Integration of Level Crossing in ETCS

Laumen, Peter; Müller, Tobias; Nießen, Nils

Institute of Transport Science, RWTH Aachen University

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1 Introduction

The European Train Control System (ETCS) is a current development urged by the European Union and European railway industry in order to replace legacy national systems of train protection. After about 30 years of development, the rollout process throughout Europe is in progress [1]. Dedicated as Class A Train Protection System, ETCS is intended to be the future single train control system throughout Europe. The aim is to fit the Trans-European Network (TEN) and main lines with ETCS at first, whereat detailed analysis of migration strategies take place. Regional lines are currently not in focus of migration unless they are crossing national borders and are equipped with various Automatic Train Protection (ATP) systems. Level crossings (LX), which do mostly exist on regional lines, were unconsidered in the specification of ETCS for a long time. Since the Baseline 3 is released, a specific packet for level crossings (packet 88: Level Crossing Information) is available [2, 3].

The consideration of LX within ETCS is analysed by taking into account the arising digital interlocking technology. Basically, bus interfaces are introduced between single components of safety systems along a line. This paper assumes the availability of a bus interface linked with digital interlocking system for LX as well [4].

This article focuses on ETCS applications that base on Full Supervision (FS) mode since it is elementary for a future automatic operation of trains. Most LX are located on regional lines, whereas the number of LX on main lines decreases. On high-speed lines, they are prohibited in general.

For basis, an explanation of the principles of ETCS, digital interlocking systems and LX is given. Afterwards follows a description of the operational implementation and the advantages and drawbacks. This text considers resulting closing times just briefly in this context.

2 State of the art

Stating the general specifications of ETCS keep valid, we assume Baseline 3 for the described solutions and ideas. On the other hand, the introduction of new requirements for interlocking and level crossing interfaces might be necessary. These functionalities are still non-specified but pay respect to the current development of these interfaces.

2.1 ETCS

Early versions of ETCS were designated to operate in mode Full Supervision and use cab signalling. A new, operationally simplified mode called Limited Supervision (LS) was implemented along with release of Baseline 3.

ETCS technical setup consists of different operational Levels. In application Level 1, Eurobalises transmit a Movement Authority (MA) and further relevant information to the train. A Lineside Electronic Unit (LEU) realizes a connection to the signal. This setting facilitates ETCS migration, as a simple adaptation to various types of interlocking systems is possible. The LEU chooses predefined messages based on the displayed signal aspect, transmitted to a passing train via attached balises. Additional information, that might be available within the interlocking system, is not considerable.

ETCS-specifications define several operational modes within the different modes. Among others, these are Full Supervision, Limited Supervision and Shunting. [3]

2.2 Digital interlocking systems

In general, digital interlocking systems are an advancement of electronic interlocking. It is possible to connect to any field element (like signals, switches and train detection systems) via a bus interface. Within a closed digital system as established electronic interlocking systems are, a specification of interfaces is not necessary. Latest electronic interlocking systems already consist of a bus interface to communicate with field elements, further interlocking systems and LX [5, 6]. The digital interlocking system used a standard IP network for the communication [7].

The EULYNX initiative, an association of European railway operators, defined communication via standardized interfaces as basic principle of a digital interlocking system [4], so called *Standard Communication Interfaces (SCI)*. A major advantage of bus communication between interlocking components is a possible separation of energy supply and transmission of information. Less cable is necessary while the depth of information simultaneously rises. Safety functionalities are more software driven than circuit driven. *Figure 1* shows a classic architecture of electronic interlocking systems as well as relay interlocking systems without bus communication on the left hand side and compares it to the architecture of a digital interlocking system with an integrated ETCS logic on the right. This paper considers the introduced new architecture as state of the art for its scope.

