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# SPECIFICS OF THE TRAFFIC SCENE IDENTIFICATION PROBLEM OBSERVED AT LEVEL CROSSINGS, ANALYSED FROM THE TRAIN DRIVER'S PERSPECTIVE

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## *Abstract:*

*Level crossing is an element of the transport infrastructure of a particular type. This is where streams of regulated and unregulated traffic interact. Vehicles of regulated, rail traffic affect on unregulated, road traffic vehicles. This process takes place over a relatively small area. But the associated processes are concerned with long distances and medium speeds. Importantly, the impact may be mutual (mainly on level crossing cat. D). Consequently, a number of diverse problems can be observed at level crossings as well as in their direct vicinity. One of them is very particular, since its intensity and scale are significantly higher compared to other points of the transport network. This is a problem of how the sight organs of a rail vehicle driver function. At level crossings, a rail vehicle driver is incapable of registering all events connected with moving objects in a horizontal plane of the field of view (often, dozens or hundreds of vehicles and pedestrians, rail vehicles, signs etc.). Especially in agglomeration areas, near the railway stations, people may violently trespass into the tracks. Before reaching a level crossing, the driver's sight organs perform specific movements of variable dynamics, having a direct impact on the traffic safety. Given the context in question, the article discusses the methods used to measure the characteristics of the train driver's sight organs by means of eye tracking devices. The measured characteristics are: saccadic movements, fixation point locations, blinking etc. The relevant studies were supported by using additional equipment and techniques, including visual and vibroacoustic ones. These studies have been illustrated with reference to the measurements performed in different sections of the railway network. The aim of the research was to analyse the behaviour of drivers of traction vehicles. The research results have been discussed in quantitative terms, thus introducing several new descriptive characteristics. The data thus obtained, e.g. concerning the functions of the driver's sight organs, have been analysed using numerical data set characteristics. With regard to the context this article the authors also conduct research addresses measurements of the characteristics of the road vehicle driver's sight organs performed by means of eye tracking devices.*

**Keywords:** *train driver, traffic scene, 3D scene, eye tracking, level crossing*

## *To cite this article:*

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## 1. Introduction

The problem of traffic safety at level crossings is currently one of the most important issues considered against the context of the railway network across Europe. Finding a solution to this problem is a task of national railway infrastructure administration bodies in individual European countries. It is at the level crossings that the highest number of railway accidents takes place compared to all such incidents recorded in the European railway network. Unfortunately, Poland is at the top of this disreputable ranking in Europe, as shown by the relevant Eurostat reports and internet communications (Eurostat, 2020). This important problem is also a matter of particular concern for the Polish railway supervision authority, i.e. the Office of Rail Transport (UTK, 2016, 2017A, 2017B). And it is precisely the Polish Office of Rail Transport which publishes studies where some detailed data concerning railway accidents happening at level crossings and other related data can be found (UTK, 2016, 2017A, 2017B). The information provided in these reports indicate the importance of the problem in question as well as the validity of the approach proposed in this article, where this problem is analysed using high technologies (Celiński, 2019).

A level crossing is an element of the transport infrastructure of a particular type. This is where streams of regulated and unregulated traffic interact. The railway traffic is regulated, as it proceeds according to a schedule. The traffic of road vehicles is the unregulated component, especially since there are rarely any chains of signal-controlled intersections nearby. Such chains are characterised by certain regulation of the road vehicle traffic, which results in spatial formation of a traffic stream subject to dispersion as it moves away from a signal-controlled intersection. Therefore, one can speak of a number of diverse problems identified at level crossings and in their direct vicinity, resulting from different characteristics of colliding traffic streams. Among the problems observed in these locations, one is particular, as it does not occur with such intensity and scale in other places of the transport network. This is a problem of how the rail vehicle driver's organs of vision function. Before reaching a level crossing, drivers performs specific horizontal and other movements (accommodation) of variable dynamics with their organs of vision, having a direct impact on the traffic safety in such locations. This problem encompasses a broader context. To a certain degree, it also pertains to other point elements of the railway infrastructure, such as passenger stations with pedestrian crossings situated upstream the departure tracks or passenger stops with a level crossing directly downstream the station platform. In these cases, besides the railway traffic, there are interactions with relatively large streams of pedestrians whose traffic randomness is much higher than that of the vehicular traffic (described, for instance, by statistical parameters, greater dispersion of time intervals, velocity, traffic paths).

With reference to the aforementioned context, the article describes a method for measuring different characteristics of the driver's organs of vision using eye tracking devices (Duchowski, 2017, Celiński, 2019). These tests were supported by the use of other equipment and techniques, such as the visual and vibroacoustic ones. The tests thus performed have been illustrated using results of measurements taken in a section of the railway network administered by PKP PLK. The study consisted in analysing the behaviour of drivers of electric traction vehicles. This article focuses only on one study concerning the interaction between a rail vehicle driver and other elements of traffic at level crossings. The research results have been discussed in quantitative terms, thus introducing several new descriptive characteristics into the literature of the subject. The data thus obtained, e.g. concerning the functions of the driver's organs of vision, have been analysed using numerical data set characteristics.

The research addressed in the article is relevant from the perspective of the traffic safety at level crossings. It is particularly important in Poland which – according to the Eurostat data – is ranked first in terms of lethal accidents at level crossings (Eurostat, 2020).

Fig. 1 schematically illustrates the aforementioned train driver's problem. Near the crossing, the driver must scrutinise not only the rail traffic of other rail vehicles (which typically happens on the route), but also the traffic of road vehicles and pedestrians, whose quantitative and qualitative characteristics are disparate. Marked in Fig. 1 with blue ovals are the objects in motion being observed by the rail vehicle driver. In order to keep track of them all, the driver intensively sweeps the three-dimensional traffic scene with the eyes, performing saccadic movements and repeatedly adjusting the organs of vision (must watch the controls at the same time).

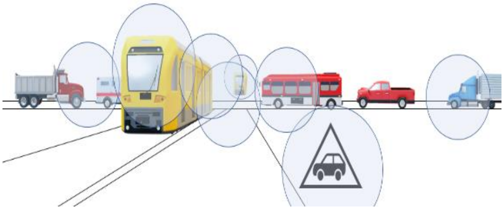

Fig. 1. Model traffic scene perceived from the train driver's perspective.

