EVALUATION OF DRIVERS' STRESS USING HEART RATE VARIABILITY IN THE MOUNTAINOUS ROAD DRIVING: IN THE CASE OF OVERTAKING AND PASSING A VEHICLE

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Abstract - It is widely known that stress can have a profound effect on driving performance and road traffic accident. Particularly driving a vehicle in the curved mountainous two-way two-lane road is relatively different from those on expressways or multi-lane roads. To evaluate the drivers' stress due to the driving environment context, for this study we used Twenty-five participants', psychological states while overtaking and passing vehicles on the actual road test displayed in the form of changes in heart rate variability. The collected test data include the participants' heart rate and vehicle speed variation when overtaking different types of vehicles on a straight road driving and passing vehicles proceeding in the opposite direction in different positions on right-turning horizontal curved road sections. Then using a linear interpolation method and formula, the result shows that the stress increment due to overtaking small car raised by 25% and when overtaking large vehicle increased by 17.85% above the normal baseline. However, overtaking large vehicle took high overtaking speed, and riskier than overtaking a small car. Also, passing a vehicle on the curve generated different level of stress based on the position which passing vehicle had been done. Accordingly, the stress level varied between 10.4% and 25.46% and driving on the beginning of the curve had more possibility of a road traffic accident existence.

Keywords - Heart Rate, Heart Rate Variation, Overtaking, Passing, Stress, Vehicle

I. INTRODUCTION

Driving a motor vehicle is a physiological and psychological process that causes much stress. Stress arising during driving has been associated with some factors such as weakened decision-making capabilities, decreased performance and the road condition [1], [2]. Then it influences the driving performance and causes the unnecessary driving speed alterations, surrounding situation perception error, reduced attention and slow reaction [3]-[5]. The identification of risky condition is essential to improve driver awareness, performance and road and traffic safety [6]. In the overtaking process, the vehicle must occupy a lane of the preceding vehicle and must return to the original lane after completed the overtaking process. There are two main reasons for the need to achieve the overtaking process on a two-lane road: one is the speed difference between vehicles that desires the vehicle has to overtake demand. The other is that the opposite lane traffic flow and the present lane can provide an overtaking. When the overtaking demand and overtaking need exist, the vehicle can complete the overtaking process [7], [8]. In this process, different drivers choose different speed, the acceleration during overtaking and the deceleration after overtaking will generate the increased driver's work tasks and cause stress. In the mountains and curved roads, the stress is much more, because the roadside by itself generates stress and the stress generated by driving tasks. Besides, the overtaking speed selected by the driver during overtaking has a significant influence on driving safety. When the vehicle speed is raised too high, it is evident that harder to control the vehicle and difficult to stop with a shorter stopping distance as well [9]. Passing vehicles proceeding in the opposite direction should pass each other by using the right lane. In this process, each driver will keep their lane and sufficient horizontal gap between the vehicles. This incident can cause stress, as well. So the choice of driving speed during overtaking or passing vehicles corresponding to the heart rate variability and a reliable indicator of stress on the road situations [10]. Much research has been conducted to analyze the driver's workload during driving by sorting into a driver's stress [11]-[14], fatigue [15]-[17], and aggressiveness [18]-[22]. Although a variety of studies applied different detection methods to identify the driver's conditions causing stress, such as speech recognition, ECG (electrocardiogram) parameters, skin temperature, and skin conductivity [23],[24], moreover, the stress level can be measured using heart rate variability (HRV) by time-domain, frequency-domain, and non-linear measurement approaches[25]. Heart rate (HR) is the number of heartbeats per minute, and the heart rate variability (HRV) is the fluctuation in the time intervals between adjacent heartbeats [26]. The analysis of the ECG data in-vehicle driving shown that drivers had higher heart rates on high traffic flow roads and narrow streets driving and then become stressed based on the actual road situations. [27], [28].

In this study, the ECG ultra-short-term HRmin-HRmax parameter of the time domain measurement, HRV detection method was used for examining drivers' stress on the overtaking and passing process of vehicles. Then comprehensively analyzed the HRV and vehicle speed samples to spectacle the driving

behavior and stress on the mountainous two-way two-lane road section driving. The outcome of this study is used to improve safe driving by showing traffic accident's black spot condition in the mountainous road.