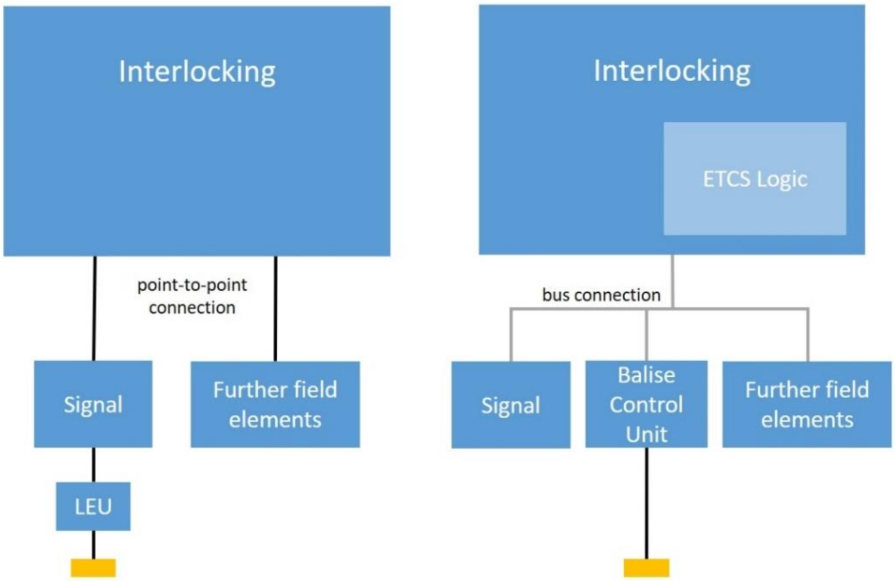

Figure 1: Classic (left) vs. new interlocking architecture (right) with integration of ETCS Level 1 functionality

2.3 Level crossing

The classification of LX distinguishes them by their manner of activation [8]. Figure 2 sketches these differences and divides active and passive LX as the two basic groups. The group of active LX consists of autonomous and route depending LX. In addition, autonomous LX divide into those with feedback to the driver and without. Route depending and autonomous LX without feedback to the driver do have an interface to the interlocking system, which processes the supervision of functionality. Autonomous LX with feedback to the driver do not need an interface and are kind of an isolated system with LX supervision signals.

Two basic versions of interfaces that developed in the past are the route depending interface (German: Hp) and remote-control interface (German: Fü). Their standardization bases on relay technology, some suppliers migrated these interfaces to bus technology in case by microprocessor technology controls the LX. The modified bus interfaces are nonstandardized since each supplier has developed its own bus protocol and system architecture.

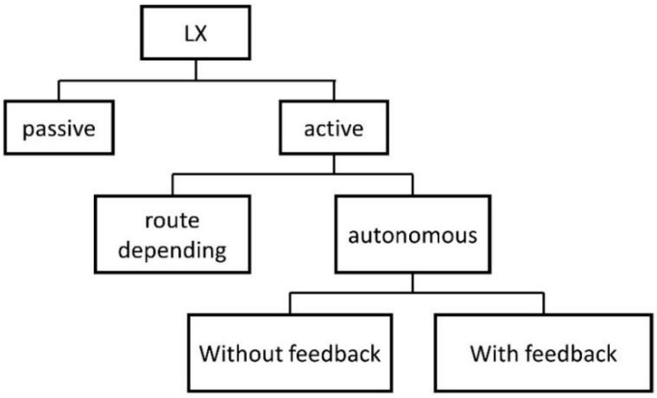

Figure 2: Classification of level crossing supervision [8]

The EULYNX initiative is attempting to standardize these interfaces. As a part of railway safety system, the LX needs to be linked to a digital interlocking system via the *Standard Communication Interface – Level Crossing* (SCI–LX). Table 1 summarises some functions and information transmitted via SCI–LX. Enabling and deactivation of LX activation points, sending of status messages and diagnosis information are possible and major improvements in comparison to legacy systems.

Table 1: SCI-LX summary, messages and commands [9]

Information	**Target**	**Comment**
Header	-	*Initialisation data and communication (shortened section)*
Activation	LX	
Deactivation	LX	
Enable an Activation Point	LX	
LX functional status	Interlocking	
LX monitoring status	Interlocking	
LX failure status	Interlocking	
LX physical status	Interlocking	

2.4 Line concept

The introduced improvements of railway safety systems and their interfaces cause impact on line topology. Figure 3 represents a common railway line. Each station is equipped with an interlocking system. Some LX (1) are connected with the neighbouring interlocking system as they are route depending; others (LX 2 and LX 3) are autonomous and are not linked to an interlocking system. The current topology bases on point-to-point connection of field components. Using relay-based level crossing control there is a big effort of wiring to connect them with the interlocking system. Its still an advantage of autonomous LX with feedback to the driver that a link with the interlocking is obsolete and long cables are expendable. An LX supervision signal reports the status of protection to the train driver.