## 2. Literature review

Investigations involving behavioural observations of train drivers have a long history. Such research supported interviews of train drivers presented in (Branton, 1979). These surveys showed that train drivers used huge amounts of information from the traffic scene, and far more than could be expected. In the present article, some practical tips for the training process and for equipment have been proposed in the conclusions. It also has a similar purpose. Other studies takes into account the risk factor associated with train driving (Naweed et al., 2016). Train drivers are responsible for safe track operations. In this context, the article highlights the fact that train driving is difficult not only in the practical sense. Attention has been drawn to braking and stopping distances in terms of visibility restrictions, while in the conclusions, the authors have focused their attention on making a distinction between freight and passenger operations (and not only). For the latter case (passenger trains), the authors have stressed the train driver's activity aimed at keeping the timetable (in Poland, according to UTK data the average delay are 5 minutes per train). The strong relationship between the driver's work and the external environment has been examined in this context, particularly with regard to level crossings different types. However, the aspect of keeping the travel schedule is also related to this problem. The model approach for the work of a train driver has been described in (Hamilton et al., 2005). According to that approach, authors tried to understand the train driver's interaction with the infrastructure (significantly different than in road traffic). Those studies are similar in concept to the investigations discussed in this paper (for the purpose of interaction with the level crossing). The authors have suggested a cognitive theory model to describe the train driver's behaviour in relation to the infrastructure. This is a class of models with a future. This research is also focused on safety issues. Similar safety issues were addressed in study (Wang et al., 2019). The authors indicated mental workload as an aspect which plays an important role in railway safety. According to the authors it is still a problem to provide a quantitative definition of mental workload. The research technique proposed in this article may be an alternative in this respect. Our research shows that after just 1 hour of driving, fatigue occurs. A similar topic was addressed by Wickens in (Wickens, 2002, 2008). In this context, one should indicate the source of this type of inquiry in the form of famous publications (Kahneman, 1973). In that publication, Kahneman highlighted terms such as: attention, effort, arousal and attention, spontaneous looking, attention and perception relationship, attention and attributes. According to the authors, this is fundamental for the kind of research as that presented in their article. However, that article focuses only on quantitative analysis. Further investigations require complex and costly studies to follow.

It should be noted that Khaneman pointed to the possibilities of using the sight organ in this area (Kahneman, 1973). In this context, research on the microsleep phenomenon should also be mentioned (Burdzik et al., 2020). This is an issue directly related to the subject of this article. Although this phenomenon has mainly been studied in road traffic, it bears a similar reference for railways and has a relatively rich literature (Amit et al., 2005, Åkerstedt et al., 2013). In this context, it should be noted that the train driver is responsible for hundreds of lives. The authors of this article also touched upon the problem of road traffic scene analysis in their publications (Celiński et al., 2019). One should mention that Khaneman's other papers pertaining to the field of psychology were also referenced in this field of research (Mcleod et al., 2005). The model described in this article emphasises the importance of understanding the state of the train driver's perception at a specific time and location, which creates a specific context, as many researchers claim. As discussed in this article, it is created by locations of 10 level crossings. In this respect, reference should be made to publications related directly to the technique used in this study (Merat et al., 2002). This paper provides the results of a study on train drivers' eye movements during a train run. However, the results of that study were referred to as initial by the authors. The research was aimed at understanding of the factors considered important to signal attention, and consequently also the signal design. This is a specific problem. The seemingly obvious importance of the organ of sight is underscored in numerous publications (Parkes et al., 2006). To quote Parkes: 'Train driving is primarily a visual task.' The authors pay attention to important aspects of visual behaviour. They claim that important aspects of train drivers' behaviour cannot be examined using data of this kind. This leads the elaboration to simulation methods (Maag et al., 2012). The studies like those addressed in this article can be considered in the context of automatic traffic control systems. The authors of article (Jacyna et al., 2018) point to the fact that both the driver and the vehicle should be subject to continuous monitoring. In the case of a train driver, it is not that simple. There are strict legal regulations here, and the role of unions is large The eye tracking technique certainly meets this criterion (continuous monitoring). The only question is whether to use mobile or stationary devices. In this context, the key question is how to translate such research into information relevant for traffic control systems. This should be the subject of further investigation, which results from the fact that, regardless of the form of train traffic control systems, one must always bear safety issues in mind (Burdzik et al., 2018). This subject (automatic train driving systems with and without the driver) has been discussed in article (Kukulski et al., 2019), where the authors present the scope of data required for the subsystem of information transfer from the track to the train. Research of this type may affect not only the control and management of railway traffic, but also its organisation (Jacyna et al., 2017). It is particularly important for HSR trains (Ranghui et al., 2016). HSR trains demand a higher safety level as more and more travels are performed using this type of trains, which run at higher speeds. The HSR accidents are larger in scale. This kind of research also addresses underground railway, despite the fact that this environment is visually poorer than conventional railway (Rjabovs et al., 2019). The authors emphasise that train driving in underground railway is a highly visual task (after all), which is even more important in the railway (Rjabovs et al., 2017). The authors have made some interesting observations in paper (Naweed et al., 2014). To quote them: 'the density of this information and the opacity of the task invoked an ergonomics profile more closely aligned with diagnostic and error detection than actual train regulation.' This article also categorises the traffic scene as perceived by the train driver. Analyses of this type, taking the strategies of train driving into account in terms of infrastructural elements, are extremely interesting in light of the assumptions of this article. The authors sum up the article in the following words: 'train driving is a visually demanding task in general, but in the urban rail-environment, this demand increased many fold.' Their case is similar to the one addressed in this article. It is a fact that the subject of the research is a suburban line studied from a significant distance, but the number of level crossings breeds similarities.

In recapitulation of the above review, it should be noted that the studies on road traffic and some related psychological aspects are still dominant in this field of research (Kapitaniak et al., 2015). However, the current transport policy horizon of the European Union encourages intensification of this type of research with regard to rail traffic, especially since the complexity of train driving operations is growing (rail vehicles and infrastructure are changing), and the speed of this traffic is increasing as well (HSR).

## 3. Scene analysis from the driver's perspective

While approaching a level crossing, the rail vehicle driver generally sees very small road vehicles (or people as well) on both sides of the railway near the level crossing from a distance of approximately one kilometre (if the track profile allows it, min. 1 arcmin). Even if they are not there, the driver still scrutinises both sides of the track in case any traffic or static object should appear, which may interfere with the movement of the rail vehicle. The road (traffic stream) can be perpendicular to the railway track, and this is often the case in practice (in Poland). It is a favourable variant of the level crossing geometry. The road can also run in parallel to the track, or at any angle up to 180 [°]. In many cases, the view of considerably large sections of roads at a certain distance from the level crossing are obscured by trees, making it impossible to observe the road sections that are distant from the crossing. Vehicles queuing at the level crossing pose no significant issue. If there are no queues, however, a threat may be caused by fast moving road vehicles in roads of higher traffic categories. The authors are familiar with such observations Excessive speeding is frequently observed in such cases (in violation of the applicable legal regulations). And although train drivers have undoubtedly the right of way, they still need to examine the traffic scene at the level crossing and on their route at the same time (railway traffic signs, preceding rail vehicles and those running in the opposite direction and much, much more). Therefore, the rail vehicle driver performs intensive horizontal eye movements, both between both sides of the level crossing and by focusing the sight on different objects looking in the direction of motion. This is required for tracking of the traffic signs being passed by, rail vehicles moving on the same route, as well as vehicles and pedestrians on the road. The action of shifting sight is more intense at level crossings of unusual road geometry (in terms of the approach routes). Consequently, the rail vehicle driver performs intensive saccadic movements and accommodates the eyes to various close objects in cabin. Drivers of all vehicles (and pedestrians as well) face similar problems while approaching the crossing, however, they may differ in certain characteristics, such as the question of what to examine, and this had provided grounds for the article to be developed, representing the train driver's perspective.

