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ANALYSIS OF THE DETECTION AND CROSSING SIGNALING SYSTEM IN SAFETY TERMS

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Summary

Crossing signaling systems used for securing the intersection traffic at the level of roads with railways are mostly triggered by rail vehicles coming towards them using sensors working in the impact zones. Modern crossing signaling detection devices due to their unification and savings in production are used not only in crossing signaling but also in many areas of the railway traffic control like, e.g. block signaling or station system. Modern sensors detect the route direction of the rail vehicles, they are much more resistant to lightning and overvoltage when compared to their predecessors, they are also resistant to winter road salinisation and also have much lower maintenance costs during their whole lifecycle.

Keywords: crossing signaling system, safety, detection systems

ANALIZA SYSTEMÓW DETEKCJI I SYGNALIZACJI PRZEJAZDOWEJ W UJĘCIU BEZPIECZEŃSTWA

Streszczenie

Systemy sygnalizacji przejazdowej służące do zabezpieczenia ruchu na skrzyżowaniach w poziomie dróg kołowych z liniami kolejowymi uruchamiane są w większości przypadków przez pojazdy szynowe zmierzające w ich kierunku za pomocą czujników pracujących w strefach oddziaływania. Współczesne urządzenia detekcji sygnalizacji przejazdowych ze względu na ich unifikację oraz oszczędności produkcji znajdują zastosowanie nie tylko w systemach sygnalizacji przejazdowej ale również w wielu innych obszarach sterowania ruchem kolejowym jak np. blokady samoczynne czy systemy stacyjne. Współczesne czujniki umożliwiają rozpoznanie kierunku jazdy pojazdów szynowych wykazują znacznie wyższą odporność w stosunku do ich poprzedników na wyładowania atmosferyczne i przepięcia, są odporne na zimowe zasolenie dróg a także wykazują znacznie niższe koszty utrzymania w całym cyklu ich życia.

Słowa kluczowe: sygnalizacja przejazdowa, bezpieczeństwo, systemy detekcji

1. INTRODUCTION

For an average road traffic participant, the most common railway system is a set of devices, commonly referred to as the crossing signaling system.

According to the Regulation of the Minister of Transport and Maritime Economy dated on the 26th February 1996 [24] each above mentioned level crossing is an intersection of railway line with public road, at its one and also at various levels.

In the newest regulation dated on 20 October 2015, while framing the definitions of the crossing signaling, the following terms for this signaling were used [25]:

- **Crossing system** as the system installed on railway crossing. It ensures steering and controlling the function of devices that are its parts;
- **Semi-automatic crossing system** as a system where the traffic protection devices on the railway crossing are controlled manually by the service worker;
- **Automatic crossing system** as a crossing system where the traffic protection devices on the railway crossing are controlled automatically by the vehicle or other railway traffic control system;

Moreover, in the last regulation mentioned above, general technical conditions for railway crossings and pedestrian railway crossings that railway intersections and railway sidings with road should meet. [2] The table No. 1 presents all possible categories for railway crossings in Poland according to the regulation dated on 20 October 2015.

In this study all attention was focused not only on the categories of railway crossings or their functions in the traffic safety but mainly rail vehicles detection systems used in them. Without them the signaling systems wouldn't maintain safety functions that they have nowadays.

Table 1.
Categories of railway crossings in accordance with the Regulation on 20 October 2015

No.	Cat	Description (designation)
1.	A	Railway crossings where the traffic is controlled by: a) authorized employees of the railway manager or railway undertaking who have the necessary qualifications, b) by using manual signals or crossing systems or devices equipped with boom barriers closing the whole width of the road
2.	B	Level crossings where the traffic is controlled by automatic crossing systems equipped with traffic lights and boom barriers closing the traffic in the following directions: a) the crossing's entrance b) the crossing's entrance and crossing's exit;
3.	C	Level crossings where the traffic is controlled by automatic crossing systems equipped only with traffic lights;
4.	D	Level crossings that are not equipped with traffic protection systems and devices;
5.	E	Pedestrian railway crossing equipped with: a) semi-automatic or automatic crossing systems or b) turnstiles, barriers or labyrinths;
6.	F	Level crossings or pedestrian railway crossings located on the internal roads, equipped in accordance with § 12 par. 2.

