

# Evaluating safe driving behavior in a driving simulator

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**Abstract**— This paper presents a methodology for evaluation of driving performance based on speeding, acceleration, lane control and safety distance. All these variables are measured in a motion-based driving simulator. We report on a user study in which we obtained the proposed variables for 29 drivers. These results will enable us to propose a general evaluation score of driving performance, which can be used for profiling driver behavior.

## I. INTRODUCTION

The number of vehicles in traffic increases every year and consequentially also the number of traffic related accidents. Despite extensive prevention activities for traffic safety has been done, more than 26 000 people died on European roads in 2015 and there was no improvement compared to 2013 and 2014 [1]. The motivation for this study is to evaluate driving behavior by examining several key driving features, such as safety distance, considering speed limits and traffic rules and accelerations. Our aim is to get an objective evaluation score of driving performance, which can be used for driver behavior profiling (i.e. safe and unsafe behavior).

The aim of this research is to classify drivers according to their overall driving behavior, considering speeding, winding, acceleration and keeping safety distance. We want to define classes of drivers with exact boundaries within they are considered safe or unsafe.

## II. RELATED WORK

Researches all over the world have tried to identify the causes for traffic accidents, to understand driver's behavior that has led to them, and categorize critical driving profiles that most commonly contribute to them. Majority of these researches has been based on examination of past events and accident records or self-evaluation questionnaires. Based on accidents, it was shown that human factors contribute to 95% of traffic accidents, and driving behavior was identified as the most important one [2, 3].

Bonsall et al. [4] explored the choices of values for safety-related parameters in simulation models. This study includes an extensive research of safety-related parameters and comparison between different sources. Parameters are desired speed and headway, reaction times, rate of acceleration and deceleration and other parameters not significant for our research.

The use of driving simulators seems much more appropriate than real vehicle particularly from a safety point of view, as they enable also simulation of various dangerous driving conditions without exposing the driver to a real physical risk. Other important advantages are controllability, reproducibility and standardization [5].

Driving simulators enable controlled and robust acquisition of various driving performance indicators, such as lane deviation, reaction time and lateral acceleration [6-8]. These kinds of indicators usually focus on operational level skills of drivers [9].

## III. EXPERIMENTAL DESIGN

We conducted a between-subject driving simulator study consisting of two driving scenarios. Participants were given no specific instructions on how to drive in each condition and they were given no explanation on what the goal of the experiment was. Our aim was for participants to drive normally and according to their typical driving behavior.

The first scenario contained the road with different technical properties (e.g. curves with different radii, different speed limits, altitude changes and changes between urban and landside surroundings) and no traffic. We measured speeding (i.e. current speed and speed violation), lateral shift (i.e. position of the vehicle on the lane), acceleration and deceleration.

The second driving simulator scenario included a motorway with varying traffic intensity. This scenario was designed to assess the safety distance (i.e. distance to the leading vehicle).

The study was performed in a NERVtch [10] motion-based driving simulator, consisting of a 4DOF motion platform and SCANeR™studio DT simulation software [11]. User study included 29 participants. They all started with a test drive to get acquainted with the simulator and then executed both conditions twice. Consequentially we collected result set of 58 trials.

## IV. MEASURED VARIABLES

### A. Speeding

Speeding is defined as the average normalized exceeded speed. The normalized exceeded speed is defined as

$$V(t) = \begin{cases} \frac{v(t)}{v_{limit}(t)} - 1, & v(t) \geq v_{limit}(t) \\ 0, & v(t) < v_{limit}(t) \end{cases}, \quad (1)$$

where  $v(t)$  is the current speed and  $v_{limit}(t)$  the current speed limit. The value of  $V$  represents the percentage of the speed excess. The average of the value  $V$  takes into account the duration and also the intensity of all the speed excesses.

