EVOLUTION OF TRAIN CONTROL SYSTEMS

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Summary: This paper presents the brief history of train control systems, with description of technologies and tendencies, including comparison, analysis and classification of existing train control systems used in Europe.

1. Introduction

In the classical model of the information chain between the dispatcher staff/system and the railway vehicles (Fig. 1.), train control (and standalone cab signalling) systems have a separate sub-chain (dotted frame on Fig. 1.). This sub-chain describes two different processes: the transmission of signalling information to the train driver in the cab, and the automated influence on the movement of the railway vehicle (marked with dotted arrow) in the form of (usually emergency) braking.

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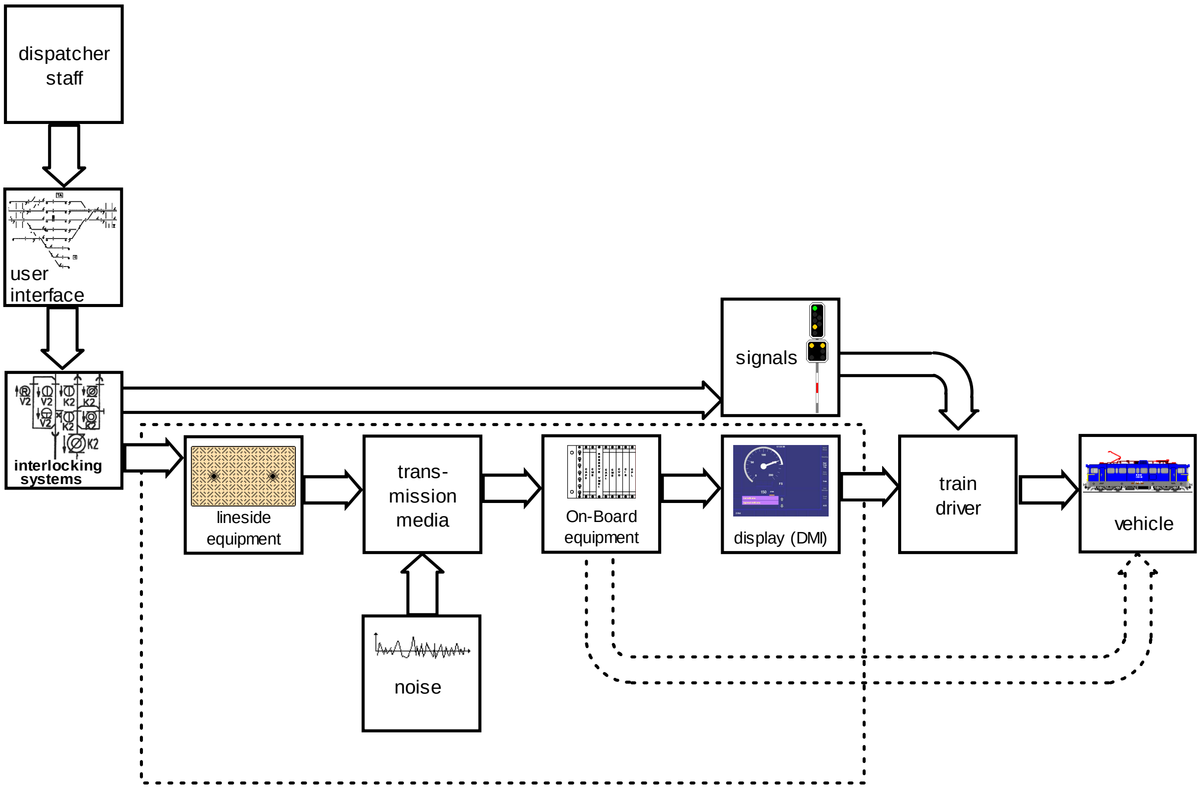

Fig. 1. The classic information chain between the dispatcher staff and the train vehicles.

Because of some historical reasons, which will be discussed later, the railway terminology often melds together the two processes under the term of “train control”. In some cases, this can be very confusing, since there are systems in operation without any influence on the train movement.

