

# Analysis of Sleep Deprivation Effect to Driving Performance Using ReactionTest Simulation

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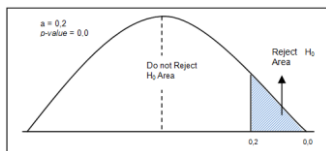
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## Graphical abstract



## Abstract

Sleep deprivation condition might lead to falling asleep through inappropriate situations, such as driving. Driving in a state of fatigue or drowsy from lack of sleep will be far worse than driving after alcohol consumption. Hence, the authors develop a driving simulator using Java to modify the control and rules of OpenDS application in order to simulate and calculate the automatic ReactionTest for 25 respondents simulating in both normal conditions and sleepy conditions when driving. Through this study, the authors obtained that the difference of driving performance in terms of reaction rate when driving the car in sleep deprivation condition and the normal condition, is equal to 1.08 seconds. The results also shown that the risk of loss of control that can occur to the driver of the car in units of meters (m), is equal to 0.3024 x the car's speed. This study aims to reduce the number of traffic accidents caused by sleep deprivation that occur in society by giving a recommendation to the driver that forced to drive in lack of sleep condition. In top of that, the authors propose to create an understanding for changing the social habits of driving toward a better way.

**Keywords:** Sleep deprivation; driving performance; reactiontest; simulator; KSS; safety driving; statistical analysis

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## 1.0 INTRODUCTION

Driving is always associated with the likelihood of accidents. Accidents can be caused by various factors, such as the condition of the vehicle, the road itself, the driver, or another people that is on the road. But, according to a statistical analysis, known that approximately 90% of accidents are caused by human or driver factors, not mechanical or other factors [1]. The latest data obtained from Indonesian Central Bureau of Statistics (known as *Badan Pusat Statistik* Indonesia in Bahasa), show that the number of accidents happened in Indonesia has reached more than 100.000 accidents in year 2011 and caused losses or economic damage in more than 200 billion Rupiah [2]. This problem can contribute a greater damage to the country if constantly left as it is.

The sleep deprivation condition is a subjective state which is able to make people feel sleepy during their works or activities. This condition can lead to falling asleep through inappropriate situations, such as while driving [3]. Sleep Health Foundation Australia stated in their research that driving in a state of fatigue or drowsy from lack of sleep will be worse than driving after alcohol consumption [4]. It happened because the reduced focus due to the sleep deprivation condition will be followed by the decrease in the driver's attention to the road and traffic.

The fact in today's society there are still many drivers who drive on the highway with the sleepy condition caused by lack of

sleep. Besides that, there are still many drivers who pay less attention to and do not consider the safety driving rules for the vehicles [5]. These circumstances make traffic accidents due to the lack of sleep are still become a major risk that is experienced by many people today.

Based on the above issues, the authors intend to conduct an analysis of sleep deprivation in relation to the driving performance especially for obtaining the driver's reaction rate to the traffic. Therefore, the authors use the ReactionTest simulation and statistical analysis as a measurement to achieve the result. By addressing the problems into this study, the authors expect to be able to provide a quantitative analysis of the results regarding the difference in driving performance between the normal conditions and sleep deprivation as well as solutions for safety driving on the road so that the society can understand the real impact and change their current habits of driving. In addition, this study also aims to reduce the number of traffic accidents that occur in society that especially caused by drivers who are in the lack of sleep conditions.

## 2.0 EXPERIMENTAL

The impact of the sleep deprivation is a sleepy feeling that has a measurement scale known as KSS. In this study, Karolinska sleepiness scale (KSS) used as a subjective measure of sleepiness

(Table 1). This scale provides direct evaluation of the driver's sleepiness [6] with a subjective self-rating scale, which consists of 1 to 9 ratings [7].

