Paper-ID: VGI_200309

Means of Navigation for Automatic Level Crossing Control and the Concept of the ECORAIL Project

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VGI – Österreichische Zeitschrift für Vermessung und Geoinformation **91** (1), S. 61–67

2003

BibTEX:

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@ARTICLE{Wasle_VGI_200309,
Title = {Means of Navigation for Automatic Level Crossing Control and the
   Concept of the ECORAIL Project},
Author = {Wasle, Elmar and Ringert, Josef},
Journal = {VGI -- {\"O}sterreichische Zeitschrift f{\"u}r Vermessung und
   Geoinformation},
Pages = {61--67},
Number = {1},
Year = {2003},
Volume = {91}
}
```

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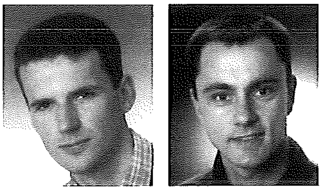

Abstract

The European Train Control and Rail Traffic Management System (ETCS/ERTMS) shall strengthen the competitiveness and attractiveness of railway transportation. Additionally it intends to facilitate the inter-European passenger and freight traffic. The evolution from conventional systems to a standardised solution will be carried out by a stepwise approach. On the highest level, most of the track-side installations will be replaced by on-board equipment. One of the applications, which will benefit from this development, is the control of automatic level crossings. The key advantages of the new system for this application are cut-back costs for operators, increasing traffic flow, and reduction of emissions. The European Space Agency and the European Commission fund several projects which further develop the ETCS/ERTMS system. These projects investigate the feasibility and potential benefit of introducing the Global Navigation Satellite Systems (GNSS) into the railway domain. The project which deals with the combination of GNSS with automatic level crossing control is the „EGNOS Controlled Railway Equipment – ECORAIL".

Zusammenfassung

Die Einführung eines European Train Control and Rail Traffic Management System (ETCS/ERTMS) soll die Konkurrenzfähigkeit und Attraktivität des Schienenverkehrs verstärken. Das heißt, dass das neue System darauf abzielt, den innereuropäischen Personen und Güterverkehr zu erleichtern. Der Übergang von den derzeitigen nationalen Lösungen zu einem einheitlichen europäischen Ansatz erfolgt schrittweise, wobei verschiedene Ebenen der Implementierung unterschieden werden. In der vollen Ausbaustufe werden die streckenseitigen (track-side) Einrichtungen durch mobile Lösungen (on-board) in den Zugsgarnituren ersetzt. Eine jener Anwendungen, die davon betroffen sein wird, ist die Steuerung von automatischen Bahnübergängen. Die Vorteile, die sich aus der Implementierung des neuen Systems ergeben, liegen für diese Anwendung in der Kostenreduktion für den Eisenbahnbetreiber, in der Förderung des Verkehrsflusses und in der Reduktion von Fahrzeug-Schadstoffemissionen. Die Europäische Weltraumbehörde und die Europäische Kommission haben mehrere Projekte ins Leben gerufen, die das ETCS/ERTMS System noch einen Schritt weiter entwickeln, um die Unabhängigkeit von streckenseitigen Einrichtungen zu vergrößern. Dabei geht es um die Einführung des Global Navigation Satellite Systems (GNSS) in den Bereich des Eisenbahnwesens. Ein Projekt, das sich mit der Verbindung von GNSS mit der Steuerung von Eisenbahnübergängen beschäftigt, ist das „EGNOS Controlled Railway Equipment – ECORAIL".

1. Introduction – Fields of Transportation

The forth going competition between different means of transportation requires an increasing implementation of technological know how and strategies in management. The railway domain is a strong and attractive business partner presuming the railway operators will succeed in a cost-effective modernisation. The improvement of efficiency, the development of new applications and services will make the railway an interesting partner for inter- and multi-modal transport. Cooperation between the authorities, system operators, and system suppliers is needed to meet these goals.

Two main user groups can be identified in railway transportation: the passenger transport and freight transport. Regarding the necessary infrastructure, both groups require, apart from an acceptable cost-value-ratio, a high level of reliability, availability and safety – resulting in low door-to-door-times. These requirements have been met by introducing systems of train control and train management. Unfortunately, within Europe most of these systems are not interoperable. Several procedures of standardisation and certification are necessary to harmonise operational and technical specifications – national as well as cross-national. Safety relevant and interoperability issues play a major role in the process of standardisation and the consecutive certification.