It is for the specific design of the human organ of vision that the best focus is produced in the central pit area referred to as *fovea centralis* (Ober et al., 2009, Bochenek et al., 2004). The eye's fovea is a part of the macula of the retina. The fovea is located precisely on the eye's horizontal axis. The image of the external object (the traffic scene at the level crossing) on which a person focuses is projected on the fovea. It is in the fovea that vision is the sharpest, and it deteriorates as one ages or as illumination of the given scene changes (Ober et al., 2009). Vision also depends on individual characteristics, which was not of interest to the authors of the study, and so it was assumed that this particular aspect had been addressed and taken into account in the process of recruitment for the train driver job. The rail vehicle driver uses the system of saccadic movements to sharply perceive consecutive distant objects in the traffic scene (e.g. both sides of the crossing). The attention is moved from object to object in different parts of the traffic scene (also over long distances), these becoming stimuli as the cognitive process continues, while either recognising or interpreting the scene. Where intensive movements take place in the driver's peripheral field of vision, this is particularly supported by what is referred to as the reptilian brain. It is very important as the rail vehicle approaches the crossing. The saccadic movement system allows the driver to focus the sight on any object in the traffic scene (Ober et al., 2009). The muscular system responsible for the saccadic movements consists of three pairs of muscles (agonistic, antagonistic) which move the eyeballs in both axes of the plane of vision and rotate them in the optical axis. The process of vision is discrete in nature. Registration (acquisition) of a sharp image takes place in intentionally isolated areas of the traffic scene, and in instants of time. Data from the scene plane of the perceiving person are intentionally sampled (Carpenter, 1999A, 1999B). In a field of sharp focus covering about 2 [°] of the field of view of the traffic scene, a very small (compared to the whole) fragment is cut out. For example, when reading a sentence, it is usually one word or a part of a longer word, although there is yet another (capacitive) context to this aspect of functioning of vision. The sampling frequency of a traffic scene is defined as several hertz (Ober et al., 2009, Carpenter, 1999A), which is due to the total time of response to a stimulus and cognitive latency. Viewing a traffic scene in saccades (Fr/Lat *jerks*) enables acquisition of interesting (selected) points in the traffic scene, where fragments of the field of view necessary for the cognitive purpose are collected (Ober et al., 2009). Another problem not analysed in this article is whether a point is selected or causes selection. A saccadic reaction spans the time from the excitation moment until the beginning of the eye movement (saccade) and the duration time of the saccade until the eye stops completely, fixed on the selected target. The saccade interval is up to 200 [ms], and often more (Carpenter, 1999A). The minimum saccade observed in the study was 49 [ms], while the maximum one was 698 [ms]. The minimum time needed to receive information from the retina and then generate the exciting stimulus and send it to the extraocular muscles is ca. 60 [ms]. Ca. 14% of the measurements performed under the tests ranged about the minimum time (reflexes). The difference between the saccade time and the minimum reaction time (relatively high) results from the functions of the cortical decision making centres which set the schedule for the areas of sharp vision in selected parts of the scene (cognitive process). A delay that often exceeds 100 [ms] is the time needed to determine the cognitive context of the scene fragment perceived. In the study discussed in the article, 8% of the saccadic movements exceeded 200 [ms]. What one can very frequently observe in tests is fast, reflex-like saccadic movements (bypassing the decision making centres, i.e. made without delay). These saccadic movements are performed in the perceptive processes related to rapid decision making about successive points of vision focusing (Ober et al., 2009). This is often associated with a moving object in the peripheral field of vision, which results from the evolutionary process and human defence against reptiles and predators. The average saccadic movement time recorded in the tests was 104 [ms], while the deviation was 67 [ms]. The movements are characterised by normal distribution.

In the rail vehicle driver's field of view, at any time in the traffic scene, there may be numerous different objects (stimuli) between which the attention associated with sharp vision is distributed. The limitation in practice is viewing a single object in sharp focus (the size of the object is also important). Viewing is a process in which the emerging objects are analysed and the most interesting one is selected from the point of view of the current state of interpretation of the traffic scene (Ober et al., 2009). The distribution of the information processing speed in such a setup is described under what is commonly referred to as the 'Later' model using a Gaussian curve (Carpenter, 199b, Nouraei et al., 2003, Leigh et al., 2006)). Saccadic movements are characterised by a maximum velocity of up to 500 [°/s]. 65% of all measurements were observed within this range. A saccadic movement with a range of one degree lasts ca. 25 [ms] (Leigh, 2006).

Fig. 3 shows some examples of paths along which eyes were pursuing individual objects of a traffic scene in saccadic movements. The shifts between the coloured objects illustrate the necessity of simultaneous eye adjustment (which applies particularly to the cabin dashboard). As the illustration shows, the process of keeping track of the traffic scene objects at the level crossing is complicated and requires mental effort.

Accommodation is described in the literature of the subject as a process of eye adjustment for the purpose of sharp vision of objects (focusing the attention of cortical elements) scattered at different distances from the observer (Lockhart, 2010). This adjustment consists in adequate adaptation of the eye's focal length so that a sharp image of the object being viewed is created on the retina. Accommodation time basically depends on the scene illumination conditions, the type of excitation, as well as the observer's age, and it can be strongly variable, ranging at ca. 200 [ms] and more, even up to several seconds in extreme cases (difficult traffic scene conditions). The accommodation capacity ranges between infinity to several centimetres. In practice, the eye resolution means that the object being observed at a certain distance must be of a certain size to be discernible at all. While observing the traffic scene and the dashboard, the driver sweeps the three-dimensional space with his eyes, performing movements in three axes. In a plane perpendicular to the axis of movement of the rail vehicle, the movement covers an area of about 6–12 [m2] (including the vehicle driver's cab, particularly the dashboard, and head movements), while in terms of depth, the movements range between several dozens of centimetres to several kilometres, when in good visibility. The problem is also that the process of blinking coincides with viewing of the traffic scene, which additionally hinders the scene acquisition. This is also connected with a phenomenon known as microsleep (Burdzik, et al., 2020).