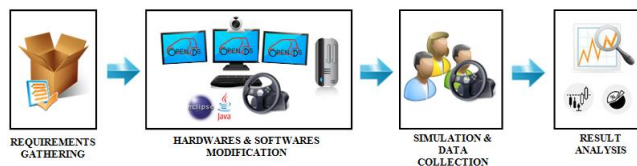
**Table 1** Karolinska sleepiness scale

Rating	Verbal Description
1	Extremely alert
2	Very alert
3	Alert
4	Rather alert
5	Neither alert nor sleepy
6	Some signs of sleepiness
7	Sleepy, no effort to stay alert
8	Sleepy, some effort to keep alert
9	Extremely sleepy, fighting sleep, an effort to keep awake

Through the analysis in this study, the authors are focused to observe the driving performance of the respondents, especially in terms of reaction rate of the driver which is included in the automotive behaviours using the modified OpenDS driving simulator<sup>8</sup>. The authors link the steer hardware from Logitech with the driving simulator program to control the movement of the car. The modification of the control and rules from the original OpenDS is created using the Java programming language to make an automatic reactiontest result that will calculate the driver's reaction rate every miliseconds when responding to a parameter. The reaction rate analyzed in this study is the driver's speed of response to the signs that appears at each gate along the arena of the driving simulator (the signs is the parameter used in calculating the reaction rate). There are two types of signs present in the arena, the red cross marker to reduce the vehicle's speed and the green tick markers to change lanes (Figure 1).



**Figure 1** The modified OpenDS Driving Simulator with signs to reduce the car's speed (left) and to change lanes (right)



**Figure 2** The step by step of doing this research

The authors' modification to the driving simulator also make a longer distance and duration to the arena. During the driving simulation in the arena, respondents will see as many as 120 gates with its sign, so that from a one time simulation will be resulted

120 data of the driver's reaction rate in XML format. The number of Reaction Time obtained from the XML result indicates the driver's responses to the sign in each gates. The whole series of activities carried out in this study are summarized in Figure 2.

To perform a testing procedures on something that is not known yet for certain truth, which is regarding to the different of driving performance in normal conditions and in the sleep deprivation, this study used a hypothesis testing for further analysis.

In this study, there are two sets of sample data:

- $\mu_1$  : is the reaction rate from respondents in the normal conditions, and
- $\mu_2$  : is the reaction rate from respondents in the sleep deprivation condition.

For that case, there is the hypothesis [9] concerning the proposed analysis to be performed in this study, i.e.:

- $H_0$ : The average value for measurements of driving performance in  $\mu_2$  is equal to  $\mu_1$ , and
- $H_1$ : The average value for measurements of driving performance in  $\mu_2$  is greater than  $\mu_1$ , so that the result will represent the difference in performance which will be used as a parameter of risk reduction of accidents which impend the driver with sleep deprivation conditions that is forced to drive.

Overall data used in this research came from 25 respondents obtained through simple random sampling techniques. All of the respondents are the student of Information Systems Departement of Institut Teknologi Sepuluh Nopember, Surabaya. Determination of respondents' sample size is based on the Slovin estimation methods [10], that formulated in Equation (1) as follows:

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

Where  $n$  is the sample size that will be tested,  $N$  is the population size, in this case  $N$  consists of 704 student of Information Systems Departement of Institut Teknologi Sepuluh Nopember, Surabaya [11].  $e$  in this methods means the critical value or the desired accuracy limits. In this study, the authors used 20% as  $e$ . The value depends on the level of accuracy that will be used, in this study the accuracy level is 80%.

Based on calculations using the above estimation method, resulting n or the number of sample size is 24.143 samples and rounded to 25 samples.

There are two types of data that will be carried into further analysis in this study, ie:

- Driving Performance Data; is the data obtained from the respondents' test in the driving simulator using reactiontest to measure the reaction rate. The driving performance data is divided again into two groups of data sets, ie: data sets results of respondents test in normal conditions, and the data sets results of respondents test on the sleep deprivation condition. Each data set consists of 120 measurements of driving performance in terms of reaction rate with millisecond units acquired from each gate in the simulator.
- Karolinska Sleepiness Scale Data; is the data obtained from subjective answers given by the respondents through the spreadsheet which indicates the level of drowsiness/alertness from respondent when driving on the simulator. Each respondent gave 120 answers on KSS spreadsheet after completing a driving simulation in the lack of sleep condition, or in normal condition.

### 3.0 RESULTS AND DISCUSSION

The test of validity and reliability analysis in this study includes the entire instrument variables or data research, there are: the instrument variable of driving performance in normal conditions at each gate, the instrument variable driving performance under conditions of sleep deprivation on each gate, KSS data under normal conditions at each gate, KSS data under normal conditions at each gate, and the age of the respondents.