To achieve this goal, the European Union initiated the specification and realization of a European Train Control System as part of the European Rail Traffic Management System (ETCS/ERTMS). Meanwhile these goals have been extended to account for new technologies and the new services provided. Before the new technologies and strategies are implemented into ETCS/ERTMS, their feasibility has to be proved and certified regarding their safety level. This article accounts for the means of navigation introduced into the railway domain and into the fields of ETCS/ERTMS. Therefore, a specific application is discussed and a project funded by the European Space Agency, which deals with the proof of feasibility, is presented.

2. ETCS/ERTMS

Train control is an important part of every railway operation management system. In the past, a number of different train control systems evolved in different countries at different times. Not all of these systems are compatible and interoperable with each other. Only a few of them are used in more than one country, and even in those cases differences in development arose. Therefore, the need of a standardised train control system is obvious.

The advantages of an internationally interoperable system are:

- cross border interoperability.
- improvement of safety.
- the possibility of an incremental introduction of new technologies.
- reducing bottle-necks by using high-tech systems.

The common literature about ETCS/ERTMS name several other advantages.

In 1990, the first initiatives started to establish a Train Control and Rail Traffic Management System. Taking into consideration the variety of train control systems and the varying needs of high-speed and/or conventional lines, a migration strategy from already existing systems to ETCS/ERTMS compatible systems was introduced. This migration strategy provides different ETCS/ERTMS application levels [1]:

Level 0 covers operation of ETCS equipped trains on lines not equipped with ETCS or national systems. Line side optical signals or other signalling techniques are used.

Level STM is used to run ETCS/ERTMS equipped trains on lines equipped with national train control and speed supervision systems. Trackside generated information is transmitted to the train via the communication channel of the underlying national system.

ETCS/ERTMS level 1 is a spot transmission based train control system to be used as an overlay for an underlying signalling system. Level 1 provides a continuous speed supervision system and is based on Eurobalises. An Eurobalise is a system for intermittent data transmission from the track to the train.

ETCS/ERTMS Level 2 is a radio based train control system which is used as an overlay of an underlying signalling system. Level 2 also provides a continuous speed supervision system and is based on Euroradio for track-to-train communication and on Eurobalises for train localization. Euroradio is a fail-safe, standardized transmission procedure via a GSM-R radio link. This system allows the transmission of fail-safe and non-secure data as well as speech.

Level 3 complements the previous levels in a way that no line-side signals are foreseen any more. Train localization and train integrity supervision are performed by a trackside radio block centre in co-operation with the train, which sends position information and integrity data to the centre.

The different levels require a demanding procedure of certification of the operational and technological solutions conducted to guarantee a high safety integrity level (SIL).

3. Automatic Level Crossing

One of the demanding applications which requires SIL 4 (cf. Section 8) is the control of automatic level crossings. Collision avoidance between the different means of transportation is done by an interaction of several technologies, which can be classified into a control, localisation, activation, monitoring, and signalling part. For a better understanding of the interrelations of these terms, the Automatic Level Crossings (ALX) are described in more detail.

A simple crossing is assumed as shown in Figure 1. Before the train is allowed to cross the road, the road traffic has to be stopped. Therefore the train activates the road signal. According to the latest Austrian legal regulations, the activation procedure begins with the yellow road signal which urges motorists and pedestrians to leave the endangered area. The red light phase follows the yellow light phase. At this point of time all road vehicles should have crossed the level crossing or stopped before it.

During the yellow and red light phase, the train approaches the level crossing with unaltered speed. To advise the train driver whether the level crossing was cleared, a monitoring signal is positioned at the monitoring distance. Having passed this signal, the driver either starts braking or proceeds with unaltered speed to pass the level crossing. The latest possible moment to activate the full braking and therefore the latest possible moment for the monitoring point is here denoted as point of no return. The monitoring signal must be clearly visible for the driver from a distance. That is the reason why the monitoring point and the point of no return do not necessarily coincide.

The point of no return is basically defined by the locally authorised train speed, the gradient of the track, and several other parameters. The distance between the activation point and the monitoring signal is denoted as striking-in distance. The distance between the monitoring signal and the level crossing refers to as monitoring distance.