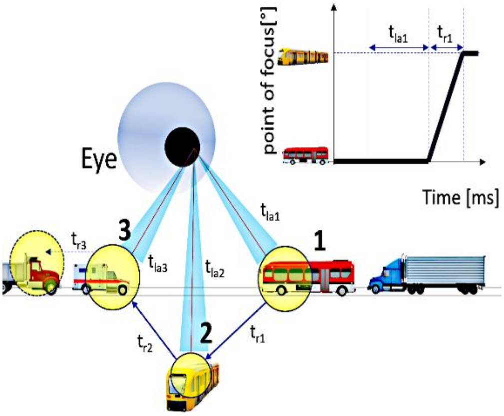

Fig. 2. Graphical representation of a sequence of saccadic movements perceived from the driver's perspective.

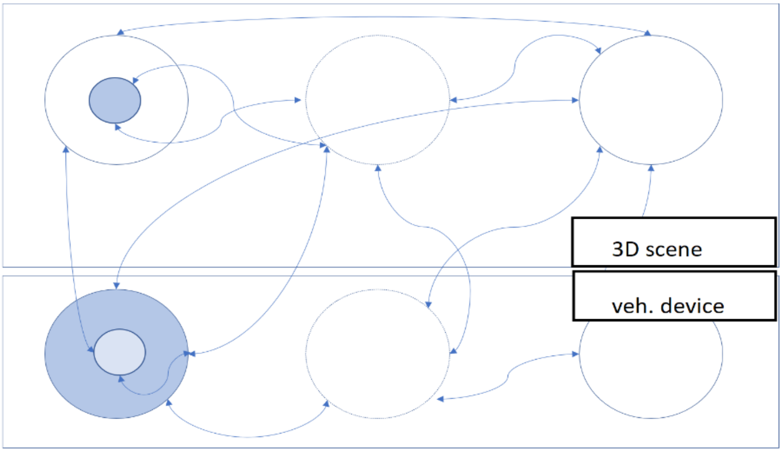

Fig. 3. Examples of the paths describing the saccades performed from the driver's perspective

## 4. Testing

In order to investigate the problem of the rail vehicle driver described in the previous sections, tests were conducted on a 30 [km] long section of a double-track line featuring 10 level crossings located at different distances from one to another. What was examined in the first place was the characteristics of the rail vehicle drivers' sight along the entire length of the test section, in both directions of traffic. The run time was ca. 1 hour and 10 minutes. The equipment used for testing comprised the SMI eye tracking glasses, 60 [Hz] and some auxiliary control and measurement instruments, the latter including a set of CCD cameras monitoring the movements of the driver's limbs by visual techniques (OpenCV), an apparatus for the rail vehicle's velocity and linear acceleration measurement, and a highly specialised logger of the rail transport infrastructure. The GPS signal, including time, was also recorded. The rail transport infrastructure logger is intended for approximate positioning of the driver's reaction with reference to the position of a given infrastructure component (mainly trackside signs and main signals) according to WGS 84.

The study was based on an assumption that the rail vehicle driver's vision characteristics such as fixations, saccadic movements, and blinking were significantly different over the entire route from those recorded directly before and at the level crossings. The foregoing constitutes the research hypothesis. Assuming that significant differences have been detected, this opens up a new research field.

Fig. 4 schematically depicts the arrangement of the control and measurement equipment. It consisted of the following elements (as designated in the diagram): CCD – set of HD cameras (from 3 to 5), ET – eye tracking glasses, ACC – three-axis linear acceleration recorder, RII – railway infrastructure logger, GPS – GPS receiver. The RII logger was manually operated by a single operator during the tests (not related to train movement).

Fig. 5 shows the driver's cab. Part of the control and measurement instrumentation, including the video camera and the RII logger, can be seen in the background.

Fig. 6A shows the distribution of the fixation points measured along the entire route of the rail vehicle (in this case EZT EN57). The plane on which the fixation points are distributed is a rectangle with the dimensions of 1280x960 [px] (camera converter). It is evident that this distribution is definitely asymmetric, both horizontally and vertically in the observed traffic scene. Fig. 6B provides the duration time of the saccadic movements, where short movements dominate, being considerably longer than 200 [ms]. Fig. 7A illustrates the amplitude of saccadic movements measured in degrees. It is consistent with the range values referred to in the literature of the subject (up to 500). Fig. 7B provides eyelid closing times. What can be seen within this range is the areas of potential microsleep (Burdzik, et al., 2020)).

In contrast, Fig. 8A and 8B show the distribution of fixation points at two different level crossings (chosen at random from a set of 10 crossings examined in the study). Even without detailed analysis, it can be seen that they represent two different ways of the traffic scene acquisition (perception). In Figure 8b, one can notice the attention being focused on the left-hand side of the crossing and at a considerable distance from it. Fig. 9 illustrates some further characteristics obtained at these crossings: time and amplitude of the sac., and blinking time.

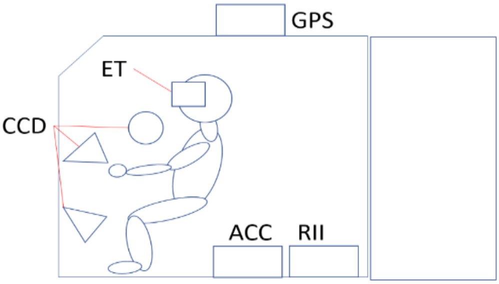

Fig. 4. Schematic diagram of the control and measurement instrumentation used in the study.