By testing the validity of each of the whole instrument variables, the results showed that all values of r obtained from SPSS are greater than the value of r table. The value of r table used in this research come from a table r by counting the number of respondents minus 2, as well as the significance level of 0.2 on a test in one-tailed test, so that the value of r table found at 0.176. Since all the values of r obtained from each instrument variable is greater than the value of r table, so it can be stated that each variable has a valid instrument.

The reliability test result of the overall instrument variables shown in Table 2, which shows that the value of reliability (Cronbach's Alpha) of each variable is greater than 0.6 so that it can be said that all the variables are reliable.

**Table 2** Result of reliability test of all instrument variables <sup>a</sup>

Conbach's Alpha	Cronbach's Alpha Based on Standardized Item	Description
0.950	0.987	Reliable

<sup>a</sup> All variabls (variabls of driving performance in normal and lack of sleep conditions, variables of Karolinska Sleepiness Scale in normal and lack of sleep conditions, and respondents' age variabls) were involved in this test at 80 % of accuracy level

To determine whether the difference in average driving performance obtained at each gate by each of the respondents did not have a significant difference, then the authors use the analysis of data variance. In one driving simulation conditions in this study, there is one factor (source diversity or variance) with 120 gates that want to be analyzed. The unit performance test results will be grouped into sets of performance data for 25 respondents. Steps taken for analyzing the data variance is to calculate the ratio between inter-group method (between methods) as the numerator

(factor divided) by the method of the group (within method) as the denominator (divisor factor). The ratio will result in the value of f calculated from analysis of variance of data. If the count value f (f test) is greater than the value f table, it can be accepted that there are no significant differences in average driving performance from each respondent obtained at each gate[12]. Results of variance data analysis under normal conditions is presented in Table 3 below:

**Table 3** Result of data variance in both conditions <sup>a</sup>

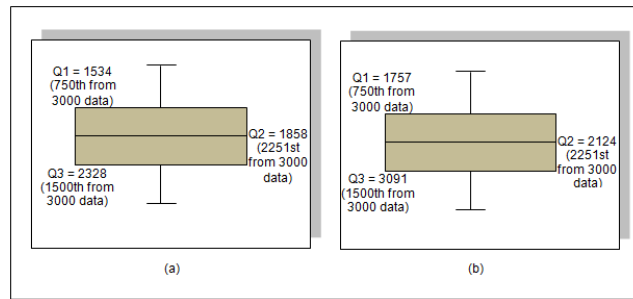
Test Condition	Sum of Square		F test	F table <sup>b</sup>
	Within Method	Between Method		
Normal	4301958589	5167890616	20.146	1.279
Lack of Sleep	17396240402	20651330076	20.387	1.279

<sup>a</sup> Conditions of the experiments consists of the driving performance data in normal condition and lack of sleep condition.

<sup>b</sup> The value of f table is derived from the number of respondents minus 1, as well as the significance level of 0.2 on a test in one-tailed test, so that the value of f table found at 1.279.

Based on the results of the calculations in the table, the value of f is gretae than the value of f tables with significance level of 20%. Thus, the average value of driving performance obtained by

each respondent from each gate does not have a significant difference between each other and can be used for further analysis. The average driving performance data of each respondent can be reviewed through the box and whiskers plot diagram [13] shown in Figure 3 as follows.



**Figure 3** Box and whiskers plot for the driving performance data of (a) normal condition and (b) lack of sleep condition

By looking at the box and whiskers plot diagrams in Figure 3, the results described that there is no significant different values on the average results of the driving performance of each respondent. It can be seen from the none of average driving performance from each of the respondents that classified as outliers or extreme values.

Outliers are the result of observations (data) that appear to have unique characteristics that look very much different from other observations and appears in the form of "extreme value". From the statistical analysis, like the box and whiskers plot, the extreme values can be seen after the measurement of quartile values (Q1, Q2, and Q3) and obtained the interquartile range value, that formulated as  $IQR=Q3-Q1$ . According to *Hair et al.*, a value will

be classified as an extreme value or outliers if it is greater than  $Q3+(3 \times IQR)$ , in this study, the value is 4710 for the normal condition and 7093 for the sleep deprivation condition, and also if the value is less than  $Q1-(3 \times IQR)$ , in this study, the value is -848 for the normal condition and -2245 for the sleep deprivation condition [14-15]. From these result, the average driving performance of each respondent nothing is classified as outliers or extreme values.