II. METHODOLOGY

A. Test Route Section

A two-way two-lane road in the Nanxi-Hongtu S103 road section in Yunyang, Chongqing, was selected as a test road. This road section has a regular traffic flow and a mountainous area road, 114 typical curves and 25 straight sections, with 3m lane width. The entire journey covered 60km with the design vehicle speed between 40 and 50 km/hr. depending on the curves and straight road sections, respectively. Fig. 1 (a and b) shows the sample of actual road condition and during the overtaking process. Twenty-five healthily and sufficiently experienced drivers were selected for the road test: sixteen males, and nine females. The age of the drivers ranging between 26 and 45 years old, with the mean (M) = 36.5, and standard deviation (SD) = 6.43. They all held a valid C1 driving license and had driving experience ranging in between 3 and 18 years (M = 9, SD = 4.69). They reported that they drove over 8000 Km/year. All participants were local drivers that often drove on mountainous roads and did not make any severe traffic accidents.

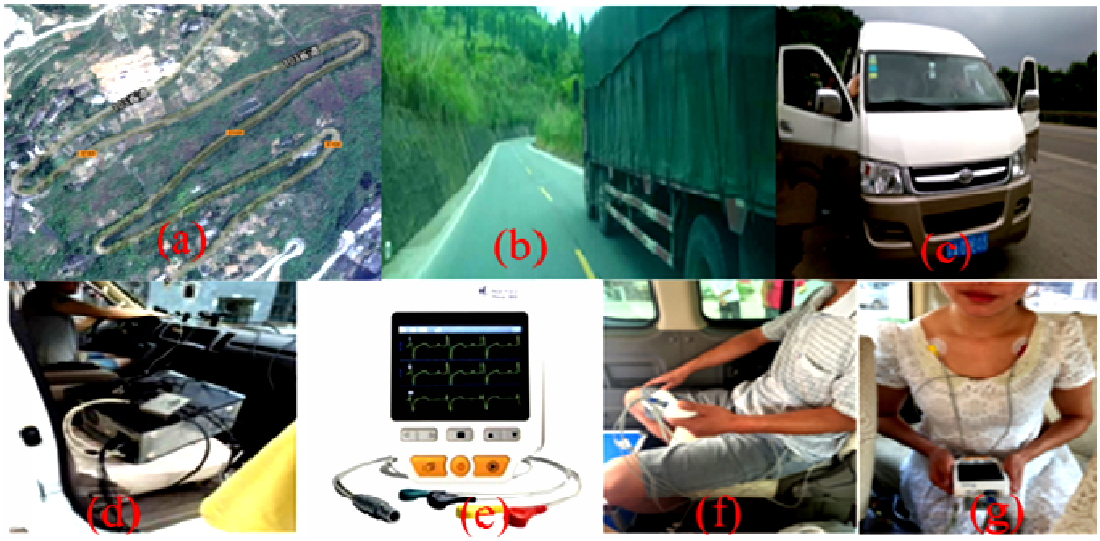

Fig.1 Selected materials and equipment for the real road experiment. (a) sample test road section, (b) overtaking process on straight road driving, (c) test vehicle, (d) participant preparation before the test, (e) Prince 180D fast ECG detector, (f-g) attachment of ECG detector on participants.

B. Materials and Apparatus

The vehicle used for the test is the 9-seat Toyota HIACE medium-size passenger van, as shown in Fig. 1c. Prince 180D fast ECG detector is used to collect heart rate signal of the drivers during the driving test. Electrodes were attached to the participants' chests before each experiment, as shown in Fig. 1 (e to g). Precordial leads were used for ECG recording. Furthermore, the GPS based V-BOX III data acquisition system, based on a new generation of a high-performance satellite receiver, was used for measuring and recording accurate data of vehicle speed and travel distance.

C. Participants

Twenty-five healthily and sufficiently experienced drivers were selected for the road test: sixteen males, and nine females. The age of the drivers ranging between 26 and 45 years old, with the mean (M) = 36.5, and standard deviation (SD) = 6.43. They all held a valid C1 driving license and had driving experience ranging in between 3 and 18 years (M = 9, SD = 4.69). They reported that they drove over 8000 Km/year. All participants were local drivers that often drove on mountainous roads and did not make any severe traffic accidents.

