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From French National Signaling Systems to ERTMS: Considering the Evolution of Track-Side Systems

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Abstract—In France, the railway lines are divided into the national and international lines. While the former has a proper implementation of the railway signalling systems as relay-based or computer-based systems, the latter follows the guidelines defined by the ERTMS standards, focusing on the interoperability throughout Europe. In a previous work we presented how the national legacy relay-based Railway Interlocking Systems (RIS) can evolve to use a computer-based technology in order to benefit from its advantages. In this present article, we present how these computer-based systems can be used in order to allow the evolution from a national line towards an ERTMS compliant international line. This proposition is based on the fact that the previous work provides the support for evolving the track-side technologies with, for instance, the use of GNSS for the train geo-localisation instead of electrical circuits-based train detection systems. Then, a discussion of the impact of this evolution over the system safety is presented.

Index Terms—railway interlocking systems, computer-based systems, French national railway lines, ERTMS

I. INTRODUCTION

Railway systems are being continuously studied with the aim of improving their safety and using trustful cost effective technologies. In France, the French National Railway Company (SNCF) works with two different lines: the national and the international. In the national lines, the signalling systems, responsible for detecting and controlling the trains in a safe manner, are implemented with relay-based (electrical circuits-based) or computer-based technologies, being this last one the most recent [1]. Regarding the international lines, these systems are implemented (or are about to be) accordingly to the European Rail Traffic Management System standards. ERTMS was developed to harmonise railway control and signalling systems to ensure railway interoperability throughout Europe [2].

The deployment of ERTMS is mandatory on railway infrastructure projects for new or upgraded rail subsystems receiving financial support from the European Union [3]. In this context, the ERTMS replaces the national conventional electrical systems where the train detection and control is built based on the electrical

circuits. Nowadays, especially in European research projects funded by Shift2rail, the ERTMS is being evolved to gain more advanced manners to detect the train position, control the trains movements and wirelessly communicate all this information with the on-board system, also known as the European Train Control System (ETCS). One example is the use of GNSS (Global Navigation Satellite Systems) [4] that allows the train can continuously and autonomously geo-localise over all the areas covered by these systems [2].

The Railway Interlocking System (RIS) is a track-side part of the signalling system and it is not yet standardized in ERTMS. It is responsible for the logic of the train control in specific areas such as junctions or crossings. In a previous work [5], we presented a safety-based approach to evolve the French RIS from relay-based to computer-based technologies in the national lines. Nonetheless, the possibility of adapting these RIS to international lines based on the improved maintainability resulted from the evolution to computer-based systems, is not yet addressed. By defining an appropriate interface to the RIS, one may evolve these track-side systems in order to suit with the defined ERTMS FIS and FFFIS (Form Fit Function Interface Specifications). However, new promising technologies for improving railway operations like GNSS, are recognized as game changer for signalling systems and introduce new challenging issues not addressed in ERTMS specifications. Hence, despite of the benefits of using such technologies as explained in [2] for GNSS, there are new risks that must be considered and analysed in an appropriate manner.

In this context, as the computer-based RIS generated in the previous work is safety proved, it is still necessary to analyse how the evolution of the track-side component technologies can impact the signalling safety. This article presents how the transformation from relay-based RIS to computer-based ones may support the evolution of the track-side components so the system can be adapted to conform to the ERTMS interface patterns. Then, we discuss the impact of the track-side system evolution over the system safety, focusing on the properties that must be met in a specific real industrial case study. The use of an approach for the transformation from national relay-based lines to international computer-based ERTMS lines is a new proposition. The benefits of using this computer-

based technology as well as the risks to the safety of the proposed system are detailed in this paper.

The next section focuses on presenting how the system may evolve from the legacy national relay-based technologies to have interfaces suitable to ERTMS. Then, the Section 3 is devoted to an analysis of the impact of this evolution to the system safety. The last section of this paper presents the conclusion and some perspectives.

II. RAILWAY SIGNALLING SYSTEMS EVOLUTION

Compared to the relay-based systems, computer-based RIS have a tendency to be easier to handle and maintain, cheaper and more flexible to extend function [6]. The transformation of the existing legacy relay-based RIS towards computer-based technology is under the interest of the industry, as long as the behaviour is preserved and the safety level of the existing systems are maintained or even improved. This is because the legacy systems safety have already been extensively tested throughout the years in a way that they have now a high level of confidence. In order to perform this transformation, in a previous work [5] we presented a methodology based on Formal Methods. By formal specifying the logic behind the electrical circuits diagrams in B-method [7], it is possible to benefit from the formal development process in order to verify the system safety and refine it until its implementation as a computer-based system.

