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CONTRIBUTING TO SHIFT2RAIL'S NEXT GENERATION OF HIGH CAPABLE AND SAFE TCMS AND BRAKES.

D8.3 – Final Report on the Contribution of CONNECTA to Shift2Rail

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EXECUTIVE SUMMARY

During the last 25 months CONNECTA has been working in the activities planned within the Multi Annual Action Plan of Shift2Rail, of which the project covered the first phases (low TRL).

In general terms the project has fulfilled the expectations and provided the required building blocks to start the implementation of technologies in the next project (i.e. CONNECTA-2). Such technologies are namely:

- Wireless Train Backbone
- Standardized train-to-ground communication
- Drive-by-data ethernet networking
- Functional open coupling
- Functional distribution framework
- Application profiles
- Safe electronics for brakes
- Virtual certification platform
- Conformance test for TCN

In addition, the project has put much effort in communicating and disseminating the results.

ABBREVIATIONS AND ACRONYMS

CTA: CONNECTA

DbD: Drive-by-data

FDF: Functional Distribution Framework

LCC: Life Cycle Costs

NG-TCN: Next Generation TCN (Train Communication Network)

OMTS: Onboard Multimedia and Telematic Services

T2G: Train-to-Ground

TDB: To be discussed

TCMS: Train Control and Monitoring System

TMT: Technical management Team

S2R: Shift2Rail

SC: Steering Committee

SIL: Safety Integrity Level

WLTB: Wireless Train Backbone

WP: Work Package

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1. INTRODUCTION

1.1 CONNECTA

CONNECTA aimed at contributing to the S2R's next generation of TCMS architectures and components with wireless capabilities as well as to the next generation of electronic braking systems.

CONNECTA has conducted research into new technological concepts, standard specifications and architectures for train control and monitoring, with specific applications in train-to-ground communications and high safety electronic control of brakes.

The specific actions undertaken within the scope of CONNECTA contributing to the S2R Multi-Annual Action Plan on TD1.2 and TD1.5 are:

- To develop the general specifications of next generation TCMS and to generate the corresponding high level system architecture;
- To incorporate wireless technologies to train communication network solutions;
- To provide a train-wide communication network for full TCMS support including the replacement of train lines, connecting safety functions up to SIL4 to provide an optimal train network for TCMS & OMTS (Onboard Multimedia and Telematic Services) as well as communication mean for non-TCMS functions (e.g. signalling);
- To standardise functional interfaces of functions and sub systems as well as to define a generic functional architecture for the next TCMS generation;
- To facilitate the coupling of two or more consists supplied by different manufacturers and which could have different train functions;
- To develop a simulation framework in which all subsystems of the train can be simulated, allowing remote and distributed testing including hardware in-the-loop through heterogeneous communication networks;
- To achieve a performance improvement in safety relevant braking functions resulting in optimisation of the braking distances in safety braking;
- To optimise onboard systems by reducing the number of sophisticated pneumatic components and improving the overall LCC, and;
- To validate non-railway standards (e.g. aviation) for use in safety-related railway applications.

These actions were implemented through the following project structure:

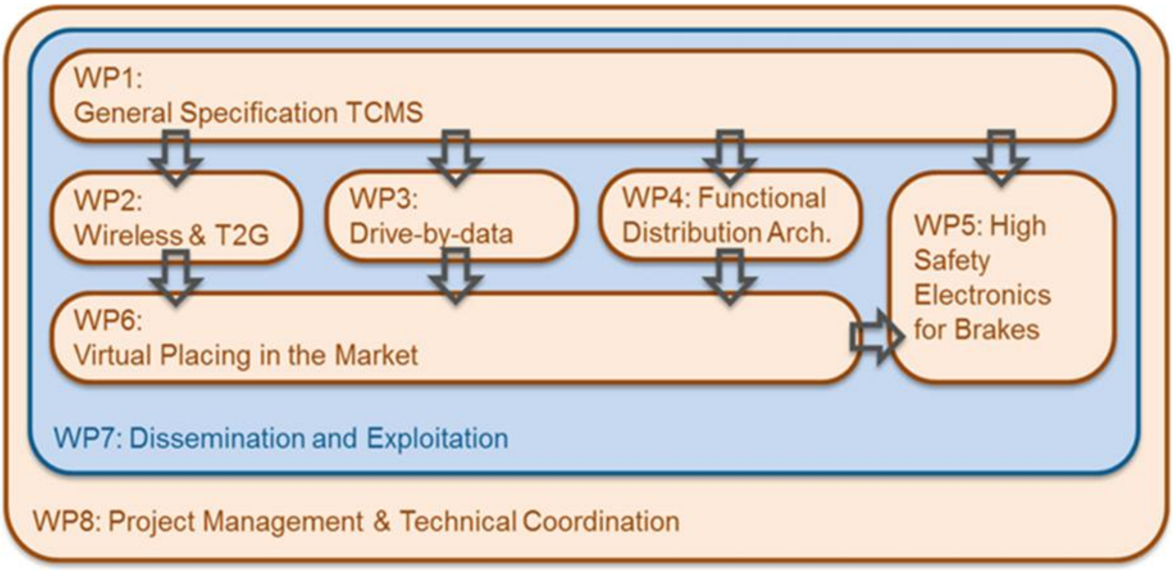

Figure 1: Project structure

Where:

- **WP1**: This WP worked out a general specification of the next generation TCMS and generated a high level system architecture that was able to provide specific requirements as input to the different tasks of the other WPs.
- **WP2**: Partners developed technical solutions consisting of hardware and software, which included wireless routers, transmitters and receivers, and adaptation of software communication layers for the complete T2G functionality. This WP continued the validation of the technologies and architectures for the wireless TCMS starting from the outcomes of Roll2Rail and taking the laboratory testing infrastructure to a real environment at first for the consist to consist application.
- **WP3**: Providing one train-wide communication network for full TCMS support, including the replacement of train lines and integration of other subsystems like signalling. It supported the secure separation of data traffic belonging to different safety integrity classes in a manner to be acceptable by regulatory authorities.
- **WP4**: The objective of functional distribution architecture was to standardise functional interfaces of functions and sub systems as well as to define a generic functional distributed architecture for the next TCMS generation. The objective of function standardisation and open coupling is to make possible the coupling of two or more consists supplied by any manufacturer and which could have different train functions.
- **WP5**: This work package aimed to develop an electronic HW-SW architecture designed to manage all the braking functions (service, holding, emergency, safety brake, wheel slide protection) according to proper high safety levels (SIL3, SIL4).
- **WP6**: The main goal of the WP6 was to develop a simulation framework in which all subsystems of the train can be simulated, allowing remote and distributed testing including hardware in-the-loop through heterogeneous communication networks.
- **WP7**: This WP targeted to ensure proper dissemination and promotion of the project results, in a way which is consistent with the wider dissemination and promotion activities of Shift2Rail. It ensured that the outputs of the project were delivered in a form which made

them immediately available for use by the complementary action SAFE4RAIL and other activities within the initiative.

- **WP8**: The objectives of this work package were to ensure efficient coordination of the project together with the TMT and the SC and to coordinate the technical work of the various WPs in order to keep the alignment with the overall objectives of the project and with Shift2Rail activities.

1.2 Objectives of the Deliverable

Deliverable D8.3 aims to summarise the contributions of CONNECTA to the Shift2Rail work programme, namely the Multi Annual Action Plan. The project, which belongs to the Innovation Programme 1, tackles activities corresponding to the work streams TD1.2 – TCMS and TD1.5 – Brakes.

A second goal of the deliverable is to report the performed communication and dissemination activities.

1.3 Structure of the Deliverable

In the following chapters a brief description of the main contributions to the Shift2Rail Work Programme will be done per work package.

2. HIGHLIGHTS OF WP1 – GENERAL SPECIFICATION TCMS

2.1 Work Methodology

In first step a common method of how to do requirement management in large international teams had to be found. A method originally developed for software development has been adapted to system engineering, which especially develops the system of the next generation TCMS.

Without the support of an IT tool, it is impossible to run a decent requirement management process. Due to the huge variety of different tools the partners are using, we came to the conclusion that it is hardly possible that every contributor will be using the same tool. Regarding this situation, the use of the ReqIF interchange format seems to be a reasonable solution to collaborate. It covers most of the requirements the WP partners have and it is a reasonable compromise to work with.

However, the best choice would be a real time collaboration platform that is accessible to all partners, so an agreement was reached to get

Deliverable D1.1 defined a guideline and basis to have a common understanding about the procedure and the workflow within CONNECTA.

2.2 User Stories and Use Cases

CONNECTA has described the procedure and the method of collecting the user stories and the use cases as high level requirements for the next generation TCMS of CONNECTA. The collection has been performed as explained in deliverable D1.1, by using excel-based templates. The final collections are attached to deliverable D1.2.

Initially it was planned to start with the use cases straight away. In the process of defining the method, it was decided to additionally apply the method of user stories for an over and above layer of abstraction. The reason is that it will be easier to find an agreement and common strategies, which apply to all countries of the European railway area, whenever the requirements management process is started at a very high level of abstraction.

The requirements set in this deliverable are the basis for a more detailed technical specification for the different subsystems of the TCMS. They will be provided to the other CONNECTA partners as agreed in D1.1. During the process of system development, in accordance to the procedure of the V model approach, there will be the need to make some iteration loops to improve and adapt the requirements. This will happen also in CONNECTA-2 and CONNECTA-3.

