The quantification of driver stress and their influencing factors

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Introduction

China's road safety problem has become an increasingly uncomforting side effect accompanying its booming car-ownership. Up until April 2002, road casualties in China amounts to over 15 percent of the total road-accident carnage worldwide, while its car-ownership amounts to just 2 percent of the global sum [1]. Skyrocketing road carnage has become a problem no one can afford not to be cautious about.

We have to fall back on the three elements of road traffic in order to tackle this problem, which are human, vehicle and road respectively. As depicted in Figure1 [4], human factors single-handedly cause about 57 percent of road accidents. Another sobering statistic is that accidents involving human factors amount to 93 percent of total accidents. Thus, drivers make a crucial causal factor in the accident generation process. In an emergency, drivers - especially learner and probationary drivers - fall prey to impatience, anxiety, stress and panic, all of which somehow lead to errors and then accidents.

Clearly, stress causes a huge amount of drivers' errors, which in turn directly or second-handedly bring about accidents. Stress, however, is still an abstract psychological term. Firstly, to incorporate it into engineering practice involves the quantification of the so-called stress and the exact values corresponding with different stress levels, which has been pre-set as 'panic', 'very nervous', 'nervous', 'comfortable' by the author. Details will be presented later in the Interpretation of Previous Studies.

Figure 1: Safety System of Roadway [4]
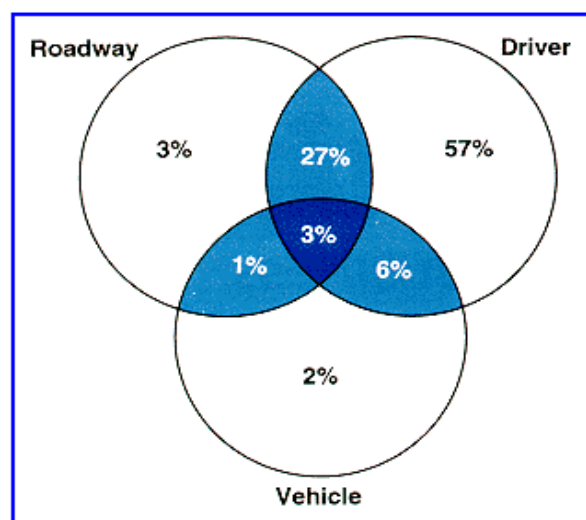
Literature Review:

Xiaodong Pan investigated the correlation between the increment of one's heart rate and radii on mountainous road in Chongqing province, China. As shown in Figure 2 and Figure 3, a person's heart rate generally assumes a larger value with drivers employing a higher speed. In a fixed speed range, the marginal gain in the increment of a heart rate, which is the observed dynamic heart rate minus average static heart rate, climbs as the radii decreases. In other words, the increment of a heart rate is intuitively reciprocal to the radius. Pan concluded that 30 meters is the critical value of radii of a comfortable and safe horizontal curve, because it represents a watershed of the first derivative of the curve: to the right of 30 meters, the curve remarkably climbs at a mild slope. Thus, it is advisable to avoid curves with a radius less than 30 meters. By the same logic, Pan concluded that the ratio between the curve angle and the curve length should take a value below 2.

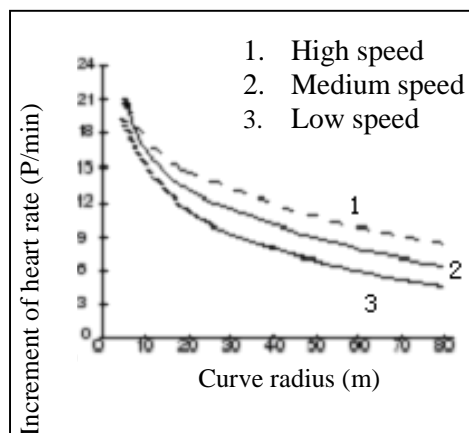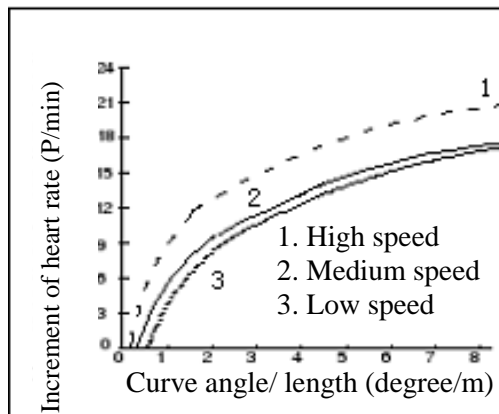Figure 2: Relations Between Increment of Heart Rate and Curve Radius