In this paper we focus mainly on crossing signaling system of B category, however, similar solutions that is rail vehicle detection devices are used also in crossing signaling systems of A and C categories. Above mentioned devices available or at least continuously used on the market were presented where possible.

Although the condition of the domestic market was mainly described, similar solutions are used widely outside our country constituting main rail vehicles detection systems.

Therefore, starting with the definition of crossing signaling, it constitutes a set of devices, so called Automatic Crossing Signaling (ACS; Polish SPP) system, used for securing the traffic at the railway crossing of B or C categories [27].

It is used mainly for securing the traffic on intersections at the level of roads with railways. The B category are railway crossings including intersections of railways or railway sidings with public roads where:
a) exposure factor is equal or bigger than 150 000 or
b) railway line or railway siding crosses the railway road.

2. RAILWAY SAFETY SYSTEM – STATE OF ART

Every year, more than 400 people are killed in over 1.200 accidents at road-rail level crossings in the European Union (European Railway Agency, 2011) [9]. Thus railway safety system is extremly important and it becomes scope of research on many institutions. Train movements on the infrastructure are regulated through a signaling system and a well dened set of rules. The traditional system is based on light signals separating portion of tracks called block sections [19].

The European Railway Traffic Management System (ERTMS) is a major industrial project that aims at replacing the many different national train control and command systems in Europe with a standardised system [7]. As the foundations of ERTMS can be pointed methodology for security-informed safety and hazard analysis.

Most of the european railway standards highlight the influence of human factors into railway system's safety. The paper [13] presents the analysis of reliability, availability and maintainability and particularly safety (RAMS). The most important and wellknown standard for the system design of railway technical components EN 50126-1 requires integration of human factors. The authors of this paper suggest that future risk assessments have to integrate the human factors of the operator, employer's measures and the risk of human error in the design phase.

The paper [14] discuss with application of public wireless computer networks in railway control applications. Exchange of information in Railway Control System using an open transmission must guarantee the safety of the transmission. As the example of application of open transmission standard instead existing cable connection authors present innovative system of cross level protection. The other method for railway safety secure is the Absolute Changeable Block Distance System conception. It assumes the time spacing control used dynamic block section between trains. The length of block section may change in time according to the current traffic situation in the controlled section of railway line [14].

One of the most innovative approaches in railway safety system can be pointed the US patent - railway system using acoustic monitoring [8]. It based on method of monitoring of a railway system which includes a track and train, with application of an acoustic transducer. This method allows for predicting the time at which a train will arrive at a level crossing. The system includes train detection module based on the phenomena that there is a significant amount of noise and vibration created during train passes. Each train has a clear signature, i.e. vibration amplitude or time-frequency characteristic which is dependent on e.g. train type, trackside infrastructure and train speed.

Other point of veiw on railway safety is focused on satelite-based localization technologies. Global Navigation Satelite Systems can offer localization services in ERTMS. But as any new solution it has to be confirmed by RAMS properties. The paper [5] presents procedure of evaluation of use GNSS in rail transportation. It discussed train localization possibilities in different cases and environments.

3. CROSSING SIGNALING SYSTEMS

The above mentioned devices are usually triggered by sensors by trains approaching the mentioned crossing and which are in the impact area of heads of the wheel sensors detecting movement in their area and movement direction of the rail vehicle.

In order to trigger the ACS in older types of crossing signaling, e.g. track circuits are used but ultimately it is also possible to control the crossing manually e.g. by the train dispatcher [18].

Crossing signaling devices are triggered by the train approaching the mentioned crossing by track-side sensors. There are following warning devices installed at the crossings: light traffic control devices most frequently with a sound signal so called bell and one or two pairs of half barriers. Triggering of the crossing takes place several dozen seconds before the nose of the train reaches the crossing and turning off few seconds after the last axle left the crossing. All the above mentioned actions are triggered by the used rail vehicle detection system which is the main subject of this paper.

The most common crossing signaling types in Poland are:

- ACS of the COB-58 type;
- COB-63type;
- SPA-1type;
- SPA-2type;
- SPA-2A type;
- SPA-2B type;
- SPA-4 type;
- SPA-5 type;
- NE BUE 90E PL type;
- BUES 2000 type;
- RASP-4 type.

Each of the above mentioned types of signaling has a different rail vehicles detection system. Some of them also have the certificates approving application with 2 or more wheel detection systems like: ACS of the SPA-4 type. This system may also cooperate with track circuit system of the EOC-1 type, as well as with the axle counter of the ELS-95 type.