Fig. 5. View of the driver's cab used in the study from the driver's perspective, with the measuring instruments in the background

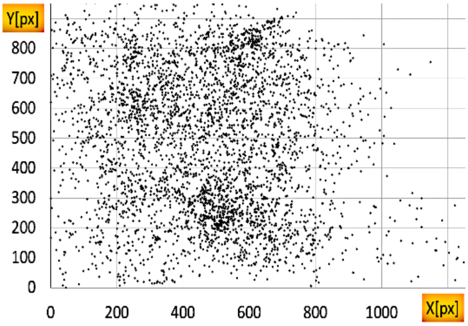

Fig. 6A. Diagram: distribution of fixation points

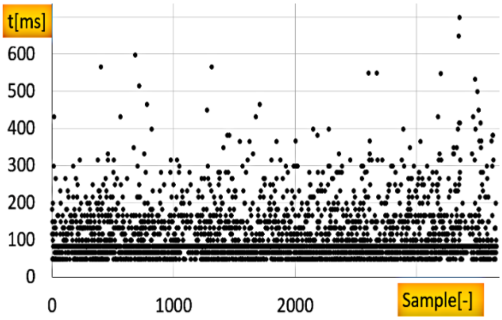

Fig. 6B. Diagram: duration of saccadic movements

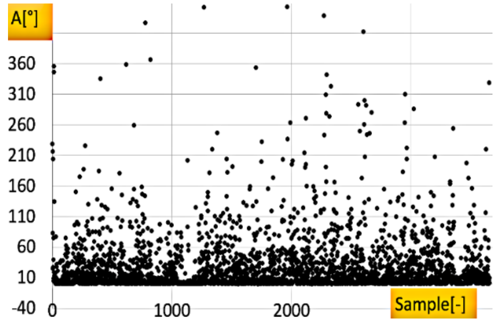

Fig. 7A. Diagram: amplitude of saccadic movements

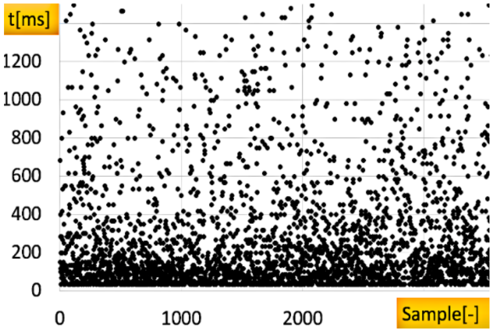

Fig. 7B. Diagram: blinking time

In each of the figures, in pairs a-b, c-d, and e-f, different functional characteristics of the driver's organs of vision have been presented: a, b – time of saccades, c, d – amplitude of saccadic movements, and e, f – blinking time. However, the ranges of maximum values of the characteristics in the respective pairs are similar, with some minor differences (Y-axis). Nevertheless, the curves of the characteristics run differently in comparison with other samples. This fact should be verified by presenting numerical data characteristics of individual level crossings such as the mean value, the median, the modal value, and the standard deviation. These statistical parameters should be additionally compared with those recorded over the entire run. It should be noted that the number of samples on the X-axis differs on account of the difference in the perception of the scene. That is why the samples have been analysed statistically and not graphically (pattern recognition). Few points obtained in the tests have values significantly different from the average values in the sample. And where there are some, this is due to the imperfections of the measuring apparatus as well as the ET calibration-related issues encountered in practice with regard to the subject of the study. The comparisons provided below also take some other saccade parameters into account. 10 consecutive crossings and the entire route have been compared (one traffic direction).

In terms of the comparison of the saccade times, the test results indicate a slight variation in the process of perception of the level crossing scene over the entire travel route, except for the fact that very short saccadic movements are predominant. In several cases, the mean times diverge from this parameter for the entire route. For nearly all runs (except 2), they are greater than the mean value for the entire route. Conclusion: a level crossing requires a larger extent of saccadic movements than a typical railway route section without a crossing. Two crossings do not match this pattern. However, what the authors expected in the study was that much more significant differences would be found in this respect. Differences between individual persons play an important part in that regard.

In terms of the comparison of the saccade amplitudes, the test results indicate a slight variation in the process of perception of the level crossing scene within this range, except for crossing no. 10. At 3 level crossings, the amplitude differed significantly from the mean. In all cases, the deviation is much smaller than this parameter calculated for the entire route. Conclusion: one can clearly notice high regularity in sweeping the traffic scene with saccadic movements at the crossing in a left–right–left sequence. This process is much more inhomogeneous over the entire route.

In terms of the comparison of the mean saccade velocities, in 3 cases, the test results indicate a considerable variation in the process of perception of the level crossing scene within this range.At 2 crossings, the mean velocity decreased, and it increased significantly at one. In all cases, the deviation was much smaller than the parameter established for the entire route. Conclusion: there is clearly high regularity in the manner in which the traffic scene is perceived by way of these movements at the crossing, and a certain velocity of this process is maintained.

In terms of the comparison of the blinking times, the test results indicate a considerable variation in the process of perception of the level crossing scene over the entire route. In several cases, the mean times exceeded the parameter established for the whole route a few times. Conclusion: the crossing requires particularly strong concentration of the driver, who blinks more. This conclusion needs to be examined in relation to the driver's total working time, as it should also take into account the effect of fatigue and whether or not the microsleep phenomenon occurred (Burdzik, et al., 2020).

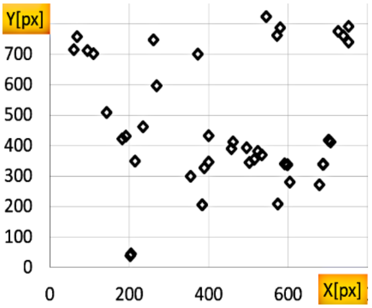

Fig. 8A. Distribution of fixation points at two selected crossings (crossing A)

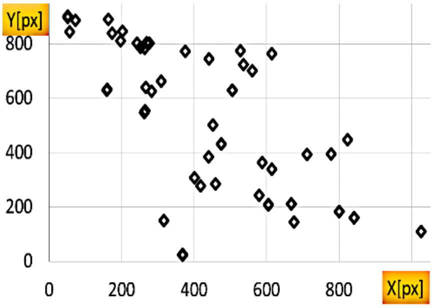

Fig. 8B. Distribution of fixation points at two selected crossings (crossing B)

