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Next Generation Train Control (NGTC): more effective railways through the convergence of main-line and urban train control systems

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Abstract

The main scope of Next Generation Train Control (NGTC) project is to analyse the commonality and differences of required functionality for mainline and urban lines and develop the convergence of both European Train Control System (ETCS) and Communication Based Train Control (CBTC) systems, determining the level of commonality of architecture, hardware platforms, and system design that can be achieved. This will be accomplished by building on the experience of ETCS and its standardised train protection kernel, where the different manufacturers can deliver equipment based on the same standardized specifications and by using the experience the suppliers have gained by having developed very sophisticated and innovative CBTC systems around the world. The paper focuses on the analyses of the already produced NGTC Functional Requirements Specifications and is summarizing other project activities on various train control technology developments suitable for future train control systems.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: Railways; signalling; automation; ERTMS / ETCS; CBTC; ATO; ATP; ATS; FRS, SRS; Moving Block; IP Radio Communication; GNSS

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1. Introduction

ETCS is a train control system developed for the mainline railways while CBTC systems have been developed separately as train control systems applied to urban rail. ETCS aims at supporting interoperability from one mainline to the other. CBTC systems in the urban domain have been designed generally to support automated operations on some lines or networks (partially or fully).

Nowadays, the actual customer needs for urban, suburban and mainline railways have started to converge. Even if the need for interoperability is not as common in the urban world as in the mainline one (due to the structure and operational requirements of most urban lines/networks), interoperability has become the topic for a couple of urban rail projects. They are typically dealing with the increasing number of commuters in large conurbations and are intending to permit a seamless transition from the mainline / suburban domain to the urban one. Mainlines, in highly populated areas, are reaching their current capacity limits, while advanced train control technologies could significantly increase operational capacity of a line. Interchangeability of system components through well-defined interfaces is a required system property, helping operators securing their signalling technology investments and decreasing related costs through the higher competition among suppliers.

1.1. State of the art

The successful deployment of ETCS technology across the EU network and worldwide is providing new opportunities for safety and capacity improvements, and cross-border operations on the mainline network. Likewise, numerous new innovative control and command signalling systems (mainly CBTC based) are being introduced in the urban rail area, equally providing capacity improvements. Despite some passed initiatives like UGTMS or MODURBAN, FP5/6 projects, to study the convergence of the Train Control Systems developed for the mainline rail (ETCS) and the urban rail (various Communication Based Train Control – CBTC), these two domains are evolving independently.

On the one hand ETCS defines a standard train protection system which is based on a set of defined functions and track-to-train messages (airgap) providing full interoperability between the infrastructure and the trains. On the other hand the various control and command systems in the urban world (CBTC) which are company specific / proprietary systems have proven to be successful solutions that meet high-performance needs, yet are not always “interoperable’’ or “interchangeable” between themselves. The same European industry is the world leader for both of these types of systems.

The development of ERTMS /ETCS specifications began as early as the late 1980s and the main purpose was to replace more than 20 train control systems with the one standardised solution and thus to provide interoperability for train operation across the European Union. Up to now, around 80.000 km’s of lines and 10.000 on-board units have been contracted-for worldwide. This demonstrates the acceptance of the ETCS specifications and the speed of its adoption. Although early implementations were mainly targeted at European high-speed line projects, ERTMS/ETCS has now been delivered for use in the conventional rail segment, and sold into many geographical areas outside Europe.

On the other hand for the urban rail segment, nearly 150 cities worldwide currently have metro networks, carrying daily more than 150 million passengers and additionally almost 400 light rail systems in about 50 countries carrying daily 45 million passengers. Dozens of systems are planned. In this fast growing market, in which automated or unattended operations are more and more implemented, the potential for new innovative technologies can clearly be identified. At this stage many kinds of CBTC systems are now in service worldwide, tailored to the requirements of individual urban rail operators. A small number of operators are in the process of implementing interoperable or interchangeable systems on their individual networks.

1.2. Vision of the future

With the continuous growth of large cities, it could be expected that the next generations of signalling solutions will provide effective, technical means for smooth connection between dense urban network and the surrounding suburban/mainline network and will be able to address the following different types of railways:

- Urban systems (metro) operated on fully independent infrastructure; many with very high performance requirements;
- Mainline systems connecting cities;
- Regional systems (sometimes suburban) which are fully part of the mainline domain;
- Suburban systems (like the Paris RER or the London Crossrail and Thameslink) which are neither “fully mainline” nor “fully urban”.