Constant communication and exchange of information regarding the other tasks and WPs was required, in order to ensure a similar understanding of the big picture.

2.3 From Device to Function

One of the major points in CONNECTA is the architectural principle, which has to be respected for the creation of the function based architecture as well as for the design of the technical architecture. Beside use cases, functional and non-functional requirements, the architectural principles express some of the basic technical demands requirements that the rail vehicle operators have.

Going from a device-centric approach to a function-centric approach will have a major impact on how the future TCMS (and the train) will look like.

Setting up the domain model will be of support to have an open, flexible and scalable NG TCMS that will be adaptable to future requirements. The short innovation cycles in the IT and smartphone world are pressuring the rail vehicle operators to move to easily adaptable passenger information solutions.

All in all it can be said, that the insights made during the creation phase of deliverable D1.3 are a very valuable basis for the further development in other tasks and work packages of the NG TCMS system.

2.4 RAMS, Standards and Norms

A collection of requirements on a very high level – according to the scope of Work Package 1 are collected in the field of RAMS (reliability, availability, maintainability and safety).

Different attacker types and attacking scenarios for the NG TCMS system were created that can possibly happen out of the operators view. They are a basis to create further IT-security mechanisms to prevent any penetration attempts.

Legal requirements, that apply for the NG TCMS were outlined and explained, as well as the important norms that are usually used in requirement specification as part of tender documents.

All the collected requirements were an important basis to make sure the NG TCMS will receive positive assessment. All this requirement, will make the development of the NG TCMS even more challenging, but will ensure a safe and reliable system, that features low lifecycle cost and supports traveling without limitations for all kind of passengers.

2.5 The Requirements

Deliverable D1.5 (public) achieved the goal to address the key questions of the high level requirements (HLR) for a NG TCMS and of CONNECTA's KPIs. These questions are linked and notably significant for the Shift2Rail MAAP goals.

Once these HLRs have been collected and listed in the section 6 of this deliverable, they will be integrated in the common Magic Draw model shared among the partners of CONNECTA. Thus they will become a part of the common knowledge of the future NG TCMS for CONNECTA's companies involved in WP1.

Indeed the HLRs of the NG TCMS contribute to the CONNECTA's KPIs as it can be seen in the deliverable D1.5, and CONNECTA's KPIs contribute to the global performance of Shift2Rail, as it is well known.

In this context CONNECTA 2, following CONNECTA, will be able to verify if the HLRs defined in this deliverable are completely reached and, by surveying the KPIs evolution, will define if the NG TCMS will be able to fulfil its promises.

3. HIGHLIGHTS OF WP2 – WIRELESS TCMS AND T2G

3.1 Getting Requirements from the IEC 61375-2-6

Working on the bases of the IEC 61375-2-6 standard has been very challenging because its lack of maturity during the project lifetime. Extracting requirements out of the standard has been very tough due to the lack of concreteness and detail of the content. Many requirements were open to interpretation and incomplete.

While producing the requirements, CONNECTA gathered comments to the standard and they were submitted to the IEC TC9 WG43 (in charge of the said standard). This feedback was much valuable to complete the IEC 61375-2-6 and to have, today, the standard published.

Among the contribution, a new chapter for the telemetry application was also included.

3.2 Implementing the Standard for the First Time

The implementation has meant a significant step towards a common agreed solution for an interoperable train to ground communication system and services. The open-minded cooperation of the members from different manufacturers in the frame of the project CONNECTA led to tangible results, which can be demonstrated with real hardware devices and not only with paper work.

The experience from the implementation also highlighted, that only real execution of tests will reveal the issues to be solved. In this implementation this was achieved by face to face meetings and remote networking over the Internet.

The implementation of the selected use cases is only a starting point, which should be continued with the implementation of further use cases (e.g. telemetry service) in CONNECTA-2. The method of accompanying verification of the TCN standard requirements has prominent predecessors like the Joint Development Project (JDP) for MVB/WTB and the TCNopen initiative for development of the Train Realtime Data Protocol (TRDP).

The continuation of implementation in successor projects of CONNECTA will provide a good base for an open collaboration of the manufacturers to achieve common agreed requirements for the train to ground communication system. This provides a significant complement to the more theoretical work of IEC standardization group.

The final goal is to prepare a feasible and applicable standard to achieve interoperability of trains from different manufacturers and the ground infrastructure of different operators.

