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CHARACTERISTICS OF EVENT RECORDERS IN AUTOMATIC TRAIN CONTROL SYSTEMS

Marianna JACYNA[1], Emilian SZCZEPAŃSKI[2], Mariusz IZDEBSKI[3], Sławomir JASIŃSKI[4], Mariusz MACIEJEWSKI[5]

[1, 2, 3] *Warsaw University of Technology, Faculty of Transport, Warsaw, Poland*
[4, 5] *Rail-Mil Computers sp. z o.o, Warsaw, Poland*

Contact:
1) maja@wt.pw.edu.pl, 2) eszczepanski@wt.pw.edu.pl, 3) mizdeb@wt.pw.edu.pl, 4) slawomir.jasinski@rail-mil.eu,
5) mariusz.maciejewski@rail-mil.eu

Abstract:

The development of railway transport in the current times is very noticeable, it is connected with the growing needs of movement as well as the development of information engineering. The increase in the demand for transport requires the implementation of solutions that increase the efficiency of the transport system. Both long-distance, agglomeration and metro railways can use different systems due to their specificity. Nevertheless, there is a noticeable trend in the development of systems supporting or even replacing the driver by the automation of selected activities. Such systems allow to reduce trains headway and thus increase the capacity of the line. CBTC class systems (Communications-based train control) belong to automatic train systems and are based on wireless transmission. The main purpose of using such systems is to increase the frequency of running trains while maintaining the level of safety. Computers that are on the system equipment record, process and analyse very large amounts of data. An essential element of such systems are recording units. The parameter recorders can be divided into technical and legal ones. However, for CBTC class systems, there is no obligation or requirement to use legal recorders as it is in the case of ETCS. However, it is necessary to use event recorders, and these are subject to the requirements set out in the PN-EN 62625-1: 2014 standard. The recorders are a very important component of safety systems, which is why they were analysed in this article. Both the driver, the vehicle and the infrastructure should be subject of continuous monitoring. The occurrence of an adverse event (not necessarily leading to an incident or accident) should be analysed and used to improve safety procedures. Currently, automatic systems are still developing and we are not able to accurately assess what the causes and effects of certain events may be, which is why data collection and analysis is particularly important.
The article presents the general specification of the CBTC system. The parameters and properties of driving recorders should be presented. This article is co-financed by the European Union POIR.01.01.01-00-0276/17

Key words:

rail transport, Automatic Train Control, Communications-Based Train Control, Juridical Recording Unit, event recording unit, CBTC, ATC, JRU

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1. Introduction

Rail transport plays an important role in passenger transport. It is a basic alternative to road transport, at the same time very often faster and safer. Undoubtedly, along with the development of technology and control systems, it is possible to introduce improvements that, for example, increase the capacity, increase speed or improve safety. An important role in today's times is played by the autonomy of all vehicles. This trend is especially noticeable in passenger cars, but for years certain activities have been automated in rail transport. Depending on the level of automation, it can be an automatic acceleration, braking, opening/closing the door, or reaction to various events (Żurkowski, 2018, Jacyna et al., 2017).
In connection with the continuous population growth in cities (United Nations, 2018) and the same increase in the demand for passenger transport, it is necessary to increase the efficiency of urban transport systems including subway and agglomeration. Productivity can be increased by using more spacious means of transport, increasing average speeds or increasing throughput. All activities to improve performance should be planned to keep in mind the safety of users and residents (exposed eg to noise, pollution, etc.).
One of the solutions in rail transport is the introduction of automated train control systems. Their use allows to increase the speed of trains and shorten the train headway on specific railway line. Depending on the degree of automation, it is possible to send signals that allow the driver to react or even replace his reactions by the machine. It is obvious that the train time cannot be shortened at any time, or their speed cannot be increased, restrictions are due to the length of the sections, accompanying infrastructure, safety systems and traffic organization (Burdzik et al., 2017; Jacyna et al., 2017).
Żurkowski (2018) indicates systematic classification of automatic systems in train traffic (Table 1). On the basis of the aforementioned classification, there can be distinguished systems supporting or automating selected driver's actions or, like APM systems, full automation systems in running trains. However, this approach requires meeting a number of criteria that can be achieved, for example, in the subway.
The above classification includes various systems that can be combined into certain solutions. An example of such a system is CBTC (Communications-based train control), which is the subject of this article. In the following chapters of the paper the general characteristics of the CBTC system and the aspect of railway traffic safety were presented. Selected regulations regarding the recording of train driving parameters and the requirements that should be met by the technical recorder in order to perform the functions of a legal recorder (JRU) in the rmCBTC system.
The proposed rmCBTC system is a unique solution. Nevertheless, its development is based on tried and tested solutions used in practice in ERTMS/ETCS system, which is fundamental for the rmCBTC system.