### B. Lateral shift (lane deviation)

Lateral shift is defined as the average factor of exceeded lateral shift, i.e. crossing the lane border. The percentage of exceeded lateral shift is defined as

$$D = \frac{1}{2} \cdot \begin{cases} \frac{|d| + \frac{W_{Car}}{2}}{\frac{W_{Lane}}{2}} - 1, & |d| \geq \frac{W_{Lane} - W_{Car}}{2} \\ 0, & |d| < \frac{W_{Lane} - W_{Car}}{2} \end{cases}, \quad (2)$$

where  $(W_{Lane}) = 3,5m$  is the lane width,  $(W_{Car}) = 1,7m$  the car width, and  $|d|$  the lateral shift from the center of the lane. The value  $D$  represents by what factor of  $W_{Lane}$  the lane borders are exceeded (e.g.  $D = 1$  means the lane border is exceeded by  $W_{Lane}$  and this means the car reached the opposite border of the opposite lane). The average factor  $D$  takes into account the duration of the lane excessing and the also the intensity.

### C. Acceleration

The maximum allowed acceleration value considered as safe driving behavior is  $1.5 m/s$  [2]. The acceleration was evaluated as the factor of maximum acceleration excess defined as

$$A(t) = \begin{cases} \frac{a(t)}{a_{max}} - 1, & |a| \geq a_{max} \\ 0, & |a| < a_{max} \end{cases}, \quad (3)$$

where  $a(t)$  is the current acceleration and  $a_{max}$  the maximal safe acceleration. We observed the average of the value  $A(t)$ , which represents the duration and intensity of acceleration excessing.

### D. Safety distance

Safety distance or headway time, defined as the ratio between distance to following vehicle and the speed as  $T(t) = X(t)/v(t)$ , where  $X(t)$  is the current distance to the leading vehicle and  $v(t)$  is the current speed.

We assumed that if  $T(t) > 5s$ , there is no leading vehicle and this data was ignored. We used the minimum safety distance  $2s$ , which is a combined value between travel time to following vehicle, reaction time and deceleration time [2]. The observed value was defined as

$$S(t) = \begin{cases} 1 - \frac{T(t)}{T_{MIN}}, & T(t) \leq T_{MIN} \\ 0, & T(t) > T_{MIN} \end{cases}, \quad (4)$$

where  $T_{MIN} = 2s$  is the minimum safety distance.

The value  $S(t)$  represents the factor by which the '2-second rule' is violated.  $S(t) = 0$  means that the safety distance is safe,  $S(t) = 0.5$  means that the safety distance is violated by half and is only  $1s$ .

## V. RESULTS AND DISCUSSION

We calculated average values of the four observed variables and defined margins for eight independent regions of results. Figures 1-4 show distributions of all four variables as histograms, where trials represent individual driving sessions.

The distribution of speeding variable shows that the highest number of drivers had an average speed excess 6 percent or less over the speed limit. However, some drivers exceeded the speed limit for up to 21 percent or even more. Those high values indicate threatening violation of the speed limits.

