Performance Prediction Model on Driving Train Simulator Based on Alertness and Sleepiness Level

Ayu Pramiarsih [*,a,1], Daniel Siswanto [b,2], Sani Susanto [c,3]
[a,b,c] Universitas Katolik Parahyangan, Bandung
[1]ayu_20190039@unpar.ac.id *,[2] daniels@unpar.ac.id ,[3] ssusanto@unpar.ac.id

Abstract

One of the causes of train accidents is fatigue. Fatigue can be caused by less sleep duration and quantity, which decreases alertness and sleepiness. It is also caused by boredom due to monotonous road conditions. One way to prevent accidents is to predict one's driving performance when carrying out the duties. This study aims to build a performance prediction model based on the level of alertness and sleepiness test results in monotonous road conditions. This study uses a Train Simulator for 120 minutes to describe a driving activity. This study involved 8 participants (5 males and 3 females) aged 22-38 years old. Each participant received the same treatment based on sleep duration (4 and 8 hours) and sleep quality (good and poor). Performance prediction models are built using multiple regression analysis based on the highest adjusted coefficient of determination (R^2). The results of a performance prediction model with an adjusted R^2 of 61.2% with the final variable entered into the model based on the Psychomotor Vigilance Test (PVT) measurement tools, Mean Reaction Time (MRTPVT), Sustained Attention Test (SAT) measurement tools are % Number of Missed Targets (NMTSAT) and SOFI measurement tools are Physical Exertion (PE).

Keywords: fatigue, sleep duration, sleep quality, the test of alertness and sleepiness level, multiple linear regression

I. Introduction

Train accidents in Indonesia are caused by several factors, humans (33%), infrastructure (41%), facilities (19%), and operations (7%) [1]. Of all the factors that cause train accidents, humans are one of the major contributing factors. Humans can cause accidents because the driver does not carry out standard operating procedures, violating the speed limit due to fatigue [1]. As an example of a train accident in Indonesia, the Argo Bromo Anggrek train hit the Senja Utama train, which stopped at Petarukan Station, Pemalang, Central Java, in 2010; this accident occurred because the Argo Bromo Anggrek train driver violated the red signal given and kept breaking through. It is due to the driver being sleepy while on duty. The Argo Bromo Orchid train accident resulted in 34 deaths and dozens of other fatalities [2].

Humans can cause fatigue accidents [3]. A person who has sleep deprivation can affect his performance when doing his job. It is due to decreased alertness due to fatigue [4]. The alert means always knowing what is happening in the surrounding conditions and being aware of the possible impacts [5]. The level of alertness is influenced by drowsiness, fatigue, and monotonous activities or work [6]. In addition to sleep deprivation, sleep quality can also affect a person's performance at work [7].

Sleep quality is a time series of a person's activity whose data is collected with a device that can record when he sleeps and when he wakes up. The most important indicator of sleep quality is sleep efficiency, which determines whether a person has good or poor sleep quality [8].

Drowsiness is caused by sleep deprivation. It is directly proportional to the feeling of wanting to sleep when a person experiences fatigue. If drowsiness appears, it can cause the response to something to be slow, causing the level of alertness to decrease [9]. Thus, it indicates that a person experiencing drowsiness can result in a decreased level of alertness, leading to accidents. In this study, fatigue is the basic thing that causes a person's drowsiness to appear.

Fatigue occurs when a person continuously performs physical and mental activities, resulting in sleep deprivation [9]. Fatigue occurs due to monotonous conditions and work duration, resulting in decreased performance [10]. Feeling tired tends to result in unsafe performance and actions in doing work that can result in accidents, injuries, and death. Fatigue has a very strong relationship with alertness and sleepiness [11]. Predicting the level of fatigue can produce a person's level of performance by building a model [12].

The model is created as something that can predict driving performance. This model aims to determine a person's job readiness based on the results of predictions of driving performance in the future. Previous research in building a model to predict driver performance is based on a person's sleep duration [12][13]. In addition, previous studies are built models to predict driving performance based on sleep duration and non-restorative sleep (NRS) [14]. The similarity of the model built in previous studies is sleep duration. However, sleep duration is not the only indicator that affects a person's performance in carrying out work activities. Therefore, this study aimed to build a model to predict the level of driving performance based on sleep duration and quality as measured by its efficiency on monotonous road conditions.