2. CBTC class systems and safety of transport

CBTC systems are automatic train systems. This system is based on bidirectional train to ground communication. Data exchange in such a configuration is to ensure safe traffic flow (Pascoe and Eichorn, 2009; Chan et al., 2018).
The system architecture is hierarchical and consists of a master station collecting information about all trains on controlled lines, wayside of transmitting devices and receiving information from trains as well as particular train-borne devices. The operations control centre knows the location of all trains their current speed and direction of traffic, which allows them to give each train the permission to drive at a certain speed on a given distance. All communication requirements are contained in IEEE 1474, this results from the need to meet strict standards in the transmission of information which is critical to safety (IEEE 1474.1-2004). Schematic representation of CBTC is shown in Fig. 1.
The CBTC architecture is based on bidirectional train to ground communication using a wireless network and access points (AP) located along the path. As a rule, these systems are redundant and the trains are equipped with at least two communication devices that look for the signal independently. In addition, considering the acceptable delays in signal transmission and ensuring continuity of communication, the train must be within a range of at least two APs at the same time. Obviously, this also involves redundancy in the field of access point assembly along the line. For reasons of safety and depending on the characteristics of the lines hybrid models supported additionally eg by GSM / LTE (Ai et al., 2015) are often used. Delays in sending information

or interruptions can lead to dangerous situations such as derailment or collision with another train. This is due to dependence on track-side infrastructure. The train switching between the AP and the switching time will prolong can cause potentially dangerous situations. Therefore, the introduction of hybrid solutions or additional communication, eg between trains, allows the increase of reliability and traffic safety (Chung et al., 2011).

The system architecture consists of 4 main elements that play important roles in the automation of train movement (Zhu et al., 2014):

– ATS – a system that supervise the current situation and affects the schedule of transport in a way that minimizes the effects of disturbances, assesses the speed and travel time between successive stations.
– ZC – zone controller is a system that has own wireless transmission system. Its purpose is to identify the current position of the train, its speed, direction of movement. On the basis of the information collected about trains located in given areas of the network, it is possible to provide movement authority for particular train.
– ATO – based on the ATS system, ATO optimizes the train's journey considering the speed, distance and determines operational speed profile depending on the position of the trains as well as stopping points, energy efficiency requirements etc.
– ATP – subsystem allowing to determine the braking curve depending on the current situation on a given section of the line, of course it also performs control functions and can start braking before the ATO system when reaching the acceptable speed (from the braking curve).

Table 1. Systems that automate train driving (Żurkowski, 2018)