4. RAIL VEHICLE DETECTION SYSTEMS

Train detection systems are most important components of the railway safety system. Especially with the recent development of high-speed railways.
Currently the ETCS Level 1 and 2 provide the train localization functionalities by using track circuits or axle counter systems. The problem of these solutions is represented by the high cost of track circuit and axle counter installation and of the related equipment management [1]. The paper [1] presents an innovative algorithm of train detection based on novelty estimation method. All assumed train quantities can be computed by means of only auto and cross-correlation operations. The track input used is the mean between the signals coming from the force sensors located on the left and right side on every sleeper.

One of the innovative technique of train detection through magnetic field sensing is presented in paper [28]. The authors present modeling and simulation results with detection of train presence, numer of rolling stocks and train speed or length.

Additionally, rail vehicle detection devices that are most commonly used on the Polish market in signaling systems were presented below.

The purpose of those devices is giving signals indicating the presence of a rail vehicle at a given place and its movement direction. Those signals are transmitted to the control cabinet by copper wires and then processed by drivers or relays into certain action of the crossing signaling.

- Double sensor of the EON - 6 type,
- ELS - 3 sensor (magnetic),
- Magnetic sensor CTI,
- Mechanical sensor ELS-6,
- Single sensor EOC-1,
- Cable-free train sensor EOC-4,
- Wheel sensor ELS - 95 produced by Bombardier, „FSSB" produced by SCHEIDT&BACHMANN, RSR110 sensor by Frauscher or pintsch-tiefenbach sensor.

4.1. EON-6 track sensor

This sensor is used for controlling the track vacancy (occupancy) and for cooperating with other devices like interlocking or information devices in ACS.

This sensor works on the basis of detecting the short-circuits of rails and works only when the rail vehicle is on the track.

The idea of its operation is based on the jointless track circuits with high frequency ranging from18 to 40 kHz. The are two independent electronic components. Those components include a transmitter and also a receiver or two receivers working on the similar basis, independent from the nominal frequency.
There are two basic types of electronic components:

- MER-112202 with a transmitter and two receivers and
- MER-112302 with a transmitter and one receiver

The transmitter generates a sinusoidal signal and powers a stretch the track with it. The signal receiver or receivers are connected at a certain distance from the place of connecting the transmitter to the track. The part of signal which is generated by the transmitter is received by the above mentioned receivers. If the axle of the train or other rail vehicle is in the area where the transmitter or receiver is connected or between the places where they are connected, it will contribute to the reduction of the signal received by the receiver. In a normal state, the receiver itself after receiving a given signal is activated and by reduced input signal, that is when the rail vehicle axle interrupts it, it reactivates [11].

If we use two receivers, so called double sensor, we will get two track circuits, one with the activity area e.g. L1 and the second with the L2 activity area. This solution is used for detecting the rail vehicle in the area of sensor activity and for determining its direction.

Another solution is a single track sensor used as e.g. sensor turning off the crossing signaling but then we only use a one transmitter.

4.2. CTI Sensor

The set of impact devices is composed of:

- Magneto-inductive heads CTI-3,
- Double base plates ELP or PCS and fenders,
- Electronics panels ECT or CTI 302K (additional sensors on the double track) and
- PM mounting plate.

The head of the sensor contains two independent sensor systems. They allow functioning of the sensor as a single or double one, where in case of using it as a single sensor and the coils have to be connected parallel. Each head is consisted of four permanent magnets located on the steel base plate. The body of the head is an aluminum mold and as a whole is hermetized by resin fluid and silicone sealing [10]

The purpose of the electronics located on the ECT panel is mainly processing the analogue electrical signals from the heads into binary signals that can be accepted by input circuits of the crossing signaling systems. Electronics panels are installed in the apparatus cabinets on PM mounting plates.

A direction detection module is connected with every head of the CTI-3 sensor [3].

While passing over the sensor, the flange of the wheel generates a voltage impulse in sinusoid-like shape. Each axle passing over the sensor corresponds to short impulses coming from both coils of the sensor head that are directed onto inputs of the direction detection modules. The CTI used as a turning off sensor does not cooperate with the direction detection sensor.