3.3 Train-to-Ground Interoperability: Yes, we have it!

Using the insight gained during the architecture and design phase, the implementation phase (and, finally, the insight gained during the interoperability test sessions, a number of conclusions can be made. As a consequence we can say that:

- A new interoperable train-to-ground system is now available, whose related standard is published.
- However, thanks to CONNECTA, we identified several proposals for inclusion in the next revision of the standard IEC 61375-2-6, and proposals to be followed up upon during the CONNECTA-2 project.
- Now it is the turn of train operating companies to start requesting the new standard in their tenders. The European Agency for Railways (ERA) can obviously accelerate the process.

3.4 The Wireless Train Backbone will be a Reality Soon

CONNECTA carried out consist-to-consist wireless communication tests in real scenarios. The tests were carried out using wireless COTS equipment from Huawei. The used antennas were specifically designed for railway environment. The tests were divided into laboratory tests, tests in depot and field tests.

From the tests carried out a set of conclusions can be highlighted. All in all, the results show that in field tests the performance is lower than expected.

In order to overcome the limitation, in CONENCTA-2 together with its complementary action S2R-OC-IP1-02-2018, the following research activities will be conducted:

a) An evolution of the WLTB architecture will be explored to incorporate PC5-based communications already introduced in 3GPP release 14 for automotive. Prototypes compliant with this new architecture will be developed.

b) A study in new beamforming techniques will be made in order to overcome the propagation problems.

c) The network requirements will be re-evaluated in order to determine if TCMS and OMTS should work in different wireless networks, e.g. network with dedicated frequency band for TCMS and network with unlicensed band for OMTS.

In addition, for future COTS equipment provisioning the capability to tune the radio transmission power will be added and an installation analysis based on the roof outline will be made. This analysis will help to overcome the possible antennas' visibility problems, as well as to adjust correctly the transmission power.

4. HIGHLIGHTS OF WP3 – DRIVE-BY-DATA

4.1 Technologies: Do not Reinvent the Wheel!

The first objective WP3 was to identify suitable methods and technologies which shall improve the usability, reliability, safety and performance of today's Train Communication Network in order to support the goals of CONNECTA in the specification of a Next Generation TCMS, and therefore contribute to the more general Shift2Rail MAAP targets. This objective has been achieved by investigating technologies in use and technology trends in different industry domains, not by starting from scratch.

A set of promising technologies were identified and have been evaluated with respect to their feasibility in railway domain applications.

The technical evaluation of the selected technologies has been performed to an extend that allows to judge about their principal readiness for railway applications. But this evaluation also revealed open items like for instance the traffic shaping in a dynamic train network, which still requires adaptation to our railway needs.

4.2 Safety First!

Comprehensive RAM, Safety and Security analyses were carried out, where the main objectives for each of the analyses could be divided in 3 aspects:

- Fulfilment of the required levels.
- Obtaining the restrictions for the architecture specification if there are any.
- Analysis of the impact of the different ETB topologies in the results.

The RAM analysis was divided in the Reliability, Availability and Maintainability analyses, and one of the conclusions obtained has been that none of the architectures proposed for ETB can fulfil the reliability target defined in the requirements without applying further improvements. However, some mitigation mechanisms were proposed in order to enhance the reliability of the network. Applying those mechanisms and selecting reliable network components, the reliability targets are achievable for some of the proposed architectures. Nevertheless, in order to define robust network architectures, it is important that any single point failure mode of the network should be analysed and required mitigation mechanisms should be defined for them.

On the other hand, it was concluded that the different ETB topologies influence differently the reliability results.

The safety analysis was divided in two parts; the analysis of the Safety Layer and the Safe Train Inauguration. The analysis of the Safety was been focused on how to reach the tolerable hazard rate for safety related data (up to SIL4) assuming the Black Channel approach.

Several mechanisms to implement the Safety Layer were presented as well although the complete specification of the Safety Layer. On the other hand, it has to be mentioned that this analysis has not concluded anything about the ETB topology selection, as the black channel approach is based on the End-to-End communication and the network architecture of ETB does not influence in the transmission of the safety related data.

In the analysis of the Safe Inauguration, the weaknesses of the current procedure were identified and different findings were identified to improve them. The inauguration process at system level was defined with a safety integrity level of SIL4, but it has been proposed an apportioning of this level into the different inauguration subfunctions. Taking into account this SIL distribution, different architecture variants were proposed. .

A security analysis was also conducted. The security levels and the countermeasures required to reach them were defined after conducting the security assessment taking into account the zone and conduits partitioning of the system. From the point of view of the selection of the ETB topology, this analysis was not conclusive either.

In conclusion, all the analyses carried out for the drive-by-data in CONNECTA allow an appropriate definition of the network architecture of the NG-TCN.

4.3 CERTIFICATION

The safety approval concept was analysed and defined from different perspectives. First, a generic safety concept for a drive-by-data centric NG-TCMS was developed by defining the generic safety architecture for the executions of safety functions up to SIL4 and more specifically by proposing a safety design for the two communication network related safety functions “safe train inauguration” and “safe data transmission”. An important aspect was to avoid or at least to minimize interference between function of different safety criticality. Here some principles for a suitable safety architecture design were described and were more specifically applied later on to NG-TCMS related components and network safety functions (sub-chapter 3.2).