Name	**Description**
AWS Automatic Warning Systems	Systems controlling driver's vigilance through visual and audible warning of approaching signalling devices, journeys or speed limit sections.
Automatic train braking system	The system (AWS class) used in Poland automatically alerts train drivers to approach signalling devices; in the absence of drivers' reaction, braking is implemented.
ATP Automatic Train Protection	Systems controlling at certain points the compliance of the driver's driving with the indication of signalling devices; they may be equipped with a simplified cabin signalling that maps track-side signals to the driver's desk but does not take into account the dynamics of the traffic.
ATC Automatic Train Control	Real-time control systems for compliance of the driver's driving with the indication of signalling devices; the speed limit, braking to the speed limit point and the end of the movement permission are also subject to control. In addition to continuous monitoring, the systems display information in the drivers' cab enabling speed and braking control.
ETCS European Train Control System	The European system (ATC class) automatically controls the running of the train, taking into account the dynamics of traffic, defined in detail in publicly available documents indicated by the European Commission's regulation. It is produced by many producers and implemented both in EU countries and outside Europe.
ATO Automatic Train Operation	Systems that automatically operate train control devices according to information received from trackside signalling devices, replacing the driver in running the train performing automatic train driving (ATD function).
ATS Automatic Train Supervision	Trackside systems for assisting the supervision of automatic train travel (ATD) implemented by automatic train systems (ATO).
APM Automatic People Movers	Separate, collision-free transport systems for the transport of persons, pendulum or looped trains without train drivers, vehicles equipped with ATO, operating under the supervision of ATS.

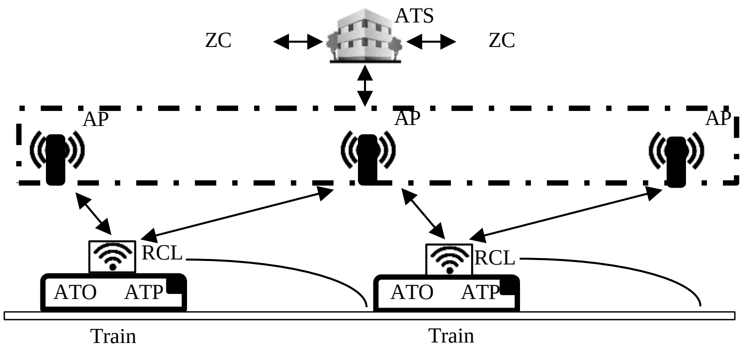

Fig 1. CBTC scheme (based on Chan et al., 2018; Zhu et al., 2014)

In addition, it should be emphasized that infrastructure is an indispensable element. Systems installed on the train, fig 2. They play a very important role in the architecture of the entire system. They are based on a series of sensors and internal units of computation and internal communication between units. Particularly important is the possibility of building a system based on ETCS components, eg balise, which perfectly identify location, direction of movement and are essential for the functioning of the ATP system. The diagram in Fig. 2 shows the equipment of the train, which will be used to measure vehicle speed, and thus also to determine the braking curve. The main role in the CBTC system will therefore be played by:

– rotational speed sensors,
– linear speed sensor,
– fixed balise at a specified distance between them,
– BTM transmission module with cell antenna unit,
– vital computer with a data processing and acquisition module for vehicle speed
– wireless, bi-directional, redundant train to ground transmission.

CBTC systems as very advanced are subject to special restrictions and must meet high requirements. Many suppliers of these systems have developed their own solutions that have been implemented and are successfully used in practice. On the basis of online sources and information from CBTC class suppliers, an estimate was prepared in Tab 2.