To calculate the difference in driving performance respondent in normal conditions as well as sleep deprivation, performed the T-test using *paired samples*. Paired Samples T-Test is a type of statistical test aimed to compare the average of a group of two. Paired samples can be interpreted as a sample with the same subject but having two different treatments or measurements, ie measurements before and after a treatment. T-test in this study is using the features on SPSS to perform the method of comparing means for paired samples (driving performance under normal conditions and lack of sleep conditions) at a significance level of 0.2 and one-tailed test.

This test resulting the differences of average driving performance of the samples and also resulting the values of t that will be compared to the t table in the significance level of 0.2 and one-tailed test. The result of the paired samples T-Test for the average driving performance for both condition presented in Table 4 as follows. According to Table 4, the results describe the difference between average driving performance in normal condition and average driving performance on the lack of sleep condition is equal to 1083.42 ms (millisecond).

**Table 4** T-Test results<sup>a</sup>

Mean Difference	Std. Deviation	Std. Error Mean	80% Confidence Interval of the Difference		t	p
			Lower	Upper		
1083.42	762.98	152.60	882.32	1284.52	7.1	0.0

<sup>a</sup> All the results are derived from the Paired Sample T-Test using the average of driving performances in both normal condition and lack of sleep condition.

In addition to the above tests, the authors also conducted correlation and regression tests. Correlation and regression are the analysis techniques used to examine the relationship between measurement variable. The closeness of the relationship is expressed by the correlation, whereas the effect of the relationship is described by the regression [16]. Correlation and regression analysis in this study are performed with SPSS. This analysis will be used to analyze the relationship between the variables of Karolinska Sleepiness Scale with the driving performance data (reaction rate) obtained from the respondents' test on driving simulator for each gate.

The results of correlation test obtained in normal conditions shows that there were only 10 of 120 subjective scale of KSS or only 8,33% that are highly correlated to the measurement of driving performance, especially in the reaction rate.

Then, the results of correlation test obtained in lack of sleep conditions shows that there were only 15 of 120 subjective scale of KSS or only 12,5% that are highly correlated to the measurement of driving performance, especially in the reaction rate. So that, according to the overall correlation analysis showed that the subjective scale of KSS does not have a high correlation with the measurement of driving performance which is affected by the lack of sleep condition especially in the term of reaction rate due to the

results of the correlation analysis that mostly show the moderate and low correlations. These results are contradict to the previous studies<sup>9</sup>, stated that KSS is closely related to high validity in performance measurement related to the driver's brainwave (EEG).

For the results of the regression test between KSS and driving performance on the gates which have strong or very strong correlation as above, obtained that the highest influence of KSS for the driving performance measurement in the normal condition is in the 120th gate (the end of the driving simulation) as 78,2%. Whereas, the highest influence of KSS for the driving performance measurement in the sleep deprivation condition is in the 12th gate (the beginning of the driving simulation) as 66,5%.

Then, to prove the hypothesis of the research, the authors conducted the hypothesis testing. This study consists of a research hypothesis (H1) that must be fulfilled based on the differences in driving performance analysis that has been done. Here is the hypothesis used:

- H0: The average value for measurements of driving performance in the lack of sleep condition is equal to driving performance in the normal condition, and H1: The average value for measurements of driving performance in the lack of sleep condition is greater than driving performance in the normal condition.

Results of hypothesis for the difference in driving performance through this study shows that the  $t$  value obtained from SPSS software is equal to 7,1 and greater than  $t$  table value, and also  $p$ -value is equal to 0 and less than a (0, 2). The results of the test indicates that there is sufficient evidence to reject  $H_0$ , means that there is a difference in the average of driving performance between the reaction rate of the simulation in the lack of sleep condition ( $\mu_2$ ) the reaction rate of the simulation in the normal condition ( $\mu_1$ ), that  $\mu_2 > \mu_1$ . The results are presented in Figure 4.