One of the most common failures of the sensor is improper connecting of the wires in the IVA box. Very frequently the water gets into the boxes. It causes malfunction of the CTI sensor.

Advantages:

- Do not have connecting lines (less devastation),
- Do not consume power as e.g. EOC,
- Very weather-resistant.

Disadvantages:

- It is impossible to detect the head failure and its e.g. defective location in relation to the rail and they have only the cable continuity control circuit [3].

4.3. ELS-6 Mechanical sensor

The purpose of the sensors is using them in SPA-1 crossing signaling devices and replacing with them the ELS-3 magnetic sensors that are ineffective on the electrified railways when it comes to their reliability.
A complete mechanical sensor ELS-6 is:

- head,
- two cantilevers,
- connector and
- two fenders.

The head as the main part of the sensor, receives the impact of the train wheel flange. The cantilevers are mounted to the rail base and are the head bear elements. The connection is an electric connection between the head with the cable box and the fenders are used only for protecting the head against the mechanical damages.

Train detection is based on the wheel load on the head lever and this causes the switchover of electrical contacts through the mechanical transmission mechanism. Due to the hydraulic return damping of the lever movement, the contacts after the wheel left the track, remain permanently closed by approx. 2,5 s.

The sensors may have one lever as single sensors or with two ones as double sensors.

A single sensor identifies only the presence of the wheel above its lever, the double sensor can additionally identify the wheel movement direction. The ELS-6 sensor occurs in 64 variants depending on the type of the rail to which the sensor may be mounted, number of levers, type and length of the connection or contacts etc. The sensors without damping, that is those that do not have the lever return delay system, are not used in the crossing signaling [4].

4.4. ELS – 3 sensor (magnetic)

The ELS – 3 sensor is a 3-pin and passive point impact device that does not require a separate power supply. In the standby mode, the contact in the sensor is open and when a rail vehicle appears above it the contact closes.

The sensor head screwed to the fixing plate can be covered on the rail base. There are four ferrite magnets placed symmetrically, between them there is a horizontal opening with a thread for screwing the filling with a reed relay inside. Each of the 4 magnets produces the magnetic field and due to their symmetrical location, their magnetic fields cancel each other out in the area of the reed relay. As soon as the rail vehicle wheel appears between the sensor head and the rail, the above mentioned field balance is interrupted and in the area of the reed relay filling a magnetic field will be produced that causes the short-circuit of contacts. A single sensor is not used for the direction detection and this can be done only by double sensors in cooperation with appropriate direction detection system.

4.5. EOC-1

EOC-1 is a single safe sensor, common for the channels „A" and „B". Its functioning is based on the jointless track circuit and it consists of a transmitter located inside the circuit that generates a signal of appropriate frequency and two receivers located on the both sides of the circuit and receiving the signal from the transmitter.in the basic state the voltage at the output of the receiver should be higher than 6V (too high voltage means a lack of connection with the load) which is treated as the logical level „1".

No voltage that is the logical level „0" is caused by:
- circuit or break of the rail by the rail vehicle,
- damage of the receiver line or receiver itself,
- damage of the transmitter,
- short circuit of the cable transmitting the signal to the cabinet or damage of the surge protection system.

The train entering the zone controlled by the given receiver shorts the rails and therefore breaks the signal transmission to the receiver. Then the output voltage is not higher than 0,5V.

The common area where the rail shunting causes the reactivation of both receivers ranges from 3 - 10 m.

Test signal of the sensor is sent on average every 3 s and lasts no longer than 20 ms. It causes closing of the channels as if the train was coming which is visible through the short term, temporary extinguishing of the LEDs of the input modules which correspond to given sensors.

4.6. EOC-4

Cable-less train sensor EOC-4 was manufactured mainly for areas where the weather conditions exclude using the standard sensors, e.g. in the mountainous terrain or by train speeds not exceeding 120 km/h. by maintaining a sufficient degree of the operational safety of the EOC-4 sensor, the manufacturer assumed that the length of the track sections corresponding to it should not be bigger than 1000 m. The EOC-4 sensor requires maintaining the rails continuity and no short circuits between rails in all of the track sections which vacancy is detected.

4.7. Wheel detectors

At this moment there are few types of wheel detectors by different manufacturers,

The basic difference are, besides the internal coil systems, the sensors without electronics and sensors with the track-side electronics.