Up until now, this has often led to the complex “multiple equipment” solution by duplicating trackside and trainborne equipment, which does not meet the performance and economic targets for the future.

Standardised future train control systems for mainline and urban domains will provide complete ATP (Automatic Train Protection), ATO (Automatic Train Operation), and ATS (Automatic Train Supervision) functionality and support train operation from Grade of Automation GOA0 to GOA4, whilst significantly reducing TCO/Life cycle costs, and achieving an overall improvement in performance at lower cost. In addition, it must be possible to offer scalability for different customer requirements (ranging from low density lines to high performance lines).

1.3. Introducing NGTC project and its consortium

In order to address all these challenges of the future, as of September 2013, Next Generation Train Control (NGTC) started its work as a 3-year research project running in the frame of the EU FP7 programme. A number of key urban and mainline railway related organisations are involved. In particular UITP, RATP, TMB and London Underground are sharing their mass-transit expertise with the leading signalling system suppliers such as ALSTOM, ANSALDO STS, AŽD, Bombardier, CAF, Siemens and THALES. Similarly, SNCF together with the ERTMS Users Group are providing their know-how for the mainline train operations.

The crucial task of the project is to analyse the commonalities and differences of required functionality of both ETCS and CBTC systems. Subsequently, the common functions of train control systems are used as a basis for the system common core specifications further evolving ETCS functionality, utilizing CBTC system solutions. A major condition for the work undertaken in the project is to preserve the backwards compatibility with the current ETCS Baseline 3 specifications in order to protect the already large investments made by the main-line railway customers and suppliers.

The intention of the project is clearly not to develop a ‘one-size-fits-all’ system, but to make progress for all railway domains in terms of increasing the commonality in system design and hardware, with various benefits including increasing economies of scale for suppliers (see Figure 1). Customers are expected to benefit from being able to choose the most competitive supplier, based on the standardised functions and interfaces.

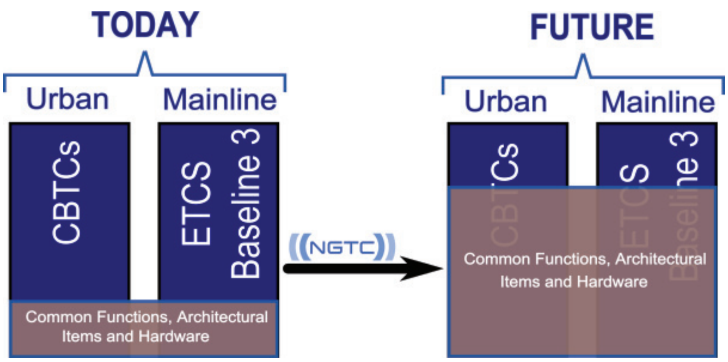

Fig. 1. Expected specifications convergence thanks to NGTC project.

Future mainline and urban applications of the NGTC system will implement the NGTC-core functions and sets of domain-specific functions (NGTC-Mainline and NGTC-Urban).

1.4. The scientific structure of the project

The NGTC project defined a number of work packages (see Figure 2), which are directly related. WP2 (ETCS/CBTC investigation of operational and functional consistencies & differences) investigated the operational and functional consistencies and differences between ERTMS and CBTC systems from the functional needs perspective. Once this was completed, WP3 (Technical Coherence) started developing a common system architecture, and as much as possible a common functional allocation for the two systems. In parallel, WP4 (Common Message Structure for Urban and Mainline) determines the necessary add-ons changes to the ERTMS message.

Other work packages are evolving more independently. These include WP5 (Moving Block Principles), the development of general moving block train separation principles applicable for all types of railways; WP6 (IP based radio communication), an investigation into the use of Internet Protocol based radios in future railways, and WP7 (Satellite Positioning) performing research into the use of satellite positioning. All of these work packages provide their results to WP3.

It should also be noted, given the diverging partnership of urban and mainline stakeholders and with the aim of a maximum convergence regarding the recommendations produced by the project, the partners have decided to set up an entire Work Package 8 dedicated to finding a common, broad agreement on the technical solutions developed under the project.