Considerations for a generic certification process were made. One aspect for certification is the handling of faults, definition of safe states and determination of the safety function response time (SFRT). Another aspect is the definition of rules for standardized interfaces, as those interfaces are more resistant to changes and enforce a clear separation between different train functions, which helps especially in incremental certification. A further aspect is the safe deployment of safety related software, including parameterization of software for deployment in a safe manner.

Finally, the process for safety cases was demonstrated exemplarily for two selected train functions, the door function and the brake function.

It should also be mentioned that the work on this activity was accompanied by Safe4Rail as complementary action. Safe4Rail provided expertise with respect to safety certification, namely through the support of TÜV SÜD as a member of Safe4Rail. With this support, the expectation of an independent assessment of the safety approach could be satisfied sufficiently.

4.4 WE CAN DRIVE-BY-DATA

Drive-by-data will be a reality and CONNECTA contributed with:

- Introduction of a new TRDP traffic class (TSN-PD) for scheduled data traffic based on standard IEEE 802.1Qbv.
- Time synchronization concept based on IEEE 802.1AS-rev as prerequisite for scheduled traffic.
- Definition of a new network architecture with separated ETB lines and diverse virtual data communication planes for scheduled data traffic.
- Safe Data Transmission protocol and safety layer definition for the transport of safety critical data up to highest safety integrity levels (SIL4).
- Safe train inauguration concept for train composition discovery with highest safety integrity levels (SIL4).
- Definition of a security architecture and security methods to achieve state-of-the-art cyber security in alignment with actual security standards.

This new architecture allows replacing conventional train lines for train control and provides the capabilities to integrate safety-related sub-systems like the Electronic Distributed Valve (EDV) brake and ETCS signalling. Due to its ability to transport data of mixed criticality, the same communication infrastructure can be used for TCMS functions and operator-/customer-oriented services. Furthermore, the possibility to reserve bandwidth for critical data supports the process of incremental certification: non-safety related communication cannot interfere with safety-related communication.

A new network topology has been defined which suits the specific needs of high reliable scheduled data traffic. On ETB level, a right and left ETB line have been introduced which is different to the nowadays used topology with aggregated ETB lines. At consist level, dual-homed critical end devices connecting to two virtual TSN planes have seamless communication also in the case of a network fault. Conventional and legacy devices are connected as today with a single Ethernet interface to the ECN ring network, which ensures backward compatibility to existing solutions.

Besides well-known services already present in existing implementations, NG-TCN introduces some modifications to some of them and also defines new services. To mention here are: data communication service for scheduled data traffic, modification of train inauguration service to cope with the changed ETB topology and support of highest safety integrity, and a new safe data transmission protocol for connecting safety function classified for SIL4.

The modified or new network services partly require new or adapted protocols, like the protocol for frame replication and elimination (IEEE 802.1CB), the modified train inauguration protocol or the safe data transmission protocol. Completely new is the precise time synchronization protocol based on the IEEE 802.1AS standard, which is a prerequisite to scheduled data traffic.

There are no really new network components compared to existing solutions, but most of the components have changed roles and provide additional functionality. First to mention is here the function of time synchronization and scheduled traffic, which affects most network components like consist switches and TSN-aware end devices. But also, the ETBN got new functionality. A list of network components and a description of their roles is provided by CONNECTA in the deliverable D3.5.

This is accomplished with a special focus on TSN-aware end devices. To connect those end devices to NG-TCN, they need to implement services and protocols which have been mentioned before. Requirements on end systems have been defined to an extend that allows to connect those end systems to NG-TCN

To be generic, end devices interfaces defined are not application profile specific, but in their generality, they are parametrizable for all relevant profiles discussed in WP4, like Doors, HVAC and BMS. In addition, in discussions and meetings with WP5 it has been ensured that brake requirements are fulfilled as well.

Network and end device configuration is very device specific and mainly in the responsibility of the component suppliers. But the defined network services and protocols constrain the functionality to be provided and by this the configuration demand.

NG-TCN as defined provides the necessary communication features for integrating the signalling system. However, the signalling system interfaces defined by UNISIG need to be adapted correspondingly.

Summarized, the specification of NG-TCN architecture and interfaces carried out in CONNECTA are considered appropriate for supporting the objectives of NG-TCMS with respect to reliable, low latency, safe and secure data communication. The concepts should be detailed enough to derive requirements for network component prototyping. The verification of the concepts is envisaged for sub-sequent projects has been outlined. In parallel, necessary standardization activities on international level will be launched.