II. Research Methods

This study used 12 participants (8 participants to build the model and 4 participants to validate the model). These eight 22-38 years old participants consisted of 5 males and 3 females. The mean and standard deviation of the male participants was 34.2 years and 5.64 years, while the mean and standard deviation of the female participants was 26.67 years and 5.91, respectively. The selection of these participants has limited availability of existing human resources, is healthy, and usually uses a Personal Computer (PC) or laptop. This study uses the within-subject method, where each participant experiences the same treatment from the independent variables and their respective levels [22].

Sleepiness is an indicator used to measure a person's level of fatigue [3]. The recommended sleep duration for adults is 7-9 hours [15]. In contrast, a person sleeping with a duration of fewer than 5 hours in the previous 24 hours may experience sleep deprivation disorders that can result in fatigue and sleepiness [16]. In addition to sleep duration, a person's performance is influenced by sleep quality. The most important indicator of sleep quality is sleep efficiency. Good sleep quality is someone who has a sleep efficiency of 85%. In comparison, poor sleep quality is someone who has a sleep efficiency of 85%. Low sleep efficiency causes a person to experience sleep deprivation [8]. Calculation of the value of sleep efficiency can use the equation:

$$DSE = SOL + TST + WASO + TASAFA \qquad (1)$$

$$SE = \frac{TST}{DSE} \times 100\% \qquad (2)$$

SE	:	Sleep Efficiency
DSE	:	Duration of the sleep episode
SOL	:	Sleep onset Latency
TST	:	Wake after sleep onset
WASO	:	Wake after sleep onset
TASAFA	:	Time Attempting to Sleep After Final Awakening

Participants in this study experienced night sleep before with 2 levels of predetermined sleep duration; 4 hours and 8 hours, and got 2 levels of sleep quality, good sleep quality, and poor sleep quality. The study was conducted for 32 days, with each participant receiving 4 treatments, as seen in Table I. So that the data taken does not produce bias due to the order effect, the scheduling to conduct the research uses Counterbalancing type of Balanced Latin Square. This method is used to minimize the order effect. Order effect occurs when the results of the responses given by participants are influenced by the level that has been done previously [22].

TABLE I. RESEARCH DESIGN

Sleep Quality	**Sleep Duration**	
	4 Hours	***8 Hours***
Good (sleep efficiency≥85%)	P1, P2, …, Pn	P1, P2, …, Pn
Poor (sleep efficiency<85%)	P1, P2, …, Pn	P1, P2, …, Pn

Participants were asked to start lying down and try to sleep at 22.00 (for the sleep duration of 8 hours) and 02.00 (for the sleep duration of 4 hours). For poor sleep quality, participants were awakened in the middle of sleeping by knocking on the bedroom door and telephone. Participants must wake up and get out of bed at 06.00 WIB. While trying to sleep, participants were not allowed to do activities such as reading, operating a computer or cell phone, watching TV, or other activities other than trying to sleep. While sleeping, participants wore a Fitbit Charge 2 to record sleep data. Fig. 1 shows the resulting chart of the Fitbit Charge 2.

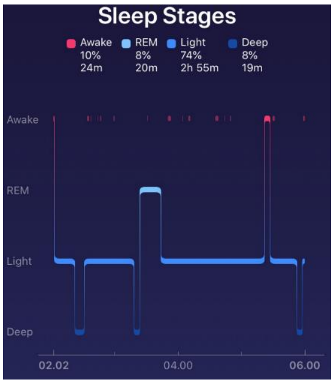

Figure 1. Sleep Quality Chart

In the data collection process, participants simulated driving a train using a laptop provided for 2 hours before a night of sleep. Before the participants did the train simulation, the participants filled out the KSS, SOFI, and VAS questionnaires and did the PVT and SAT. The PVT and SAT produced reaction times in milliseconds (ms). Each was carried out for 10 minutes using a Xierra G7 gaming mouse because a gaming mouse can provide significantly more results than an ordinary mouse [23].

A. Train Simulator

The application used for driving the train simulator is Train Simulator 2016. The driving performance data for the train simulator is %speeding. Speeding occurs when the train simulator driver exceeds the speed limit given by the train simulator. The speeding percentage is derived from the total time from starting to experience speeding until the speed returns below the speed limit divided by the total train simulator driving. Fig. 2 shows an example in the case of speeding. The red box shows the speed limit given by the Train Simulator 2016 application, while the blue box shows the participant's speed while driving the train simulator. It shows that the participant's speed exceeds the given speed limit.