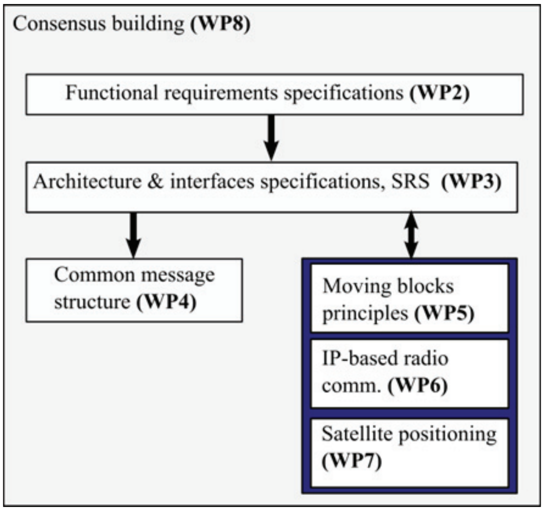

Fig. 2. NGTC technical work-packages and their relations.

2. ETCS/CBTC investigation of operational and functional consistencies & differences

NGTC Work Package 2 had an objective to investigate operational and functional consistencies & differences in order to prepare the basis for Next Generation Train Control system design developed in the scope of WP3. The actual organisation of the work was divided into three major steps:

- Collections and comparison of the existing “AS IS” functional requirements of the two major railway domains – main line and urban;
- Identification and comparison of the expected “TO BE” functional requirements for the future train control systems; and

- Development of a Functional Requirement Specifications document combining 'Common' main line and urban functional requirements into a core NGTC FRS, as well as specifying those functional requirements specific only for each railway domain.

2.1. Mainline Functional Requirements

The essential requirements for the mainline are specified in the Control Command System Technical Specifications for Interoperability [European Union (2012/88/EU)] and its amendment [European Union (2012/696/EU)]. The Annex A in the CCS TSI details the legal ERTMS specifications:

- Baseline 2 (based on Subset-026, (SRS) v2.3.0d) – The first standardisation of ERTMS, which is still legal and can be implemented on European Railways.
- Baseline 3 (based on Subset-026, (SRS) v3.4.0) - Developed to clarify some requirements in Baseline 2 and to introduce some new functionality to ETCS.

For the purposes of the "AS IS" comparison, ERTMS Baseline 3 has been considered. However, as there is no ETCS FRS in the Baseline 3, a list of functional requirements was extracted from the specifications. There were 288 ETCS functional requirements identified.

In addition to the functional requirements which were extracted from the ERTMS Baseline 3 specifications as part of the "AS IS" analysis, the future functionality that the mainline railways want to include as part of NGTC are related to the introduction of Automatic Train Operation up to GOA4. The input for the mainline railways is the functional requirements taken from the ATO Operational Concept [TEN-T (ATO project)] that were developed as part of a TEN-T project to include ATO into the ERTMS specifications. There were 186 ATO functional requirements identified.

2.2. Urban Functional Requirements

During the "AS IS" analysis the scope of the Urban domain functional requirements were taken from the following documents:

- IEC 62290-1 and 2, Railway Applications – UGTMS [IEC 62290-1], [IEC 62290-2]
- MODURBAN D80, Comprehensive operational, functional and performance requirements [MODURBAN D80]

In addition to this as part of the "TO BE" analysis the scope of the urban functional requirements was increased by introducing some requirements from IEEE that were not covered by the specifications used in the "AS IS" analysis:

- IEEE 1474-1, CBTC Performance and Functional Requirements [IEEE 1474.1]

In addition to the IEEE requirements some requirements were identified from the CBTC market survey of the UITP members. After discussion with the NGTC Urban Network of End Users it was agreed to include one additional function related to restricting the use of flip chairs during peak hours.

2.3. Comparison analyses

The mainline/urban functional requirements were analysed to determine whether the function exists in both sets of specifications and whether the purpose of the functional requirement is the same. For this analysis there were 5 statuses defined for the comparison, as described in the Table 1:

Table 1. Functional Requirement Status Definition.

	Requirement Status	Definition
Comparable Requirements	Common	The purpose of the functional requirement is the same, only the wording is different.
	Similar	The purpose of the functional requirement is comparable, more than an editorial change is required to make them common.
	Different	The purpose of the functional requirement varies in approach to an operational need for mainline and urban railways
Specific to the Domain	Urban only	The functional requirement exists only in the Urban specification
	Mainline only	The functional requirement exists only in the Mainline specification

It should be noted that if a requirement is identified as 'Urban only' or 'Mainline only' then it does not mean that the function does not exist as part of the train control or railway system, just that it is not specified in the reference documents listed in previous sections. The main limiting factors can be listed as follows:

- The current ERTMS Baseline 3 specifies only the ATP (ETCS), including the radio system (GSM-R). ATO functionality may be included in the next versions of the ERTMS specifications as an optional functional enhancement. It is also introduced for the mainline domain in the NGTC system as an optional functional enhancement, resulting in an increased common core of functional requirements in the NGTC train control system.
- As well as ATO and ATP the urban specifications describe functional requirements for the OCC, including the ATS functional requirements. For the NGTC FRS the areas for convergence have been the ATO and ATP systems, whereas OCC/ATS functional requirements are specified for the urban domain only.
- Interlocking requirements are also specified in the urban specifications but are not specified as part of the train control system for mainline, therefore any interlocking requirements are urban domain only. It should be noted that there are many requirements that refer to information being sent to or from the trackside. This is open as to whether the information is sent directly to the NGTC Trackside or to the OCC.

The results of the "AS IS" analysis, as demonstrated in the following Table 2, were the initial starting point for the second comparison, the "TO BE" analysis.

Table 2. NGTC Functional Requirements: "AS IS" analysis.

Status	Total
Common	5
Similar	73
Different	62
Urban Only	356
Mainline Only	283
Total	779

The first step of the "TO BE" comparison used further inputs as documented in section 2.1 for the mainline domain and section 2.2 for the urban domain.

The second stage of the "TO BE" analysis required all the additional requirements from the mainline and urban domain to be added to the analysis and compared to the existing requirements. This led to an increase in those requirements where commonality could be identified, particularly the inclusion of the ATO requirements for the mainline domain as this functionality is already well established in urban train control systems.

The third stage was to analyse all those functional requirements that were analysed 'Similar' and 'Different' to try and make them 'Common' by adapting the wording of the requirement and coming to a common proposal for an NGTC functional requirement. In order to reword the requirements to make them 'Common' agreed NGTC terminology and definitions were required. These were included in an NGTC Glossary and the final results are summarised in the Table 3:

Table 3. NGTC Functional Requirements: "TO BE" analysis

Status	Total
Common	275
Urban Only	257
Mainline Only	293
Total	825

Note: Those functions that were 'Similar' or 'Different' in Table 2 and could not be made "Common" were highlighted as 'Remain Urban & Mainline only' in the final Functional comparison sheet. These mainline and urban functional requirements have been checked to see if they were covered by a 'Common' requirement or had to be considered as 'Mainline Only' or 'Urban Only'.

2.4. NGTC FRS specifications and convergence in Mainline and Urban functionality

The number of 'Common' requirements from the "AS IS" analysis was only 5 out of 779 and the number of comparable requirements 140. After the "TO BE" analysis the number of 'Common' requirements has increased to 275 out of 825.

The number of 'Common' requirements has increased significantly after the introduction of new requirements mainly due to the introduction of the ATO for the mainline.

For those that have been identified as 'Common' an NGTC requirement has been proposed that is part of the NGTC-core in the NGTC Functional Requirement Specification [NGTC D2.5]. Those requirements that are specific to each domain are part of the NGTC-Mainline and the NGTC-Urban in the NGTC FRS. Any future mainline and urban application would need as a minimum the following functions:

- Mainline application **–** NGTC-Core and NGTC-Mainline;
- Urban application **–** NGTC-Core and NGTC-Urban.

3. Technology evolutions in the scope of NGTC

To achieve a high performance, cost effective and reliable public rail transport networks in and around major cities, interconnecting /interoperating urban rail sub-urban and mainline solutions shall play a key role in the future. NGTC project, in addition to work on system convergence, has identified other common working areas like Internet Protocol (IP) based communications, implementation of moving blocks and satellite positioning as being able to significantly improve the operational efficiency of the overall rail transport network and reduce its life cycle costs.

3.1. Generic definition of Moving Block concepts and principles

The aim of this project activity is to define common Moving Block concepts and principles in a generic way, applicable to different railway types and to investigate possible enhancements it can provide to some functions of a train control system. These enhanced functions are mainly the Train Separation function, and some functions related to interlocking.

The work is based primarily on the practical experience within urban railways, but is taking into account the specifications contained within the ETCS Baseline 3 for ETCS Level 3 systems. Basic assumption applied is that there is no trackside train detection available for the moving blocks.

By migrating to a moving block system, the system operator gains the following:

- Capability to run trains much closer together resulting in shorter headways;
- Adaptive distance between trains according to actual train speed, which makes efficient use of the infrastructure;
- Reduced wayside equipment, resulting in reduced maintenance & life cycle costs;
- Reduced wayside equipment, resulting in improved reliability;
- Bi-directional operation at much reduced cost;

Developed principles in the scope of NGTC are then validated by conceptual experiments containing different types of railways.