After the train passed the level crossing the road signal has to be activated again to allow the road traffic to continue to pass the crossing – this is denoted as deactivation point. Furthermore, there is a control system which is the core element of an automatic level crossing. Refer to Figure 1 to get an impression of the situation and to identify the different parameters.

4. Track-side vs On-Board System

The conventional realisation of an automatic level crossing relies on so-called track-side technologies. Currently, different track-side based automatic level crossing control systems are used in different countries and at different lines. In a step of evolution the ALX control should be replaced by a radio based ALX control system. ETCS/ERTMS therefore introduces a combination of Eurobalises, train sensors (odometer,...) and GSM-R.

For the conventional track-side system wheel detectors, vehicle sensors, rail treadles, or switching contacts are used at the activation point to activate the closing of the level crossing. These instruments are connected by wire to the control system, normally placed right beside the level crossing (local). The control system activates the road signal and in return activates the monitoring signal in case that the road was closed. The monitoring signal is also connected to the control system by wires.

In case of the track-side system the striking-in distance is defined by the maximum speed (locally authorised speed) and activation delay. The activation delay is a function of maximum length of a road vehicle, duration of yellow light signalling, dimension of the level crossing, closing time of the barrier, etc. For the calculation of this distance the „worst-case-scenario" is assumed to guarantee maximum safety and security.

The system introduced by ETCS/ERTMS relies on Eurobalises for absolute position information and on an odometer for relative position information. Using Eurobalises, distributed along the line, and an odometer the actual position of the train is determined. In case that the train passes the virtual activation point the train transmits an

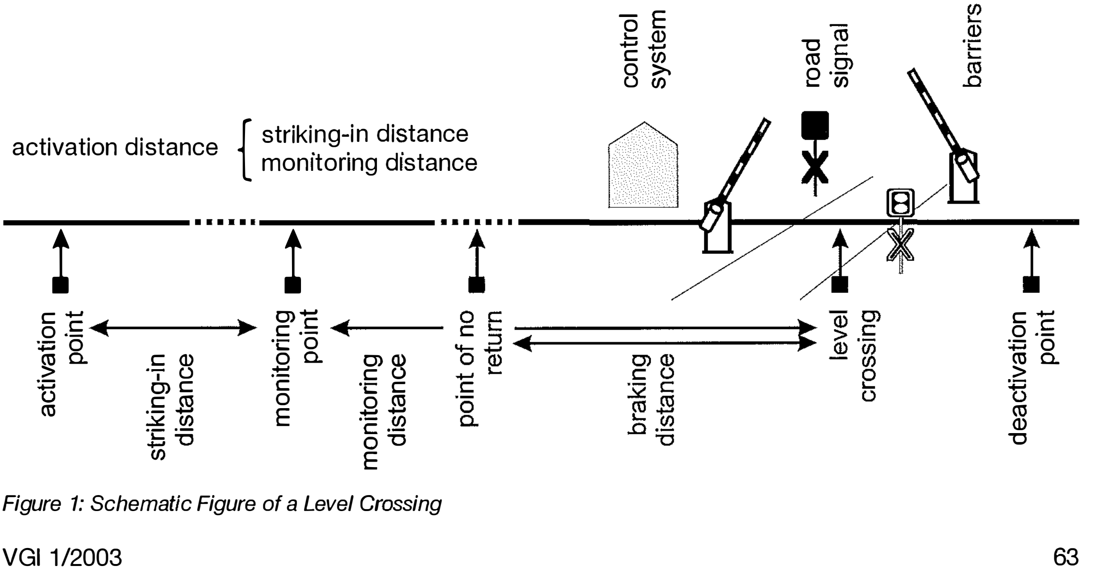

Figure 1: Schematic Figure of a Level Crossing

activation signal by GSM-R to the control system, which in contrast to the track-side system is placed either locally or remotely. The control system activates the road signal and in return sends a pass signal to the train. The certification of this system, where the main drivers are safety and interoperability, has been harmonised at the European level in ETCS/ERTMS pilot projects.

5. Advantage of an On-Board System

The main advantage of the on-board system is a speed-dependent activation of the level crossing. In case of the track-side system, the sum of striking-in distance and monitoring distance – further denoted as activation distance – is a function of a worst-case-scenario. In case of the on-board system, the activation distance as well as the monitoring distance can be adjusted to actual train parameters (speed, length, weight, etc.).