The wheel sensor is used mainly in places where all common track circuits are useless. It functions perfectly in heavily soiled areas with, e.g. conductive materials, in places rarely used, that is subject to rust where it is necessary for the rails to be constantly shorted, e.g. on bridges and places where the length of tracks sections is bigger than the outreach of track circuits that are used nowadays. The main limitation is the diameter of the wheel of the rail vehicle.

The general operating principle of the wheel sensor is based on swinging the force lines of the magnetic field of the elements built in the sensor.

Usually they are made out of on or few transmitting coils and of few receiving coils covered with special waterproof mass in one housing. The force lines of the field of the transmitting coil cross the receiving coils. As a result of the wheel flange appearing under or above the receiving coil, it comes to the swinging of force lines of the magnetic field and change of inductivities of the coil that influences the current flowing through the coil.

The sensor is mounted using a special claw or directly to the rail web.

An example of wheel sensor, ELS-95 sensor produced by Bombardier company consists of the following elements:
- the EFM head,
- track-side electronics system of the EDS type connected with the head with sufficiently long cables.

The head of the ELS-95 wheel sensor consists of few transmitting coils mounted on the rail, outside the track and few receiving coils mounted on the rail inside the track ensuring appropriate coupling. Each of coils is supplied by a signal of different frequency. The receiving coils are connected counter parallel. Due to this type of connection we get a signal that is much more resistant to traction interferences caused by the current flowing along the rail.

The passing over of the rail vehicle wheel causes coupling changes that is changes of the signal induced in the receiving system.

The track-side electronics systems consists of metal housing and electronics cassette that contains logic, power supply and transmission modules and modules of cable connections and identifier.

The most important element of the cassette is logic module that generates two sinusoidal signals with different frequencies and amplitudes. They supply power to the head.

The filtration-reinforcing systems process the signals transmitted from the head from the receiving coils and demodulators change the slow-rated signals that allow detecting the wheel above the head.

Two channels designated for processing the demodulated signal change it into the digital form and process the input signals. Moreover, they perform also the self-testing procedures, they formulate telegrams and exchange information with the evaluator by the transmission system.

The identifier module contains the address of the given wheel sensor and the power supply/transmission module contains the power supply and adaptation systems.

4.8. The direction of development

Detection systems currently used in railway level crossings are the evaluation systems developed decades ago. It is difficult to predict their life time, however, present work focused more on the use of widely available devices with high reliability that can provide safe and reproducible detection of rail vehicles.

An example might be a proposal Frauscher applying optical fiber which, through its natural properties as impurities and inclusions detects vehicles causing vibration of these inclusions caused by the approaching rail vehicles. The system is based on the reflection wave from the vibrating particles by measuring the distance is able to determine the vehicle's position in relation to the interesting railway crossing and start closing level crossing.

Similarly, the use of other available devices, such as. Honeywell radar enables the detection of a rail vehicle by specifying it with a broad background, measuring its speed and distance at the same time and as a result of the advance implementation of appropriate level crossing signaling devices. Honeywell's Vehicle Detector is a radar based sensor That uses Doppler and FMCW mode Simultaneously for detection of vehicles, E.G. trains.

At the moment it is difficult to say which system obtains the status of a secure system on the model of the sensor wheel and will allow its use as a stand-alone for the detection of rail vehicles. The work are in progress and about the effects we will see probably in the coming years.

5. SUPPORT SYSTEM

Despite the constant development of level crossing safety systems, it is reasonable to conduct more research on increase of safety in such important field of rail transport system. Thus it was assumed that an important issue is to consider some support system to increase the reliability of the safety system [22, 23]. Also the authors assumed that the support system has to work as the alternative for fundamentals systems and it has to base on different phenomena.

The authors have conducted some preliminary research on application of vibration signals for analysis of driving properties of rail vehicles. The paper [15] presents the research on possibilities of applicability of vibration signals of train driver's cab for train control. The acceleration of vibrations in the train driver 's cab was registered. The paper [17] describes implementation of the method for the sake of application of remote monitoring in the course of shunting of the SM42 locomotive. uses the accelerometer system (MEMS) to record linear accelerations in 3 axes occurring in the course of the shunting locomotive's operation. The paper [16] presents results of proposed metric calculated as inverse tangent function of current longitudinal and transverse accelerations. As the result we obtain resultant angle and information on relation between longitudinal and transverse interactions.