D. Procedure and Data Analysis

A preliminary test was executed in a single trip to avoid apparatus failure and driver route confusion that misleads to the wrong data recording and conclusions. Also, the mean HRV baseline data were taken at this stage. During the actual driving test, each participant was driving once on the test road with their driving style and habits without additional instructions but to observe traffic laws and safety. Then the heartbeat changes and vehicle driving parameters were collected and stored. The test was carried out in the daytime with the normal traffic flow from 10:00 a.m. to 6 p.m. and adverse or dangerous weather such as wind, rainstorms, and intense light weather were avoided. Finally, participants completed the driving self-evaluation questionnaire to a survey about their information such as age, gender and driving experience, including mileages driven and years.

For the convenience and accuracy of data analysis, the ordinary's driving average HRV was used as a

baseline and considered as no stress level. This value was taken in the preliminary test on the long straight road section driving (429.62m) without overtaking or passing the vehicle. Each sample data was collected and recorded throughout the journey. Then, we filtered and analyzed the data only while overtaking and passing process on straight and curved road sections, respectively. In the overtaking process, the data clustered into overtaking small cars and large vehicles. Besides, in the vehicle passing condition, curves were divided into three parts: beginning, middle and the end of the curve. In the test road, there are ten right-turning and eight left-turning horizontal curve sections. And then we choose only right-turning curved road sections without a leading vehicle circumstance. In this study, a large vehicle represented buses, trucks and tankers, and a small car includes cars and vans.

III. RESULTS AND DISCUSSION

A. Stress due to the Straight Road Overtaking Process

HRV and vehicle speed data on the straight road overtaking process were collected in 429.62m, 378.02m, 315.04m, and 279.33m road lengths. On these road sections overtaking small cars and overtaking large vehicle data were used to analyze stress. Then the heartbeat R-R minimum and maximum values filtered from each participant, as shown in the sample Fig. 2a. Similarly, the minimum and maximum driving speed from each participant extracted, too, as shown in the sample Fig. 2b. Finally, we use a linear interpolation method to get the graph of all participants' HRV and speed variations relating with time on the straight road overtaking process of small cars, as shown in Fig. 2c.

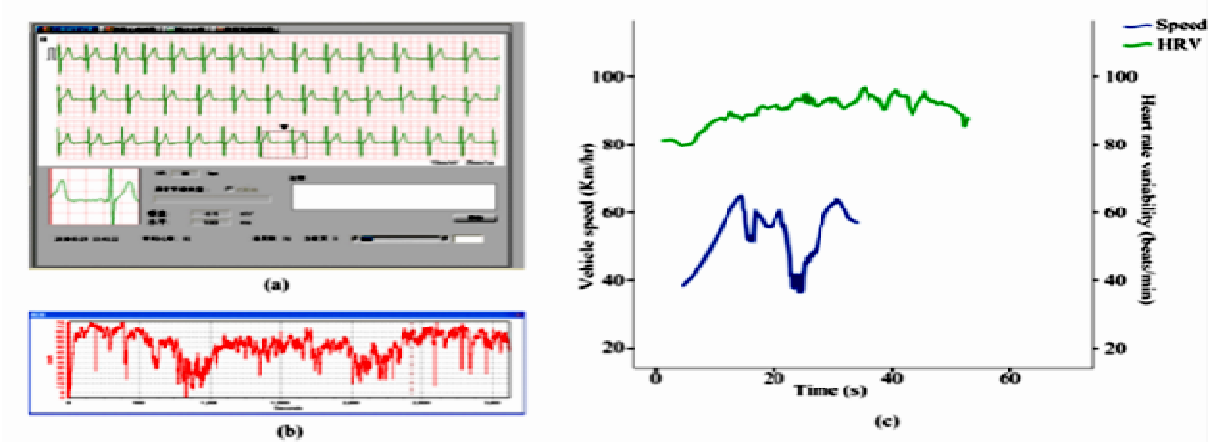

Fig.2 Participants' HRV and vehicle speed over the time domain during overtaking small car process with (a) unevenly sampled heartbeats demonstration of a participant using ECG, (b) unevenly sampled of a vehicle speed demonstration in V-box.

As seen in the above graph, the minimum vehicle driving speed was 38km/hr. and reached a maximum of 64 km/hr. (M= 56.33, SD=10.746) in the overtaking process of small cars. This result illustrates that the vehicle speed gradually increased during overtaking and then decreased after the completion of the overtaking process. Likewise, the minimum HRV value was 79bpm, and the maximum was 96bpm (M= 90.44, SD = 9.648). The HRV also increased during the overtaking process. The Pearson coefficient of correlation (r) analysis between HRV and vehicle speed in the overtaking small cars (OSC) process was 0.503 with p-value (p) <0.01, as shown in table 1. This result shows that the correlation between HRV and vehicle speed was positive and significant. Therefore, the vehicle speed and HRV value simultaneously increased when overtaking a small car.