To give an example, a locally authorised speed of 100 km/h is assumed. The striking-in distance therefore amounts to about 1000 m, and another 1000 m have to be added for the braking distance. The overall distance of 2 km is covered by a train in about 72s. Taking into consideration that the position of the activating contact is fixed and some trains do not achieve the locally authorised speed, the time motorists have to wait behind red road signals and closed barriers can amount up to several minutes. Consequently, a train running at 50 km/h causes an increase in the waiting period for motorists of about 100 %.

Therefore an on-board / speed-dependent system guarantees an increase of traffic flow for motorist by means of optimised closing time, and a reduction of air polluting emissions due to shorter waiting periods. Reconsidering the example mentioned before and taking into account that 1 m of wiring would cost approximately € 70,– the presumed activation distance of 2 km amounts to € 140.000,–, for one activation direction. Therefore the railway operators would save considerable costs for the wiring by installing an on-board system.

Note that the replacement of the track-side system by an on-board system is only applicable in case that it provides a sufficient safety level.

6. GNSS On-Board System

ETCS Level 1 is a combination of a track-side and an on-board system. The system still relies on the Eurobalises. Although the location of a Eurobalise along the track is rather arbitrary, the number and distribution is a function of the accuracy of position information required. Since the odometer shows an accumulating error, the relative information of the odometer has to be updated by absolute information on a regular basis.

This leads to the idea to replace the track-side Eurobalises by virtual balises. Thereby new means of navigation are introduced into the field of railway transportation. In future systems, the Global Navigation Satellite Systems shall provide the absolute position information (cf. Figure 2).

The train determines its position autonomously. Approaching a level crossing the train transmits, dependent on its speed, an activation signal at the virtual activation point to the control

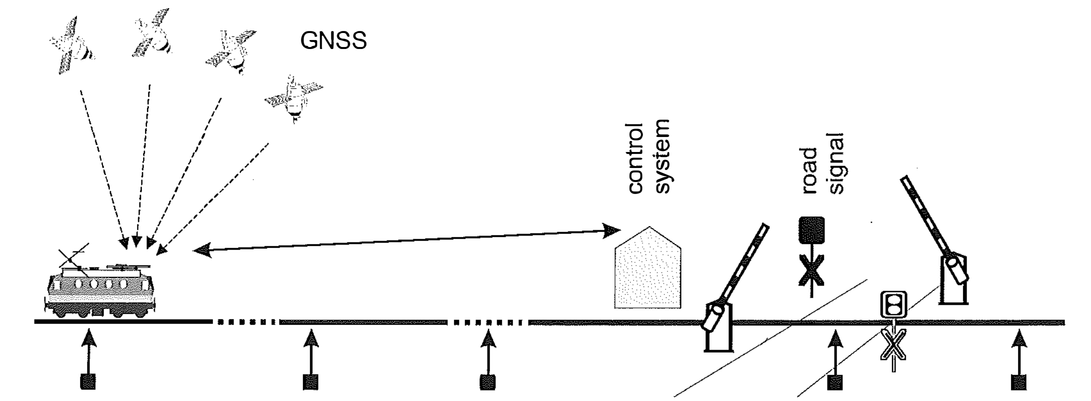

Figure 2: The train determines its position autonomously and transmits an activation request to the control system. The control system closes the level crossing and triggers the information to pass.

system via GSM-R. At the deactivation point, the train again sends a signal to the control system that the level crossing is cleared.

Assuming an ETCS Level 2 network the cost reduction by replacing the fixed Eurobalises by GNSS equipment could be considerable. Fixed balises for 2500 km of railway lines will cost less than M€ 10. The comparable technical equipment relying on GNSS, is estimated to cost only a fraction.

7. Database

The control of an automatic level crossing requires the on-board system to have information about the relative position of the train and the level crossing. In particular, the information about the distance between the ALX and the train is needed. The on-board unit uses this distance to identify, whether the point of activation has been reached. Since GNSS provides a three-dimensional position information, this position has to be matched to the railway line. Therefore, a database including the geometry of the railway line, all ALX and ALX-related points, also including all relevant information like authorised speed etc. have to be provided to the on-board unit.