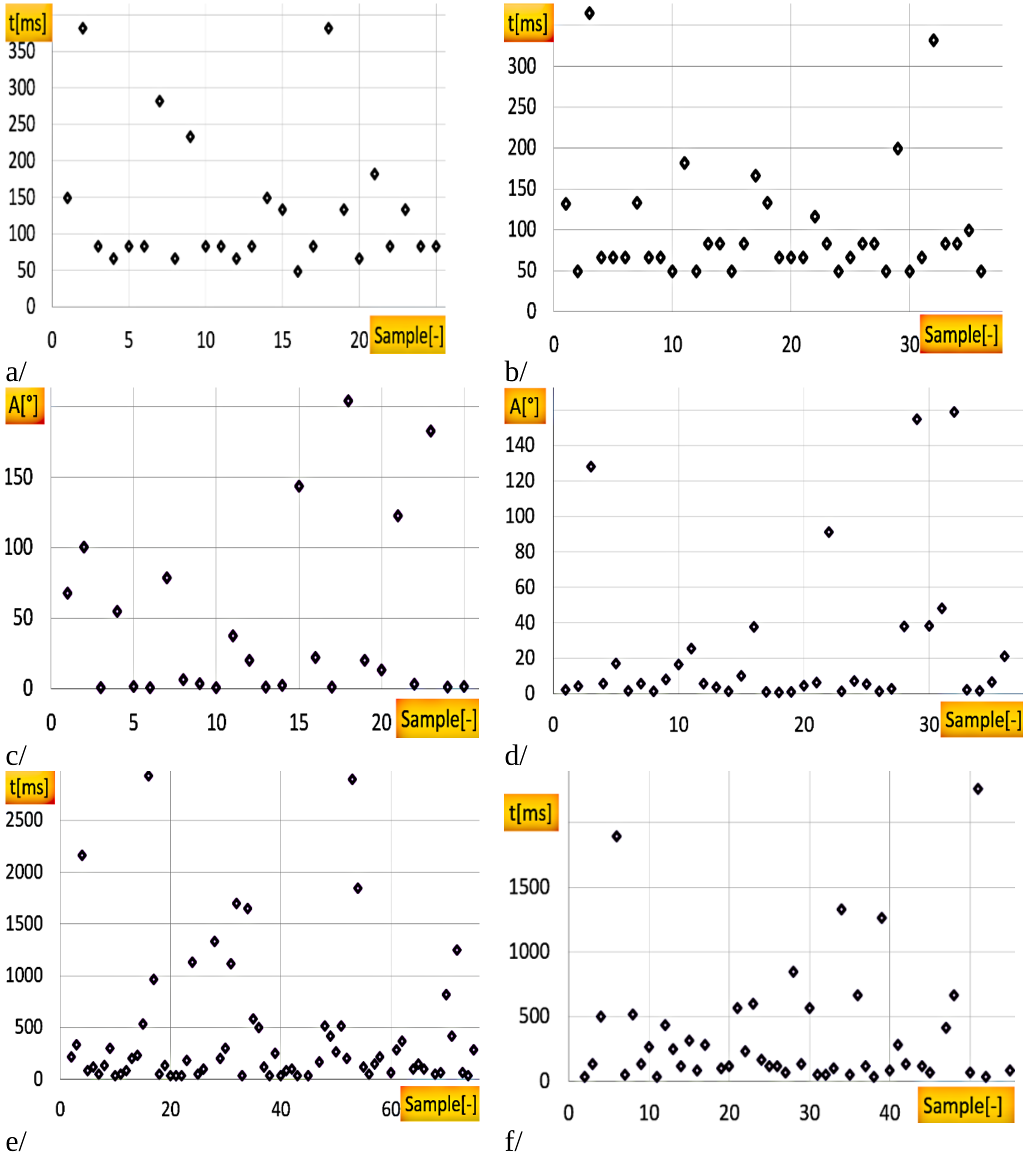

Fig. 9. Diagrams: a, b: time of saccades, c, d: amplitude of saccades, e, f: blinking time

Table 1. Comparison of saccade times [ms]

| **Object no.** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 123.78 | 113.14 | 121.03 | 115.19 | 92.76 | 99.25 | 109.75 | 109.43 | 109.09 | 117.04 | 104.35 |
| Modal value | 83 | 83.00 | 83.00 | 83.00 | 83.00 | 66.00 | 83.00 | 66.00 | 83.00 | 66.00 | 83.00 |
| Median | 83 | 83.00 | 83.00 | 83.00 | 83.00 | 74.50 | 83.00 | 83.00 | 83.00 | 91.00 | 83.00 |
| Standard deviation | 71.75 | 85.26 | 72.03 | 71.12 | 68.71 | 72.32 | 70.96 | 74.12 | 58.69 | 70.32 | 67.17 |

Table 2. Comparison of saccade amplitudes [°]

| **Object no.** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 38.27 | 35.93 | 37.39 | 34.26 | 12.96 | 24.11 | 33.24 | 32.08 | 31.68 | 67.85 | 31.75 |
| Modal value | 3.50 | 0.80 | 1.30 | 1.30 | 1.50 | 5.80 | 1.50 | 73.80 | 1.20 | - | 0.70 |
| Median | 18.60 | 13.10 | 8.15 | 11.80 | 4.20 | 5.80 | 7.50 | 18.35 | 3.10 | 43.30 | 8.60 |
| Standard deviation | 49.73 | 53.41 | 56.19 | 51.51 | 23.93 | 42.04 | 60.36 | 39.85 | 46.75 | 72.96 | 148.75 |

Table 3. Comparison of mean saccade velocities [°/s]

| **Object no.** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 291.79 | 280.00 | 271.17 | 34.25946 | 124.18 | 211.65 | 260.54 | 262.55 | 283.14 | 506.02 | 258.23 |
| Modal value | -- | -- | -- | 1.3 | -- | 15.60 | -- | 183.70 | 14.20 | -- | 8.90 |
| Median | 160.40 | 149.40 | 79.95 | 11.8 | 70.20 | 85.30 | 109.35 | 184.10 | 40.50 | 476.00 | 117.20 |
| Standard deviation | 400.49 | 327.99 | 347.96 | 51.50661 | 150.71 | 259.92 | 472.32 | 267.36 | 406.73 | 379.60 | 1,022.22 |

Table 4. Comparison of mean saccade accelerations (rounded values) [°/s]

| **Object no.** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 27,288 | 29,485 | 27,890 | 28,153 | 12,335 | 21,734 | 28,196 | 26,571 | 29,585 | 56,347 | 26,888 |
| Modal value | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 948 |
| Median | 12,289 | 13,472 | 4,928 | 7,136 | 4,235 | 4,978 | 9,937 | 10,564 | 4,034 | 56,687 | 8,869 |
| Standard deviation | 39,928 | 35,372 | 37,875 | 37,529 | 17,207 | 30,019 | 56,092 | 29,983 | 43,885 | 43,183 | 119,603 |

Table 5. Comparison of blinking times [ms]

| **Object no.** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 2,945.4 | 858.6 | 1,667.5 | 1,533.4 | 1,245.4 | 1,203.7 | 1,642.6 | 857.2 | 820.3 | 903.8 | 814.7 |
| Modal value | 66 | 33 | 66 | 66 | 83 | 116 | 66 | 249 | 33 | 216 | 33 |
| Median | 731 | 199 | 274 | 282 | 266 | 232 | 224 | 266 | 149 | 216 | 183 |
| Standard deviation | 6,493 | 1,502. | 2,842. | 2,796 | 2,351 | 2,389 | 2,775 | 1,690 | 1,963 | 1,918 | 1,950 |

The Fig. 10. below shows the data from Tables 1-5 and represents an attempt to collectively compare the mean values of the parameters observed:

- saccade times [ms]
- saccade amplitudes [°]
- saccade velocities [°/s]
- saccade accelerations (rounded values) [°/s]
- blinking times [ms].