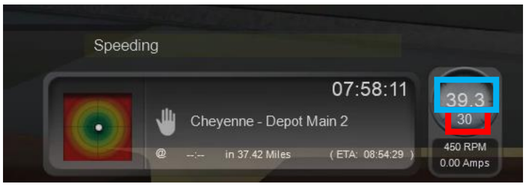

Figure 2. Proses Speeding.

B. *PVT*

The level of alertness and sleepiness can measure a person's level of performance. Measurement of the level of alertness and sleepiness in this study was carried out with objective and subjective measurements. Objective measurements were carried out using the Psychomotor Vigilance Test (PVT) and the Sustained Attention Test (SAT). PVT tool measures the level of alertness due to sleep deprivation [17]. The way PVT works are by the appearance of a number on a black screen that shows the running time in milliseconds. The time recorded for each stimulus is when pressing the response button (gaming mouse). The PVT was carried out for 10 minutes with the PVT variables used were mean reaction time (MRTPVT), % minor lapses (MLPVT) when the response to the stimulus is more than 500 ms, 10% fastest (FPVT), and 10% slowest (SPVT).

C. *SAT*

SAT is a measuring tool to see a person's level of alertness [18]. The difference between the two methods is that PVT is more concerned with the speed of responding to the stimulus, while the SAT is concerned with working memory and responding to the stimulus. The SAT works by appearing with white numbers from 0 to 9 with a black background on the monitor screen. When there are missing numbers from the loop number 0 to 9, participants must respond as quickly as possible by pressing the response button (gaming mouse). The SAT was conducted for 10 minutes, with the variables seen from the SAT being % number of missed targets (NMTSAT) and % number of delayed responses (NDRSAT) when the reaction time is greater than 850 ms.

D. *KSS*

Subjective measurements were performed using the Karolinska Sleepiness Scale (KSS), Swedish Occupational Fatigue Inventory (SOFI), and Visual Analog Scale (VAS). KSS is a tool used to measure a person's level of sleepiness [19]. KSS consists of 9 scales (1 to 9), where a scale of 1 indicates a very high alert level, and a scale of 9 indicates a very sleepy state and requires great effort to stay alert [19]. SSC is displayed in the form of a questionnaire.

E. *SOFI*

SOFI is a tool used to measure the level of fatigue divided into several factors. SOFI is determined based on five factors: lack of energy (LE), physical exertion (PE), physical discomfort (PD), lack of motivation (LM), and sleepiness (SL) [20]. Each factor in SOFI comprises 11 grades (0-10), where grade 0 does not feel at all and grade 10 feels very much [20]. SOFI is presented in the form of a questionnaire.

F. *VAS*

The VAS was used to measure the participant's level of alertness subjectively [21]. The scale used in the VAS is 0-100, with a value of 0 located on the far left, which means that the participant is in a state of trying to stay awake, while the scale of 100 on the far right indicates that the participant is very awake and alert [21]. This VAS is displayed in the form of a questionnaire.

III. RESULT AND DISCUSSION

A. *Sleep Quality*

Equation (1) is used to calculate sleep quality (SQ) which can be seen in Table II. There is no TASAFA time (TASAFA=0).

TABLE II. SLEEP QUALITY CALCULATION RESULT

n-	DSE	SOL	TST	WASO	EF	SQ
1	240	3	207	30	0.86	Good
		26	184	30	0.77	Poor
	480	8	420	52	0.88	Good
		2	393	85	0.82	Poor
. . .	. . .	. . .	. . .	. . .	. . .	. . .
8	480	29	385	66	0.80	Poor

B. *ANOVA (Analysis of Variance) Test*

The ANOVA test conducted in this study was conducted to determine whether the factors of sleep duration and sleep quality affect the magnitude of driving performance (% speeding). Table III shows the value of %speeding.

