1 Towards integrated digital automatic train operation - the perspective by SmartRaCon

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1.1 Smart Rail Control Systems - SmartRaCon

Innovative automation and digitalization technologies enable new approaches for train control, command and signaling systems and lead to completely new concepts. The partners RAILENIUM, GMV-UK, CEIT and DLR founded the consortium Smart Rail Control (SmartRaCon) to develop new concepts, approaches and technologies for the train control, command and signaling systems of the future in the frame of the European Programme Shift2Rail. In this contribution, the developments in the areas of Adaptable Communication, Moving Block, Train Positioning, Environment Perception, Digital Maps, Formal Modelling and Laboratory Testing are covered.

Figure 1-1: SmartRaCon Logo

SmartRaCon consortium has been actively involed in a number of Shift2Rail research project since 2016, where the X2Rail series projects can be highlighted. In this context, in the frame of the two projects TAURO [1] and X2Rail-5 [2], SmartRaCon aimed to work on design and development of technology for automation especially in the following fields:

- Adaptable Communication Systems (ACS)
    - Laboratory testing environments
    - On field (Regional demonstrator) characterization tool

    - Satellite Communication
- Fail-Safe Train Positioning (FSTP)
    - Key Performance Indicators and Analysis Tools
    - Ground truth and validation tools
    - Railway infrastructure network representations
- Moving Block (MB)
    - Description of use cases and specification
- Zero on-site Testing (ZOST)
    - Adaptable Architecture of the Lab test bench including Safety requirements
- Digital Maps
    - Data models
- Environment Perception
    - AI-based strategies
- Remote Driving and Control
    - Video and sensors streaming
- Formal Modelling
    - Guidelines for the Railway Signalling Domain
- Cyber Security
    - Cybersecurity Risk Assessment methodology

The overall concept is based on developing novel analyses and tools required for the development, validation and certification, with the idea to reuse COTS and integrating them into a railway network in a modular way. This allows, on the one hand a flexible scaling of the rail control system in a cost-efficient way, and on the other hand a building block approach for certification and modulewise change of technology.

1.2 The methodology

Smart Railway Control (SmartRaCon) aimed to be the core to enable high capacity and cost-efficient rail systems for the next century. The proposed approach of SmartRaCon is to control smartly intelligent, autonomous trains on a scalable and more flexible infrastructure. Main challenges for the rail system are the enhancement of capacity, the reduction of investment and operations cost. The reductions of energy consumption as well as the reduction of cost for test and certification are two aspects for the cost reduction. These are the conceptual objectives of SmartRaCon [3] and are coherent with the Master Plan topics of Shift2Rail [4]. The SmartRaCon idea for a credible, coherent and long-term approach to achieve the Master Plan Objectives is to meet those challenges by:

- intelligent trains, which communicate safely & securely, localize & supervise integrity autonomously and operate as virtual coupled train-sets;
- infrastructure which is flexible, easy & fast to configure, less fixed (e.g. wired) & scalable, communicating safely & securely with trains and operating them in moving block;
- traffic management system operating both with optimization algorithms;
- supported by cost-efficient process for design, test and certification which uses highly automated test labs to avoid on-site tests based on formal test specifications.

For the capacity increase, an integrated Moving Block (MB) and Automatic Train Operation (ATO) system has to be implemented. Further technologies are needed as enablers: Fail-Safe Train Positioning need to determine safely & securely in real-time to the trackside train control and Traffic Management System (TMS) together with the support of Digital Maps. Positioning and Adaptable Communications are ensured by combining different technologies. Envrionmental perception is needed, too, to ensure safe and highly automatic operation with remote operation as addition for fallback and specific situations. At the end, everything needs to be secure against cyber attacks which is realized among others by an ISAC. The approach is fully in line with the standardized European Rail Traffic Management System (ERTMS) and the European Train Control System (ETCS) and enhances interoperability. New functionalities & technological solutions require being formally specified and tested. Hence testing needs to be automated & moved from on-site to lab. This achieves the objectives of reliability, improved standardization, lower costs & simplified processes. This prioritization is justified since traffic management, positioning and communication are enabling technologies that need to be tested and certified. The complementary work in areas as e.g. moving block and decentralized interlocking technologies extends the concept to reach a significant and sustainable effect on capacity & cost.

