhill, Gender: Male

$$98.68384-(0.13333\times \text{Driving Duration})-(0.10000\times \text{Driving Speed})+(1.00875\times \text{BMI})-(0.024385\times \text{BMI}^2) \quad (2)$$

iii. Road: Straight, Gender: Female

$$100.68384-(0.13333 \times \text{Driving Duration})-(0.10000 \times \text{Driving Speed})+(1.00875\times \text{BMI})-(0.024385 \times \text{BMI}^2) \quad (3)$$

iv. Road: Uphill/Downhill, Gender: Male

$$99.68384-(0.13333 \times \text{Driving Duration})-(0.10000 \times \text{Driving Speed})+(1.00875\times \text{BMI})-(0.024385 \times \text{BMI}^2) \quad (4)$$

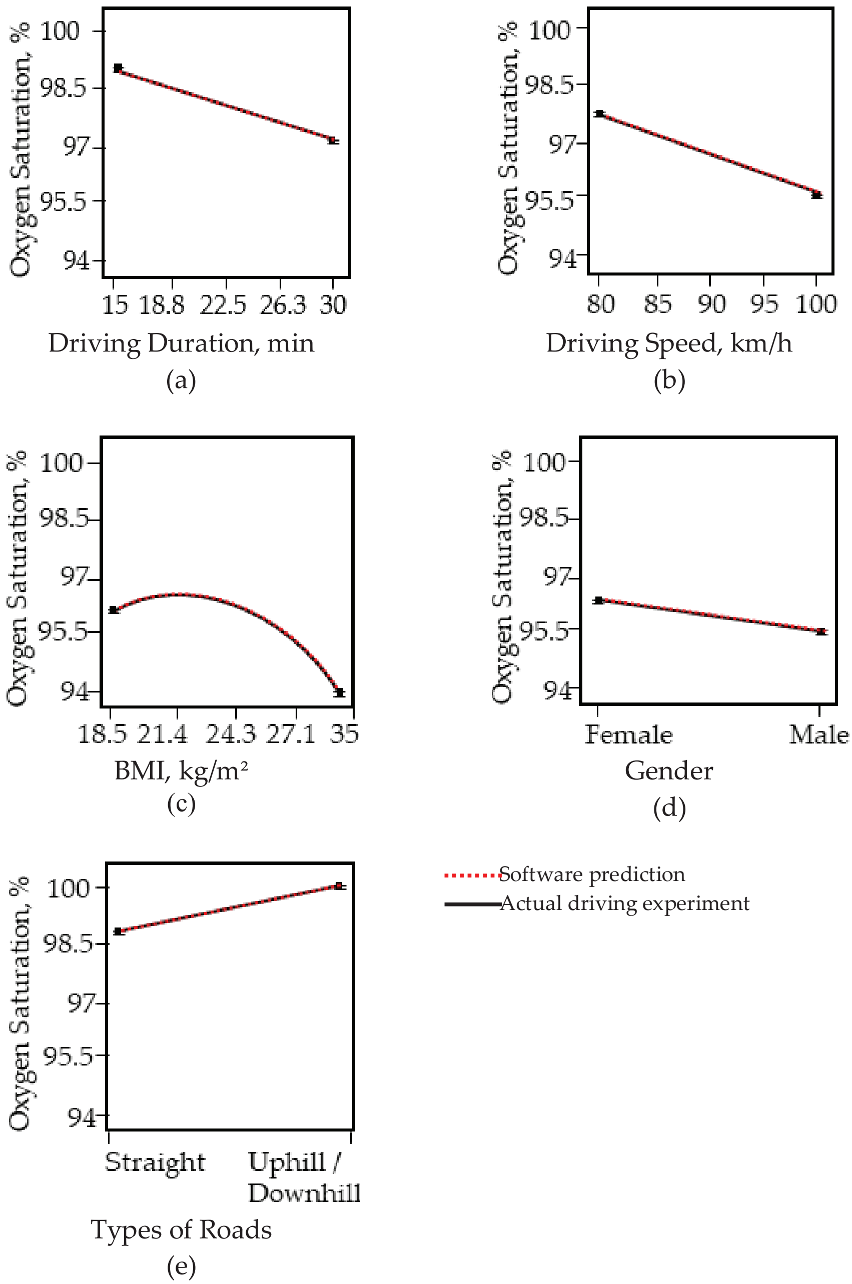

Figure 2: Interaction between independent variables and oxygen saturation levels (a) driving duration, (b) driving speed, (c) BMI, (d) gender and (e) types of roads

Driving Duration: Figure 2(a) shows the decline in the oxygen saturation levels as the driving duration decreased from 15 minutes to 30 minutes. The decrement could be attributed to the stress caused by the extended hours of driving. Driving comprises a succession of high-risk situations, such as driving during rush hour, feeling out of control, and being delayed in traffic, all of which raise stress levels and affect emotions [11]. Stress can induce breathing problems like shallow breathing and fast breathing because the passageway between the nose and the lungs narrows, lowering oxygen saturation levels in the body. According to one study [12], short breathing made individuals more worried and less calm than the other three circumstances, which are (i) breathing shallower at a normal rate, (ii) breathing at a normal depth and pace, and (iii) breathing at a slower rate than usual.