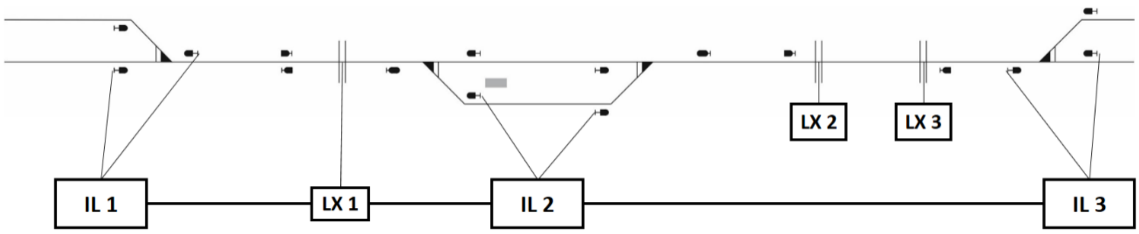

Figure 3: Current line concept

Figure 4 launches a new line concept, reachable by using bus interfaces. Eliminating the point-to-point connection of elements, all operation units (e.g. interlocking systems and level crossing) along the line connect via a bus cable, reducing the number of necessary wires. Lineside Element Controllers (EC) or Balise Control Units (BCU) are necessary to link components with the bus system. This concept realizes a connection between former autonomous LX without feedback and an interlocking system. Depending on the interfaces between field components, LX, and interlocking system, field components can be used by interlocking and LX in parallel.

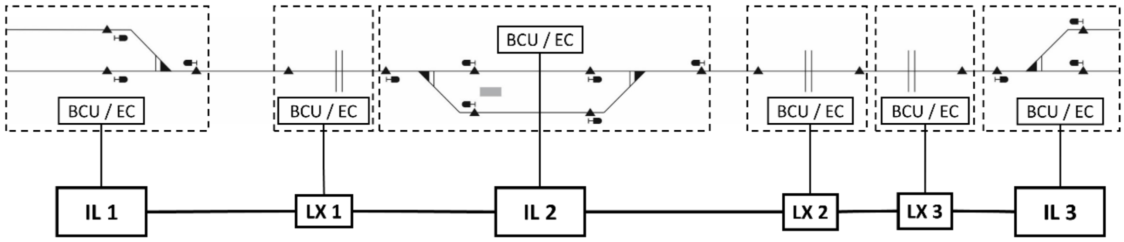

Figure 4: New line concept with an integrated architecture

2.5 Introducing new manners of activation

Within its Project “NeuPro” (roughly “New processes of production”), that merged into EULYNX, the Deutsche Bahn AG developed a new type of LX activation, taking into account some principles that were described in the previous section. NeuPro specified the interface SCI-LX so far.

Beneath existing and adapted manners of activation, new concepts called FSÜ(B) and FSÜ(E) (FSÜ=“Fahrstraßenüberwacht” (depending on route setting)) are introduced. They base on common signalling, but try to combine both autonomous and route depending behaviour.

The way of LX activation depends on the occupancy of the section between activation point and LX, if a main signal is positioned in there. Either the LX itself (FSÜ(B)) or the interlocking system (FSÜ(E)) influence the activation point. As long as the LX does not detect a train, an activation point depending on the locked route is in use, behaving like an autonomous LX. Otherwise, the LX processes the activation on the interlocking system's demand, what realises a signal dependency. [10]

3 Level crossing in ETCS

To approach the integration of LX in ETCS, at first we describe the adaption of the basic LX types. The following chapter explains an improved integration concept, connecting ETCS and LX via the digital interlocking system. Finally, this paper mentions different operational cases and advantages of ETCS in context of LX.

3.1 Basic LX principles in ETCS

Route depending LX are easy to adapt to ETCS. By setting a route, the mandatory activation is processed; afterwards the signal clearance is possible. *Figure 5* outlines the position of the signals related to the LX. Balises replace the signals in transformation to ETCS. The LX' activation is mandatory once the MA telegram is available at a balise. A malfunction of the LX inhibits route locking. As usual, the LX needs an interface to the interlocking system. The train is forced to stop at the former location of main or block signal. Since the signal is not necessary within ETCS surrounding, the End of Authority (EoA) protects the LX.

