Introducing a new Train Collision Avoidance System for Railways

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To improve the safety in the operation of a completely single-track narrow-gauge railway network in the Harz, a new type of train-collision avoidance system is currently being introduced. It is fully autarkic and will be superimposed on the current train-protection system. It uses direct radio connections between trains, with no need for fixed installations along the lines. 31 motor vehicles are being equipped.

1 Introduction

The company *Harzer Schmalspurbahnen GmbH* (Harz Narrow Gauge Railways, HSB) operates the metre-gauge railways in the Harz as an integrated railway-infrastructure and railway-transport company. The lines with a total length of 140 km form a closed railway network, with no connection to other railway networks (Figure 1). In Nordhausen Nord there is a track connection to the likewise metre-gauge Nordhausen tramway. The 400 m brake panels are valid.

Figure 1: HSB Line Scheme (Graphics: HSB).

On request of the regulating authority of the federal state Saxony-Anhalt, HSB installs an independent safety system which will be superimposed onto the existing – and already stepwise improved – train-announcement and train-protection system.

2 Background

2.1 HSB existing train-protection system

On 1 February 1993 when the narrow-gauge railways in the Harz were taken over by HSB, the safety for the train journeys followed the regulations of the former Deutsche Reichsbahn (German Imperial Railway, DR). The operation was thereby carried out according to the regulations of the so-called *simplified secondary railway service* (train control operation). There were three train control areas: Nordhausen Nord, Wernigerode Westerntor and Alexisbad. However, the systems in Wernigerode station were controlled by the DR movements inspector. The safety of the railway operation thereby largely relied on the correct handling of the responsible operating staff. The dispatcher kept a corresponding occupancy log, which documented the occupied or free line sections on the basis of the reports of the train staff. The train drivers always received permission to drive from the dispatcher via radio on the basis of the timetable. They had to stop at a preset point and ask again for permission to drive.

When train traffic to the Brocken was taken up again on 15 September 1991 (Figure 2), there was a strong increase in the train density on the section Wernigerode – Drei Annen Hohne – Brocken. This led HSB to consider whether – in the long-term – the train-control operation between Wernigerode and the Brocken was still the correct way to operate.

Figure 2: Impression Harz Narrow Gauge Railways (Photo: IoW).

Deliberations were speeded up after two trains collided in August 1994 on the densely wooded stretch with numerous curves between Drängetal and Steinerne Renne stations in the Thumkuhlen valley. Human error had caused the accident: the driver of the train heading for Wernigerode left out the planned crossing in Drängetal station and had driven his train beyond the destination of the last permission to drive.

The technical support of the train control operation for the line Wernigerode – Drei Annen Hohne – Brocken was then planned via an electronic signal box (EStw). In preparation for this on 1 January 1999 the operation was switched from the regulations of the former DR to the regulations of the Association of German Transport Companies (*Verbande Deutscher Verkehrsunternehmen*, VDV). From 2000 to 2002 the EStw was brought into operation stepwise from Wernigerode to the Brocken. The dispatcher is in Wernigerode. The lack of occupancy of the stations or stretch of track to be driven by the train was from then on checked by axle-counting circuits and the safe permission to drive communicated from the dispatcher to the train driver via combination signals showing *drive*. Thereby dispatcher error could be virtually excluded from the regular operation from Wernigerode to the Brocken. Also the probability for train driver error was significantly reduced, as the destinations for permission to drive were now main signals showing *stop* instead of the previous trapezoid-shaped panels before the station entrance and stop signs before the station exit.

In 2004 the Nordhausen tramway started continuous operation with dual-system vehicles between their network and the HSB station at Ilfeld. As the train traffic on this section of the line also increased significantly, the section Nordhausen Nord (excluded) to Ilfeld (included) was also equipped with an EStw. Nordhausen Nord station retained its mechanical signal box with geographical interlocking panel, whilst between Drei Annen Hohne and Ilfeld stations traditional train-control operation continued, as on the Selke Valley Railway (Figure 1).

2.,2 Railway accident at Hordorf

In January 2011 there was a grave collision between a freight train and a passenger train on the DB mainline Magdeburg Hbf – Halberstadt on the single-track section between Oschersleben (Bode) station and transfer point Hordorf. Also here the cause was human error: a train driver overran a main signal showing stop. Thereafter there was intensive discussion about the necessity for intermittent train-protection (PZB) even on lines for which this had not yet been mandatory under the Railway Construction and Operating Order (EBO).

2.3 Consequences

As a result PZB was stipulated for normal-gauge railways, as soon as a line has more than one passenger train. On the other hand EBO regulations for narrow-gauge railways were not changed. The regulatory authority came to the conclusion that the benefits of introducing PZB did not justify the expense, particularly as – in contrast to normal-gauge railways – the vehicles were not equipped for it. Thereby it remained the case that for narrow-gauge railways the regulatory body can order equipment with train protection.