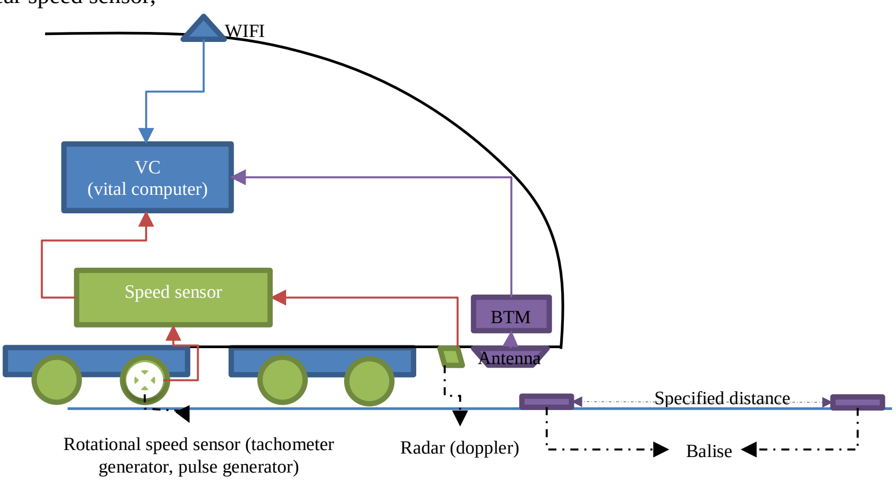

Fig 2. Selected train components in CBTC system

Table 2. Estimated number of CBTC system implementations according to the manufacturer (Thales, 2018°, 2018b; Siemens, 2018; Bombardier, 2018; Alstom, 2018)

Name	**Manufacturer**	**Number of implementations up to 2017**
SelTrac	Thales	38
CITYFLO 650	Bombardier	23
Urbalis	Alstom	30
Trainguard MT CBTC	Siemens	20
Invensys	Sirius	5
SPARCS	Nippon Signal	5
CBTC	Ansaldo STS	5
Others		5

Based on the above list, it can be seen that the majority of the market is held by four companies: Thales, Bombardier, Alstom and Siemens. These companies have developed their own ways to conduct traffic and there is no detailed information on the methods used, the architecture of the system is often similar and has similar elements. Nevertheless, each of them must meet strict standards, especially when it comes to safety.

In the field of railway traffic safety, the use of ATC is crucial because it ensures a high level of reliability and safety regarding the consequences of train speed and braking distance. This subsystem allows for an increase in the level of automation. Of course, full automation can only occur on specific railway networks, eg in the metro where there is full work. On other lines, eg suburban, the influence of the environment and the multitude of events and risks associated with them are too large to talk about the full automation of railway traffic. Driver's supervision is necessary for this area to be able to react properly to the current situation, and automatic systems only have to support it. Due to the possibility of events leading to incidents and even railway disasters, it is necessary to use systems that allow to assess the cause of their occurrence. Computers that are on the system equipment record, process and analyse very large amounts of data. An essential element of such systems are driving recorders (Żurkowski, 2018; Burdzik, 2017).

3. Legal regulations for registration of train driving parameters

Recorders of train parameters can be divided into technical and legal. In CBTC class systems, there is no obligation or requirement to use legal recorders as it is in the case of ETCS. However, it is necessary to use event recorders and these are subject to some regulations. The recorders are a very important component of safety systems, which is why they were analysed in this article.

JRU (Juridical Recording Unit) is defined as an element ensuring the functionality of a "black box" storing the most important data and parameters of a moving train and allows for their later analysis. These devices are also referred to as Event Recorders. At the moment, there are no uniform requirements as to the technical specifications of these recorders. Each country defines the requirements they must meet.

Juridical Recording Unit have to enable systematic recording of train driving parameters (from recording devices) and constitute an important component of the safety system. They allow the data to be read directly after the incident or accident and thus allow identification of the causes of the event. The registration concerns the operation of the locomotive (traction unit) and driver. Based on the analysis of the sequence of events leading to the incident, it is possible to introduce new safety measures to prevent their occurrence in the future.

At present, the current document defining the requirements for JRU is ERTMS/ETCS SUBSET-027 3.3.0 from 2016. It contains information about events that JRU has to store (in the form of standardized messages) and situations that trigger the recording of a given event (message recording by JRU). SUBSET refers to the TSI, which clearly indicates the function of the device as "Interface for data registration for legal purposes". It performs a function registering the traffic and vehicle condition parameters from on-board devices compliant with ETCS. TSI (OPE, CCS) does not explicitly define technical requirements for the recorder, but only provides a functional description of the recorded information.