TABLE III. %SPEEDING DATA

n-	Good Sleep Quality		Poor Sleep Quality	
	Sleep Duration (4h)	Sleep Duration (8h)	Sleep Duration (4h)	Sleep Duration (8h)
1	12.79	3.76	18.43	7.76
2	13.63	7.89	16.19	11.29
3	9.19	2.76	15.22	7.04
4	7.5	1.17	20.15	5.13
5	6.01	2.29	8.42	3.5
6	7.22	0	9.99	4.29
7	16.38	11.58	19.11	13.29
8	7.42	6.18	12.9	10.68

The ANOVA test was repeated because the participants performed the same level of each treatment (within-subject) with a 95% confidence level (α=5%). The Repeated Measures ANOVA test needs to meet the ANOVA assumptions, the order of treatment is independent, the residual data is normally distributed, and the variance is homogeneous. Based on the data processing in Table III using SPSS version 25, it has been proven to meet the three assumptions.

The recapitulation of the Repeated Measures ANOVA test results can be seen in Table IV.

TABLE IV. RECAPITULATION OF REPEATED MEASURES ANOVA TEST RESULT

Factor	Uji F	Sig.
Sleep Duration	38.215	0.000
Sleep Quality	32.972	0.001
Sleep Duration* Sleep Quality	2.185	0.183

Table IV shows that sleep duration and quality factors affect driving performance. It can happen because sleeping for a longer duration fulfills a person's sleep needs. Besides, good sleep quality has a total sleep time greater than the total sleep time of poor sleep.

C. Multiple Linear Regression Analysis

Regression analysis is a tool used to create a model or find the relationship between two or more variables related to the existing problem. Multiple regression analysis is a model used when it has more than one independent variable [24].

In making a regression model, several approaches were used to select the independent variables: enter, backward, stepwise, and forward. Regression equation analysis was conducted after selecting the model based on the approach, then analyzing the regression equation. The coefficient of determination (R^2) is a measure used to assess the adequacy of the model [24]. The adjusted R^2 value is considered easier to detect the impact of the newly added independent variable [24]. Table V shows the initial independent and dependent variables used in building a performance prediction model on driving using subjective and objective measuring instruments.

TABLE V. RECAPITULATION OF RESEARCH VARIABLES

Measuring Instrument		Initial Independent Variable	Dependent Variable
Objective	PVT	MRTPVT, MLPVT, FPVT, SPVT	%Speeding
	SAT	NMSAT, NDRSAT	
Subjective	KSS	KSS	
	SOFI	LE, PE, PD, LM, SL	
	VAS	VAS	

When a regression equation has a negative slope constant value, the outlier data will be removed using the Mahalanobis Distance statistical test. A large sample (N=500) with a value of Mahalanobis above 25 is a problem that must be considered. At the same time, a small sample (N=100) with a value of Mahalanobis above 15 must be considered, and a small sample (N=30) with a value of Mahalanobis above 11 also needs to be considered [25].

Three candidate models are built based on objective, subjective measuring tools and a combination of objective and subjective measuring tools. Table VI shows the recapitulation of the results of the model built using SPSS, which has met the assumptions of multiple regression analysis (normally distributed, homoscedasticity, non-autocorrelation, and non-multicollinearity) with a backward approach with an equation that does not have a negative value on the slope constant by using the Mahalanobis Distance statistical test.

TABLE VI. RECAPITULATION OF THE RESULTS OF THREE MODEL CANDIDATES

Measuring Instrument	Final Independent Variable	*Adjusted* R^2	*Std.Error of the Estimate*
Objective	MRTPVT, NMTSAT	0.439	0.792
Subjective	SL	0.108	5.072
Objective and Subjective	PE, MRTPVT, NMTSAT	0.612	3.344

D. Paired-T Test

The Paired-T test is a special case of T-test used to compare the difference between two populations collected in pairs. A Paired-T test was conducted to test the model's validity with a 95% confidence level (α=5%). This test was carried out on four new participants, and the results of the recapitulation of power processing results using SPSS were obtained, which can be seen in Table VII.

TABLE VII. RECAPITULATION PAIRED T-TEST RESULT

Measuring Instrument	t	Sig.
Objective	2.644	0.077
Subjective	1.640	0.200
Objective and Subjective	0.671	0.550

E. Performance Prediction Model

Based on the three models formed, these three candidate models have been proven valid in predicting driving performance, as evidenced by the sig value of the Paired-T test results. The performance prediction model chosen is a prediction model using a combination of objective and subjective independent variables (5), which has the largest adjusted R^2 of 0.612 and a standard error of 3.344.