5. HIGHLIGHTS OF WP4 – FUNCTIONAL ARCHITECTURE

5.1 FUNCTIONAL OPEN COUPLING (FOC)

The FOC concept allows the coupling of different types of rolling stock and addresses the most important barriers for interoperability to be surmounted.

CONNECTA has defined the mechanisms that are needed to be put in place to ensure compatibility between consists. It is then important to highlight that, besides communication mechanisms, it addresses also extensive description of existing technical hurdles and proposes solutions to overpass them.

Following topics have been deep dived within CONNECTA:

- Diversity of Rolling Stock and their characteristics,
- SIL of the functions,
- Sustainability of the concept, and,
- FOC Standard definition and maintainability.

It has been realised that the more the functions will be standardised for all consists, the easier the introduction of Functional Open Coupling will be. To facilitate the process, CONNECTA has defined a methodology, which gives in that sense a detailed view of the processes to be put in place to standardise them.

Two case studies provided are giving examples of functional studies definition and the reflexion needed to define a function standard.

The implementation of WP3 (drive-by-data) results, the suppression of train lines and their respective voltage, the implementation of WP5 (brake-by-wire) are concurrent research activities allowing, at term, to suppress most of the non-functional interfaces, easing the implementation of Functional Open Coupling on trains.

5.2 APPLICATION PROFILES

Application profiles aim to reduce engineering costs due to standardization of the integration of subsystems. By defining interfaces between the system integrators and the subsystem suppliers the engineering effort can be reduced. Thus, it is also possible to reuse documentation, tests etc. in other projects. This shall lead to reduced project duration and less problems during system introduction phase due to less hard- and software changes during a project.

Since no appropriate methods were found during the state of the art analysis, it was decided to use SysML as method to model the Application Profiles. With this approach it was possible to efficiently define the use cases that have to be supported, the static and dynamic architecture of the TCMS and the subsystems as well as the interfaces. Furthermore, reports for different purposes have been implemented to generate documents out of the SysML model.

The method defined for the Application Profiles was also used for the specification of the static and dynamic architecture for the Functional Open Coupling. The engineering environment to use SysML inside CONNECTA was set up on a MagicDraw Server provided by NoMagic. This SysML infrastructure was also used by the other work packages of the project.

In order to gain a standardized integration of subsystems three Application Profiles for HVAC (Heating, Ventilation and Air-Conditioning), Doors and BMS (Bogie Monitoring System) were successfully defined and reviewed several times until full agreement of all partners was achieved. The exports from the SysML of the Application Profiles where successfully included in this document. The used approach to first explicitly model the Application Profile in SysML proofed as being very successful during this project and may be recommended for future activities to define Application Profiles.

Besides that, CONNECTA supported the ongoing standardization activities inside X2Rail with the review of the functional specification of the ATO subset 139. We gave comprehensive inputs with high impact to the proposed functional specification. In a sequence of one onsite and several remote review meetings, that were held in a very good cooperative atmosphere, an agreement on the change requests from CONNECTA was mainly achieved. The comprehensiveness and consistency of Application Profiles will be evaluated during CONNECTA phase 2.

Last but not least, CONNECTA has been thoroughly contribution to the UIC/IEC TRAINET subgroup by providing the doors application profile and models.

5.3 FUNCTIONAL DISTRIBUTION FRAMEWORK (FDF)

The AUTOSAR Adaptive Platform and ARINC 653 were identified as standards that provide multiple features of relevance to a TCMS FDF. ARINC 653 represents a thinner stack (comparable to a real-time operating system with a few extra services) compared to AUTOSAR. The main conclusion of the study of these standards was that it was necessary to first specify the needs of the TCMS FDF, in the form of a detailed specification. Then, particular implementations can make use of AUTOSAR or ARINC 653 in different ways.

The list of train functions from standard EN15380-4 was analysed in order to detect the functions that could be implemented on top of the FDF. Only a few functions with very specific hardware demands, such as low-level traction control, were left out.

A key part activity was the definition of the basic architectural concepts and a detailed specification of the FDF. The architectural concepts are based on general ideas that are common to most safe real-time operating systems and also to ARINC 653 and AUTOSAR Adaptive Platform. For the detailed specification, these two standards were also analysed, together with additional services required to implement train functions, based on the experience of the contributors to the document.

For safety and certification, many advantages but also challenges posed by the FDF were detected. Different scenarios for rolling stock initial certification and recertification were analysed. The main conclusion is that the FDF can contribute to a significant reduction of the effort in both processes, as long as the FDF and also the TCMS system are designed correctly.

Cybersecurity has become an important aspect of rolling stock and the FDF cannot ignore this area. A specific functional component for cybersecurity was specified. The lack of a widely accepted standard for rolling stock cybersecurity is underlined. It is concluded that the FDF introduces new risks which need to be handled adequately in order to build robust systems.