Figure 3: Relations Between Increment of Heart Rate and Curve angle/ length

Using linear regression, Ke Zheng derived the functional form [5] of the relationship between speed and the increment of heart rate, as well as, a multivariate model [6] between heart rate, curve radius and speed on a straight segment of freeway. With the speed of the vehicle at 40 km/h, comes a functional form powered by –0.203. Zheng concluded that the radius at the value of 509 makes for the watershed of the slope of the curve. With a radius larger than 509, the curve has a fairly mild slope; however, when the radius takes a value less than 509, heart rates surge at an increasingly higher rate as the radius diminishes. Zheng believed that 509 meters might make a good reference point for a minimum radius for similar horizontal curves with a design speed of 80 km/h.

Interpretation of Previous Studies:

First and foremost, to interpret the abstract concept of driver stress, a numerical interpretation of that term is in order. Several medical measurements can represent the stress levels of drivers, such as heart rate, breath rate, skin electrodes, etc. For practical reasons, this research measures the heart rate of subject drivers. As previously stated, the increment of a heart rate is one choice, since it offsets the individual differences between drivers, which can be attributed to age, gender, or genetic factors other than road system elements. Alternatively, the ratio between the increment of a heart rate and the static heart rate for a specific driver makes an even more sensible choice, since it takes into consideration the static heart rate of individual drivers. Thus, this study takes the latter choice and names it by 'changing rate of heart rate'.

Another question one needs to consider is: why bother to study stress? In my opinion, transportation engineers should consult the future stress level manual for roadway design to make sure that their designs are in accordance with the safety and security of drivers. As shown in previous studies, roadway geometry has a noticeable impact on the stress levels of drivers. Furthermore, researches have produced preliminary estimates of critical stress values on drivers.

Their results, however, are more intuitive. For example, the underlying logic is that the point marking the noticeable change in a slope makes the threshold value for stress. This deserves much consideration from two aspects. First, the so-called marking point is subjected to such strong personal preferences that it lacks an appropriate mathematical foundation. As a result, person B may probably give a different estimate of the threshold: such as 15 rather than 30, as the critical value in Pan's research shows. In addition, this contention lacks solid evidence that when the radii are less than 30, the curve presents a hazard to safe driving. Even if point with 30–meter radius makes the exact watershed of slope, the fact that heart rate surges at an extraordinarily higher rate as radius decreases from 30 meters does not necessarily mean that horizontal curves with radii less than 30 meters bring on so much stress that the drivers are actually paralyzed to anxiety and indecision. In all likelihood, a healthy portion of stress may keep drivers alert and thus boost driving performance. The possibility cannot be overlooked that the point with 30–meter radius may very well fit in this mold. All in all, that follows a necessity for the quantification of different levels of.

In conclusion, only when researchers have quantified different intensity of stress, i.e. the independent variable on the right side of the function, can the critical geometry values (which is the dependent variable) be obtained by assigning X a justified value.

Study Design

Subject selection

To represent average drivers, this research chooses as subjects those skillful, healthy and non-commercial drivers aged from 26 to 50. Care should also be taken that subjects do not have medical conditions or drug usage that may cause an upsurge or dramatic reduction in heart rate. Other reasons for such a selection method are: firstly, inexperienced or novice drivers tend to over-react when an incident occurs on the road. Thus, the corresponding changing rate of one's heart rate is prone to assume a much higher value, which can hardly represent the average drivers. Secondly, commercial drivers are not representative since they have different driving behaviors and this research focuses on average drivers. It follows, therefore, the ruling out of commercial drivers. Lastly, age plays an important role on driver behavior. Although it is still not clear what the influence of age on heart rate in driving plays, it has been widely accepted that young drivers are subjected to aggressiveness and risk-taking. The elderly have a relatively longer reaction time and are more vulnerable to fatigue and errors. Thus, to move out "irregulars" from the beginning, the age groups residing over the extremes of the spectrum are excluded.