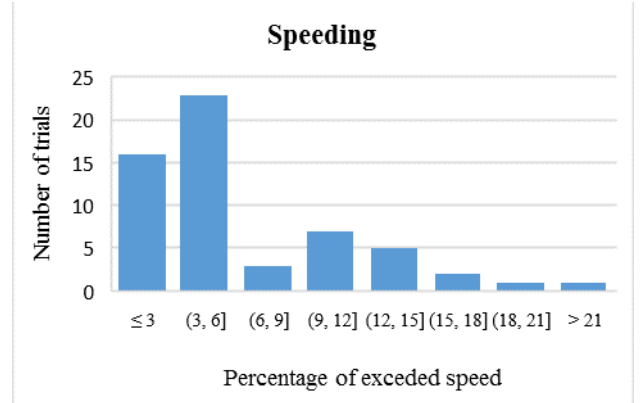


Figure 1: Distribution of the percentage of speed violation

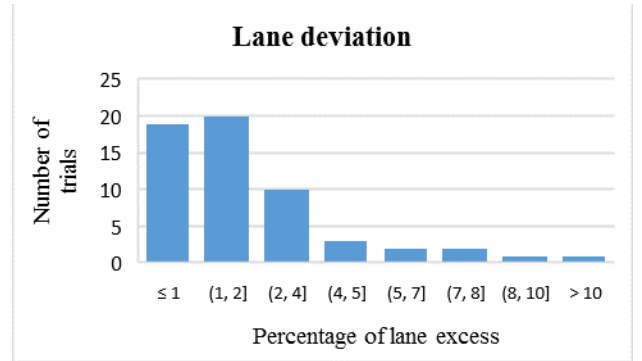


Figure 2: Distribution of the percentage of lane excess

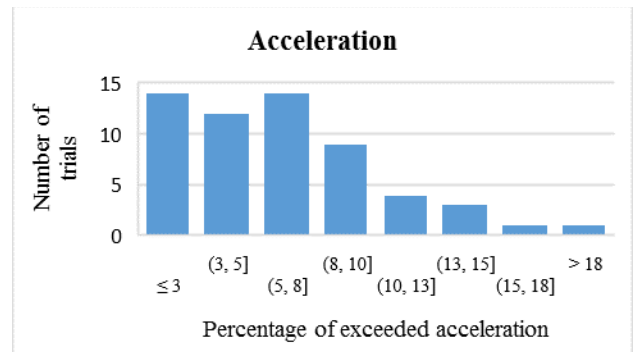


Figure 3: Distribution of the percentage of exceeded acceleration

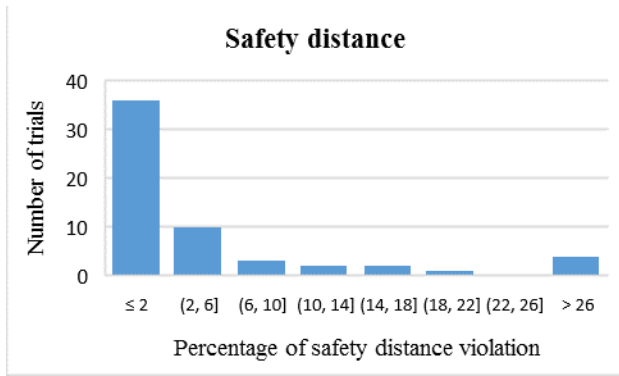


Figure 4: Distribution of safety distance violation

Distribution of lane excess or lateral shifting shows that the majority of test subjects drove without swerving and did not cross the lane border in more than two percent of the cases. The other drivers exceeded the border in up to the average of 10 percent road lane. Contrary to these results, we expected the majority of drivers to drive without the lane crossing (lane deviation of 0 percent), since the width of the car was less than half of the lane width and there should be enough space to keep the car on the driving lane.

The distribution of the acceleration shows that approximately equal number of drivers exceeded the safety acceleration limit (1.5 m/s) for 0 to 8 percent. For higher exceeds (for up to 18 percent) the number of drivers drops significantly. Compared to other distributions this one is shifted towards the higher values. All drivers had to accelerate from a complete stop to the desired driving speed and decelerate due to speed limits and sharp curves, which in some cases caused unavoidable exceeding of the predefined maximum acceleration for safe driving. Consequently, each driver recorded an inevitable amount of acceleration exceeds, which resulted in higher average value and shifted the distribution to higher values compared to the other three variables.

The safety distance, which was measured in a separate scenario, was violated averagely for less than two percent by the majority of drivers. The rest of the drivers violated the safety distance for up to 26 percent, which means only 1.5 s of headway time.