In Ref. [5], an SNCF real case study is detailed and modelled: the Temporary Reversed Direction Installations (ITCS - *Installations Temporaires de Contre Sens*). In this case study, due to a problem on one of the tracks of a double-way train route, a train must pass through the opposite-way track. Because of the possibility of occurring a frontal collision, it is necessary to use the ITCS interlocking system in order to detect the trains presence and control the signals in a safe manner. A track plan of this example is presented in Fig. 1.

In ITCS, all the equipment necessary to detect and control the trains as well as the control logic are implemented based on electrical circuits. For instance, the train detection is made by pedals or buttons, which close electrical circuits that are directly linked to the system

logic. While Pedals indicate the presence of a train on a track, a button express the intent of entering in a portion of the track. On the other hand, the train control is made by track-side signals or by controlling the turnouts. All this equipment activation and deactivation are based on the electrification provided by the interlocking logic circuit. Regarding the ITCS case study, the left side of the Fig. 2 presents the electrical circuit responsible for controlling the Control Area A in the track plan presented in Fig. 1. The electrical components highlighted in yellow represent the inputs of the system, while the green components are the outputs that control the signals presented in the track plan.

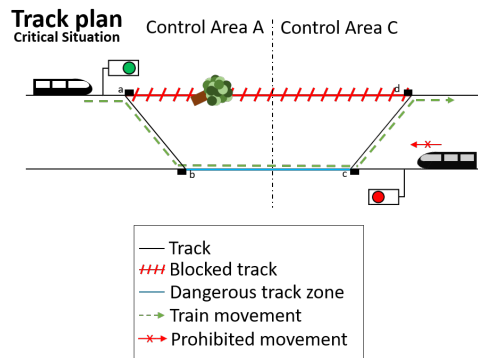


Figure 1. ITCS case study track plan.

After the specification, proof and transformation of the RIS into a computer-based system, the system logic can now be executed in a microprocessor, as abstracted in the right side of the Fig. 2. In this format, the system inputs and outputs, which were once part of the electrical circuit, can now be directly connected to the microprocessor, which is less expensive and more maintainable [6]. However, a contribution of this approach not discussed in previous work is the improvement of the maintainability and modularity of the system as a way to allow the track-side systems to evolve separately. One interesting benefit of this modularity is the possibility of using the ERTMS technologies together with the new computer-based RIS in such a way that the national system interact in an interoperable manner with ERTMS.

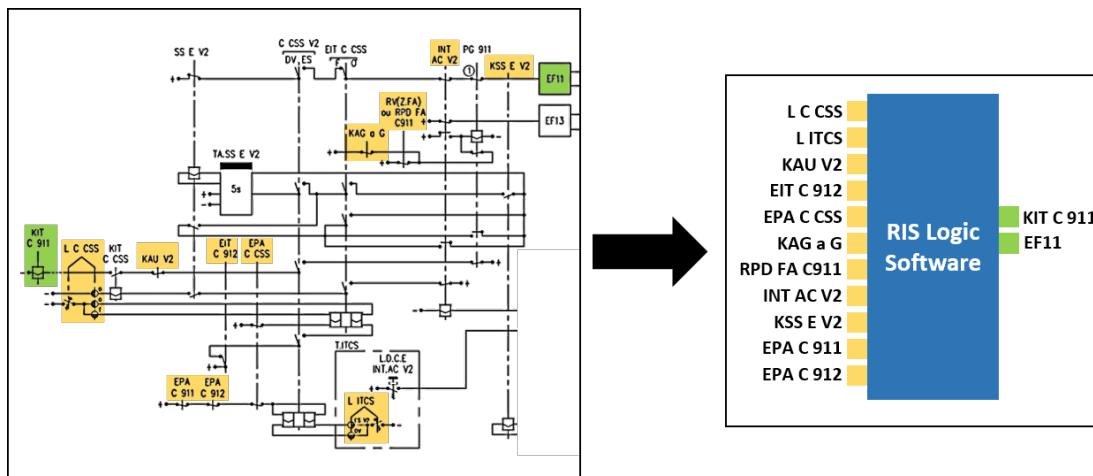


Figure 1. Abstraction representing the transformation of part of the ITCS system from electrical circuits to a computer-based system.