The database stores the railway line in a hierarchic model, where the railway line itself represents the highest level, followed by a track segment within the line. The lowest level is represented by an edge, delimited by two vertices. Edges and vertices, as well as nodes, tracks, and lines are attributed with a number of information. In this context the database is denoted as digital route map or in a more common sense as Geo Information System (GIS).

By evaluating the GNSS signal, monitoring the speed of the train, and comparing this information with the stored track data, the activation of the level crossing is initiated automatically at the latest possible moment.

8. Integrity

As mentioned before, the on-board system has to guarantee the same security standards as the track-side system. Therefore, the on-board system has to pass a number of certification procedures. Extensive risk assessment and hazard analysis have to be applied to analyse the implemented architectures, methods, and techniques. This procedure shall provide a probability measure, that all functions are satisfactorily performed.

The risk analysis encompasses [2]

- the definition of the requirements of the railway system (independent of the technical realisation).
- the identification of hazards relevant to the system.
- the derivation of the tolerable hazard rates.
- the guarantee that the resulting risk is tolerable (with respect to the appropriate risk tolerability criteria).

The safety integrity of a function is defined by the probability of satisfactorily performing the required functions under all stated conditions within a stated period of time [3]. Five different levels (0 ... 4) of safety integrity have been defined, where level 4 is the highest. SIL 4 has to be met to guarantee an ETCS/ERTMS level 3 application.

9. Sensor Fusion

The GNSS as a sole means of navigation is not able to provide the high level of safety integrity. Although the US Global Positioning System (GPS) does not provide any information on integrity, the satellite based augmentation system (SBAS) EGNOS (European Geostationary Navigation Overlay Service) provides timely warnings and therefore integrity information within 6s. However, GNSS suffer too often from signal outages especially in topographic demanding areas due to shadowing.

A hybridised positioning system composed of GNSS equipment and train sensors would be able to overcome the data gaps in position determination and integrity information. However, the increasing complexity of the positioning system, key-word sensor fusion, follows a complex certification process caused by satellites geometry, hybridisation, and database.

10. ECORAIL

The European Space Agency (ESA) and the European Commission (EC) recognised the potential of introducing GNSS into the fields of ETCS/ERTMS. Both fund a number of projects, which deal with the implementation of satellite navigation into the railway domain to demonstrate the feasibility and benefits of GNSS in combination with ETCS/ERTMS.

One of these projects funded by ESA is the „EGNOS Controlled Railway Equipment – ECORAIL" (cf. Figure 3). The project consortium led by Technicatome (Project Manager V. Thevenot) combines experts of the fields of satellite navigation, interlocking and train control systems, geoinformation (ST Microelectronics, Systra, TeleConsult-Austria, Alcatel Austria) as well as the suppliers for and operators of railway networks (Technicatome, Alcatel Austria, Stern & Hafferl).

The project aims at the use of GNSS means of navigation to control automatic level crossing. ECORAIL therefore combines on-board and ground equipment:

- an on-board equipment which will be able to localise the train on the track. Beside the GNSS components GPS and EGNOS, also an odometer will be integrated into the system
- an on-board and a ground equipment which allow to exchange information (communication link)
- a ground equipment, which allows to record and compare the virtual actions coming from the on board equipment to the real command coming from the existing wired system

Figure 3: The ECORAIL project as seen by an artist's sketch combined with a real photo

Despite the ECORAIL system can not be allocated to a specific ETCS/ERTMS application level, it can be seen as a possible supplement. Relations to the different levels are obvious. The continuous positioning of the train fulfils level 3. Both, the ECORAIL system and ETCS/ERTMS – starting at level 2 – use a radio link for communication. Furthermore, the ECORAIL project and ETCS/ERTMS share common goals:

- improve the safety.
- save environmental resources.
- reduce costs by saving the expensive wiring.
- raise the ability to survive the commercial competition.
- integrate additional services based on satellite navigation.

11. Demonstration Phase

For the demonstration phase of the ECORAIL project, the on-board and the ground equipment will be installed on the Linzer Lokalbahn, a railway network of Stern & Hafferl in the federal province of Upper Austria. The demonstration has two main objectives. It should prove the feasibility of the satellite navigation positioning system for the chosen application. Apart from that, it should also be used to evaluate the performance of the navigation unit, both with respect to the particular application and to its general capabilities.