1.3 Technological research areas

The overall SmartRaCon concept is based on technology-independent adaptable train-to-ground, gound-to-train communications resilient to radio technology evolution, ensuring safety levels for GNSS-based on-board positioning and train integrity supervision. Some of the most relevant areas of SmartRaCon technological research are shown in Fig. 1-2 and the conceptual groups part of the 5th SmartRaCon Scientific Seminar (SRC5SS) "Automatic Train Operation (ATO)", "Adaptable Communication", "Moving Block", "Fail-Safe Train Positioning", "Digital Maps" and "Cyber Security" as well as procedural innovations like "Formal Modelling (FM)" and "Zero On-Site Testing (ZOST)" coming from the projectcs TAURO [1] and X2Rail-5 [2] and are discussed below.

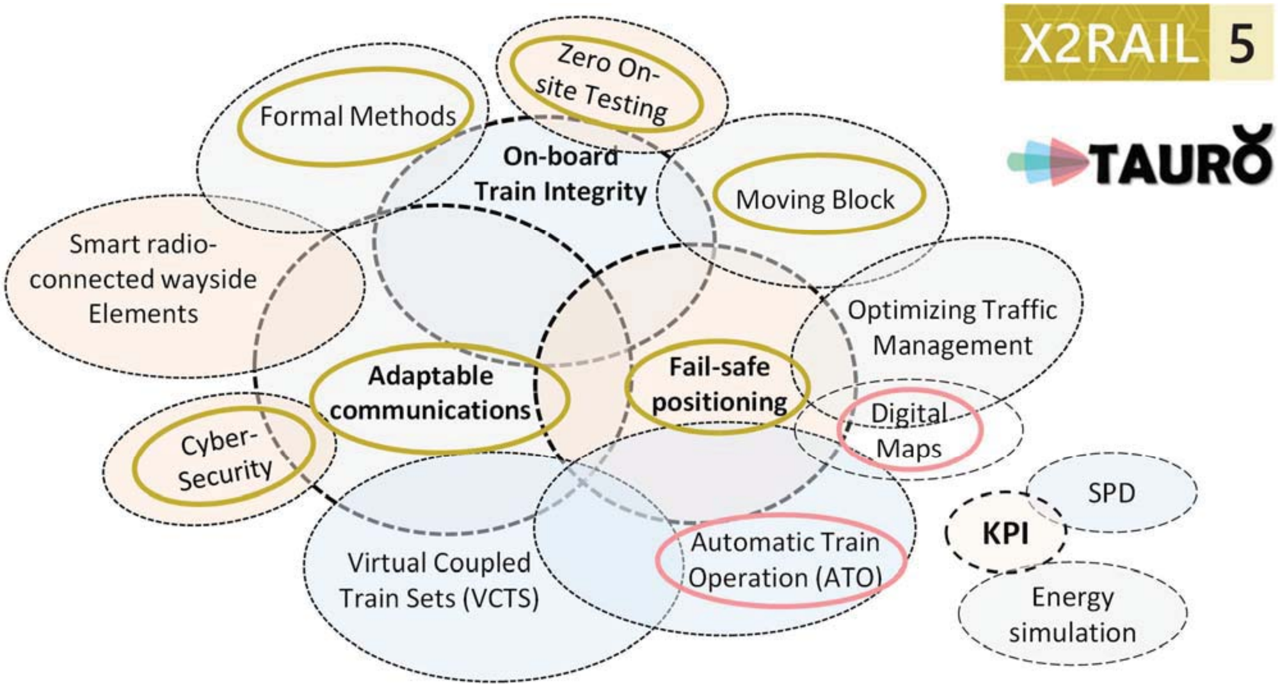

Figure 1-2: Core Areas of Research in SmartRaCon and related projects for the SRC5SS

In the following sections details of each of the conceptual groups and procedural innovations refered are shown.

1.3.1 Conceptual group "Adaptable Communications"

The contribution from communication is based on the idea to reuse COTS and to integrate them into a railway network. For that, SmartRaCon will design and develop a technology-independent system for an adaptable train-to-ground communications system resilient to radio technology evolution considering threats such as interferences or cyber-attacks. Some of the concepts to be explored are a) the anticipation of the 5G standardization; b) Software Defined Networks (SDN) and Network Function Virtualization (NFV); c) radio system KPI evaluation; d) hardware development using Software Defined Radio (SDR) platforms, e) IP-based communication gateway with bandwidth aggregation, dynamic spectrum allocation and mobility support; f) traffic pattern recognition tool to ensure minimum conditions; g) innovative use of satellite communications technologies.