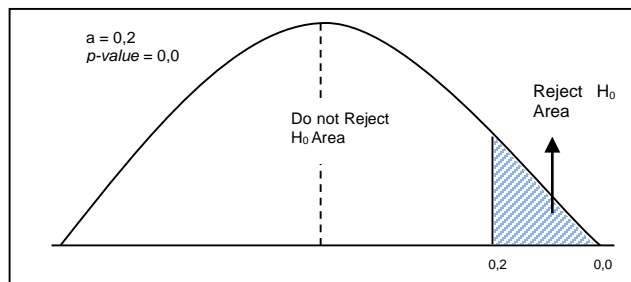


Figure 4 Result of the hypothesis testing: Reject  $H_0$

The rejection of  $H_0$  is related to means comparison results, that the average difference between  $\mu_2$  and  $\mu_1$  is equal to 1083,42 ms. This means that the more drowsy is the driver, the lower driving performance will the driver has, proven by the longer reaction rate (response) of the driver into the track for the simulation in the lack of sleep conditions. Therefore, this analysis shows that  $H_1$  (the research hypothesis) can be fulfilled in this study.

Through the analysis to the result obtained in this study, can be given recommendations for driver as follows:

1. The results of the means comparison test show that the difference of the driver's reaction rate between driving in simulator in the lack of sleep condition and driving in simulator in the normal condition is equal to 1083.42 ms. That is, when a driver forcing him to drive in a state of sleep deprivation, the performance would go down as much as 1083.42 ms or 1.08 seconds. But, for the worst case it is possible that the driving performance, especially in terms of reaction rate, can fall to 1284.52 ms or 1.8 seconds.
2. Assumed that a driver with the lack of sleep, driving a car with a speed of  $x$  km/hour. If the value of the difference in driving performance is converted, it will obtain the results of the following risks:

$$\begin{aligned} x \text{ km/h} \times 1,08 \text{ sec} &= \left(\frac{1000x}{3600}\right) \text{ m/sec} \times 1,08 \text{ sec} \\ &= 0,28x \text{ m/sec} \times 1,08 \text{ sec} \\ &= 0,3024x \text{ m} \end{aligned} \quad (2)$$

So, the risk of loss of control due to a decrease in driving performance (reaction rate) will be obtained when a driver with the lack of sleep driving a car with a speed of  $x$  km/h is equal to  $0.3024x$  m.

The drivers should avoid driving in the sleep deprived conditions, because due to this study, it has been proven through the test results on the condition that there is a decrease in driving performance for 1.08 seconds. When the driver is forced to drive in the conditions of sleep deprivation, as anticipated in order to reduce the risk of accidents, the driver can set a safe distance in meters for a minimum  $0.3024 \times$  the car's speed plus the safe distance required by the vehicle to perform the braking effort for 3 seconds [17-18], and if the distance is converted via the formula  $x$  km/hours  $\times$  3 seconds then the result is equivalent to  $0.84x$  m. So, total safety distance required by the driver of the car is equal to  $0.3024x$  m +  $0.84x$  m, or equal to a minimum of  $1.1424 \times$  the car's speed. These

results support the guidance given by the Department of Transportation, Communications, and Information of Indonesia (known as *Dishubkominfo* in Bahasa) concerning safe distance with other vehicles while driving in the range of 1-3 seconds, or equivalent to 22-56 meters [18-19].

#### 4.0 CONCLUSION

All of the research in this study was concluded as follows:

1. Through the calculation results and analysis in this study, obtained the difference of driving performance in terms of reaction rate to the population of students in Information Systems Department of ITS, when driving the car in sleep deprivation condition and the normal condition, which is equal to 1.08 seconds. In the worst case, it is possible that driving performance can be reduced by as much as 1.28 seconds.
2. The risk of loss of control that can occur to the driver of the car in units of m, is equal to  $0.3024 \times$  the car's speed. Thus, recommendations are given to the driver for a safety driving solution when driving in forced conditions of sleep deprivation, that the driver has to give the minimum distance of  $1.1424 \times$  the car's speed in units of meters.
3. The use of a subjective Karolinska Sleepiness Scale does not have a high degree of correlation with measurements of driving performance, especially in terms of reaction rate influenced by the condition of the driver's lack of sleep.