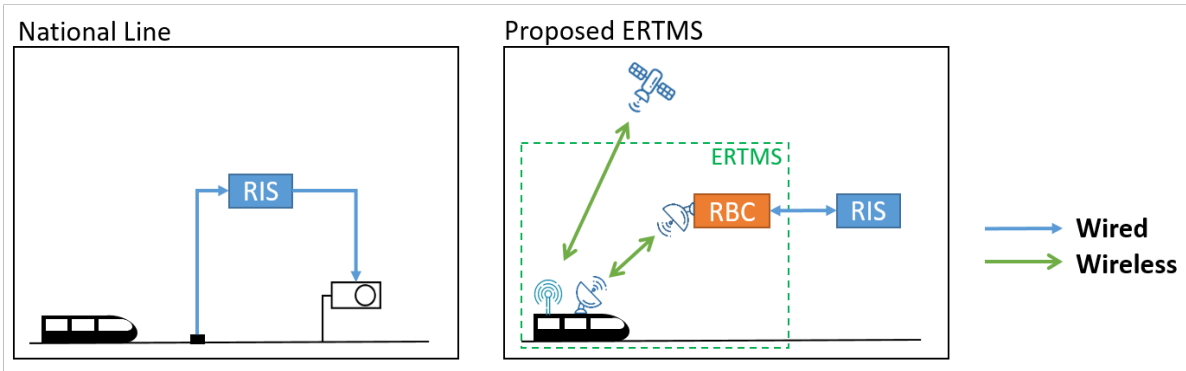


Figure 2. Difference between the French national lines and an ERTMS using geo-localisation.

In an ERTMS, all the information regarding the train localisation, velocity and the status of the tracks must be available in the on-board system (ETCS), offering the possibility for substantial line capacity increase [8]. In this case, the outputs of the interlocking system, indicating the signals status, must be sent to the ETCS on-board, via the RBC (Radio Block Center), as presented in Fig. 3. On the other hand, the train localisation system, which can be implemented with many different technologies (or a conjunction of them), must also be shared with the interlocking system via the RBC, allowing it to control the trains by determining the signals status. All these technologies can be connected to the new interface provided by the computer-based RIS.

Nevertheless, it is important to observe that the focus of the interlocking systems is the safety. The previous work proposed a methodology for evolving the system logic from relay-based to computer-based technologies through a formal development process, providing safety proof at each step [5]. By changing the system inputs and outputs, one must guarantee that the system safety is not compromised. The legacy electrical components have a high degree of confidence as the system logic and safety depend on them, so, the new chosen technologies connected to the RIS must provide the same functionalities with at least the same performance.

III. THE RISKS OF EVOLVING THE NATIONAL TRACK-SIDE TECHNOLOGIES

The evolution of the track-side systems to conform to the ERTMS standards must consider the complete absence of electrical circuits for their communication. The system logic, now running in a computer, must communicate the RIS outputs (track status) with the ERTMS (via RBC), which provides movement authority information to the on-board ETCS. Regarding the train localisation, the introduction of GNSS-related systems will permit to continuously provide the train localisation. This information can be processed by an adaptor in order to inform to the RIS whether a train is present in a track section that requires an interlocking response. So, the analysis of the track-side systems evolution impact over the system safety can be analysed through two different points of view: the reliability of the RIS outputs transmission to the ETCS and the conformity of the train

localisation with the safety requirements of the interlocking systems.

A. Outputs Evolution

The outputs of the RIS can be understood as the permission for the train to move in areas where train routes may conflict. In a French national line, these outputs are implemented as light signals, which must be interpreted by the driver as a guidance for inducing the train movement or braking operations. In last implementations of ERTMS (levels 2 and 3), light signals are no longer necessary, the track information is sent directly via the RBC to an on-board system. This information can be read by the driver as it is now shared via computerised systems and displayed in the DMI (Driver Machine Interface).

By adapting the system from the national to the ERTMS lines, it is important to consider that the information received by the driver is different in each of these lines. In the national relay-based RIS, the light signals colours and flashing patterns visually indicate to the driver the situation of the tracks, the top velocity the train may operate and whether it must stop or continue running [9]-[11]. As these patterns are not the same as in the ERTMS, they must be incorporated and transcribed to the ERTMS patterns. The ETCS generally presents a complete set of specific information, like the Movement Authority, which includes the information about the top speed allowed and the distance in order to guarantee the safe train operation. Thus, in the transformation from the national to the ERTMS lines, the RIS outputs that control the lights states must be interpreted by the ETCS (or even by an adaptor connected to the RIS) in a correct manner. It is important to consider that the signals can have different meaning in the national and international lines, thus one must provide all the necessary adaptations. Therefore, it is possible to establish the following safety property:

Safety Property 1 (Output Comprehension) - *The output provided by the Railway Interlocking System must be comprehended and assimilated to the train on-board system. The information presented to the driver must be provably the same as the one defined in the light signal patterns.*

Another problem that must be considered is the time spent on forwarding the output information to the on-board system. As the light signals are directly connected to the relay-based RIS in the legacy systems, the time spent for changing the lights states is the time for the electrical current to electrify them. When considering the transmission of this information to the on-board system, the technology must be able to transmit this information with minimal delay so it cannot cause dangerous situations. Therefore, the time taken by the wireless communication system to transmit the information has to be considered in the safety process, as well as the possible interruptions in the wireless transmissions (the Euroradio protocol is used in ERTMS concerning these aspects). Thus, the Safety Property 2 can be defined.

Safety Property 2 (Output Delay) - *The output provided by the Railway Interlocking system must be sent to the train on-board system with controlled delays to not cause dangerous situations.*

In this context, the time for this delay depends on each specific case, since the train distances and velocities are some factors to be considered. In the ITCS case study, for instance, a delay on the information about a closed signal can cause the train to brake after the signal, which may cause an unintended collision. However, one of the best advantages of using this ERTMS technology is the possibility for the train to obtain an information about the tracks in an earlier moment. In this context, it is important to consider that the vision of the driver is limited and, depending on the weather or other physical factors, the light signals may not be clear or even visible. So, giving the information earlier by radio signals can compensate any time lost on processing the information as it is the case for the wireless transmission.

Besides the possibility of sending the track information to the driver in an earlier moment, the ERTMS wireless technologies have the advantage of allowing the maintenance without blocking the tracks, as it offers a better support for component redundancy. Furthermore, it is a less expensive solution than the wired one. Nonetheless, in order to benefit from all these advantages, one must guarantee that the safety properties above are respected when transforming a national relay-based line to ERTMS.

B. Inputs Evolution: The Use of GNSS-based Localisation Systems

There are many technologies for the train localisation and detection, like the use of legacy pedals, track circuits, axle counters, or balises, which detect the train presence once it passes through these components. However, there is an innovative technology that has the capabilities of being more effective and less costly for locating the trains: GNSS. While the legacy systems are able to detect the train presence in specific areas of the route, the geo-localisation allows to continuously determine their position. This functionality can be extremely useful not only as an input for the new computer-controlled RIS, but also for future extensions of this system.

In this context, it is no longer necessary to put several train detectors along the route, as the train position can be now estimated autonomously by the train using embedded localisation system. Nonetheless, the possible drawbacks of using this technology regarding the system safety must also be analysed. Therefore, the introduction of GNSS localization techniques have been studied for years [4] with the objective of improving them in order to be safely used in a critical context, especially in railway signalling systems.

However, the signal propagation between the satellites and a train can suffer from unexpected perturbations [2]. This is mainly due to environment elements around the train (tunnels, rail canyons, stations, foliage, etc.). Moreover, in addition to the fact that signal data can be corrupted (interference, spoofing, jamming), the utilisation of GNSS-based localisation system can be extremely dangerous for railway operations if not completely controlled. The information about the train position is critical for its safety, especially when we consider the high-speed operations. In the ITCS case study, the delay on obtaining the information about the train localisation can cause the train to pass the signals, causing it to be misplaced. As a consequence, it may cause a collision with another train that is supposed to pass through the "invaded" track portion. In order to use the GNSS-based train localisation system one must guarantee that the delay for obtaining the satellite information cannot cause dangerous situations, as presented in the Safety Property 3.

Safety Property 3 (GNSS Delay) - *As the information given by the GNSS satellites can be delayed, in order to use this technology when making the signalling system into a ERTMS compliant, one must guarantee that this delay cannot cause dangerous situations.*

Many approaches for reducing the problems caused by this delay can be implemented with the use of some fixed balises to correct the position obtained with satellite information or even considering the average delay time and the train velocity when informing of the train localisation. Anyhow, the impact of using the geo-localisation in this context must always be analysed and the safety must be proved. In the legacy relay-based technologies, when the train detection system fails, it keeps an "occupied" state that forces the logic to maintain a safe state. A solution proposed with the use of other recent technologies must be able to deal with dysfunctional problems in the same manner.