Due to the CBTC system, it is necessary to equip it with a technical recorder, which allows identification of the cause of failure and incorrect operation of CBTC devices. It must store information, the scope of which should be agreed with the carrier. The registrar may simultaneously perform legal functions provided that the standardized format of event registration in the form of messages is maintained. An essential requirement resulting from the CBTC system for legal registrars is related to ensuring safety at the SIL-4 level.

The requirements for event recorders are regulated by national or international standards. In the case of Poland, this is the standard PN-EN 62625-1: 2014. It is at the same time a European norm. The scope of this standard includes the specification of the driving parameter registration system. The data recorded includes the operation of on-board systems and the driver's actions taken. The purpose of using such a recorder is to be able to read data in the event of an event (accidents and incidents) or for the purpose of monitoring the activities of train drivers and the possibility of analysing them. The standard presents functional requirements that coincide with the requirements specified in (SUBSET-027 3.3.0, 2016), but they are much more precisely specified. System requirements were also presented, including operating modes, recording performance, fault tolerance, hardware requirements and range of recorded data, as well as optional modes.

Other countries use their own standards, which often have similar scope and requirements. For example, the United Kingdom according to the applied standard (GM/RT 2472, 2014) specifies protection requirements that must be met by the recorder. The standards and standards used in other countries are similar to each other. Legal recorders are to act primarily as "black boxes", therefore the requirements for these registration systems are very high and must be regulated. In addition, the regulatory authorities of individual countries are trying to ensure the compatibility of these systems at the international level.

4. Requirements and selected characteristics of recorders

For the needs of ETCS, the normalized in the subset is the method of data registration and triggers that register them. In addition, it should be mentioned that the technical recorder can be both legal, or they can be two separate recorders. In CBTC systems, it was considered that the system should meet the requirements of ETCS, but above all comply with international standards to meet the requirements of the TSI.

According to TSI OPE and ERTMS/ETCS SUBSET-027 3.3.0, the driving parameter registration system consists of a unit installed on the vehicle, but in accordance with the recommendations for CBTC, it should be composed of two parts (stationary and vehicle). Each of the parts has the task of collecting data and in the event of a disorderly event taking place, the sequence of events that led to it. The scope of recorded data for the CBTC system should be established with the carrier (IEEE 1474.1 – 2004; European Commision, 2006, Szkopiński, 2014).

In summary, in the ETCS must be a legal recorder, in other systems it does not have to (unless it is to meet the requirements of interoperability), but the registration of events should be and it results from the laws and procedures for the admission of the vehicle into service (The Act of 28 March 2003 on railway transport– Sejm RP, 2016 and UTK, 2017)

In accordance with the generally accepted characteristics for the CBTC system, the main functional and system features of such recorders were specified on the basis of standards and practices and the values that the legal registrar for the CBTC system could be selected for. The minimum requirements for recorders are contained in the standard (PN-EN 62625-1: 2014), only the main features and their possible values are shown below (which are similar or more restrictive than in the said standard).

Functional features that have been adopted and what should a legal recorder characterize in the CBTC system:

1) Train running data must be recorded in a way that allows identification of significant events that occurred while driving.
2) Each recorded event must be recorded together with the date, time and location of its occurrence.
3) Data can be recorded in a loop, but data can be overwritten no earlier than 10 days after registration.
4) The list of registered parameters and data includes (PN-EN 62625-1: 2014):
   – Date,
   – Time,
   – Synchronization / regulation - date and time,
   – Vehicle identifier,
   – Driver's identifier,
   – Train identifier,
   – Starting the first / second cabin,
   – Distance,

– Speed of the train,
– Status of train service operations and safety brake devices,
– Brake control signal,
– Braking state of another train control line,
– Braking status of on-board signalling systems,
– Driver's actions and reactions to on-board warning and control systems,
– Operation of the driver when the passenger's alarm system is activated,
– Operation of the driver when activating the fire detection system,
– Activation of a device resembling a driver's driving principle,
– Operation by the crew of door control devices
– Disconnection / omission of a safety-relevant system,
– Activation of safety-relevant systems,
– Input of driver input data to safety-relevant systems,
– Operation of the train warning sound signal,
– The condition of the pantograph,
– Driving direction,