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#### References

- [1] Hamid, Fajri. 2008. Analisis Tingkat Pengetahuan Pekerja Mengenai Cara Mengemudi yang Aman (Safety Driving) pada PT. X Tahun 2008. Skripsi Program Sarjana Kesehatan Masyarakat, Fakultas Kesehatan Masyarakat, Universitas Indonesia, Depok.
- [2] Badan Pusat Statistik. 2012. Jumlah Kecelakaan, Koban Mati, Luka Berat, Luka Ringan, dan Kerugian Materi yang Diderita Tahun 1992-2011. Retrieved July, 10 2013 from Badan Pusat Statistik: [http://www.bps.go.id/tab\\_sub/view.php?label=1&id\\_subyek=17&notab=14](http://www.bps.go.id/tab_sub/view.php?label=1&id_subyek=17&notab=14).
- [3] Sivaramakrishnan, R., Ramanathan, P. K., Vidhya, S., Arun, C. 2011. Performance Evaluation of EEG and MEG Based Sleep Onset Detection Using Mean Comparison Test. India: *International Journal on Applied Bioengineering*.
- [4] Sleep Health Foundation. 2011. *Drowsy Driving*. New South Wales: Sleep Health Foundation.
- [5] Suhendi, Adi. 2013. 184 Kecelakaan Lalu Lintas karena Pengemudi Mengantuk. Retrieved September, 29 2013 from Tribun Network: <http://www.tribunnews.com/ramadan/2013/08/06/184-kecelakaan-lalu-lintas-karena-pengemudi-mengantuk>.
- [6] Picot, Antonie., Charbonnier, Sylvie., Caplier, Alice. 2008. On-Line Automatic Detection of Driver Drowsiness Using a Single Electroencephalographic Channel. Vancouver: 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society.
- [7] Reyner, L. A., Horne, J. A. 1998. Falling Asleep Whilst Driving: Are Drivers Aware of Prior Sleepiness? *Leicestershire: Int. J. Legal Med.*
- [8] Verster, J. C., Pandi-Perumal, S. R., Ramaekers, J. G., Gier, J. J. de. 2008. *Drugs, Driving, and Traffic Safety*. Switzerland: Springer.
- [9] Ropella, Kristina M. *Introduction to Statistics for Biomedical Engineers*. Morgan & Claypool Publisher.
- [10] Umar, Husein. 2002. *Metode Riset Bisnis*. Jakarta: Gramedia Pustaka Utama.
- [11] BTSI ITS. 2013. Rekapitulasi Jumlah Mahasiswa Semester Genap Tahun 2012/2013 per April 2013. Retrieved November, 24 2013 from Badan



- Teknologi dan Sistem Informasi ITS:  
<http://btsi.its.ac.id/adminbtsi/jumlah-mahasiswa/>.
- [12] Turner, J. Rick., and Thayer, Julian F. 2001. *Introduction to Analysis of Variance: Design, Analysis & Interpretation*. California: Sage Publication.
- [13] Sitompul, Ellen Gunawan. 1996. *Teknik Statistika untuk Bisnis & Ekonomi*. Edisi 9 Jilid 1. Jakarta: Erlangga.
- [14] J. Hair, W. Black, B. Babin, R. Anderson. 2005. *Multivariate Data Analysis*. 6th edition. New Jersey: Prentice Hall.
- [15] Meyers, Lawrence S., Gamst, Glenn, Guarino, A. J. 2013. *Applied Multivariate Research: Design and Interpretation*. Second Edition. California: Sage Publication.
- [16] Saefuddin, Asep, Notodiputro, Khairil Anwar., Alamudi, Aam., Sadik, Kusman. 2009. *Statistika Dasar*. Bogor: Grasindo.
- [17] Al-Farouk, Panji Mitiqo. 2010. Rem ABS (Anti-Lock Braking Sistem). Retrieved February, 15 2014 from Ikhwafillah's Blog: <http://panjimitiqo.wordpress.com/2010/05/22/rem-abs-anti-lock-braking-sistem/>.
- [18] Dishubkominfo Serang. Sesuaikan Kecepatan Kendaraan Dengan Kondisi Lalu Lintas. Retrieved February, 15 2014 from Website Resmi Dishubkominfo Kabupaten Serang: <http://www.dishubkominfo.serangkab.go.id/index.php/web/berita/detail/11/Sesuaikan-Kecepatan-Kendaraan-Dengan-Kondisi-Lalu-Lintas>.
- [19] Harvenda, Aris F. 2012. Nih, Jarak Aman Berkendara. Retrieved February, 15 2014 from Kompas.com Otomotif: <http://otomotif.kompas.com/read/2012/03/17/1308/Nih.Jarak.Aman.Berkendara>.