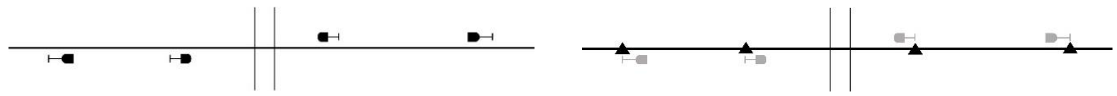

Figure 5: route depending LX – classic setup (left) and a simple ETCS setup (right)

An LX signal protects an autonomous LX with feedback to the driver. The signal indicates the status of the LX, which is activated by the train itself. Therefore, the LX needs activation points. Transformed to ETCS, trains need a stopping order as well if the LX has a malfunction. Within the interlocking system, any information is available so that it cannot act in case of a malfunction. A balise located in braking distance replaces the former LX signal and substitutes its function by transmission of packet 88. This packet carries information on the protection state of the LX. An interface to the interlocking system is not necessary as well. Another solution is the shortage of the current MA, which causes the necessity of a connection to the interlocking system for safety reasons. The LX might shorten the MA to the beginning of the LX if required; causing the transmission of a new MA to the train in rear of the LX is necessary. The train needs a permission to pass the affected LX with Release Speed. It is essential that a train driver has information the MA ends due to an LX failure at his disposal. *Figure 6* illustrates both concepts.

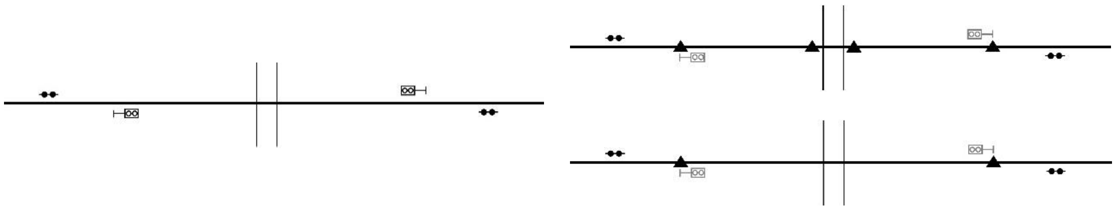

Figure 6: autonomous LX with feedback – classic setup (left) and ETCS setup with MA integration (above right) and packet 88 (downright)

Autonomous LX without feedback to the driver, which supervise their functionality continuously, in theory do not need consideration within ETCS. The train driver is not informed about the LX' status, in case of a malfunction, the controller must inform the train driver. No technical backup to stop an approaching train is in service today. Because an interface to the interlocking system is already available, the transmission of packet 88 via any balise at minimum of braking distance is conceivable to improve safety. Since this LX has no feedback to the driver, the approach distance depends on the technical time necessary to protect the LX.

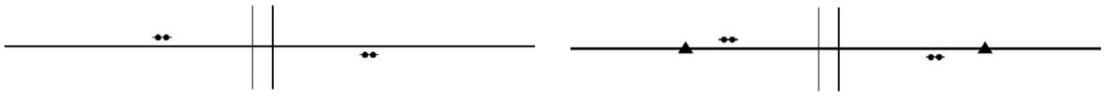

Figure 7: autonomous LX without feedback – classic setup (left) and ETCS setup (right)

The drafted adaptions to ETCS base on the classic architecture with an electronic interlocking system. We did not consider digital interlocking systems so far.

3.2 Improved LX handling within digital interlocking

The introduction of digital interlocking systems opens new strategies to integrate LX into ETCS. As innovation, the balise telegrams generation takes place at runtime in an ETCS module linked to the interlocking system. A modification of current ETCS specifications is not necessary - neither hardware specifications nor definition of telegrams. In general, an LX integrated into the presented architecture shall have an interface to the interlocking system as SCI-LX interface hands over LX functionality to the interlocking.

Autonomous LX with feedback to the driver

An autonomous LX with feedback to the driver is modified in comparison to the classic setup as an interface to the interlocking is supplemented. For ETCS Level 1 FS applications, lineside signals are not necessary. To transmit packet 88, which replaces the LX signal, e.g. balises are placed at minimum in braking distance to the LX – considering both sides and each direction. With respect to the standardized interface SCI-LX, the LX transmits its status information to the interlocking system. Then a balise, connected with the interlocking, transmits packet 88 to the train.

Now, a configuration as an LX with feedback to the driver, meaning an approaching train activates the LX and always receives a response about protection status, is possible. This concept could be realised by a shortened MA as well. The number of types of interlocking systems and the different configurations reduce.

Autonomous LX without feedback to the driver

As described in the previous section, a feedback to the driver in braking distance is simple to realise if an interface is available. The advantage of an LX without feedback to the driver instead is the short approach distance. The LX activation point is located within the potential braking distance of the LX so that a general feedback after activation is impossible. Since the LX is ready for activation, a supervision by the controller is sufficient. Nevertheless, Packet 88 might be used as indication whether the LX is ready for activation. Doing so, a balise shall transmit the packet in front of the activation point, reporting the LX as protected if it is ready for activation. Otherwise, the LX is reported as non-protected and a train's deceleration is supervised, which is a benefit in safety compared to established LX concepts without feedback to the driver.