2. The brief story of train control

The first non-visual elements used in the information chain dates back to the XIX. century. In 1842, E. A. Cowper patented the first acoustic signal, the “detonator”, which was practically a petard attached to the railhead, which exploded when a train ran over. Since it had to be placed manually, the application was limited to emergency situations. [2]

The next step was the automation of the acoustic signalling, by the means of mechanical contacts between the signals and the locomotives. Inventions for automated operation date from as early as 1850, in Britain and the U.S. In the early implementations, the acoustic signal (typically a gong) was installed on the trackside, e.g. on the signalmast. When the signal showed stop aspect, a bar raised enough that it was depressed by the flanges of the wheels of the train. Since the bar was connected mechanically to the gong, each axle gave an audible signal in case of passing the stop aspect. Later the gong was placed on the locomotive, thus, the earliest form of cab signalling was born. [3]

Around 1872, the “Crocodile” acoustic warning system came, which has the longest lifecycle of all train control systems, as it is still in operation on the French and Belgian network, in almost unchanged form. The name “Crocodile” refers to the shape of the trackside device (actually a ramp placed between the rails), which is used to establish a galvanic contact to transmit signalling information to the locomotive.

From this point, the introduction of the first true train control system was just one step ahead. Around 1870, Axel Vogt, Master Mechanic of the Pennsylvania Railroad placed a glass tube above the cab, connected to the air brake pipe. As the train passed a distant signal showing “prepare for stop” aspect, a lever from the signal hit the glass tube so that it would be broken, and the brakes applied. [3]

The first widely used train control system was the British GWR’s “ATC – Automatic Train Control”, which was introduced in 1906. The basic principle of ATC came from the French “Crocodile” system. But, beside the acoustic warning signal, this system also had a mechanical display in the cab, and automatic emergency brake intervention. Although the ATC and the similar systems went through several modifications, the basic principle remained the same, and still works in various systems today. [1]

In 1920, the American Pennsylvania Railroad introduced the CCS (Continuous Cab Signals) system, which if often considered a milestone in the history of train control. The CCS is the ancestor is many existing systems, including the Hungarian EVM, the Italian BACC and the Holland ATB. Instead of electro-mechanical contacts, the CCS relies on an inductive contact between the fail-safe coded track circuits and the locomotive’s receiver coils. From the very beginning, coloured lights were used to display the aspect of the next signal in the cab. The original system had automatic brake intervention, but this was later removed by some companies. The CCS was so successful as a standalone cab signalling system, that some American railway companies removed the trackside signals from the CCS equipped lines to reduce operating costs. After the First World War, CCS was transferred to the Soviet union among other railway technologies. Considering the equipped track length, it is still the most spread system on the world.

Meanwhile in Europe, Siemens started to equip the German railways with INDUSI, the first widely used train control system which incorporated brake curve monitoring. Similarly to the American CCS, it also uses inductive coupling to transmit signalling information, but transmission occurs only at discrete points, by the means of wayside magnets. Due to its reliability, simplicity and the ability to stop the train before the danger point, INDUSI and its variants became the most popular train control system in Europe [9].

With the introduction of high-speed trains in the 1980s and 1990s, even more, sophisticated train control systems were developed, with static speed profile transmission and realtime dynamic speed profile calculation. However, usually these are used only on a national level, on isolated network sections.

Based on the three common ancestors (the French Crocodile, the American CSS and the German INDUSI) train control systems have been developed historically in many different ways throughout the railway companies. In 1990, there were at least 30 different train control systems in operation on the standard gauge European network [11]. (Fig. 2.) Despite the common ancestors, almost all existing systems are fully incompatible with each other.

Summing up, at the end of the 1980s, the evolution of train control systems seemed to end up in a babel of standards. Time has come to standardization on a European level [7] [8], which is the ultimate target of the new European Train Control System, the ETCS.

