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Modern Railway Signaling and Control Systems

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Abstract
Nowadays, railway signaling is based on automatic blocks, which does not require manual intervention. The modern railway signaling systems currently used today are intelligent and automatic high-performance systems. A line equipped with automatic blocks (interlocking) is divided into sections of length not shorter than the braking distance of the faster train running on the route. The function of detecting the presence or transit of the vehicles in a particular section can be realized through different equipment. In this paper, we recommend the radio communication network as new solution for detecting the presence of the vehicles in a particular section. For the development of High Speed Lines it become essential to ensure high performances regarding interoperability and safety.

Keywords
automatic train protection, interlocking, railway signaling and communication, GSM-R

1. Introduction

Railway signaling is defined as all systems used to control railway traffic safely, fundamentally to prevent trains from colliding. Over the years the technology able to satisfy this issue, have been implemented.

Since the beginning, there has always been the need to develop applications able to satisfy the railway traffic control. Train control systems are the mechanisms put in place to ensure that trains stop where necessary and travel at the safe speed for the line. All railway safety systems, starting from the first railroads, to the most advanced systems nowadays used, share a basic concept: Trains cannot collide with each other if they are not permitted to occupy the same section of track at the same time.

For this purpose, state of art of signaling has followed and continues improvement, starting from hand signals until to the most modern technologies for train partition. Historically it was simply the train driver's responsibility to follow the signals, but over time automatic systems were developed to ensure trains stopped automatically when a signal was red.

To increase the operational efficiency of the infrastructure, the communications network needs to develop more capacity and systems need to become faster, embracing an Ethernet and IP architecture able to replace old networking technologies. This network must meet the requirements of reliability, bandwidth capacity, and resistance to unkind environments and extreme temperatures.

Due considerable penetration of electric trains /vehicles, the study included creating scenarios for transport, using the virtual environment. Railway signaling and communication networks have to be capable of handling increasing bandwidth requirements while meeting uncompromising safety and reliability standards.

2. Automatic Train Protection

The modern railway, signaling and communication network systems are achieved by replacing and upgrading existing signaling and communication networks, while at the same time installing new networks with increasingly sophisticated systems. Systems for railway signaling and communication integrates technologies is interfaced with the fields of control engineering, track, architecture and electric power. This system ensures rapidness, correctness and safety of train operation by interconnecting the technologies of system engineering and reliability systematically.

The signaling systems must enables train to be operated safely by detecting the location and measure the speed of train. Researchers must develop new equipment to transmit and receive information as an alternative of using conventional track and wire cable.

Signaling system is divided into on-board and wayside, automatic train stop equipment currently being used in manual operation is the main result of development in on-board. The wayside has switching equipment, track circuit equipment and centralized train control system.

Modern systems are defined as the systems using continuous bi-directional data link of wayside and on-board equipment.

Data link is the system to decide the location of train and control the location speed and direction without conventional physical track circuit by using pattern belt, leakage coaxial cable, inductive loop or radio frequency, and etc. Researches for the development of optimal system through systematic analysis and build-up of technologies necessary for constructing the system for driverless operation are in progress.

The automatic train protection (ATP) systems in use are non-compatible. Sometimes, it even requires changing locomotive or driver at frontiers as each country generally has its own signaling system for which the drivers have to be trained. A train must be equipped with different automatic train protection systems as it travels along different lines across the country borders.

The train control system is a innovative solution which improves safety, makes operation easier, and introduces an interesting level of automation of boarded installations.

One of the key principles of an ATP system is the braking model concept, a mathematical model applicable to any land vehicle with a constrained guide.

It allows predicting the maximum safe speed of the vehicle, starting from the following data:

- Target distance (a potential obstacle during the route);
- Current speed;
- Physical characteristics of the vehicle.

Once known the braking pattern, it's easy to determine what the maximum speed is at which the vehicle can travel, so that it can stop safely before the target\danger point.

Nowadays, railway signaling is based on automatic blocks, which does not require manual intervention. For this reason, railway lines are divided into sections, known as blocks (or block sections). A line equipped with automatic blocks (interlocking) is divided into sections of length not shorter than the braking distance of the faster train running on the route. In a common operative mode, only one train is permitted in each block at a time.

Automatic Train Protection (*ATP*) systems are able to constantly monitor the speed of the train in order to increase the railway safety. Automatic Train Protection System constantly calculates the maximum safe speed of the train and applies the breaks if the train exceeds the safe speed.