A collective comparison of the parameters observed illustrates the problem of driving in a suburban area with a large number of level crossings (Fig. 10). Starting from a half of the route, mental workload (very high) is observed. In practice, it represents 5 hours of work (work in the depot and preparation for tests), and some microsleep may appear which will drastically inflate this data. In the second level crossing, it may be associated with stopping.

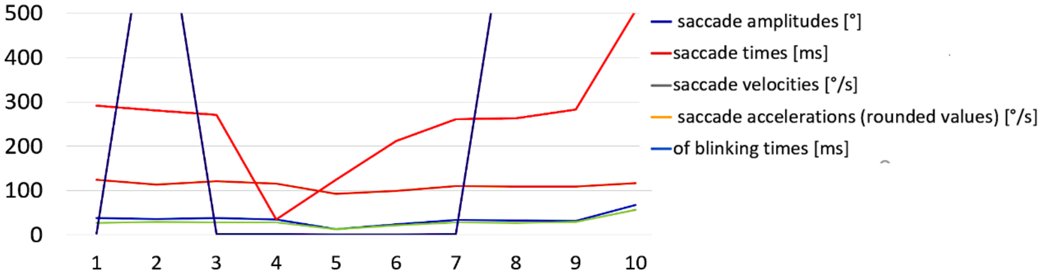

Fig. 10. Comparison of the parameters observed in the profile of the railway line in relation to the runs analysed.

The behaviour of the saccade velocity parameter is a bit unsteady. After the initial decrease at the fourth object, a significant increase in the parameter value is observed further on. In conjunction with mental workload, this is puzzling. One should rather observe slow and sluggish eye movement. In this context, it is interesting that the remaining parameters are stable along the entire route. One of the reasons for these atypical parameter relationships may be the variable source of external illumination (sun).
The saccade velocities are best described by a polynomial trendline:

$$y = -0{,}1291x^6 + 4{,}6458x^5 - 65{,}442x^4 + 453{,}96x^3 - 1583{,}2x^2 + 2476{,}5x - 1006{,}4 \quad (1)$$

The blinking time is best described by the following polynomial trendline:

$$y = -0{,}1443x6 + 5{,}959x5 - 98{,}741x4 + 821{,}03x3 - 3463{,}4x2 + 6588{,}6x - 3813{,}6 \quad (2)$$

The remaining parameters can be described linearly, e.g. saccade amplitudes by the following linear trendline:

$$y = 1{,}3213x + 27{,}51 \quad (3)$$

Generalisation of any observations in this area requires that a larger number of train drivers and a larger number of sections should be examined. However, with pre-selected shorter sections, the one subject to examination may be representative of the entire railway line section.
The following are the *a priori* assumptions which should be made with regard to these parameters:

- saccade times [ms] should be closely related to the route configuration and the way the vehicle is driven, perhaps for temporary objects, but in this case the analysis must be manual and extremely time-consuming,
- saccade amplitudes [°] should be closely related to the route configuration and the way the vehicle is driven,
- saccade velocities [°/s] should rather be constant in the absence of unusual incidents along the route, and assuming normal activity and psychophysical state of the train driver,
- saccade accelerations (rounded values) [°/s] should rather be constant in the absence of unusual incidents along the route,
- blinking times [ms] should increase with the driving time; the increase in the value of this time, being a function of working time, is significant.

## 5. Comments on the test

With reference to the studies discussed in the previous section of the paper, it should be noted that differences in the functional characteristics of the organs of vision were found at each of the 10 analysed crossings. However, across all tests, 1/3 of the crossings in question showed significant differences compared to the other crossings as well as to the entire route. In each case of the runs subject to analysis, the standard deviation was significantly different from the standard deviation established for the whole route. This implies that studying the rail vehicle driver's behaviour on the route has well-grounded rationale.
One could propose a level crossing classification criterion (LCC) based on the differences revealed between the values of the parameters investigated, expressed as the following function:

$$LCC = f(t, a, \bar{v}, \overline{acc}, bt) \quad (4)$$

Where:
$t$ - saccade time [ms]
$a$ - sacade amplitude [°]
$\bar{v}$ - mean saccade velocity [°/s]
$\overline{acc}$ - mean saccade acceleration [°/s]
$bt$ - blinking time [ms]

This criterion requires further and more extensive research to be conducted, taking the structure of the level crossings in the Polish railway network into consideration. The majority of the crossings analysed in the study in question were those of category A and B. Similar tests should also be performed for the remaining categories, i.e. C and D, as well as for pedestrian crossings. One can also define some criteria for the classification of crossings with regard to the distribution of the fixation points on the traffic scene observed directly before the crossing and until it has been passed. What highlights the differences in the traffic scene perception at the crossings is the deviations of the fixation points in both axes. The values of these deviations have been provided in Table 6.

The data presented in Fig. 11 have the following values: average at x – 225.4 [px], average at y – 226.6 [px]. In the middle section, the graph shows the deviation of variability at the individual objects passed by the train (10 level crossings). This figure illustrates the difference between these objects from the train driver's point of view and considering his driving technique. The question to be solved in further studies is to what extent the observed variability results from the objects located on level crossings (people, vehicles, houses, rail infrastructure, etc.). This is where algorithmisation is needed for the data (one journey equals to >2 GB of recorded data). Interestingly, the spread of this data increases with the driving time. But this is not necessarily due to the mental workload; it is rather a question of the extent to which the mental workload contributes to this spread.

Table 6. Comparison of the fixation point deviations [px]

| Object no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\partial_x$ | 181 | 203 | 195 | 202 | 255 | 228 | 222 | 224 | 308 | 236 | 244 |
| $\partial_y$ | 203 | 202 | 209 | 231 | 254 | 285 | 169 | 203 | 307 | 203 | 262 |