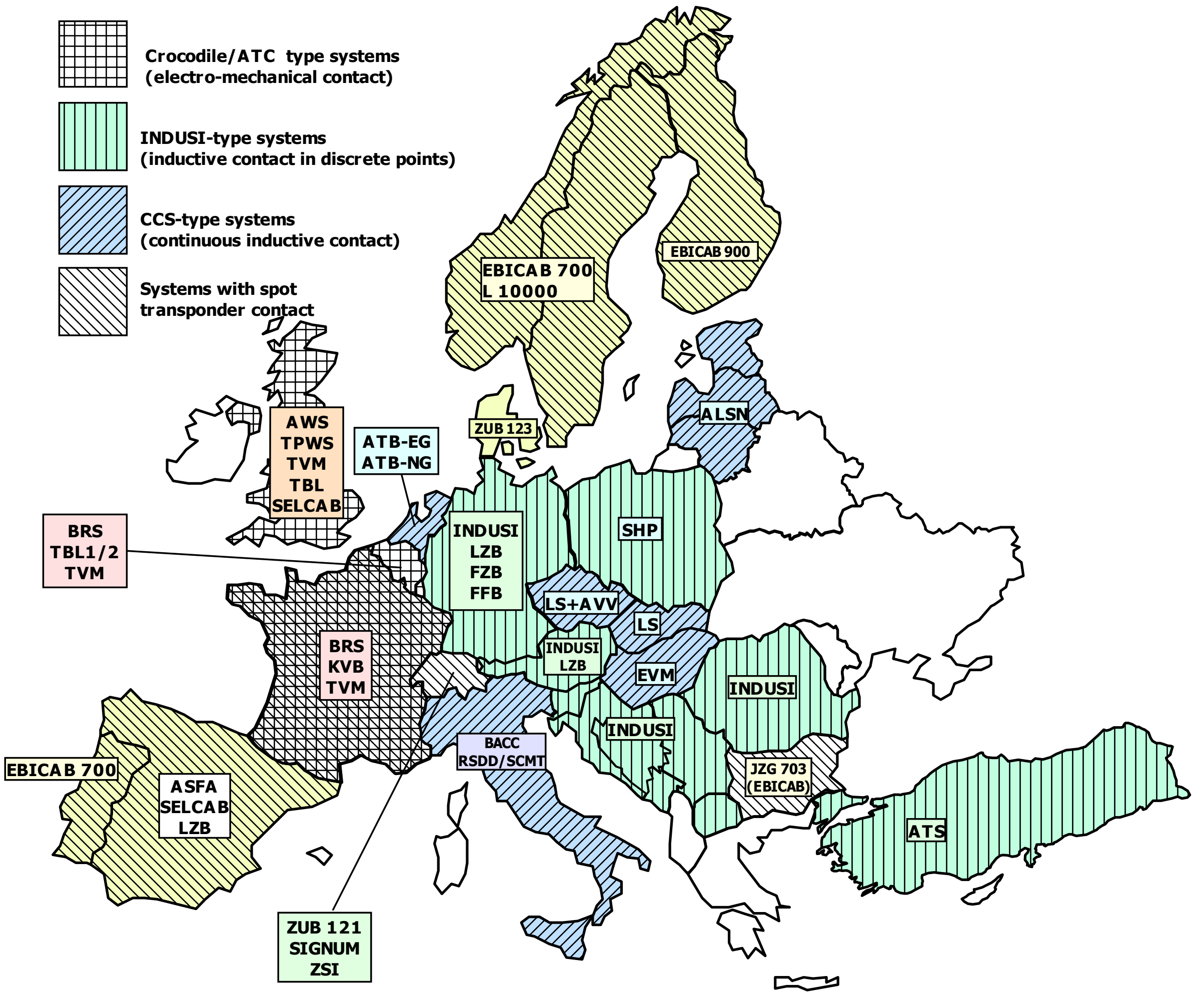

Fig. 2. Train control systems in Europe, without ERTMS/ETCS.

In the following sections of this paper, the pre-ETCS European train control systems will be classified using multiple criteria: functionality, the place and continuity of transmission of signalling information, the method of transmission, the type of the transmitted information, the type of the intervention and method used for determining the position of the train [9].

3. Functional classification

Considering the purpose of the train control, we can distinguish between two basic system types (Tab.1.):

There are **auxiliary systems**, which just give additional safety, but trains are still driven according to the trackside signals (e.g. Hungarian EVM, the German INDUSI or the Slovakian LS). Since the operation of these systems is based only on the aspect of the next signal, the static speed profile is not taken into consideration. The minimum safety requirement for such systems is quite simple: the display in the cab cannot show higher destination speed than the trackside signal. This also means that a dangerous situation can be caused by only simultaneous errors of the train control system and the train driver.