In the most modern railway lines, at the start and the end of each block section, equipment called *Axle Counter* are placed. It acts as a counting head, detecting all the axles of rolling stock travelling on a track and also their direction of travel, using two electronic wheel sensor systems.

By comparing the result for the axles counted in with the result for those counted out, it is possible to know the status of the track section (free or occupied).

Referring to Figure 1, until the number of axles counted by Ax2 (train leaving from TS1) is not equal to that counted by Ax1 (train entering in TS1), then the track section TS1 shall be considered "occupied".

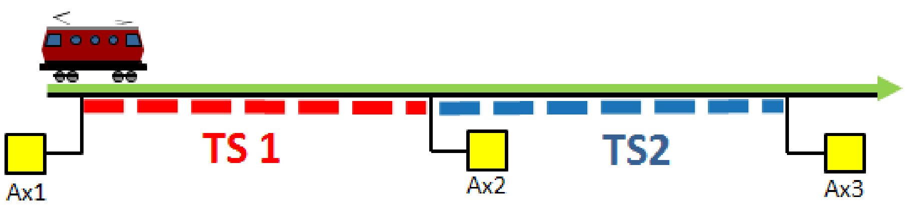

Fig. 1. Railroad divided in Block Sections equipped with axle counters for track occupation detection

Another type of traffic control is to divide the line into sections or blocks and permit only one train in a block. Initially the system required a person at each end of each block to record trains entering and leaving the blocks, and a way for them to communicate with each other. The manual block system still exists on many lines but with different names and different technology - the communication is by radio.

The function of detecting the presence or transit of the vehicles in a particular section can be realized through different equipments: an electromagnetic device (relay) realizes the *track circuit*, an electrical circuit that used as conductor, the two rails of the track. The transit of a vehicle on the track causes the electrical contact on the two rails, so the circuit is closed, the relay is characterized by zero current and the block signal is set at danger (or occupied). The track circuit is the foundation of any signal circuit, without it, no way to tell if a train is in a block.

The track circuit has a battery as the source of voltage, a series limiting resistor to set the loop current and adjust the pick-up point of the relay, the track itself, and a track relay. With no train in the block, the battery (placed at one end of the block) voltage is put out onto the tracks, the tracks carry the voltage down to the opposite end of the block to the relay, where the relay will become energized.

When a train enters the block, the wheels and axles shunt, or shorts out the circuit so the relay is no longer energized. With the relay de-energized, the important contacts of the relay are opened. This gives us the failsafe operation for safety, this way, if the track is broken, or the battery dies on us, the contacts will be open, and force the signal to a red aspect. Allowed for automatic route setting.

With conventional track circuits, this eventuality causes all track circuits to indicate occupancy, but when the signal power is restored, the real occupancy situation is still indicated. With the Axle Counter system, the loss of signal power may destroy the “memory” circuits in charge of “remembering” that a train has entered a block. Thus, when the signal power is restored, the information on block sections which are occupied may have been lost. In this case the identity and location of each train in the affected portion of the system must be established before the entire transit system can be operated again safely.

More recently it has been possible to pass signaling information from the track to a train. This has led to the development of Automatic Warning System which provides a warning if the train approaches a non-proceed aspect and applies the breaks if the warning is not acknowledged. Cab signals and ATS are yet other types of protective overlays, created to keep trains apart and operations safe. First ATP systems used a target speed indication and audible warnings to advise the driver if the train passed a red (danger) signal or exceed a speed restriction. In these cases, the system applied an automatic brake if the driver fails to respond to the warnings [2].

The additional ATP systems take up a lot of space on-board. It also adds to travel time, operational and maintenance costs. Unifying the multiple signaling systems will provide better interoperability of freight and passenger rail services, minimize technical and cultural problems of cross-border rail operations, reduce costs, improve the overall quality of rail transport and increase competitiveness.

Some railroads use cab signals (small signals in the locomotive cab) to supplement or even replace wayside signals. These may be associated with an Automatic Train Stop System (ATS), which requires acknowledgment and/or observance of signals. System constantly calculates the maximum safe speed of the train and applies the breaks if the train exceeds the safe speed.

3. Train Communication System

The train control system is based on autonomous determination of train location using differential GPS and an odometer with data radio communication between the central computer and the on-board computer in the train. The basic idea of the train control system is to leave the operational principle as it is, but the entire operation gets computer aided support by adding a radio data system for communication between trains and central train controller.