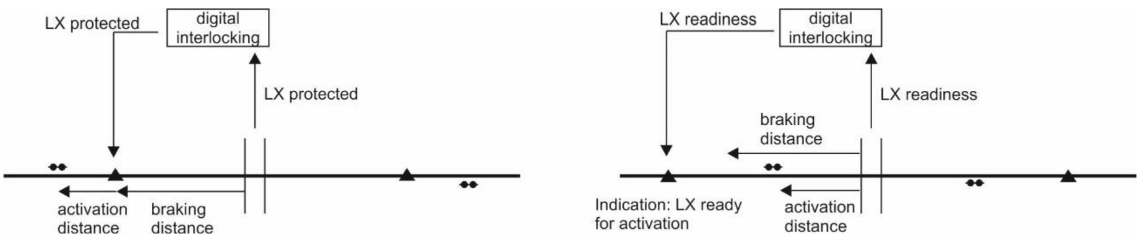

Figure 8: Examples of integrating autonomous LX with (left) and without (right) feedback to the driver into digital interlocking systems

As a result, both types of autonomous LX merge since all LX have an interface to the interlocking system. If the characteristic "without feedback" is not allowed due to full closure of the crossing road, then the LX must be route depending.

Route depending LX

Like described in section 3.1, integration of route depending LX is simple by using a modified MA. In general, route depending LX approach distance is the longest. The calculation of that distance refers to the distant signal. When a train passes the distance signal the indication of protection state is necessary (in the ideal case, the LX is protected at this moment). Now, taking into account the new ETCS architecture, a (shortened) route can be locked without information on the protection state of the LX. Under these circumstances the MA is generated only right to the LX in a first instance, the LX' activation is delayed. After a successful protection, the MA shall extend. The calculated closure time must refer to the indication point of the MA whose EoA is located just in front of the LX.

Summarized, the three presented classical types of LX protection reduce to only two remaining types: route depending and autonomous LX. Both types cover all applications needed and both can be configured with or without supervision of functionality. Every LX needs an interface to connect with an interlocking system via bus for an optimal ETCS integration.

3.3 Speed-depending activation

Approach distances design refers to the maximum speed allowed on the line. In case of slow trains, e.g. freight services or slow passenger trains, the closing time of the road massively extends. The acceptance of railway systems may suffer from these long closing times. Activation of the LX by a time delay due to speed measuring is an option. This allows adjusting the closing time of the road. In past it was not possible to shape speed depending activation solidly. By measuring speed, a guarantee the train does not accelerate is necessary. If the train passes the measuring point with maximum speed, the system is well working. If the activation point for a reduced speed was selected and the train accelerates, the LX closes too late.

On lines equipped with classic light signals and background supervision of running trains, PZB e.g., it is impossible to limit the speed dynamical of a train by a technical system. Using ETCS Level 1 FS with cab signalling instead allows to limit a train's speed by using a TSR or changing the SSP. The train driver is able to notice the adapted speed limit that is visualised on the Driver Machine Interface (DMI).

The presented architecture allows selecting a proper activation point for use of the current train. In the case that a single activation point is used, this must be the activation point for maximum speed. A delay calculated due to speed measuring or handled by train number applies to activate the LX.

In Levels 2 and 3, a transmission from train to track is possible. That opportunity might be useful to send train data to the interlocking system and LX. Currently ETCS specifications do not provide this option. Train speed or maximum train speed can be used for a TSR or adjusting the SSP at runtime instead of using predefined speed limits. In Level 1, data transmission from train to track is generally not possible since the balises do not read telegrams a train might transmit.

3.4 Stop-related activation

In some LX applications, a stop in approach distance occurs, which massively extends the closing time for the road. For these special applications, specific operational cases are defined. The aim is to reduce the closing time for the road and avoid the obligation of full closure of the road. Examples of these operational cases are a stop in approach distance or a block signal in approach distance.

Scheduled Stop in approach distance

A scheduled stop of some trains in approach distance extends the closing time of the road. To reduce the closing time, the activation is proceeded after the stop. Therefore, a second detector for activation is necessary. It must be guaranteed that the train actually stops at the intended position if the second activation detector is enabled. The first activation point (for the train without stop) is disabled at this time.

ETCS can force a stop of the train at the intended stopping position due to an EoA. A second detection point must be placed between stopping point and LX for a train participated activation. The distance between second activation point and the related LX need to be sufficient for final protection of the LX. If the distance is inadequate, a TSR may help to reduce speed until the LX is safe.