There are also full-featured **cab-signalling systems** (like the French TVM or the German LZB), where the trackside signals are missing, or their role in the information chain is subsidiary. In most cases, these systems are installed on high-speed tracks, with very high safety requirements [4]:

- The transmitted signalling information must conform to the actual traffic situation. This also means that the connection to the locomotive from the traffic control system must be permanent.
- The integrity of the transmitted signalling information must be maintained on the whole transmission route, by using some form of CRC checking.
- The on-board equipment must provide high reliability and safety level. Usually it is achieved with active redundancy.
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Functional type	**Systems and countries**
Auxiliary systems	PZB/INDUSI (Austria, Germany, Romania, Serbia, Croatia, Slovenia), EVM (Hungary), LS (Czech Republic, Slovakia), Crocodile (France, Belgium, Luxemburg), SHP (Poland), BACC (Italy), AWS/TPWS (Great Britain), ATB (Netherlands), ASFA (Spain)
Cab signalling systems	LZB (Austria, Germany, Spain), TVM (France, Belgium, Great Britain), TBL (Great Britain), SELCAB (Great Britain), ZUB 123 (Denmark)

Tab. 1. Functional grouping of train control systems (without ETCS).

4. The place and continuity of transmission of signalling information

Transmission of the signalling information can be done continuously, or at discrete locations (e.g. at signals). When **non-continuous (spot) transmission** used, the vehicles pick up the information from active or passive devices placed along the railway track. Thus, the validity of the information also depends on the location of the train, and each message is valid until the train reaches the next trackside device. In some cases, this can be a real disadvantage, since a restrictive change of the following signal can not be transmitted after the train passed the last device. However, such systems are widely used, since they are cheap, easy to install and operate, and can operate independently from other systems.

With **continuous transmission**, there is permanent connection between the trackside devices and the locomotive's on-board unit. This is essential for high-speed operation.

5. The method of transmission

As presented in the historical section, train control systems use four different ways to transmit the signalling information [9] [11] (Tab.2.):

The oldest method is the **mechanic contact,** where the active trackside device directly hits or pulls a brake valve to release the brake pressure and force the train to stop. This technique is still used on some underground/metro lines (usually called ATS – Automatic Train Stop).

The **electro-mechanic contact** (used by the French Crocodile system) is somewhat advanced, as the information is carried by a mechanic activation and an electric pulse. However, because of the complicated moving parts and the sliding contact, these systems are not considered to be reliable nowadays.

To overcome the problem of the moving and sliding parts, the next step of the evolution was the appearance of **inductive contacts**. Currently this is far the most widely used method for both of continuous and non- continuous systems.

Older non- continuous systems use magnets (low frequency transmission), as trackside devices. The transmission media for continuous systems can be the rails (CCS-descendant systems), or a separate loop. When using the rails, the amount of transferable information is very limited, due to the poor transfer characteristics of the rails as a conductor. Moreover, the track and traction circuits may disturb the transmission. On the other hand, the loop allows high bandwidth and error-free transmission, but the installation and maintenance is much more complicated.

The modern form of the spot inductive contact is the **transponder contact**, which operates at high frequency, and allows transmitting complex telegrams with short range radio beacons or balises.

With the spread of mobile communication technologies such as GSM, even more sophisticated train control systems were introduced (e.g. the German FZB and FFB) in the 1990s, where the communication between the traffic control system and vehicle is done via **wireless link**. It has many operational advantages, as there is no need for traditional wayside devices, just aerials and base stations. The highly integrated train control systems of the future (like ETCS level 2) will use this method [6] [7].