The collaboration with Safe4RAIL was very important during the development of the project. On the one hand, they provided a different type of expertise which enriched the FDF concept. On the other hand, they realised three different proof-of-concept instantiations of the CONNECTA FDF specification based on three different existing solutions. The evaluation of these base technologies was done in collaboration between the two working groups. The main conclusion is that all the proposed technologies offer advantages and disadvantages and it was not possible to agree on the best one. Future FDF implementers will have to decide which basic technology better suits their needs.

Three TCMS subsystems were evaluated as candidates to be implemented in a FDF: doors, HVAC and Bogie Monitoring System. The objective is to see if the specified FDF was sufficient to implement them on top of it. The main conclusion is that the FDF can host the most common TCMS functions and that it offers a lot of flexibility for different system architectures.

The initial expectations and plans for the FDF have been fulfilled during the development of CONNECTA. As a result of the study, it was agreed not to link the TCMS FDF to any of existing technology, but to define a set of requirements based on functional components, which is the approach taken by AUTOSAR Adaptive Platform. The level of adherence to AUTOSAR or ARINC 653 was left to the implementation level. This is facilitated by the specified FDF, which can be seen as a superset of ARINC 653 and a subset of AUTOSAR Adaptive Platform.

Although FDF use examples were analysed to validate the specified FDF, it can be expected that the need for modifications may arise when real FDF implementations start and also when different functions are implemented on top of those implementations. This risk was partially mitigated by the collaboration with Safe4RAIL, which realised three basic FDF implementations based on different available technologies.

The FDF implementations were out of the scope of the project and will be considered in CONNECTA-2. However, it must be noted that the quality of these implementations will be a key factor in the deployment of the FDF concept, since errors in the FDF will affect the availability of the complete train functionality.

Future work, beginning with CONNECTA-2, may help discover points that need to be improved in order build a FDF that contributes decisively to the next generation TCMS and the Shift2Rail MAAP objectives.

6. HIGHLIGHTS OF WP5 – SAFE ELECTRONICS FOR BRAKES

6.1 NEW REQUIREMENTS FOR NEW BRAKE SYSTEMS

A general brake system functional structure was defined including the possibilities given by the innovative functionalities of the Electronic Distributor Valve (hereinafter EDV), providing many advantages.

The sub-functions of EDV were identified and were the base for writing the functional requirements, where a top-down process was put in place, to be able to propagate the initial functionality expected by brake system (reduce or maintain the speed and stop the train in predefined stopping distances) to the EDV sub-functions of brake system, guaranteeing a coherent definition of the EDV requirements (requirements of EDV derived from a general brake system functional “model”).

An exhaustive set of functional requirements were defined for the control performed by EDV of the adhesion dependent friction brake force, taking care of the norms and standard and justifying the different choices.

Clear interfaces were defined between the sub-functions in charge of EDV and the other sub-functions of brake system or of the technical system involved in brake system functionality, which led to exporting requirements to other sub-functions and technical system.

The complete set of requirements covers not all the possible brake system functional models able to use the improved functionalities of the EDV, but the functional model is as much as possible open to the largest number of brake system architectures.

The set of requirements, joint with the safety requirements will allow the development of the EDV architecture and its technical and practical solution.

6.2 GOING SAFE

The objectives concerning safety were satisfied as follows:

1. “Selected system and sub systems architecture and safety analysis have to be assessed to verify the consistency and compliance to the relevant safety standards.” The new braking system with related function and safety architecture, the safety planning and

strategy and the safety analysis were evaluated by an Independent Safety Assessor for compliant compliance with the safety standards EN50126 and EN50129.

2. "If not the railways safety standard will be used for sub systems and components and when the use of such standards will be justified, a standard harmonisation proposal will be included in the assessment report." The safety analysis was so far compliant with the railways safety standards and directives.

7. HIGHLIGHTS OF WP6 – VIRTUAL CERTIFICATION

7.1 THE SIMULATION FRAMEWORK

The specification of the Simulation Framework was developed to describe the high-level requirements of the simulation framework and train virtualisation in order to support the remote and distributed testing of train subsystems including Hardware-in-the-Loop scenarios. This specification also described the high-level architecture defining the relationship between the main architecture subsystems.

Then it was specified an architecture and design of the Simulation Framework (hereinafter SF) defining also its interfaces with the Software Tool Set, Communications Emulator (hereinafter CE) as well as End Device and Electro-Mechanical Simulations in order to allow testing a TCMS in a virtualised environment. This objective was achieved by designing a SF with the following main aspects:

- The SF internal modules and their interfaces were specified using Systems Modelling Language that provides a flexible and expressive description of the design artefacts independent from its implementation language. Static and dynamic descriptions of the SF design were provided by using different SysML diagrams such as block definition, state machine and sequence diagrams, covering all the requirements.