3.2. IP based radio communication for the future train control systems

For mainlines, the technology providers guarantee to support currently used, interoperable radio communication system (GSM-R) until 2028. As a consequence, ETCS system authority (ERA - European Railways Agency) has launched a program of activities for the definition of future communications systems for railways and UIC (International Union of Railways) has launched a new group of expertise on the Future Radio Mobile Communication System (FRMCS).

NGTC is contributing to current ongoing research activities with the provision of NGTC Requirements Specifications for future IP – based communication systems, developed jointly by mainline and urban railways. The major objective is to describe both mainline and urban functional requirements and system performance requirements in a way which highlight the convergence and the differences of the required radio communication system for both railway systems (ETCS and CBTC).

The second objective is to evaluate a possible common solution for underlying radio communication technologies, by performing the following actions:

- Defining a list of candidate technologies, taking into account the conditions for their use in the railway context (e.g. licensing and the share of wayside infrastructures);
- For each identified candidate assessing the application throughput, QoS capabilities and radio coverage quality that can be achieved in a railway environment. As a result of the relevant research, the experts have defined a set of recommendations for external stakeholders;
- Studying the relevant aspects to be applied for the future communicating systems, specifically IT-security, relevant IP rules and the definition of external interfaces of the IP-based communication system, suitable for CBTC and ETCS.

3.3. Satellite-based train positioning

With regards to GNSS (Global Navigation Satellite Systems) technology, there have been several European projects like Locoprol-Lococoloc, GRAIL-2, Satloc and 3InSat just to name a few to foster the introduction of this technology in the railway domain. NGTC started from the basis of these projects to achieve a smooth integration of satellite navigation technology in ETCS, compatible with current specifications.

Based on the results of the UNISIG Satellite Positioning Workgroup that has specified the virtual balise functionality to the current ETCS architecture, the following activities are being performed in the scope of the WP7:

- Collection of information about current status of GNSS performances in railway environment and analysis of the impacts on ETCS virtual balise functionality and on functional architectures;

- Definition and quantification of GNSS parameters relevant for the signalling application in railway environment, including the definition of a standard process for the measurement of the coverage and the accuracy delivered by GNSS;
- Definition of engineering rules for virtual balise positioning and operational management of the positioning related database;;
- Analysis of other applications of satellite positioning functionality, like train integrity or cold movement;
- Safety concept and safety analysis, in collaboration with RAMS experts.

Currently, WP7 is undertaking its work with the close cooperation with GSA (European GNSS Agency), ESA (European Space Agency), ESSP (EGNOS Service Provider) and JRC (Joint Research Center at EU) experts. The involved experts are thus covering all the satellite fields which are impacting the areas taken into consideration by NGTC team (Receiver, Safety, Testing and Service provisioning).

4. Conclusions

It has been demonstrated by the NGTC project, that the introduction of ATO to the ETCS system greatly increases the functional convergence with the urban train control systems. The majority of the ATO and ATP functions can be found in both the mainline and urban train control systems; although the level of the current specifications can be different within each function. There are number of functions that are still specific to each domain, but with further analysis and work, it can be expected that greater functional convergence could be achieved. The convergence of the NGTC system and the mainline and urban domain could also be increased by specifying additional functionalities for mainline domain, such as ATS, including the Traffic Management functionality. The complexity of mainline operational rules means that all ETCS operational modes may not be applicable in the Urban domain. This results in quite a lot of ‘Mainline Only’ functions specific to Mainline operating modes. Performance requirements for the mainline and urban domain are not currently comparable due to the different operational requirements of the applications in each domain. Harmonised performance requirements for different mainline applications (e.g. high-speed, conventional, regional, freight etc.) do not exist in the scope of ETCS, because they are mostly not relevant for interoperability.

Overall, the NGTC project is working on a number of areas shaping the future of the next generation of train control systems, with the clear focus on the convergence between ETCS and CBTC systems. For the full benefit of the signalling expert community, most of the project documentation will be freely downloadable from the NGTC website. Strong project links to other initiatives and organisations, including UNISIG and Shift2Rail, confirm the relevancy and competence of the project towards the future developments. During the upcoming period, the project partners are committed to work closely on system specifications, integrating the required functionalities for the future CBTC and ETCS systems, fully benefiting from the identified areas of system convergence as part of the already produced NGTC FRS.

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