Transmission type	**Systems and countries**
Electro-mechanic (galvanic) contact	Crocodile (France, Belgium, Luxemburg), AWS/TPWS (Great Britain)
Conventional inductive contact	PZB/INDUSI (Austria, Germany, Romania, Serbia, Croatia, Slovenia), EVM (Hungary), LS (Czeh Republic, Slovakia), SHP (Poland), BACC (Italy), ATB (Netherlands), LZB (Austria, Germany, Spain), TVM (France, Belgium, Great Britain)
Transponder contact	ZUB 121/122/123 (Germany, Switzerland, Denmark, Bulgaria, Spain), Ebicab (Sweden, Portugal, Finland, Norway) KVB (France)
Wireless link	FFB (Germany), FZB (Germany)

Tab. 2. Grouping of train control systems by transmission type (without ETCS)

5. The type of the transmitted information

The earliest systems were used only for **location-dependent warning** purposes [2], and transmitted only that the train has passed or just approaching a signal, regardless its aspect. Later, some systems extended the operation with the “dead-man handle”, and the driver had to acknowledge the warning, otherwise an automatic emergency brake intervention occurred.

To achieve higher safety, location dependent **stop warning** was introduced (e.g. with the French “Crocodile”), to warn the driver that the train is approaching a signal which shows stop aspect.

The American CCS provided even higher comfort and safety, as it was the first system with **target aspect transmission.** However, (like most of its later descendants) it did not transmit distance information for the brake target at all.

Proper automatic target braking is possible only when both static and dynamic speed profile is calculated [5]. This requires the **transmission of movement authorities,** which define braking targets by distance and speed. Some systems are also able to **transmit the static speed profile** (or at least the temporary speed restrictions) as well.

6. The type of intervention

As discussed in the previous section, some systems give only warnings, and have **no automatic brake intervention** at all.

Most train control systems are designed with the assumption that the train can be safely stopped with **emergency brake intervention**, within a given brake distance in most cases. Usually the implementation is quite simple, since only a special valve is required.

The most advanced systems have **full speed supervision.** The dynamic speed profile is calculated on-board, and the trainborne equipment decides when to give warning, when to apply service brakes, and when to apply emergency brake.

7. Determining the position of the train

Some systems operate **without position information** at all. This means that there is no way to do target braking; therefore warning and intervention can be triggered by only a timer and/or an event (e.g. passing a signal with stop).

The German INDUSI uses **relative position information**, determined by odometry, which is measured from the recently passed distant signal. Thus, the position of the train is calculated only when braking to target.

The latest systems operate with **absolute position information,** so that the exact location of the train is always known. Usually this is done by measuring the distance from reference points, marked by trackside devices (e.g. balises). The accuracy of the position information depends on the accuracy of the odometry and the distance between the reference points. The typical accuracy is better than 3-4%, but this can be further improved by using wheel-slip detectors [10]. Since the exact location is known, the static speed profile can be retrieved from the on-board track map. Thus, there is no need to store infrastructure information in the wayside devices. Some systems determine the **absolute location from GPS combined with odometry**. According to the current researches, this will be widely used on low density traffic lines (LDTL) in the future [6]. This is far the cheapest method, as there is no need to deploy wayside devices at all.

9. Interoperability and standardization

As presented in the previous sections, several train control systems with different functionalities and technologies are used in Europe, so there has always been a problem of interoperability and migration of new systems – even on national level. The most popular systems are included in Table. 3. [9].

System	**Countries**	**Equipped track length**
PZB/INDUSI	Austria, Germany, Romania, Serbia, Croatia, Slovenia	~75.000 km
Crocodile	France, Belgium, Luxemburg	~35.000 km
CCS-type systems	Czech Republic, Slovakia, Hungary, Italy, Netherlands	~19.000 km

Tab. 3. Most popular train control systems in Europe.

The long term target is to replace the existing train control system with ETCS on the standard gauge European network. This will require a relatively long (10-20 years) migration period at the infrastructural side.

According to the current plans, more than 16.000 kilometres of track on the international corridor routes will be equipped with the new ETCS system at the end of 2008. This is great leap forward to the full interoperability, but it is important to note that not just the freight and passenger operators will benefit from the ETCS. Beside the higher safety level, a European-wide standardisation can significantly reduce operational costs for the infrastructure operators [6] [9].

10. Conclusions

The history of train control is a long and adventurous story [2]. As shown on the map in Fig.2., the operating principles and network coverage of the different systems perfectly reflect the past 150 years of the colourful European history. With the ERTMS/ETCS, the evolution of train control systems is now accelerating along the path to the interoperability and the united Europe.

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