Abstract — Behavior of road users on railway crossings has still not been investigated enough. This paper presents the recent results of a study focused on road users’ behavior at level crossings. The study was performed on our driving simulators, equipped with a full car mockup and 360° horizontal field of view. On the virtual track, six different level crossing warnings and traffic signs were tested. This includes an alternative signalization with common road traffic semaphore lights. The paper describes the whole procedure of experiment and measured data. Finally, the paper presents the results of data analyses and discussion based on eye-tracking measurements.

Keywords — Driving simulator, Eye tracking, Level crossing, Human-Machine Interaction

I. INTRODUCTION

Recent studies [2] show that dangerous behavior of car drivers can be divided into three basic groups: driver’s errors, lapses and violations. Each of them has different psychological nature and consequently each of them requires a different way of treatment. The errors usually come from insufficient knowledge of (local) rules or poor driving skills of a particular driver. Lapses are caused by distracted or inattentive driver’s behavior. Both of the previous cases are not performed intentionally. Unfortunately the most serious accidents are caused by intentional violations [2], which forms the third group.

On the other hand, dangerous behavior on level crossings seems to be much more complex [4]. There are many parallel influencing factors which factor into dangerous situations. These are mainly:

- Character of the level crossing (size etc.)
- Character of the signalization of the level crossing
- Knowledge of rules for safe use of the level crossing
- Environmental factors (weather condition etc.)

Several studies [1] [3] have already proven that most of the accidents at level crossings are caused just by the fault of car (whichever category of fault it is). This is the reason why it is necessary to investigate the ways of eliminating such faults. This paper deals with an objective evaluation of the suitability of different types of signalization (warning) systems for level crossings with the use of driving simulators.

II. EQUIPMENT

The experiment was performed on the driving simulator developed by the Driving Simulation Research Group of the Faculty of Transportation at the Czech Technical University in Prague (see for more details). The experiment protocol was derived from a series of experiments which has been performed in this laboratory for almost seven years. The methodology of measurement was revised with respect to the needs of the specifics of level crossings, which will later be described in more detail.

A. Driving simulator

The compact (or full bodied) simulator is based on the compact middle class car Skoda Octavia II (Fig. 1), equipped with an automatic gearbox. The projection screen of the simulator is cylindrical, covering about 210° (horizontally) of the driver’s frontal field of view. The image in all three mirrors is reflected from a planar projection screen staying behind the car body. The tested driver is surrounded by an almost complete all-around picture of virtual reality. Such an arrangement maximizes immersion into the testing scenarios and consequently the validity of the measured data.

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B. Testing track

Because the experiment with level crossings is very specific and significantly differs from the previous experiments, it was advisable to build a new testing track. The virtual scenery had to fulfill several requirements of which the most important ones are:

- Creation of six types of level crossings including their respective signalization systems
- Creation of a model of an animated train
- Enhancements of road traffic with the ability to stop correctly in front of the crossing signalization if signaling for approaching train
- Railway body
- Specific buildings and trackside objects

During the testing drives, the drivers had to pass four rounds of the testing track, so that he/she had a chance to meet each of the level crossings twice in “active” state. The circuit is composed of two parts – an easy one and a demanding one. Both are of a length approximately 10 km. The easy part is composed of straight roads and curves with big radii and the drivers had to keep a velocity of 80 km/h while the demanding part is composed of sharper curves and therefore the speed here is set at 50 km/h. The road is 2 lanes (each for one direction) with a lane width of 3.5m as it is recommended for this kind of road. The traffic was generated only for the contra lane, so that the driver’s behavior would not be influenced by traffic.

Six level crossings were distributed uniformly over the track, each equipped with a respective warning system. They differ in several parameters (gate, lights, view conditions, etc.). In the next set of pictures, all of them are shown as live screenshots from a virtual reality generator. These are level crossing:

- With a blinking set of red lights and white light signal (Fig. 2)
- Simple cross with a static STOP sign (Fig. 3)
- With a blinking set of red lights (Fig. 4)
- With a blinking set of red lights and gates (Fig. 5)
- With alternative road traffic lights (semaphores) (Fig. 6)
- With a blinking set of red lights in an urban environment (Fig. 7)
C. Eye tracking

The eye tracking approach is a method widely used in experiments which need to analyze an actual proband’s gaze point - focus (Fig. 8). It is very often used in the advertisement industry but it is a very useful tool for experimentation in the human behavior area. This is because the visual channel usually carries most of the information utilized by the cognition processes.

In this experiment eye tracking was used to analyze the driver’s gaze nearby and at the level crossings. The investigation was done to find out the driver’s scanning process at the crossings, look for possible approaching trains and perception of the particular warning signalization elements. Such data is also a reliable marker of the driver’s attentiveness and ability to fulfill the primary driving tasks.

III. Experiment

A. Experiment setup

The tested drivers had to pass four rounds of testing track (all after a familiarization with the driving simulator) during which they needed to stop at railway crossings. The sequence of “closed” crossings was distributed over the whole experiment so that the drivers had to stop at all of them twice.

Before driving, the drivers were fitted with the eye tracking helmet which is additionally equipped with a front camera which records the driver’s actual view. After driving the drivers had to fill out a questionnaire about their knowledge in the area of level crossing use.