Block section in approach distance

Similar to a stop in approach distance is a border of a block section in approach distance. Due to an occupied block section, the MA ends in the approach distance of the LX.

Within an ETCS Level 1 FS application, signals are eliminated. The train does not enter the section since the EoA ends at the end of the block. In these cases, today's autonomous LX systems cannot apply. Within EULYNX interlocking architecture, a new opportunity reveals. The interlocking system knows the state of a route or the block section. The activation point is enabled in dependency of the block occupancy. If the MA does not end between the potential activation point and the corresponding LX, the activation point is enabled by the interlocking system, and autonomous-like LX characteristic is realised. Otherwise, LX protection must depend on the MA extension and the distance from block border to LX.

If a shortened MA or packet 88 indicates an unprotected LX, the interlocking might deactivate the regular activation point. Another activation point located near the stopping position replaces it. It depends on the remaining distance between stop location and LX whether the LX needs to be activated before standstill or after departure, as the minimum time interval between LX protection and train passage needs to be hold. If a 2nd activation point for a shorter approach distance does not allow to activate the LX timely, a reduction of speed or a delay for transmitting the driving order can be used.

3.5 Level crossing chains

If there are further LX located within the approach distance of an LX, these merge to a LX chain. A single activation point activates all concatenated LX. In classic applications, it is a big issue if one of these LX has a malfunction. The train driver is not able to identify the disrupted LX, he must stop at each LX since he gets the information of a disruption but does not know which LX failed. The SCI-LX interface allows identifying the disrupted LX by its assigned ID so that packet 88 can be used to inform the train driver about the malfunction. Doing so, the train driver does not need to stop at each LX of the chain, but only stops at the disrupted LX. The result would be arising operational quality.

4 Outlook

Today, bidirectional data transmission is only practised via radio communication, but is not specified in [3] and in the *FFFIS for Eurobalise* [11]. According to its modification history, that functionality was specified for Eurobalises as well but was removed in 2011. Furthermore, [3] does not contain any packets to use for downlink communication via balise. Basically, two types of data flow are conceivable, which are permanent transmission of generic data and generation of specific information on request by route/interlocking system.

Taking into account data provided by a specific train, speed-depending activation may be more optimised. That requires an adaption of ETCS specification. If the train transmits the current speed, it is possible to introduce a speed depending LX activation.

If a balise is available which allows sending a telegram from train to track, the LX may be activated via balise-transmission. Detectors for activation and deactivation are not used (but shall be kept as fall-back mode) and the functionality is handled via ETCS.

5 Resume

After presenting the different types of LX, we explained a possible adaption to ETCS. ETCS allows a reduction of LX activation types. The number of LX fitted with supervision of functionality shall rise, which helps to reduce the approach distance for this LX and in succession the closing time of the road. The calculation of closing times was not part of this article and shall be investigated in further research. Using the ETCS braking curve model, the braking distance may rise due to a more restrictive calculation as in today’s train protection systems [12]. This aspect has to be analysed in future. Operational cases are still handled in ETCS; examples of a stop and block border in the approach distance were given.

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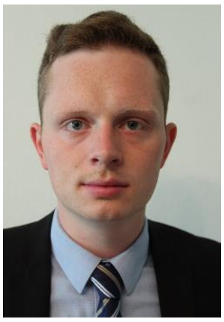
Autoren

Laumen, Peter

Dipl.-Ing. Peter Laumen studierte an der RWTH Aachen Elektrotechnik. Seit 2014 arbeitet er als Wissenschaftlicher Mitarbeiter am Verkehrswissenschaftlichen Institut der RWTH Aachen. Sein Forschungsschwerpunkt ist die Eisenbahn-sicherungstechnik.



Müller, Tobias

Tobias Müller, M. Sc. studierte an der RWTH Aachen Verkehrsingenieurwesen und Mobilität. Seit 2019 arbeitet er als Wissenschaftlicher Mitarbeiter am Verkehrswissenschaftlichen Institut der RWTH Aachen.

Nießen, Nils

Univ.-Prof. Dr.-Ing. Nils Nießen leitet seit 2013 das Verkehrswissenschaftliche Institut der RWTH Aachen. Nach dem Studium des Bauingenieurwesens und der Wirtschaftsgeographie an der RWTH Aachen promovierte er dort 2008. Anschließend war er Projektingenieur bei HaCon in Hannover und Geschäftsführer der VIA Consulting & Development GmbH.