The figures 1 and 2 present some example results of vibrations of rail vehicle which were measured for 3 orthogonal axis. For the presented results it can be observed accumulation of vibration energy in wide range around the 15 Hz.

Based on analysis of results of vibration signals it was assumed that support system can be consider as analyser of vibration signals. The requirements for such a system are as follow: train vehicle detection, speed or braking identification. The concept of the complex system (with support) have been depicted in Fig. 3.

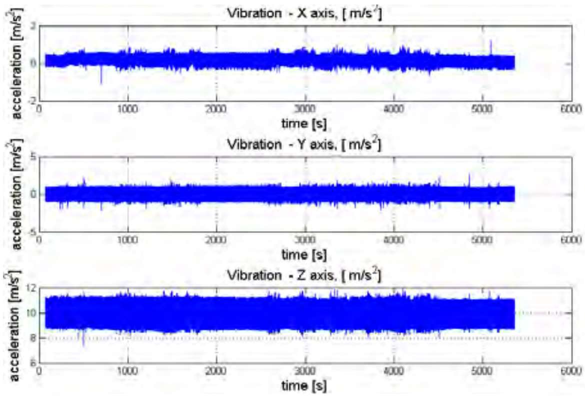

Fig. 1. Waveforms of train vibrations in 3 axis

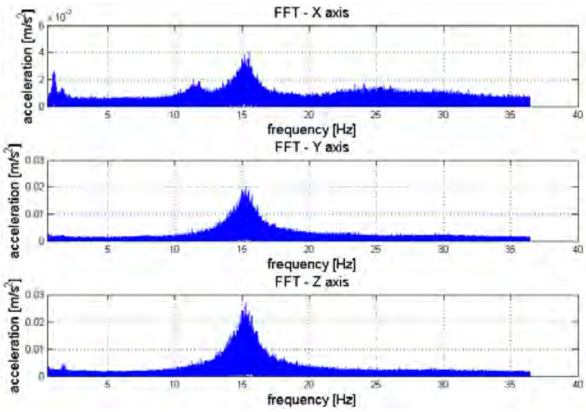

Fig. 2. Spectrums of train vibrations in 3 axis

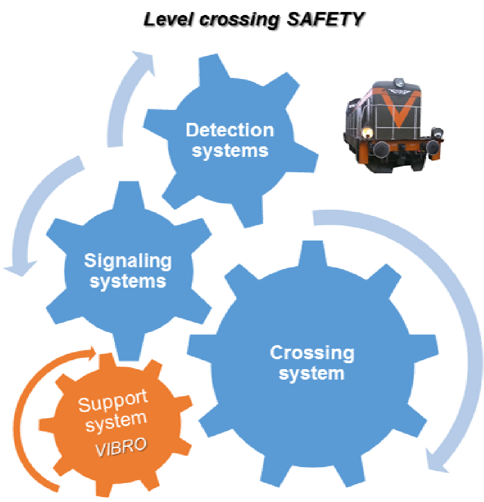

Fig. 3. Fundamentals and support of level crossing safety

6. SUMMARY

With the development of automatic crossing signaling systems and high speed rails, the rail vehicles detection systems were also developing, starting with magnetic sensors through track circuits to axle counters. The last ones seem to be the only widely used and adapted to rail vehicles detection now. Their resistance to disturbances, to very commonly bad quality of rails and track bases, resistance to the weather conditions and their results e.g. salinisation of the crossing by the snow-blowers results in the displacement of the track circuits used till now in the vehicles detection.

The producers still work on new ways of the train detection using the newest technologies, like e.g. radars, photocells or cameras that allow the detection of the train as soon as it appears in the viewfinder of the lens. The paper presents conception of support system based on vibration signals.

In the future years we will probably observe a boom in the detection systems for which the crossing signaling system producers will seek to obtain approvals of use. Regardless of which one of those devices will be responsible for detecting the approaching rail vehicle, they all, independently of its kind, type or size, will have to meet the highest safety standards and therefore protect all the participants in the road-rail traffic.

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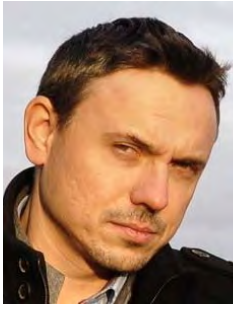

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