Although the selected model has a negative constant value, this model has been proven valid based on the validation that has been done. In addition, based on the selected model, model-building variables such as PE and NMTSAT have a minimum value of 0, so there is only one model-building variable that will not result in 0 (MRTPVT). It is because the response value is considered valid at 100 milliseconds [17]. Besides, during the PVT in 10 minutes, it has an inter-stimulus interval of 2-10 seconds that must be responded to produce a time value when responding to the stimulus that appears.

Suppose the driving performance value (% speeding) when the PE and NMTSAT variables are 0, the MRTPVT value with a constant of 0.067 so as not to produce a negative driving performance value is 254.746 ms (the constant number is divided by the MRTPVT constant). However, this is unlikely to happen; it can be proven from the average value of MRTPVT at the time of the study before driving the train simulator from the data taken was 297.019 ms in the best conditions, sleep duration of 8 hours with good sleep quality, so that if entered into the selected model it does not produces a negative performance value. The negative intercept constant is not a problem in building a model but in estimating the intercept coefficient [26]. In the selected model, the PE, MRTPVT, and MRTPVT variables have a positive slope value so that when there is a decrease in performance, an increase in the value of each variable results in an increase in % speeding.

IV. CONCLUSIONS

Based on the three models built, the model for predicting the train simulator's driving performance based on the level of alertness and sleepiness test was selected using objective and subjective measuring instruments. The model formed has an adjusted R^2 value of 61.2%, meaning that the value of driving performance (% speeding) is influenced by the variables that make up the model. In contrast, 38.8% were caused by other factors not examined in this study.

This model is used to decide the driver's readiness each time before driving the train by knowing the performance produced by the driver before carrying out his duties. It is used to determine the prevention that can be done so as not to cause accidents due to decreased alertness and increased sleepiness, such as regulating sleep hours the night before driving. The results of research evidence it conducted that sleep duration and sleep quality can affect a person's performance driving.

REFERENCES

[1] KNKT, "Introduction, Railway Safety" Internet: http://knkt.dephub.go.id/knkt/ntsc_railway/railway.htm, 2016 [Jan. 10, 2020].

[2] Liputan6. "Tragedi Dini Hari di Petarukan". Internet: https://www.liputan6.com/news/read/299834, Oct. 5, 2010 [Feb. 3, 2020].

[3] A.Williamson, D.A. Lombardi, S. Folkard, J.Stutts, T.K. Courtney, J.L. Connor. "The Link Between Fatigue and Safety." Accident Analysis and Prevention, vol. 43, pp. 498-515, 2011.

[4] J. Dorrian, F. Hussey, D. Dawson. "Train driving efficiency and safety: Examining the cost of fatigue." Journal of Sleep Research, vol. 16, pp. 1–11, 2007.

[5] J. Eisert, F. Di Nocera, C. Baldwin, J. Lee, J. S. Higgins, W. S. Helton, P. Hancock. "Vigilance and Fatigue : A Double-Sided Coin ?". Proceedings of the Human Factors and Ergonomics Society Annual Meeting, pp. 1563–1568, 2016.

[6] A.V. Desai, M.A Haque. "Vigilance Monitoring for Operator Safety: A Simulation study on Highway Driving." Journal of Safety Research, vol. 37, pp. 139-147, 2006.

[7] E.-M. Elmenhorst, D. Elmenhorst, N. Luks, H. Maass, M. Vejvoda, A. Samel. "Partial sleep deprivation: Impact on the architecture and quality of sleep". Sleep Medicine, vol. 9(8), pp. 840–850, 2008.

[8] A. Sathyanarayana, S. Joty, L. Fernandez-Luque, F. Ofli, J. Srivastava, A. Elmagarmid, T. Arora, S. Taheri. "Sleep Quality Prediction from Wearable Data Using Deep Learning." JMIR Mhealth Uhealth, vol. 4, 2016.

[9] S. E. Lerman, E. Eskin, D. J. Flower, E. C. George, B. Gerson, N. Hartenbaum, S. R. Hursh, M. Moore-Ede. "Fatigue Risk Management in the Workplace." Journal of Occupational and Environmental Medicine, vol. 54 (2), pp. 231-258, 2012.