Road and environment

For practical reasons, this study is conducted on a virtual 50-kilometer urban road segment in a car-simulator. It includes several horizontal and vertical curves with pedestrians crossing the road. Researchers have previously programmed this in advance without acknowledging the pedestrian's presence to drivers. Generally speaking, the road resembles urban freeways in terms of design standard and speed limit; e.g. the ring roads in Beijing. What's more, subjects must be free from distractions in order to reflect the effect of roadway design on stress and to remove sundry factors, such as noise, interrupting co-workers, etc.

It is crucial that subjects have an orientation session before the actual test is run to familiarize them with the vehicle and the 'road' they will be driving on. Some reported dizziness during the orientation run.

Equipment

Two major pieces of equipment were used in the study. For practical reasons, the study was conducted in a car-simulator, which helps to increase the ease of conducting a driving test, as well as to observe desirable phenomena. The differences between a virtual setting and the real-world road, however, may impair the validity of the result. The other is Holter, which measures and stores the heart rate every 0.01-second.

Timing

It has been concluded that people generally are at their peak of performance from 9:00 to 11:00 am, whilst they tend to be prone to fatigue and sleepiness during 2:00 to 4:00 pm [2]. Therefore, the time for the experiments was fixed at the optimum performance period.

Procedure

Two fellow researchers were needed in the study with one recording the moment when a subject reports his/her stress level, the trigger and also every noticeable event on the road, while the other making sure that the Holter was working properly and the wires were attached properly to the driver. Here, the term 'noticeable events' refers to events on a road that is both observable and that might influence drivers both psychologically or behaviorally, e.g. overtaking or being overtaken; maneuvering on a curve; or a crossing pedestrian, etc. As a subject undergoes road curves, pedestrians, overtakes or is overtaken, he/she reports the stress levels to the researcher. It is highly important that time zero must be synchronized for the stress-reporting procedure and Holter. (Please refer to Appendix Table 2 for a copy of the form).

It turns out, however, that the number of subjects reporting 'panic' was too small to yield any result with reasonable statistical precision.

Sample size

Samples must be large enough to justify the statistical precision of the conclusion. Equation 1, which can be found in any statistical textbook, is used in determining the number of observations.

$$N \geq (SK/E)^2 \qquad\qquad [1]$$

N – sample

S – standard deviation

K – constant given a confidence level

E – margin of error

Standard deviation in Equation 1 can be estimated by range/4 [3]. The range is approximately calculated by the subtraction between the maximum and minimum of the changing rate of a person's heart rate from previous experiments. We also need the margin of error to be less than 3%. Appendix Table 1 shows that K is to be 1.96 for confidence coefficient 95%. In sum, we have 7.56% for standard deviation and 2.75% for margin of error. Solving for N, we obtain N≥29.03. Finally, measurements are 30 for each of the four stress levels.

Data Analysis and Result

A descriptive statistical analysis is presented in Table 1 and Figure 4.

Table1. Descriptive statistical analysis:

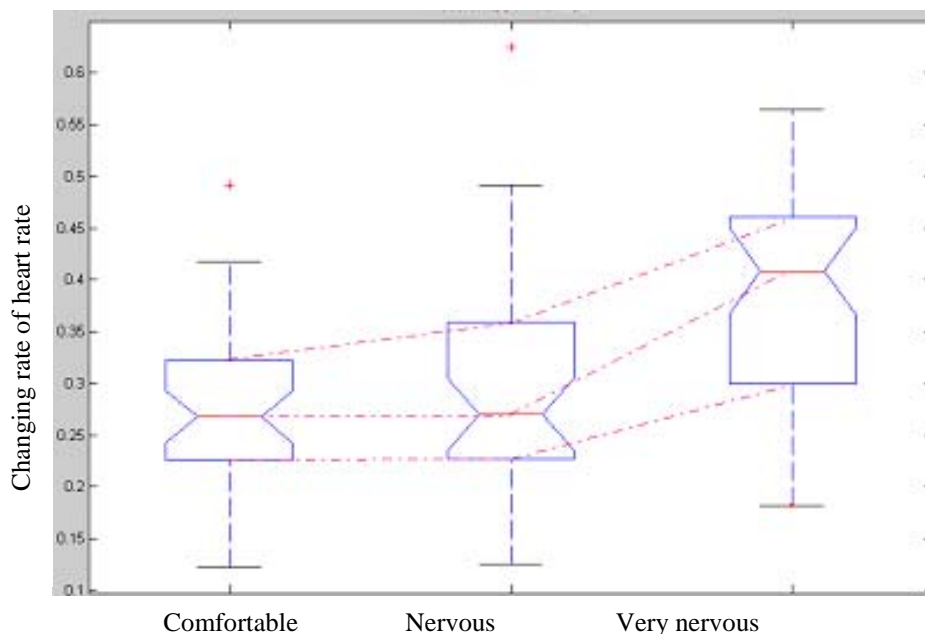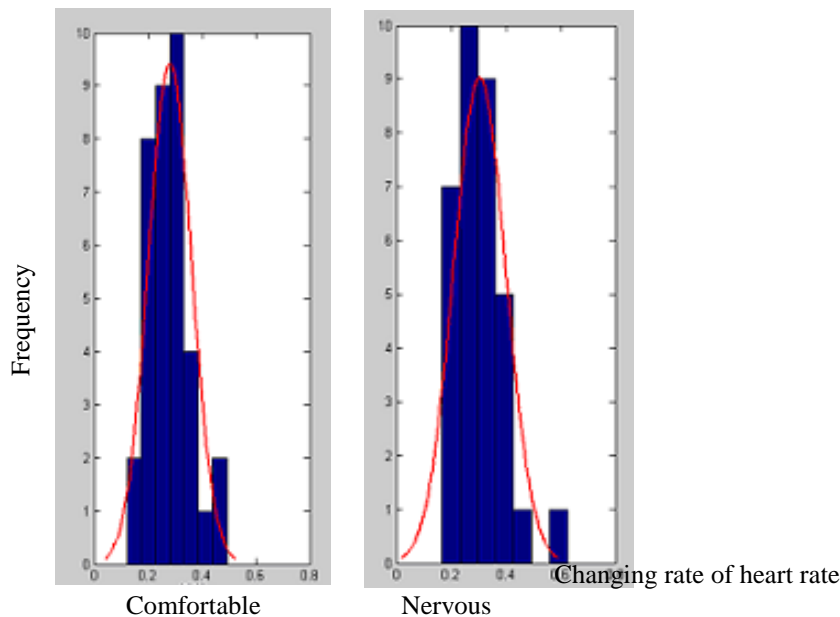| Stress Level	Comfortable	Nervous	Very Nervous
Minimum	12.26%	16.69%	18.17%
15th percentile	19.82%	20.55%	27.93%
50th percentile	24.76%	33.38%	39.28%
85th percentile	36.46%	40.31%	49.63%
Maximum	49.19%	62.48%	56.39%
Mean	28.14%	30.43%	38.78%
Standard deviation	8.03%	9.53%	10.47%
Range	36.93%	45.79%	38.22%

Figure 4: Box Plot

Figure 5: Frequency Histograms for 'Comfortable' and 'Nervous' Level

From descriptive analysis, we have made the following conclusions:

Firstly, the changing rate of one's heart rate increases as one's stress level intensifies, which is well manifested in the box plot. We do, however, discover that despite the fact that 'Comfortable' and 'Very nervous' levels have distinct range, the 'Nervous' category overlaps considerably with the other two. One reason lies in the establishment of the stress level in the beginning of this study. The medium category may confuse subject drivers in distinguishing between 'Comfortable' and 'Nervous' and between 'Nervous' and 'Very nervous'. In addition, the range of 'Nervous' is 45.79%, the largest of the three categories, 8.86 percent larger than 'Comfortable' and 7.57 percent than 'Very nervous', which shows the changing rate of heart rate of 'Nervous' is more dispersed than the other two. The same reason applies to the wider range of the 'Nervous' group.

Secondly, the three categories have different statistical distributions. The 'Comfortable' level is normally distributed with a mean of 0.2814 and a standard deviation of 0.0803, whilst the other two are not. Intuitively, the 'Nervous' level may very well have a χ^2 distribution as shown in Figure 5. Since the statistical distribution is not the focus of this research, no further investigation will be devoted to the distribution functions of the other two stress levels. The distinct distributions of the 'Comfortable' and 'Nervous' do reflect, however, to some extent, the difference in the nature of the two stress levels. While the comfortable level is normally distributed, as the stress accumulates, people develop a different psychological manner, and probably, a distinct driver behavior.