Statistical analysis / Tasks	r	p
OSC	0.503**	0.000
OLV	-0.258	0.000
PVB	-0.378*	0.042
PVM	-0.456**	0.002
PVE	0.263*	0.013

Table I - Pearson Coefficient of Correlation and p-value in the Overtaking, and Vehicle Passing Conditions.

Overtaking Small Car (OSC), Overtaking Large Vehicle (OLV), Passing Vehicle at the Beginning (PVB), Passing Vehicle in the Middle (PVM), Passing Vehicle at the End (PVE), **Correlation is significant at the 0.05 level (2-tailed), *Correlation is significant at the 0.01 level (2-tailed)

The correlation of HRV based on the increment of vehicle speed during overtaking small cars using the linear regression formula is presented in equation 1.

$$\mathrm{HRV(small)} = 67.944 + 0.426 \times \mathrm{V} \qquad (1)$$

Where HRV(small) is Heart rate variability during overtaking small car and V is the increased vehicle speed in the overtaking process.

Driver's stress is different in the overtaking process of the small car and large vehicle [29]. Fig. 3 shows the total HRV value and vehicle speed in the overtaking process of large vehicles.

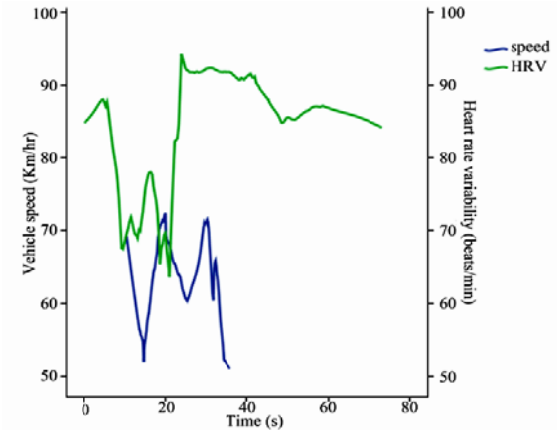

Fig.3 The line graph of HRV and vehicle speed on overtaking large vehicles process on the four straight roads.

During the overtaking process of large vehicles, the driving speed was varied between 51km/hr. and 72km/hr. (M=62.2, SD = 11.33), as shown in Fig.3. Similarly, HRV fluctuated between 64bpm and 95bpm (M= 80.69, SD= 15.85). The statistical analysis of OLV was r= -0.258 and p<0.01, as shown in table 1. The statistical result shows there was a significant and negative correlation between HRV and speed in the overtaking process of large vehicle. This result indicates that HRV due to overtaking had irregular change triggered by the stress, which is known as heart palpitation [30]. Equation 2 used to calculate the HRV due to the increment of vehicle speed when overtaking a large vehicle.

$$\mathrm{HRV(large)} = 111.378 - 0.482 \times \mathrm{V} \qquad (2)$$

Where HRV(large) is Heart rate variability during overtaking large vehicle and V is the increased vehicle speed in the overtaking process. Using the increased vehicle speed data in both overtaking processes of small cars and large vehicles with Equation 1 and 2, we developed the following model.

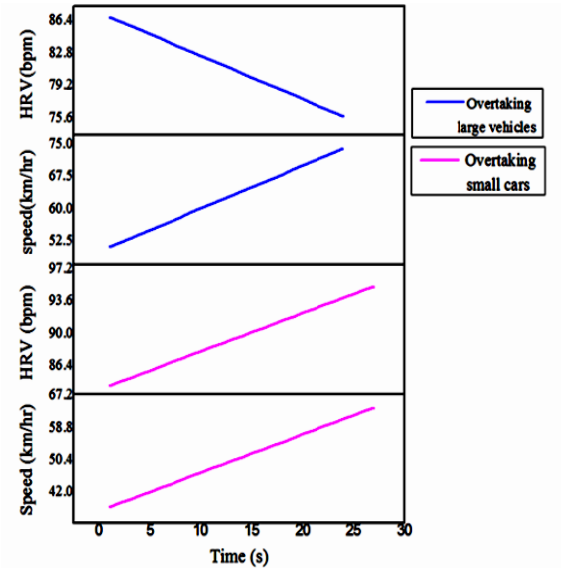

Fig.4 Stack plot model of HRV value for the vehicle speed increment in the overtaking process of a small car and large vehicle.