Notwithstanding this regulation there were intensive discussions about possibilities for further improvement to the safety of the HSB operation with the Ministry for Regional Development and Transport of the federal state of Saxony-Anhalt (MLV). MLV demanded sustainable measures. However, it soon became clear that the necessary finances for equipping the lines as well as the vehicles of the HSB with PZB could not be met.

With this background a system developed by the German Aerospace Center (*Deutsches Zentrum für Luft- und Raumfahrt*, DLR) in the scope of the research project *Railway Collision Avoidance System* (RCAS) from 2005 became interesting. With this system there is no need for any line equipment; the trains communicate directly with each other and in the very unlikely case of a possible collision of two trains there is a warning alert. The investment necessary for this system is only around 10 to 20 percent of that for PZB equipment. At the initiative of MLV the system was presented to HSB.

3 Function and technology of the train collision avoidance system

3.1 General

The new train collision avoidance system brings the TCAS/ADS-B procedure from aviation to the rail, where this type of *Safety Overlay System* had not yet been used. Central to this system is the regular exchange of relevant information about position, direction of travel and speed, via train-to-train radio communication without a base station (Figure 3).

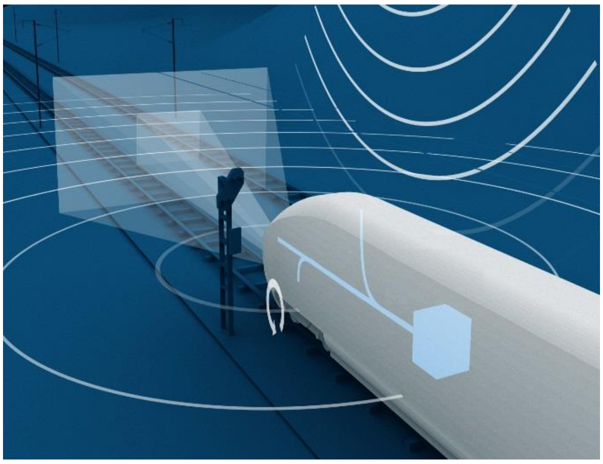

Figure 3: System animation (Graphics: IoW).

All leading rail vehicles, i.e., locomotives, motorcars and possibly control cars, are equipped with a vehicle unit. This comprises a positioning and a communication component. The latter sends the own driving parameters continually via radio directly to all trains in the immediate surroundings and at the same time receives this information from other vehicle units in the vicinity. It can identify situations of potential conflict by comparison of own and received data.

Figure 4: Installation on steam – tender locomotive (Photo: IoW).

The equipped vehicles determine their own position in the network with very high precision. The entire network topology is stored in the positioning unit like an atlas with all tracks and points in stations and on multi-track railway lines. It also includes local inclinations, curves and superelevations. GPS serves only for rough positioning. In this network the device finds its position continually with an inertial measuring unit (IMU). The vehicle path measurement by odometry can be included, but isn't essential.

The software continually evaluates the operating situation and in critical situations can signal the train driver with up to five configurable warning alerts, so that trains in danger of colliding can be stopped in time. Thereby – although it would be possible – in the basic version the system does not intervene directly with the train control. Rather, it functions as a train-driver assistance system. Possible collision points are ascertained dependent on path *and* speed, so that alarm signals don't come unnecessarily early.

Figure 5:
Display in the driver's cab (Photo: IoW).

The system works in the 400 MHz band on a secure frequency, licenced for this purpose. GSM-R would require a network of base stations along the lines, take a long time to establish connections and is expensive; all of these points are exclusion criteria for the concept.

Depending on operating conditions and topography the radio connections reach from around 1 km up to *n* x 10 km. As an example, in the Harz the roughly 15 km linear distance and visibility Wernigerode – Brocken are covered, and on a demonstration run on the high-speed line Rome – Naples two trains travelling towards each other with a relative speed of 560 km/h positioned each other at a distance of 33 km.

The new system supplements rather than replaces other safety technology which may already be present. If an operated line section still doesn't have a technical train protection such as PZB or line train protection (LZB), the new system supports the train driver by recognising critical situations long before they appear on the visual horizon. With the two accidents mentioned above human error was the main reason for the collisions. However, also in the case of technical problems and with deviation from regular operation, the direct, real-time communication between the trains and the autonomous conflict recognition offer the shortest reaction times and paths to avoidance or reduction of damage. The so-called remaining collision probability is significantly reduced through diverse independence of the information sources, communication paths, sensors and procedures. Furthermore, the concept as train-autonomous system is particularly attractive from an economical point of view, as the investment only increases with the number of existing or operated leading vehicles and not with the length of the line. In addition, a migration strategy is inherently given: equipped vehicles can use the system whilst vehicles which are not equipped remain for the time being with the actual safety standards. In this way the system can be introduced stepwise, i.e., one vehicle after another.