3.1. Security of data transmission

The command and control system chosen is a standardized, interoperable ATP/ATC system, called Train Control System (TCS). In order to allow the save communication between trains, trackside and railway regulation control centers, the sub-system chosen is GSM-R, the international wireless communications standard for railway communication and applications. It is composed essentially by the command and control system ETCS and the radio communication network Global System for Mobile Communications – Railways (GSM-R). Based on GSM radio technology, GSM-R uses exclusive frequency bands to communicate the train with traffic control centers and devices alongside the track [3].

An overview of the presented train communication system is given in Figure 2. The original version of this figure can be found in [1].

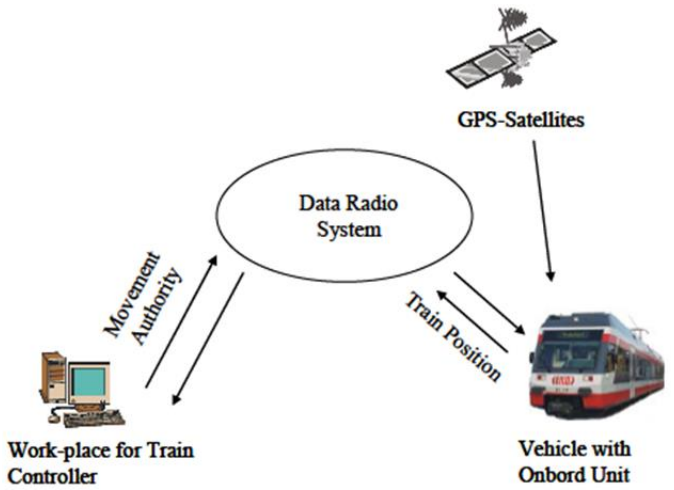

Fig. 2. Schematic overview of the train communication system [1]

The main features to ensure the safety are:

- Using message authentication codes to encrypt the transmitted telegrams to ensure their integrity and authenticity;
- The telegram encryption algorithm is comparable to the EuroRadio ETCS counterpart with a simplified key management structure due to the reduced system architecture complexity;
- Since the transmission hardware is untrusted, the safety layer ensures that unauthorized telegrams are detected;
- Besides ensuring the authenticity, the integrity is ensured due to timestamps and acknowledgements for critical telegrams.

The train communication system consists of an on-board-computer in each train and a central computer.

3.2. On-board-computer

The on-board-computer is responsible for determining the train location, based on GPS position data and odometer. The odometer is used for measuring the trains speed and relative position during normal operation while the GPS data provides a point of reference and acts as a supervision and backup system. The result is matched with a digital line atlas to retrieve a position using line-based coordinates, hence an accuracy of the train position better than +/- 10 meters is achieved.

The on-board-computer receives the movement authorities from the central train controller and displays them to the train driver (cab signaling). It also supervises their correct execution by the train driver. Furthermore it monitors the movement of the train and will automatically activate the emergency brake if the train driver tries to pass beyond the limitations of the given movement authority. The communication between the central device and the trains relies on a line specific data radio system, thus no further line-side equipment has to be installed.

3.3. Central computer

The central computer is located where the train controller is situated and consists of two main parts. The first part is the collision avoidance algorithm. Furthermore it maintains the communication to the trains via the data radio system and transmits the correction information data from a stationary GPS-receiver to the trains.

The second part is the GUI which presents a real-time view of the full operation on the line. It gives the train controller a schematic view of the line on the one hand and on the other hand a scaled electronic time table that includes both the planned and the actual train movements.

4. Signals and Automatic Block Signaling

Signals have two purposes, protection and control. There are two types of signals, permissive and absolute. Permissive signals only provide protection. Absolute signals provide both control and protection. Functionally, the basic difference between permissive and absolute signals is the most restrictive type of indication each can display.

A red permissive signal means stop and proceed. After stopping (which is no longer required on some railroads) the train can proceed at restricted speed until a more favorable signal is reached.

4.1. Permissive signals and automatic block signaling

Permissive signals respond to track occupancy. Automatic block signals as a low voltage battery current runs up one rail and down the other. As long as current flows from the battery through one rail to the relay and back through the other rail, the relay remains energized and routes current from another battery to the green lamp of a clear signal.

But when a train is present, the circuit is short circuited by the steel wheels and axles of the cars; a broken rail or an open switch will also break the circuit. As a result the relay is opened and the signal displays red. The system is arranged so the failure of any component results in a red indication or a dark signal (which must be interpreted as the most restrictive aspect that signal can display).