The questions about 'outliers' begin to emerge. Figure 4 shows that two outliers are observed in the 'Comfortable' and 'Nervous' categories. Outliers can be caused by recording errors of an observer, or by a random malfunction of the equipment, or by an absent-minded researcher who transposes data, or possibly by the misreporting of the subjects. Most importantly, outliers may serve as a manifestation of the random nature of our study of interests.

It is of use to take a closer look, however, at the two outliers in the research and figure out, if possible, the potential causes. The outlier in the 'Comfortable' category was recorded when the driver underwent a tight curve. Normally, the point would fall into the latter two categories. In this case, the driver reported a relatively lower stress level than his changing

rate of heart rate indicated. It could be attributed to the unsatisfactory sample size. For the scarce number of drivers suitable for the experiment, each driver being selected had to perform the task several times in order to fulfill the sample size requirement. The driver from which the outlier was recorded had gone through several runs and thus became fairly familiar with road features. Even if the tight curve had had an effect on the driver physically, (which was shown in the surging heart rate), the driver himself might feel nothing about it and thus reported a rather low stress level. This constitutes an alternative reason for the outlier.

From a different angle, this outlier shows that stress is a complicated concept. Not only is it related to the physical environment, such as noise or disturbing roadway design, it also had a strong connection with the perception of drivers themselves. Thus, what a driver will report depends on both his/her physical indicator, such as heart rate, and his/her own perception of the situation. Despite the subjective trait of stress, it is still valid to figure out the approximate range of a heart rate that a certain level of stress generally resides within.

Another conclusion is that standard deviation steadily increases as stress level intensifies. From 'Comfortable' to 'Very nervous', the standard deviations are 8.03%, 9.53% and 10.47% respectively. This research comes to a conclusion that as stimuli intensifies and/or multiplies; human's eccentricity takes hold, which manifests in this case an increasingly dispersed changing rate of heart rate. It follows a possibility that in information-overloaded or a stressful setting, such as urban roads in peak hours, drivers tend to exhibit various behaviors depending on their own preferences or even genes. For road departments, however, it is impossible to accommodate the entire range human beings exhibit in face of exasperating or unsettling stimuli, which in turn makes a necessity keeping the information load under control.

Conclusion

First, the changing rate of a heart rate increases as stress intensifies. The following data reveals the 50 percentiles of 'Comfortable', 'Nervous' and 'Very nervous': 28.14%, 30.43%, and 38.78% respectively.

Second, the three categories have different statistical distributions, amongst which the 'Comfortable' category is normally distributed.

Third, stress is a complicated concept. Of course, the word 'concept' does not mean that it cannot be understood in a concrete way. As shown in previous illustrations, however, a drivers' perception of stress and their resistance to stimuli heavily influence reported stress levels. Other influencing factors include road environment, violation of drivers' expectancy, incidence, geometry, driving experience and physique, etc.

Last but not least, the standard deviation increases as one's stress level intensifies. This follows the conclusion that people's eccentricity, which usually posts a hazard to safety, takes hold as stimuli surge. Road departments should put a cap on the stimuli or information that drivers are exposed to, since it is impossible to build a facility accommodating various traits of road users.

Problems for Further Study

First, the micro-classification of stress levels, which partially causes the medium category overlapping with the other two categories and having the largest range. In future studies, a less complicated stress classification is in order. Besides, a sample size of the 'Very nervous' category is far from yielding satisfactory and precise statistics. Therefore, a great room has been left to investigate drivers' response in an extreme frustrating scenario.

Second, the outlier in the 'Comfortable' category reflects a deficiency in sample size. To improve this research, it is necessary to recruit more suitable drivers to remove subjective influences from stress reporting.

Despite the fact that thresholds for different stress levels are obtained in this research, it is overwhelmingly important to bear in mind that a fundamental assumption is the equality between a car-simulator and the real road. In a car simulator, however, drivers tend to be more relaxed than in a real-world situation where a crash results in possible injury or death. Thus, to better the results, it is advisable to conduct research in a real road, or to obtain a conversion factor for data obtained by car-simulator.

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Appendix

Table 1. K values for a given confidence level

K	Confidence level %
1.00	68.3
1.50	86.6
1.64	90.0
1.96	95.0
2.00	95.5
2.50	98.8
2.58	99.0
3.00	99.7

Table 2. Form for recording stimuli

No.	Time (x'y'')	Stimulus					Others
		Overtake	Overtaken	Pedestrian	Horizontal curve	Vertical curve	
1							
2							
3							