3.2 Treatment of points

The treatment of points on the path is particularly interesting. If they are trailing, the further path is always clearly defined; a simultaneous vehicle movement on the other track, i.e. a threatening side-on collision, is discovered by the system. On the other hand, with facing points there are different situations. If, behind the point both tracks are free or both tracks are occupied, the system can react clearly, i.e., in the latter case it calculates both paths up to a probable collision point. Although normally one of the two tracks is free and the point set correctly towards this track, as the system acts independently of route logic, the potential danger is calculated for both driving paths behind the point. The operator can set parameters to determine if and when an alarm is given in the more dangerous case. It would be possible, for instance, to have a forewarning corresponding to the signal colour *yellow* which should have the significance *drive on sight* and the concrete danger warning only then when the IMU actually detects the movement on the false track. For HSB it has been decided only to trigger an alarm in this case. This decision lies with the appropriate railway company and regulating authority.

4 Introduction of the train collision avoidance system at HSB

The decision to introduce the new train collision avoidance system for HSB as the first operators worldwide was not easy. Even for this system a seven figure Euro investment is necessary. Therefore, it was first decided to carry out a trial installation on two stream engines in March 2014, to test whether the system works in the regular HSB operation. On the one hand it concerned the basic functioning capability and on the other the special conditions of the HSB. This involved operation on steam engines and under the special climatic conditions of a railway with more than 1000 m altitude difference in the network – especially in winter and thereby in particular on the Brocken – as well as possible radio shadows through the woods, rockfaces and tunnels.

The first point could be confirmed by the trials. Additional test runs were also carried out, in particular to see how the system reacts to different possibly-critical operational constellations in situations which virtually never occur in regular operation. It was thereby ascertained, that threatening collisions on single-track lines and with trailing points were recognised and alerted through a warning signal. On the other hand, before the facing points at the crossing stations, as expected, the manufacturer settings triggered warnings to the train drivers, which from the operational point of view must be considered as false alarms. For the acceptance of such a system with train staff, however, this cannot be constructive. Therefore, together with MLV HSB has decided to suppress the alarm for calculated possible collision points in stations and in the first instance only activate the system for tracks on the open line. The shunting stop signs have been set as the limit. Thereby for impending accidents, such as the collisions at Hordorf and in the Thumkuhlen valley, there will be an alarm.

A pragmatic approach was chosen for the approval of the system through MLV. It was agreed that the current operating procedures provide a safe railway operation. With the new system a likewise safe system will be added, which can warn of possible collisions. The two systems function completely independently of each other. The probability that an error will occur in both systems can be multiplied, whereby the probability for the occurrence of an accident is significantly reduced again.

Operationally it was decided that the system will only signal the highest level, i.e., imminent threat of collision. In this case the train must stop and the train driver must receive new permission to drive before the journey can be continued.

There is a test point comparable with the 2000 Hz test magnets of the PZB in the exit area of the operational works at Wernigerode and also at four further selected points on the HSB network. If the onboard equipment shows a fault at the Wernigerode site the vehicle will not be operated. If the equipment fails once underway there will be no operational measures until all vehicles have been equipped. How to proceed in this case once all vehicles are equipped is currently being considered.

With this background, the train collision avoidance system and the first operational experience on two HSB steam engines could be presented at the InnoTrans 2014 in Berlin. The decision to introduce the system had basically already been taken. After the financing through the federal states Saxony-Anhalt and Thüringen was secured, HSB awarded the contract for the supply and installation of 31 vehicle units at the beginning of 2015, and a further five units for the named test points and for mobile use. This should take place in 2016 and enable the commissioning of the entire system by the first half of 2017. For the steam engines the system is powered by a battery with >48 hours operating time (Figure 4) and displayed in the driver's cab (Figure 5), for motorcars there is a display in every driver's cab and the supply comes from the onboard network.

The system supplier is the company *Intelligence on Wheels* (IoW), founded in 2012 from DLR for the purpose of marketing the RCAS technology. Vehicle units and function can be viewed for reference at HSB.

5 Closing comment

The system is particularly suitable for – although in no way limited to – the operation on regional lines or industrial railways and sidings, as well as for temporary deviation from regular operation, e.g. at building sites. Thereby construction vehicles or line workers can also be equipped with mobile devices.

During the preparation of this report at the beginning of February 2016 there was a frontal collision of two non-DB EMUs on the single-track DB line Holzkirchen – Rosenheim by Bad Aibling. According to current knowledge the cause was human error: a mistake in which the technology of a normally working signal box was overridden. Basically, this must be possible when faults occur in railway operation, although there can be no protection against mistakes in a system which inherently allows technology to be overridden. The train collision avoidance system presented here can thereby fill in certain gaps in the safety. HSB implements this step on their network and comparable railway companies now have the possibility to follow suit.

6 Contact

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