The primary aim is to prove that the ECORAIL equipment works in a full-size railway environment and that the specified functions are performed correctly (feasibility). It is also important to show that the system works reliably over a long period (reliability). Further it shall be shown that shorter closing times of the ALX barriers can be achieved by optimised activation (benefit potential).

The evaluation of the demonstration results will concentrate on the navigation system performance, on the robustness of ALX control and on possible reduction of ALX closing time. To evaluate and prove the performance of the ECORAIL system, three different modes of operation are considered:

- the simulated Operational Mode (OM) which sends the "close message" when the fixed activation point has been met.
- the Optimized Operational Mode (OOM) which sends the "close message" when the speed dependent virtual activation point has been met.
- the navigation test mode (NTM) which is similar to the OM but uses a constant confidence interval of 0.

Phase two of the ECORAIL project started with generating the digital route map (DRM). Therefore, the geometry of the railway line was acquired by a kinematic DGPS measurement campaign. In parallel to that, an EGNOS receiver was already installed on one of the trains to get a first impression about the EGNOS performance along the railway line. Figure 4 shows five different trajectories, offset by 1000 m in southward direction. Dark blue indicates the location where GPS and EGNOS are visible, the locations in red indicate where only GPS but no EGNOS is available.

EGNOS, as a reminder, provides the integrity information in the GNSS system. As shown in

Figure 4 there are some outages before and during approaching the activation distance. Further, the figure indicates that the EGNOS receiver performance varies with time. Therefore the integrity level has to be additionally guaranteed by the train sensors (odometer) in combination with the sensor fusion algorithm.

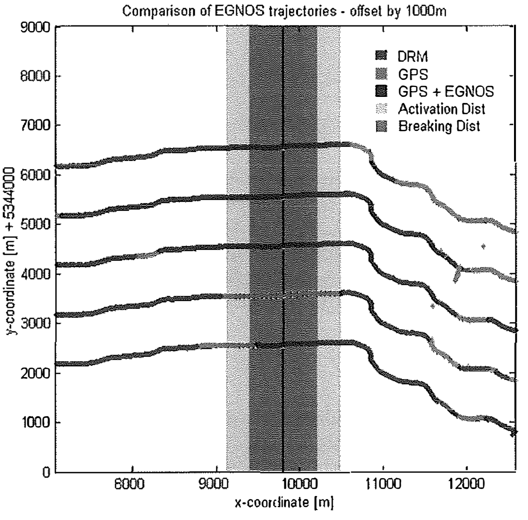

Figure 4: EGNOS availability during five survey runs at a railway network in Upper Austria (Stern & Hafferl) – the trajectories are offset by 1000m in southward direction

12. Outlook and Conclusions

The introduction of ETCS/ERTMS shall strengthen the competitiveness and attractiveness of the railway transportation. Additionally it intends to facilitate the inter-European passenger and freight traffic. ETCS/ERTMS train positioning is designed to use relative distances from known points along one-dimensional routes (no geo-referenced information).

The implementation of new means of navigation promises positioning functionality without Eurobalises. The introduction of GNSS as a global system increases the interoperability between national and regional systems. Within a demonstration phase, the feasibility of integration will be proved, and the performance of the system evaluated. A consecutive certification process is needed to guarantee the compatibility with the high safety requirements of the rail applications.

The high safety requirements however will require that GNSS operators provide a service guarantee, and as far as possible a risk analysis. Galileo as a future and enhanced European controlled GNSS will provide additional service and integrity information. This will further facilitate the implementation of the means of navigation into the railway domain.

Beside the safety critical application of train control, a position information system will also enhance non-safety critical applications like fleet management, service to the passenger, or optimisation of energy consumption.

References

[1] *ADTRANZ, ALCATEL, ALSTOM, ANSALDO SIGNAL, INVENSYS RAIL, SIEMENS (1999):* ERTSM/ETCS - Class 1 System Requirements Specification, Chapter 2, Basic System Description; Ref: SUBSET-026-2; Issue: 2.0.0; Date: 991222

[2] *CENELEC (1999):* Railway applications – Systematic Allocation of Safety Integrity Requirements (Ref. n°: prR009-004:1999 E) European Committee for Electrotechnical Standardization

[3] IEC 61508 – Functional Safety of Electrical / Electronic / Programmable Electronic Safety-Related Systems. International Electrotechnical Commission.

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