5) The recorder should be protected from damage and data loss.
6) Data integrity must be maintained for the most extreme conditions (defined as systemic resistance in system features).
7) Data must be protected against unauthorized access, against loss (eg in the event of power disconnection), against unauthorized typing, modification and deletion of data.
8) Data reading based on the communication interface (data transmission, if errors occur, will be repeated until it is carried out without error).
9) Multiple readings must be allowed (without affecting integrity).
10) The reading should be limited to performing by authorized personnel.
11) For unquoted data, provide signalling, how much% of the data has not yet been downloaded (not to lose them and allow recording) or provide a signalling device activated when 80% of the memory is exceeded with non-acquired data.
12) The last 24 hours of recorded data is stored on a "protected storage medium" that enables data acquisition and is additionally removable, provides protection as for the recorder, lasts for a minimum of two years and is easily recognizable (marked RAL2003 to easily identify it and recover after an accident).
13) The data obtained should be able to be processed (based on the manufacturer's program) into the standard CSV data exchange format.

System features that have been adopted and what should be characterized by the legal recorder in the CBTC system are:

1) Operating modes: power off, initiation, registration, standby. Transitions between modes and requirements for transition times for a given mode are shown in Figure 3. Four transition times are distinguished ie T1 - transition to initialization mode from the moment of switching on the power supply, T2 - transition to registration mode after initialisation, T3 - transition from standby mode to registration mode, T4 - transition to standby mode after 600 s, if there was no signal to register. Transitions from the registration mode to another mode do not have a time regime.

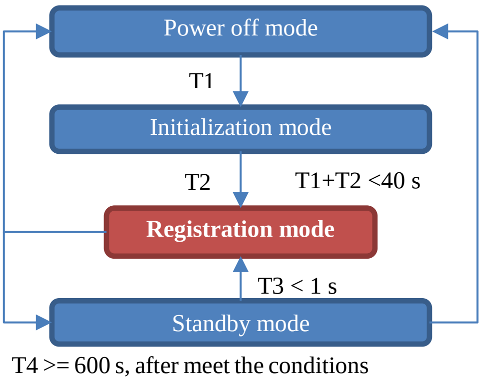

Fig. 3. Recorder operation modes along with transitions between modes (based on PN-EN 62625-1:2014)

2) The recorder will be equipped with two physical storage media.
3) The first with a capacity to register data for 10 days.
4) The second (protected) registrant of the last 24 hours.
5) Registration of data after the occurrence of the event will take place within 400 ms or within 2 seconds (the distinction of the registration time is aimed at extending the memory life depending on the severity of the event).

6) Incoming data will be saved at intervals of 200 ms.
7) The recorder will comply with the IEC 62948-1 environmental standard.
8) The average time between failures of the recorder will be 100,000 h, and the unit will be replaced in less than 1 hour.
9) The non-incoming data logging indicator will be 10^{-5} h^{-1}.
10) Access to data downloading will be limited by means of an authorization system.
11) Data integrity will be protected based on checksums.
12) Verification that the data being saved is unambiguous to incoming data.
13) The legal recorder in the initiation mode carries out correctness tests, in the case of a failure detection it signals it.
14) The recorder protection has been set for resistance to FB-SB-PA-CA-IB-HA-MA acc. (PN-EN 62625-1: 2014), i.e.:
   – Fire - 700 ° C for 5 minutes,
   – Impact shock - three shocks in each direction with a value of 100g and a duration of 10 ms, ½ of the sinusoidal impulse,
   – Penetration - weight 23 kg with a steel pin protruding 6.4 mm from the height of 1.5 m,
   – Static crush - 110 kN for 5 min,
   – Immersion in liquid - immersion for 60 minutes separately in water, extinguishing fluid, refrigerants (eg R134A),
   – Hydrostatic pressure - immersion in salt water at a depth of 15 m for 2 days,
   – Magnetic field - magnetic field generated by a current pulse from 0 to 64 kA, rising at a speed of 10 MA / s from the centre of the protected storage medium from a parallel wire to each of three orthogonal axes and from the field in both directions in each axis.
15) Resolution and frequency of recording of selected parameters are presented in Table 3.
16) Required entries of the legal recorder are presented in Table 4. In addition, a service connector (USB) and data transmission for reading the memory (USB, ethernet) are required.