[10] S. K. L. Lal, A. Craig. "A Critical Review of the Psychophysiology of Driver Fatigue." Biological Psychology, vol. 55, pp. 173- 194, 2001.

[11] D. F. Dinges. "Critical Research Issues in Development of Biomathematical Models of Fatigue and Performance." In Aviation Space and Environmental Medicine, vol. 75, 2004.

[12] D. Dawson, Y. Ian Noy, M. Härmä, T. Kerstedt, G. Belenky. "Modelling fatigue and the use of fatigue models in work settings." Accident Analysis & Prevention, vol. 43(2), pp. 549– 564, 2011.

[13] F. Valentino. "Pengembangan Model Prediksi Kinerja Sebagai Fungsi Kelelahan pada Aktivitas Mengemudi Simulator Kereta Api". Bandung, Indonesia, 2018, unpublished.

[14] R, Tinajero, P.G. Williams, M.R. Cribbet, H.K. Rau, D.L. Bride, Y. Suchy. "Nonrestorative Sleep in Healthy, Young Adults without Insomnia: Associations with Executive Functioning, Fatigue, and Pre-Sleep Arousal." Sleep Health, vol. 4, pp. 284-291, 2018.

[15] M. Hirshkowitz, K. Whiton, S. M. Albert, C. Alessi, O. Bruni, L. DonCarlos, N. Hazen, J. Herman, P. J. A. Hillard, E. S. Katz, L. Kheirandish-Gozal, D. N. Neubauer, A. E. O'Donn'ell, M. Ohayon, J. Peever, R. Rawding, R. C. Sachdeva, B. Setters, M. V. Vitiello, J. C. Ware. "National Sleep Foundation's Update Sleep Duration Recommendations: Final Report." Sleep Health, vol. 1(4), pp. 233-243, 2011.

[16] D. Dawson, K. McCulloch. "Managing fatigue: It's about sleep." Sleep Medicine Reviews, vol. 9, pp. 365–380, 2005.

[17] M. Basner, D. F. Dinges. "Maximizing sensitivity of the Psychomotor Vigilance Test (PVT) to sleep loss." Sleep, vol. 34, pp. 581–591, 2011.

[18] E. De Valck, L. Smeekens, L. Vantrappen. "Periodic Psychological Examination of Train Drivers' Fitness in Belgium Deficits Observed and Efficacy of the Screening Procedure." Journal of Occupational and Environmental Medicine, vol. 57, pp 445-452, 2015.

[19] P. Philip, P. Sagaspe, M. Prague, P. Tassi, A. Capelli, B. Bioulac, C. Daniel, J. Taillard. "Acute Versus Chronic Partial Sleep Deprivation in Middle-Aged People: Differential Effect on Performance and Sleepiness." Sleep, vol. 35(7), pp. 997–1002, 2012.

[20] E. Ahsberg, F. Garnberale, A. Kjellberg, "Perceived quality of fatigue during different occupational tasks Development of a questionnaire," International Journal of Industrial Ergonomics, vol. 20(2), pp. 121–135, 1997.

[21] R. M. Petrilli, S. M. Jay, D. Dawson, N. Lamond. "The Impact of Sustained Wakefulness and Time-of-day on OSPAT Performance." Industrial Health, vol. 43(1), pp.186–192, 2005.

[22] D.W. Martin. Doing Psychology Experiment, 7th ed, Belmont, CA: Thomson Wadsworth, 2008, pp. 151-155.

[23] M.Y. Khitrov, S. Laxminarayan, D. Thorsley, S. Ramakrishnan, S. Rajaraman, N. J. Wesensten, J. Reifman. "PC-PVT: A Platform for Psychomotor Vigilance Task Testing, Analysis, and Prediction." Behavior Research Methods, vol. 46, pp. 140-147, 2014.

[24] D. C. Montgomery. Design and Analysis of Experiment, 8th ed, Hoboken, NJ: John Wiley & Sons, Inc., 2013, pp. 449-464.

[25] A. Field. Discovering Statistics Using SPSS, 3rd ed, London: SAGE Publications Ltd, 2009, pp. 207-

[26] R. C. Allen, J. H. Stone. "Textbook Neglect of the Constant Coefficient." The Journal of Economic Education, vol. 36(4), pp. 379-384, 2005