TABLE I.  
SCORING SYSTEM FOR SAFE DRIVER BEHAVIOR PROFILING

	5	4	3	2	1
Speeding	0 - 1	1 - 3	3 - 7	7 - 15	15 - ∞
Lane shift	0 - 0.5	0.5 - 2.5	2.5 - 5.5	5.5 - 10	10 - ∞
Accel.	0 - 3	3 - 6	6 - 10	10 - 15	15 - ∞
Safety distance	0 - 0.3	0.3 - 1.5	1.5 - 5	5 - 10	10 - ∞

In general, these results show overall driving behavior since they have been calculated as averages over the complete driving period. Even if these numbers are averages, we should take into consideration that in some cases temporary violations were very high. For example, violations of safety distance for an average of 25 percent corresponds to only 1.5 second of headway time (in some cases this value was even higher, e.g. 1.0 seconds or even 0.5 seconds), which is an extremely dangerous behavior. We could assume that such dangerous behavior could very likely lead to an accident. The average values of individual parameters used in our model take into consideration those extreme values and also the duration of these violations. Thus, they are very good estimates of typical driving behavior of each individual drivers.

Based on these results we could identify groups of drivers based on driving behavior, i.e. their results in each category. We proposed also a simple scoring system, which ranks and profiles individual drivers based on their performance in a simulator. An example of such scoring system is presented in Table 1. The safest driver gets the score 5 and the most dangerous gets 1. The proposed limits for each score were set in a way, to get a normal distribution of drivers among the scores. The score distributions of our trials for all four values are shown in Figures 5-8.

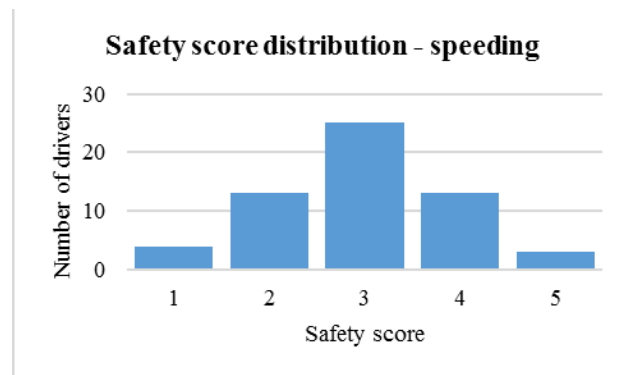


Figure 5: Distribution of speeding score

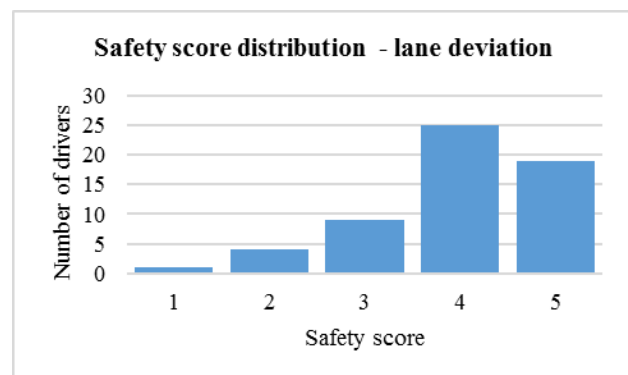


Figure 6: Distribution of lane deviation score



Figure 7: Distribution of acceleration score



Figure 8: Distribution of safety distance

We conclude that the data collected in driving simulator is very useful in the means of driver classification. The results are showing realistic distributions among the four observed values. These results enabled us to propose five classes of driver behavior from very safe to very dangerous. With such scoring system, we can create also a profile of each individual driver. Such profile gives us a valuable insight into his or her driving behavior and offers an opportunity to reconsider his or her driving habits in real life situations.

In this study we considered the average values, calculated from total number of violations in the driving session. Therefore this metric is linear. However, breaking distance and collision severity don't increase linearly with the driving speed. There is a quadratic relation between these variables and the driving speed, since there is a quadratic dependency of kinematic energy on velocity. Future profiling should therefore penalize higher speed

violation more than other behavior variables. Also for other variables, the new model should evaluate drivers who violate the rules less frequently but more intensively as more dangerous, than drivers who violate the rule less intense but over a much longer time period.

#### ACKNOWLEDGMENT

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