Due to the specificity and diversity of systems, it is possible to develop your own solutions entirely or only to a certain extent. The recorders used currently perform well and the standards they meet ensure their full functionality.

Table 3. Data/parameters registered by the system as well as resolution and frequency of registration (PN-EN 62625-1:2014)

No.	Data or parameter	Resolution	Frequency
1	Date	1 day	Every hour or in the registration mode
2	Time	1 s	Every hour or in the registration mode
3	Synchronization / regulation - date and time	1 s	Every change
8	Distance	1 m	1000 m difference
9	Speed of the train	1 km/h	2.5 km / h change for train speed <50 km / h Otherwise, change by 5 km / h and every 1000 m distance
10	Status of train service operations and safety brake devices	Discrete	
11	Brake control signal	1 kPA for pneumatic brake	Transition between pressure thresholds for brake release and brake actuation
	OTHER PARAMETERS	Not applicable	Registration with every change

Table 4. Inputs of the recorder (PN-EN 62625-1:2014)

No.	Input type	Sampling
1	Digital input	200 ms
2	Analog input	200 ms
3	Frequency input	200 ms
4	PWM input	200 ms
5	Bus for identification data	2s
6	Bus for other data	200 ms

5. Conclusions

Automatic systems in railway traffic management are undoubtedly the future and will be the subject of research, but also implementations in the coming years. They allow achieving additional benefits from the already existing infrastructure and vehicle equipment components, retrofitting them with small elements and necessary software. However, increasing efficiency is not without a cost, and special emphasis must be placed on safety systems. This applies to full autonomy as well as CBTC type systems. The algorithms for calculating the braking curve and time of train headway, etc., are one of the important aspects of safety, but it is also important to constantly monitor the current situation and its archiving. To this end, it is necessary to implement systems recording all events that are to help in ensuring safety. In Figure 4, a diagram of this operation is shown. The driver, vehicle and infrastructure should be subject to continuous monitoring. The occurrence of an adverse event (not necessarily leading to an incident or accident) should be analysed and used to improve safety procedures. Currently, automatic systems are still developing and we are not able to accurately assess what the causes and effects of certain events may be, which is why data collection and analysis is particularly important.

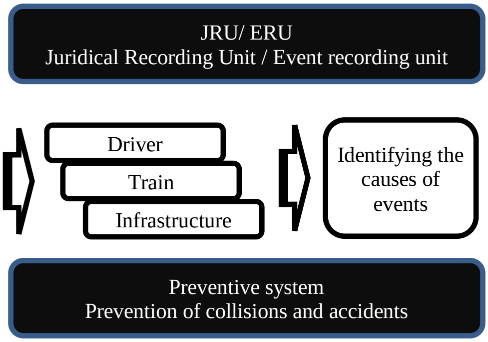

Fig 4. System components subject to registration

At the moment, most vehicles are equipped with various registration systems. However, it is important to provide the legislation and minimum requirements for registrars. Suppliers of trains or control systems can develop their solutions or use solutions of experienced producers. As the main providers of recorders, you can indicate: HaslerRail, EKE-Electronics, Deuta-Werke, Elte GPS, ATM PP, PIAP. The solutions they offer include technical recorders, which have certificates (broadcast in individual countries) ensuring compliance with internal regulations (range of parameters, technical and functional specifications) and certificates of functionality for the ETCS system or safety at the appropriate SIL.

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