Driving Speed: Figure 2(b) depicts the decline in oxygen saturation levels as the driving speed rose from 80km/h to 100km/h. The symptoms could be the result of breathing problems. A task-capability interface model reveals that a driver's cognitive workload could have a detrimental effect on vehicle speed choices [13]. Drivers tend to alter their pace in order to properly regulate the task complexity and increase their attention levels, such as while trapped in traffic flow or start-stop driving due to congestion, which could result in stress. A study that examined the emotional states of cab drivers while they were on the job validated these findings, as stress emotions, like grief and anger, have a high link with increasing driving speed [14]. In addition, as described in Figure 2a, an emotional person has respiratory symptoms such as shallow breathing and quick breathing. This breathing pattern disrupts the body's oxygen balance and causes tension.

BMI: Figure 2(c) depicts the decline in the oxygen saturation levels when BMI increased from 18.50 (healthy) to 30.00 (obesity). This pattern could be linked to the obesity-related health issues. According to one study [15], obesity is the leading cause of low oxygen saturation levels, with effects greater than other clinical variables such as heart failure and smoking. Obesity, along with hypercholesterolemia and hypertension, is generally identified as one of the major contributors to OSA. OSA develops when the upper airway is constantly occluded while sleeping. Obese people have nearly double the prevalence of OSA compared to normal-BMI adults (18.5-24.9 kg/m2) because fat deposits around the upper airway limit upper airway size and increase airflow resistance [15]. The condition reduces oxygen supply to the organs, resulting in a drop in the oxygen saturation levels. Thus, obesity has an adverse effect on lung function to deliver oxygen to the organs [16]. Moreover, the most frequent sleep-related breathing problem associated with car accidents is obstructive sleep apnea (OSA)

[17]. According to one study [18], people with sleep-breathing disorders had a 4% decrease in oxygen saturation levels.

Gender: Figure 2(d) depicts the drop in the oxygen saturation levels when the drivers were switched from female to male. The variation in sex hormones could explain the drop in the oxygen saturation levels. A study supports this statement as differences in respiratory diseases between genders such as oxygen transport and haemoglobin affinity for oxygen influencing the oxygen saturation level [19]. Another study examined the differences in pulse oximetry between 209 young healthy volunteers, 132 of which were women and 77 were men. The study found that women have higher oxygen saturation levels than males, with 98.6% and 97.9%, respectively [20]. The study reveals that differences in sex hormones are the most important element influencing red blood cell formation, resulting in considerable alterations in the cellular phase of respiration.

Types of roads: Figure 2(e) depicts the oxygen saturation levels, which increased as the road geometry changed from straight to uphill/downhill paths. The findings revealed that road shapes and the roadside environment had a substantial impact on driving performance by influencing oxygen saturation levels. Oxygen saturation levels decreased during low-demanding straight driving compared to when driving on a more tough uphill/downhill road condition because this environment provided less geometric variety and demanded minimal task effort, resulting in a physiological signature of boredom. These findings are consistent with prior research. For instance, a study found that drivers' awareness is greatly reduced when driving on a monotonous route design and environment [21]. Another study examining the influence of passive tiredness on lane placement and steering wheel control discovered that drivers experience more passive fatigue symptoms when driving on straight roads rather than curving or winding roads [22]. In addition, boredom has a significant association with stress. In a stress-driving environment, the pulse rate tends to beat quicker than in a less demanding driving environment. When the heart beats too quickly, the blood pumping capability deteriorates, resulting in decreased blood flow to the organs, including the heart. As a result, boredom caused by a dull straight road with little sensory stimulation affects the heart rate's effectiveness in pumping oxygen.

3.2 Regression Model Validation

The regression model was validated by comparing output data obtained from software prediction and actual driving experiments under these two conditions:

i. The predicted interval between the output data acquired from software prediction and actual driving experiments must be within 90%.

ii. If the residual error percentage is less than 10%, the regression model has acceptable accuracy.

Table 3 indicates that all three samples met both quantitative parameters for accurately predicting the significant variables and their interactions in indicating driving fatigue. First, the output data predictive interval obtained by software and actual driving experiments was within 95% of the minimal condition of 90%. Second, residual errors were less than 10%.

Table 3: Data validation (parameters (A= Driving Duration, B= Driving Speed, C= BMI, D= Gender and E= Types of Roads)

Input Parameter (Independent Variable)					Prediction (%)	95% PI low (%)	95% PI high (%)	Actual (%)	Error, (%)
A	B	C	D	E					
22.5	90.0	24.25	Male	Uphill/ Downhill	97	97	97	97	0
30.0	90.0	30.00	Female	Straight	95	95	95	95	0
15.0	80.0	27.45	Female	Straight	99	99	99	99	0

4.0 CONCLUSION

The goal of this study which was to conduct a regression analysis to determine driving duration, driving speed, BMI, gender and types of road variables in influencing oxygen saturation levels and how these variables interact to suggest driving fatigue was achieved. The ANOVA demonstrates that the values of Prob > F for all independent variables were less than 0.01%, indicating that all factors have a significant effect on oxygen saturation levels. First, the increase in driving duration and speed causes a drop in oxygen saturation levels because of the influence of stress on the respiratory system. The same trend emerges as BMI rises due to obesity-related health conditions and the driver shifts from female to male due to sex hormone differences, respectively. However, when driving on a less challenging route, the oxygen saturation levels decline because the environment delivers a less geometric variety that results in a physiological hallmark of boredom.

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AUTHOR CONTRIBUTIONS

M.S. Ibrahim: Conceptualization, Methodology, Software, Writing-Original Draft Preparation, S.R. Kamat: Data Curation, Validation, Supervision; Software, Validation, Writing Reviewing; S. Shamsuddin, M.H.M. Isa and M. Fukumi: Writing-Reviewing and Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission and declare no conflict of interest on the manuscript.

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