The impact for future communication infrastructure relying on standardized technologies and COTS products is high for the European railway, telecom and space industry as well. The use of satellite communications is especially relevant for railway lines, where the availability of a reliable communication infrastructure is critical. By using cognitive radio systems maximum use of surrounding infrastructures will be achieved. Through the use of cognitive radio, 5G, satellite and adaptable, resilient architecture CAPEX will be reduced and moreover IP communication technology supporting a fast radio technology evolution will reduce OPEX.

Current radio technology, i.e. GSM-R, will become obsolete by 2030 and therefore 4G is being analyzed. 5G is already planned to be commercialized by 2020, which will limit the life-cycle of a 4G-only solution. The main advance relies in the ability to successfully integrate a number of heterogeneous technologies and communication protocols into one network in order to take advantage of various deployments (3G, 4G, 5G, Satellites) provided by external network operators (Network as a service) and/or dedicated infrastructures (Network as an asset). Thus, CAPEX and OPEX of communication systems can be minimized. Smooth migration will be enabled by designing middleware platforms for transparent switching radio components.

Impacts on the infrastructure, line capacity and definition of certification processes will be made thanks to the future communications and on-board positioning.

Among SmartRaCon activities there are wireless communication antenna integration, SDN-based slicing and network resource distribution and channel charactersation tool communication system testing.

1.3.2 Conceptual Group “Fail-Safe Positioning”

The overall concept for localization is based on the need to ensure that the safety levels provided by existing signaling systems are not compromised when a train-borne positioning system is employed. SmartRaCon has set up and undertaken test campaigns, analyzed the data from such campaigns, improve specifications, provided inputs to the development of a safety case, as well as making other more specific contributions building on the positioning technology expertise within the consortium such as simulation based KPI evaluation, multi-constellation, sensor integration, etc.

In terms of impacts of localization, future business will be generated. A core of safety expertise concerning the use of train-borne positioning technology for railway applications will be established. A Route Clearance service will be used to safely introduce the technology to specific new lines and applications. SmartRaCon will bring an important support to the involved supply chain by developing and certifying dedicated hardware, algorithms and the infrastructure required to deliver the services. The impact will be the contribution to the optimization of global railway operation by providing very efficiently all the needed information to facilitate decision-making process at different stakeholder levels (engineering, exploitation, maintenance, customer services, etc.). Such systems will achieve decentralized control of remote track-side objects without cable connections.

Testing processes and the route to acceptance of GNSS and associated technology will be enhanced such that standardized methods are set in terms of the equipment used, measurements made, analysis tools and results delivery (Route Clearance service, simulation tools for railway KPIs evaluation, Digital Route Maps (DRM)). A consolidated set of specifications and a methodology for testing COTS equipment capabilities will be defined. The need for lab simulations will be identified and a 3D Local Environment Model will be developed. Performance optimization will be proposed through hybridization of GNSS with inertial sensors, odometry, dead reckoning, DRM and Wireless Communications Technologies. Further specific proposed tasks are related to the Safety assessment.

1.3.3 Conceptual Group “Digital Maps”

Automatic and digital operation of railways is unavoidably based on very precise and highly safe localization of trains with respect to the railway infrastructure. This raises the need of highly accurate but formal description of the railway network in the form of a digital map. Architectures, concepts and data models of those highly formal and safe digital maps on of the focus topics, too.

1.3.4 Further Conceptual Groups

The three above mentioned conceptual groups are related to many others in the context of future systems. Some examples are given below and visualization is given in Fig. 1-2:

- Moving block operation requires safe localization and train integrity as well as reliable as well as adaptable communication.

Automatic Train Operation (ATO) requires environment perception to ensure that trains can run in higher grades of automation. Especially in unattended operation in grade of automation 4 the preception is needed to enable the train to operate. Finally, the dramatic development in the field of Artificial Intelligence (AI) will have major impacts on the railway’s ecosystem, too. There are already a lot of applications from scheduling up to condition monitoring as well as many different optimisations. Nevetheless, a massive multiplication of those applications can be expected in the near future.

1.3.5 Procedural innovations

Procedural innovations listed in section 1.2 are described as follows:

- Zero On-Site Testing (ZOST) aims to improve standardization and integration of laboratory testing methodologies reducing time to market and improving effectiveness in the introduction of new signalling and supervision systems. Due to the complexity of signalling systems and the differences between specific deployments, a large number of tests are required to be carried out on-site. It is considered that on-site tests take about 5 to 10 times the effort compared to similar tests done in the laboratory. Reduction of on-site tests for signalling and telecom systems is hence the way forward to reduce testing costs. Moreover, and adding more complexity to the process, procedures of verification & validation testing might differ in differnet countries around Europe. Overcoming these differences by standardizing the procedures and test scopes will improve the interoperability and reduce the time to market.