A possible second challenge related to the use of GNSS is the risk of losing contact with the satellites, which is generally caused when the train is passing through tunnels. By using this technology, one has to provide means for the trains to continue safely moving when the satellite signal is lost. Although there are some approaches to overcome this problem, they are still under studies by the research community. A mixed approach using both GNSS and local detection systems still seems to be the better solution. Regarding the possibility of

losing connection with the satellites, the Safety Property 4 must be satisfied.

Safety Property 4 (Train Localisation Continuous Transmission) - *The train using a GNSS-based localisation system must continuously know its localisation, i.e., the on-board system must have an accurate information about its localisation. The GNSS has to be combined with other technologies to support the satisfaction of this property.*

In the worst scenario, when losing the information about the train localisation, the train must have certain procedures to avoid any danger. In a national line, when a train cannot be detected, the system assumes its constant presence in order to force the safety. Although it is still an availability problem, it is the best measure in order to guarantee the system safety. The ERTMS, on the other hand, may support the use of different technologies, allowing the train localisation and presence detection in different manners as a way to guarantee the right functioning.

In the hypothetical case where only the train geo-localisation is used in the ITCS case study, losing the localisation information may cause the train to stop on the shared portion of the tracks. If the RIS treats the track section as occupied, the system safety can be maintained although it blocks the transit for an undefined time. Otherwise, if the RIS do not has the train localisation as occupied, it cannot avoid collisions with other trains. Besides, as the train position is not detected the alteration of a turnout state under use may cause derailments. The opposite situation may as well cause inconveniences: if the localisation provides a false alarm detection of a train in a portion of the tracks, it also causes the control system to maintain the safety in spite of the availability. The implementation of geo-localisation systems in this context must consider all these possibilities. In order to avoid all these problems, other detection systems must be used as a way to support the GNSS weakness points, which puts in doubt the inexpensiveness of this technology. The use of such advanced technologies requires a complete risk evaluation in order to guarantee the system safety.

IV. CONCLUSION

The transformation from Relay-based Railway Interlocking Systems to computer-based ones provides a basis for the evolution of the track-side components technologies in an independent manner. Grounded on this evolution, it is possible to adapt the French national lines towards the ERTMS standards, giving a support for the system evolution to the European standards. However, given the high safety degree of the national and international lines, the careless transition between the legacy track-side system to the new technologies may impact on the interlocking system safety.

Regarding the train control, the translation of the signal patterns and the delay of the information transmission can represent some problems to the signalling safety when

maintaining the pre-existing RIS logic. Therefore, it is necessary to guarantee that the information received in the on-board system is understandable and conform to the previous system outputs. Besides, this information must arrive early enough for controlling the train movement as a way to avoid dangerous situations. Regarding the train detection and localisation, the GNSS technologies is investigated, in order to provide a solution for continuously determining the train localisation. Nonetheless, the main challenge of this technology regarding the loss and perturbations of signals in harsh environment must still be addressed in order to avoid dangerous situations. In this context, a complete risk analysis of using the GNSS-based localisation system in this context must still be made.

In a future work, we aim to extend the analysis of the impact of evolving the track-side components presented in this paper as a way to present a methodology for making these transitions to the new technologies. In this context, we aim to study the existing more advanced technologies for the train detection and control that can be used and compare them with the technologies used in the national lines. This comparison must consider the European standards regarding reliability, availability, maintainability and safety, as presented in the CENELEC Norm 50128 [12]. The impact of evolving these systems must be analysed as a way to be able to propose a complete methodology for adapting the national systems to the ERTMS standards maintaining the existing safety degree

CONFLICT OF INTEREST

The authors declare that the submitted work was carried out with no conflict of interest.

AUTHOR CONTRIBUTIONS

Dalay Israel de Almeida Pereira and Ouail Himrane proposed the paper subject and wrote it. This work was directed and revised by Philippe Bon and Julie Beugin, whose experience on this field was essential in order to improve the contribution. All authors had approved the final version.

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Julie Beugin received the engineering degree from INSA Hauts-de-France (National Institute of Applied Sciences) in 2002, the master's degree in automation engineering from Polytechnic University of Hauts-de-France in 2002, and the PhD degree in automation and computing sciences in 2006. Since 2007, she has been with Gustave Eiffel University as a researcher. Her research interest in the ESTAS laboratory (Evaluation of Automated Transport Systems and their Safety) deals with dependability and safety evaluation of complex guided transportation systems. Part of her activities addresses RAMS demonstration issues of GNSS-based solutions embedded in train control applications. She participated to the GaLoROI, ERSAT-GGC, STARS European projects. She has secondment agreements with Railenium to participate to projects in her research fields and with Certifer to realize ISA missions.