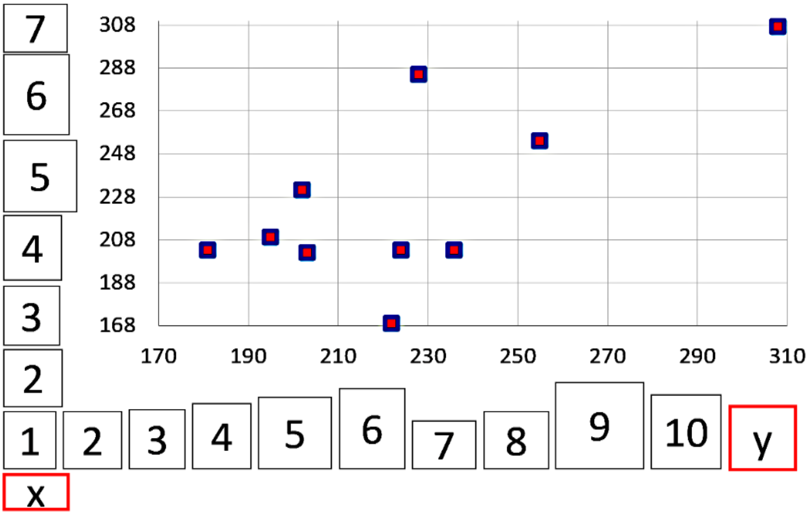

Fig.11 Comparison of the fixation point deviations

With respect to the comparison of deviations of the fixation points, in individual axes, the test results indicate a considerable variation in the process of perception of the level crossing scene over the entire route. The larger the deviation, the broader and more diversified the sweeping of the analysed scene with eyes. In several cases, the deviations differed significantly from the value established for the whole route. The deviation parameters in all axes can be entered as variables to the above equation. Besides the physical parameters describing the behaviour of the organs of vision, which specifically include the parameters describing the spatial distribution of sight fixation points, what also matters is the data concerning the road traffic parameters. This applies to the geometric characteristics of the approach routes leading to the crossing and to what is commonly referred to as the level crossing's traffic movement. The model of the driver's traffic scene perception (MPRS) can be noted as follows:

$$MPSR = \langle PP, SD, IG, TM \rangle \tag{5}$$

where:

PP - physical parameters of the organs of vision;
SD - spatial distribution of fixation points;
IG - level crossing's infrastructural geometry;
TM - traffic movement [15].

It requires further research to develop the model in the form of an ordered quadruple given by expression (2). Nevertheless, the final effect is the parameterisation of level crossings in terms of traffic safety.

All the researchers studying train drivers and mentioned in the literature used for purposes of this article indicate the importance of these studies. Technology has changed, and so they can now be tested by way of eye tracking, EEG, EMG, etc. Distance measurement, e.g. using Lidar, can be performed with the centimetre's accuracy, and so can the distance from a train to any infrastructure or other 3D scene object be measured. In the past, such studies were mainly based on interviews with train drivers and railway workers, as well as observations or measurements of railway traffic characteristics. The testing technique has therefore become objective, not as it used to be in the past, when in the 20th century it was based on subjective interviews with train drivers. However, it should be noted that these are large data sets, and their interpretation may be not so much difficult as burdensome and subjective. It is determined by the number of variables that affect the driver's perception process. How complicated the process can be was described by Kahneman (Kahneman, 1973). Moreover, it is difficult to compare this perception process in train drivers without analysing the variability of the traffic scene. At each level crossing, traffic should be analysed at least in terms of average values. However, for exact conclusions, each absolute position of an object located on the 3D traffic scene is important (vehicles, houses, people, etc.). An intermediate solution to this problem may be the statistical analyses presented in (Burdzik et al., 2020, Celiński et al., 2019). However, such analyses are not capable of providing the exact values of the parameters observed throughout the research. The number and variety of the data obtained in this kind of research means that companies involved in development of testing equipment may find them interesting (Fig. 12).

Fig. 12 schematically depicts the arrangement of the control and measurement equipment. It consists of the following elements (as designated in the diagram):

- CCD – set of HD cameras (from 3 to 5);
- ET – eye tracking glasses;
- ACC – three-axis linear acceleration recorder;
- RII – railway infrastructure logger;
- GPS – GPS receiver;
- EEG – electroencephalography device;
- EMG – surface electromyography device.

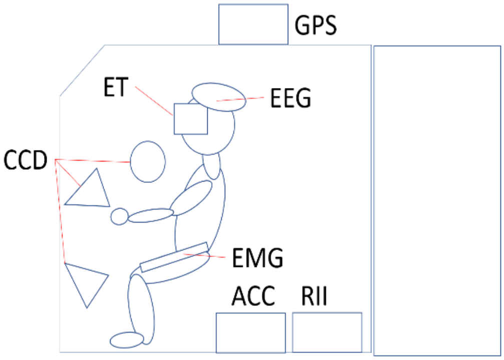

Fig. 12 Schematic diagram of the control and measurement instrumentation to be used in the future study

As proposed in this study, the electrodiagnostic technique can be used to establish the electrical activity of skeletal muscles, since the EMG enables identification of the train driver's reflexes. Similarly, electroencephalography (EEG) makes it possible to record the brain's electrical activity, and consequently also to correlate the on-route objects and railway infrastructure with the corresponding waves in the train driver's brain. This, in turn, makes it possible to capture the train driver's characteristic reactions (including emotions), and should therefore guide the future research.

Another interesting utilitarian function of the present research is the application of the technique in question while preparing post-accident documentation. In this sense, eye trackers should become standard equipment in future trains, but their stationary versions rather than the mobile ones (not glasses), which also results from the authors' research. This aspect will be discussed in further publications addressing studies performed on a test track.

## 6. Conclusions

Our data suggest that we still have a long way to go to explaining the problem of the traffic scene identification observed at level crossings, analysed from the train driver's perspective. Nevertheless, we emphasize that majority of the crossings analysed in the study in question were those of category A and B.

Note that from the point of view of traffic safety, they are the most interesting is category D. The most accidents and number of deaths in Poland due to level crossing each year in the long period (several decades) took place on category D. This is the worst result in the European Union. Unfortunately, these level crossings are scattered in space especially in Silesian voivodship (Poland) and in the immediate vicinity. Research must be conducted in other provinces (in Poland, voivodship).

The present findings confirm that:

- there are significant differences in the functional characteristics of the organs of vision at each of the 10 analysed crossings, the study should be supported by other techniques: EEG, EMG;
- 1/3 of the crossings in question showed significant differences compared to the other crossings as well as to the entire route;
- in our research have been established difference between crossings from the train driver's point of view and considering his driving technique, driving technique testing is a different problem;
- results indicate a considerable variation in the process of perception of the level crossing scene over the entire route, these differences should be explained in the course of further research;
- obtained in our research large data sets, and their interpretation may be not so much difficult as burdensome and subjective, this requires the definition of a strict methodology for this type of research;
- comparison perception process in train drivers without analysing the variability of the traffic scene is difficult, this is the most difficult problem at the moment.

Another interesting utilitarian function of the present research is the application of the technique in question while preparing post-accident documentation. This is an most interesting direction for future work. In this context, the dynamic development of the eye trackers market is beneficial. Device prices have fallen by around 100% over the past 7 years. The stationary eye trackers market is developing in an interesting way. It is favored by the development of the mobile telephony market.

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