  Activities related to Zero On-site testing include new functionalities to complete the general test architecture, generic communication model between the different components of the test environment(s) defined, standardized interfaces between the products from the test environments of different suppliers and operators and between the test environments and the subsystems under test, simulators to support automated testing in the laboratory. Among SmartRaCon activities there are tools for safety testing of ETCS radio communication link at laboratory and test architecture to integrate operational data related to the driver's actions.

- Formal modelling helps to describe use cases as well as specifications in a coherent and consistent way. Hence, they are the core of a formal description of the railway assets, functionalities, dynamic behavior and condition state. By bringing this approach to a consequent level, a digital twin environment will be realized and used as a complete digital representation of the entire system from high-level socio-economic aspects down to detailed technical as well as functional descriptions.

1.4 Outlook for the Europe’s Rail JU in Horizon Europe

The research work for future mobility management multimodal environments, digital automated up to autonomous train operation and digital enabler in the frame of the Eruope’s Rail Joint Undertaking is taking over results from many projects from Shift2Rail, especially from TAURO and X2Rail-project series [1, 2, 5, 6, 7, 8]. The results of all the work are paving the way for demonstrations in higher technology readiness levels. This Rail European Partnership will focus on accelerating, with an integrated system approach, research, development and demonstrations of innovative technologies and operational solutions (enabled by digitalization and automation) for future deployment to deliver on European Union policies towards “European Green Deal“ objectives “a Europe fit for the digital age”, “an economy that works for people” and “a stronger Europe in the world”[9].

Europe’s Rail will implement an ambitious research and innovation programme, designed in line with the Sustainable and Smart Mobility Strategy, and delivered by the System and Innovation Pillars, bringing the most advanced technological and operational solutions to rail. Steered by an integrated system approach, implemented with a multi-annual programme enabled by the JU’s Members, the new Programme will start delivering major flagship solutions as from 2025-26 to be demonstrated at large scale in the following years, and to bridge the future activities in the post-2028 era [13]. Among the innovation topics that would be covered there are the evolution of operational and business aspects such as:

- Configuration of the new European reference operations framework and architecture for Control, Command and Signalling (CMS).
- Future evolution of the ERTMS system.
- Advances in telecommunications (5G developments with specific railway service and business use cases).
- Traffic management platforms.
- Automation of logistics chain, terminals and freight operations.
- Intelligent rail asset management and maintenance.
- BIM development for use in digital rail twins.

1.5 Conclusions

The SmartRaCon Partners are performing research work on innovative technologies for Digitalization and Automation to prepare the ground for new generations of train control and railway management systems. Some of the core elements are technologies covered in the 5th SmatRaCon Workshop 2023 topics, namely Adaptable Communication Systems, Fail-Safe Train Positioning, Digital Maps, Automatic Train Operation, Moving Block, and others linked to the both projects TAURO and X2Rail-5. In parallel to the technological research, SmartRaCon Partners are developing and operating simulators and research infrastructures as well as carrying out analyses for the validation of the technologies.

To disseminate the results of the scientific work, SmartRaCon organizes the yearly Scientific Seminars to present and discuss their results on a high scientific level. The first SmartRaCon Scientific Seminar took place on the 25th of June 2019 in Villeneuve d'Ascq in France [10] in presence. Due to the pandemic situation in Europe, the second seminar was held the 24th of November 2020 in a digital online format from San Sebastian in Spain [11]. The third seminar, in the #EUYearOfRail, on the 2nd of September 2021 from Braunschweig in Germany again online [12]. The fourth SmartRaCon Scientific Seminar took place the 20th October 2022 in Donostia/San Sebastian, Gipuzkoa, Spain [13]. Finally, to close the SmartRaCon Scientific Seminars in the frame of the Shift2Rail programme, the fifth SmartRaCon Scientific Seminar will be hosted by GMV and DLR together and takes place in May 2023 in the DLR facilities in Berlin-Adlershof, Germany.

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1.7 Acknowledgements

The project X2Rail-5 has received funding from the Shift2Rail Joint Undertaking (JU) under grant agreement No. 101014520. The project TAURO has received funding from the Shift2Rail Joint Undertaking (JU) under grant agreement No. 101014984. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Shift2Rail JU members other than the Union.

Disclaimer: This dissemination of results reflects only the authors' view and the Shift2Rail Joint Undertaking is not responsible for any use that may be made of the information it contains.

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Horizon 2020
European Union Funding
for Research & Innovation