In Fig.4, the blue and pink stacks line plot represents the relationship between the HRV value and the vehicle speed while overtaking a large vehicle and small car, respectively. During the overtaking process of a large vehicle, when the vehicle speed increased, the HRV value declined. This irregular decline of HRV was caused by high stress (It means the heart has skipped a beat). On the overtaking process of small cars, when the vehicle speed increased the HRV value increased as well. Also, the time taken duration for overtaking small car was longer than overtaking large vehicle because the overtaking small car driving speed was slower than the overtaking large vehicle.

B. Stress Level due to Passing a Vehicle in Different Positions of the Curved Road Section

Passing vehicle was done on the road length of 42.8, 45.22, 51.25, 55.6, 63.71, 67, 67.07, 89.65, 116.51, 158.15m curved road sections. After completing the curve driving, all the curved sections had a straight road condition, as shown in the sample Fig. 1a. The correlation of HRV and vehicle speed at the beginning, middle and end of the right-turning curves is presented separately in Fig.5.

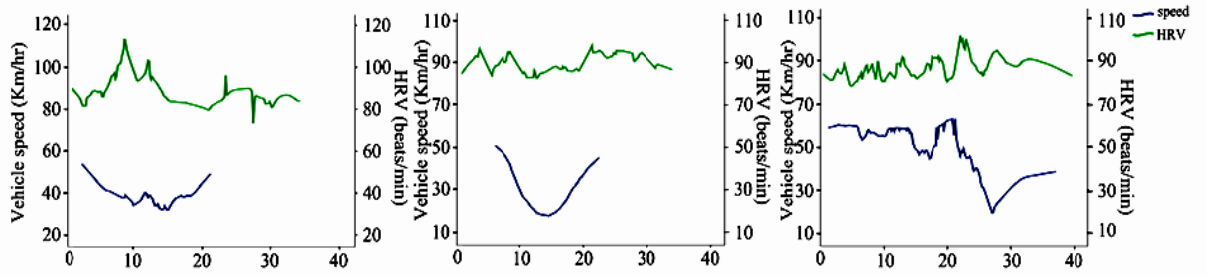

Fig.5 The correlation between HRV and speed on right-turning curved road sections; (a) at the beginning of the curves, (b) at the middle of the curves, (c) at the end of the curves.

1) At the Beginning of the Curve: On the curve driving when the vehicle speed changed, the HRV varied also. During passing vehicles at the beginning of the curve, the speed decreased from 53km/hr. to 33km/hr. (M=40.07, SD= 7.908), as shown in Fig. 5a. Simultaneously, the HRV fluctuated between 79beats/min and 115 beats/min (M= 89.89, SD= 10.404). These show that the speed of vehicle gradually decreased when passing a vehicle at the beginning of a curve. Conversely, The HRV increased to the maximum. The statistical analysis of PVB was r = -0.374, and p<0.01, as shown in table 1. The statistical data shows that there was a significant and negative correlation between HRV and speed in the passing vehicle process at the beginning of the curve. It shows that the HRV increased while the speed of vehicle reduced due to passing vehicle at the beginning of the curve. Then we formulate Equation 3 used to calculate the HRV increment due to the speed change during passing vehicles at the beginning of the curves.

$$\mathrm{HRV} = 114.857 - 0.635 \times \mathrm{V} \qquad (3)$$

2) In the Middle of the Curve: Fig.5b shows, Passing vehicle in the middle of the curve, and the driving speed decreased from 50km/hr. to 20km/hr. (M=35.50, SD= 11.409), and the HRV fluctuated between 88beats/min and 99 beats/min (M= 89.29, SD= 7.676). Speed of the vehicle still decreased when passing the vehicle in the middle of the curve with slightly reduced HRV relatively to the HRV value at the beginning of the curve. The statistical analysis PVM was r = -0.456, and p<0.01, as shown in table 1. The statistical result shows that there was a significant and negative correlation between HRV and speed on the vehicle passing process in the middle of the curve. This result indicates that the passing vehicle driving speed still declined with the increased of HRV. However, the HRV value relatively reduced than passing the vehicle at the beginning of the curve. Equation 4 used to calculate the HRV increment due to the speed alteration when passing the vehicle in the middle of the curves.