B. Testing cohort

We tested a set of 23 experimental drivers of mixed age and sex. The cohort consisted of 15 men and 8 women in the age range of 25 to 35 years (glasses limits the use of eye tracking, so elderly drivers are problematic). All of them were active but nonprofessional drivers.

C. Measured data

During driving, all of the data from the simulator, as well as the data from eye-tracking, were recorded. We also recorded the driver’s face view. The simulator records a complete set of variables allowing the reconstruction of car/driver behavior in each particular moment. The most important for us are:

- Car position in world coordinates
- Car heading
- Car position within the lane
- Car speed
- Steering wheel angle and pedal positions
• Position and state of functional elements in the scenarios (trains, signalizations…)

Synchronously the eye gaze position and video from the driver’s view are recorded.

IV. Analysis of measured data

All of the analyses were focused on objective measures (besides the evaluation of the questionnaires). Primarily the analysis of driving parameters (from the simulator) was done, mainly concerning the position and speed of the car. The depression of the brake and throttle pedals was also considered [5]. The methodology of analyses was derived from our previous experimental work focused on drivers’ fatigue and distraction ([6,7]).

The analytical work was done in the following three directions:
• Analysis of video records and record of the gaze from the eye tracker
• Analysis of the technical parameters of driving
• Evaluation of the questionnaires

A. Analysis of eye tracking videos

Besides the gaze point trajectory, the video recordings were also analyzed. The video recording contains in each frame the cross showing an actual drivers point of visual interest. In the next picture an illustrative path tracking the driver’s gaze put into a static image is shown (Fig. 9).

![Fig. 9. Trajectory of the driver’s focus (on the background of driver’s view)](image)

Based on these videos, an analysis of the drivers’ “visual behavior” at the crossings was done. We investigated mainly if and how the drivers looked at the possible train approaching, from which side, correlated with the type of crossing and its state (warning, clear, stop, gates going up etc.). In the next table the most significant situations are shown (Table I).

<table>
<thead>
<tr>
<th>Situations</th>
<th>Crossing 1</th>
<th>Crossing 2</th>
<th>Crossing 3</th>
<th>Crossing 4</th>
<th>Crossing 5</th>
<th>Crossing 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Situation I After switching off the warning signalization lights the driver did not look over the crossing (did not checked the situation) and went over it.</td>
<td>75%</td>
<td>-</td>
<td>50%</td>
<td>80%</td>
<td>100%</td>
<td>30%</td>
</tr>
<tr>
<td>Situation II Percentage of drivers did not look over when approaching to a “clear” crossing (warning lights are switched off).</td>
<td>75%</td>
<td>-</td>
<td>75%</td>
<td>80%</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>Situation III Percentage of drivers, who did not stop in front of the crossing without any active warning system, equipped with across and STOP sign.</td>
<td>-</td>
<td>10%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Based on the table above it is possible to derive that the drivers respond relatively high on the expected function of the warning system and if the level crossing system signalizes CLEAR (blinking white, not blinking red, gate up etc.), they often do not check visually whether the crossing is clear or not. This is also valid for the crossing equipped with alternative signalization (traffic light), moreover they bypass the yellow signal. Only the crossing with a cross and STOP sign was the exception, where all the drivers carefully looked over both sides for a possible approaching train. On the other hand, some of them did not stop at STOP sign but only slowed down.

B. Analysis of technical data

When analyzing the measured data, besides the driver’s gaze we focused on so called performance outputs from the simulator, which characterize the driver’s behavior on the road and his/her particular reactions to displayed situations at and in front of the particular level crossings. First of all, it was investigated whether or not the driver slowed down to the prescribed speed, stopped in a safe distance and respected the signalization and signs. The results for example showed that a certain part of the driver population do not respect light warning signalization and start to go just after the gates go up (which could be extremely dangerous on some level crossings).

Because the output from the simulator contains additional data (car speed, actual position), it is possible to extend the analysis of the driver’s behavior before entering the area of level crossing and investigate the changes of driving behavior (sharpness of braking, response to signalization, time gap...).
between car and train passing through the level crossing and many others).

V. CONCLUSION

In this paper we presented methodology for measurements of experiments focused on the evaluation of level crossing signalization, which was developed by the Driving Simulation Research Group of the Faculty of Transportation Sciences at the Czech Technical University in Prague. It was proven that the use of a driving simulator in combination with suitable methodology is very suitable for safe and flexible measurements. The main advantage of simulator use is that it is possible to model any type of level crossing, including the alternative variants which can be built as virtual prototypes only. Results from the experiments (as well as the drivers’ responses to simulated driving) showed that the driving simulators can be used as a valid experimental tool for such measurements. Analysis of some of the measured data (eye tracking, speed analysis etc.) proved our hypothesis that a big part of the driver population generally does not behave safely at level crossings and does not respect rules strictly. This is caused by either their insufficient knowledge of rules, bad driving habits or inconvenient warning signalization at the level crossings. This conclusion shows that it is necessary to more deeply investigate driver behavior at level crossings and also a more convenient design of level crossing warning signalization.

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REFERENCES