4.2. Absolute signals and interlocking signals

Absolute signals guard each end of an interlocking plant. Absolute signals are most often used at interlockings or in Centralized Traffic Control (CTC) territory where it is desired to control when, and if, a train passes a signal. Absolute signals by also functioning as block signals to protect trains from colliding with each other, while they do not permit trains to pass a red signal after stopping.

Absolute signals are found at railroad crossings and drawbridges, and at places where trains pass over powered switches, such as at the ends of sidings or at main track crossovers. For two lightly trafficked rail lines in a remote area, stop signs may be sufficient as a type of absolute signal. However, just as four-way stop signs are an inefficient way to control the intersection of two roads streets, stop signs are not efficient on rail routes with heavy traffic. A red absolute signal means stop - and stay stopped. The only way to pass a red absolute signal is with the dispatcher's verbal permission or, in rare circumstances, under the protection of a flagman.

When a train enters a siding and stops at the red absolute signal at the far end, the dispatcher obviously does not want it to "stop and proceed" down the line toward an oncoming train. Usually the signals are manually controlled from a remote office. Outside CTC limits, a sophisticated ABS system that can detect train direction also will use them to protect movement between sidings. Such a system is termed an Absolute Permissive Block System [4].

Absolute signals usually "wear two hats" by also functioning as block signals to protect trains from colliding with each other, although they do not permit trains to pass a red signal after stopping. For example, in single-track CTC territory absolute signals protect the switches at the ends of sidings; permissive signals are placed at 2-3 mile intervals along the single track. The introduction of microprocessors caused a review of this situation. A new generation of solid state interlockings was designed.

4.3. Technical safety

Technical safety of train location is a one important part of the safety of the train control system. But system safety does not only depend on this technical safety. Safety of train location is assured by a combination of technical safety and human supervision [6].

The trackside vital computer sends cyclically, to every on board computer, data concerning the length of the available braking distance and the localization of braking initiation in respect of the braking train capacity. To avoid the collision the alarm signals and voice messages became the key focus.

The sequence of the alarm is:

- Calculation of a reliable train location including plausibility checks of the raw data and comparison between GPS receiver and odometer;

- If unreliability is detected an automatic alarm to the engine driver and to the train controller will be generated;
- Human supervision assures safety wrong train location must be corrected and/or ignored.

Technical safety of the on-board-unit and the central computer is achieved by the means of:

- Software redundancies and numerous plausibility checks, but in general without explicit hardware redundancy. The software development process must be structured in compliance with most of standard specifies procedures and technical requirements for the development of programmable electronic systems for use in railway control and protection applications. All safety relevant software components have been designed using Unified Modeling Language. Unified Modeling Language is a standardized modeling language consisting of an integrated set of diagrams, developed to help system and software developers for specifying, visualizing, constructing, and documenting of software systems:
- The movement authority is only valid if it has been acknowledged by the train driver and the on-board-computer;
- The determination of the train s location is based on a redundancy of location sensors and in addition to plausibility checks within the location algorithm;
- The on-board-computer automatically activates the emergency brake if the train driver tries to pass beyond the limitation of the given movement authority;
- Implementation of a highly independent collision-avoidance algorithm which automatically sends an emergency brake command to trains in danger of colliding. This occurs when the distance between two trains is smaller than the double braking distance and there is no station between them.

5. Conclusions

Track circuit was the first to be developed and it is the fundamental method of train detection, and while there has been experimentation with other methods over the years it remains the more reliable.

Railway tracks are divided into blocks of varying length. Each block stands out from the adjacent ones by means of an insulated joint between rails and it permits the detection of the presence of a train. Track circuits operational principle is based on an electrical signal impressed between the two running rails.

The presence of a train is detected by the electrical connection between the rails, provided by the wheels and the axles of the train (wheel-to-rail shunting). As described there are several types of track circuits, but the detection principle is similar for each. ATP systems are true closed-loop systems. Feedback is used to monitor the response to propulsion and braking commands and regulate the system performances on a continuous real-time basis. The speed control technology for transit vehicles is based on track circuits. The signals used for train detection can also be used for the transmission of speed commands to wayside signaling devices and to the trains.

Track circuits contributes for train detection but also for the vehicle's speed control, since the electrical signals used for train detection can be exchanged between wayside and on-board for the transmission of speed commands. In the next paper the decoded speed command will be used in automatic systems to control the speed of the train.

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