$$\mathrm{HRV} = 99.445 - 0.323 \times \mathrm{V}(4)$$

3)At the End of the Curve: The driving speed changed between 22km/hr. and 67km/hr. (M=43.586, SD= 15.026) when passing vehicles at the end of the curve. Alike, HRV fluctuated between 78beats/min and 98 beats/min (M= 86.06, SD= 8.545), as shown in Figure 5c. The PVE statistical data was r = 0.263 and p<0.01, as shown in table1, and it shows that there was a significant and positive correlation between HRV and speed in the passing process of a vehicle at the end of the curve. It describes that when passing the vehicle at the end of the curve the HRV increased due to the increment of speed, but it is the smallest HRV increment comparing to passing the vehicle at the beginning and middle of the curve. Then equation 5 used to calculate the HRV increment due to the speed variation during passing vehicle at the end of the curves.

$$\mathrm{HRV} = 78.111 + 0.156 \times \mathrm{V}(5)$$

After the combined data result from Equation 3 to Equation 5, the heart rate variation because of speed change in different positions of the curve section presented in Fig. 6.

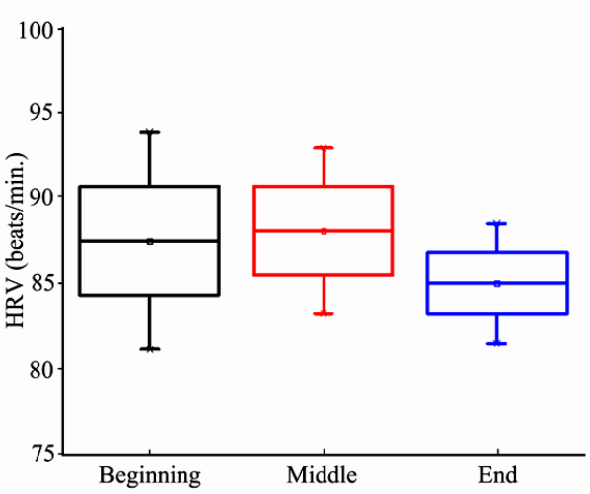

Fig.6 Box plot of mean HRV alterations based on the speed change on different road curvature positions (at the beginning, middle and end of the curve).

Fig.6 shows that the HRV increased when passing vehicle on the curve mainly increased and reached a maximum in the passing process of the vehicle at the beginning of the curve. The increased HRV result means there was high stress and can affect the driving performance [3-4]. Some reasons for the high stress were afraid of the horizontal distance between the

vehicles and size of the incoming vehicle. In the middle of the curve, the HRV reduced relative to the beginning of the curve. Because the driver was familiar with the curve and the speed is reduced to maneuver the vehicle easily. The HRV decreased while passing the vehicle at the end of the curve. Because the stress would reduce for the end of curve driving and relaxed driving attitude would be in the ahead of the road.

III. CONCLUSION

The drivers' stress due to the overtaking and passing process of vehicles on the mountainous road driving using heart rate variability were studied, and major conclusions are as follows:

1. The driver's stress in the mountainous straight road overtaking process, HRV as the indicator of stress, was varied based on the size of overtaken vehicles. The stress level due to overtaking small car increased by 23%; however, the stress level caused due to overtaking large vehicles was raised to 17.85%, which is an abnormal variation due to high stress. In addition, the driving speed for overtaking large vehicles was higher than the overtaking small cars driving speed. Therefore, overtaking large vehicle was more stressed and prone to traffic accident than overtaking a small car on a mountainous road.
2. The stress due to passing vehicle proceeding in opposite directions increased by 10.4% - 25.46% based on the location which passing a vehicle had done on the curve. The stress of the driver was increased by 25.46% while passing vehicles at the beginning of the curve. In the middle of the curve decreased slightly and became 20.37%. Finally, at the end of the curve, declined to 10.14%. Therefore, the driver was more stressed when passing vehicle at the beginning of curve, and it is more prone to accident.

Future investigation could focus upon influence of the stress on the pressure applied on brake and acceleration pedals with including large vehicle drivers (bus drivers) data will explicitly be studied on the identification of traffic accident spot areas in mountainous road driving condition.

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