- A Configuration Model was defined that allows the definition of a Simulation Host connected to real End Devices located in Local Communication Networks and Remote Communication Networks. This Configuration Model allows the co-simulation of Multiple Traction Units and Distributed Simulations defining simple and complex operations to be executed by the Simulation Host from data provided by each simulation entity.

- The SF design allows the use of different HIL-IF devices provided by different manufacturers. A detailed interface was defined to integrate the protocols of each supplier.

- Abstract Syntax Notation One was selected for the protocol definition between the SF and the SWTS and other SF instances. ASN.1 allows defining data structures that can be serialised and de-serialised in a standard, cross-platform way.

- A method of fault injection was defined to force values of the signal data provided or received from Simulations.

The CE interface description in this design is based on the specification provided by the complementary action of CONNECTA, the project Safe4RAIL.

The SF together with its components, like the software toolbox and the train virtualization will pave the way for the further integration of train subsystems (real or modelled) and for supporting the virtual certification of them and the TCMS itself, thus contributing significantly to the time and cost reduction of rolling stock certification.

7.2 VIRTUALISING THE TRAIN

During the work it was identified, that the scope Electro-Mechanical Simulations (EMS) could be split into simulations of the physical and the electrical behaviour. But both types of simulation, and thus the Electro-Mechanical Simulations (EMS) in general are not that different from a 'normal' End Device Simulation (EDS). The main difference is the architectural scope of the simulation, since an End Device Simulation (EDS) is acting in a specific consist only, so can be executed on a single Simulation Host (SH) instance. In contrast to this an Electro-Mechanical Simulation (EMS) has to act in a train-wide scope, which requires splitting it into consist specific parts, which are executed by consist specific Simulation Host (SH) instances. This split requires that the consist specific partitions are synchronised for the train wide functionalities using a co-simulation architecture, which is the most important difference, and one of the specific requirements for Electro-Mechanical Simulations (EMS).

The next difference is the kind of interface to other End Devices (ED). An End Device (ED) or an End Device Simulation (EDS) will communicate to other End Devices (ED) or End Device Simulations (EDS) using one of the communication busses like an Ethernet Consist Network (ECN). On the opposite the Electro-Mechanical (EM) environment is connected to End Devices (ED) by physical inputs and outputs on that device. For the Electro-Mechanical Simulation (EMS) this means that the inputs and outputs have to be provided using a Hardware-in-the-Loop Interface (HIL-IF), which will then interface with the physical inputs and outputs of an End Device (ED) replacing the real Electro-Mechanical (EM) environment.

The main achievements that were obtained are the following ones:

- The requirements to emulate the behaviour of the train based on Electro-Mechanical Simulations and HIL interfaces have been defined. General services to be offered by EM Simulations, and requirements for the Physical and Electrical Simulations were detailed, where the main logics of them have been ruled. Some general requirements for the HIL interfaces were defined as well.
- A proposal of the internal architectures of the Physical and Electrical Simulations were made where the internal blocks of the simulations were described in order to execute their required logics. Two possible ways of implementing the simulations were defined; one based on configuration files with a generic logic implementation, and another based on the generation of the simulation through the Software Tool Set.
- In order to provide the electrical signals to the End Devices, a high level architecture of the HIL interfaces was defined where the two main interfaces were identified; the interface with the End Devices with the access to the electrical signals, and the communication interface which will act as the interface to the rest of the testing network to send and receive values of the electrical signals.

- A more detailed design of the Electro-Mechanical Simulations was agreed on by defining their state machines and their dynamic behaviour through sequence diagrams.
- As defined in the initial objectives, a standardised interface between the Simulation Host and the Electro-Mechanical Simulation was detailed in order to integrate the EM Simulations in the Simulation and Virtualisation Framework.

On the other hand, once the specification of the Electro-Mechanical Simulations was completed, the implementation of the Electrical and Physical Simulations were also realised. These implementations that will emulate the train behaviour will be integrated with the Simulation Framework in the next phase of the project, in CONNECTA-2.

7.3 The Toolbox

The main achievement was the implementation of a SW Toolset that will allow to perform tests of TCMS System and subsystems with some of the devices under test being simulated and some being located remotely.

The main difficulty was to set the high level requirements and the architecture. Since all partners had currently our own SW Tools for the configuration of our TCMSs implemented and wanted to take these tools as a base for the development of the SW Toolset for this WP, it was difficult to get to a solution that could satisfy all.

Even though the SW Toolset implementation was done, there are further activities recommended for the future. To assure that the defined architecture for the SW Toolset is correct other partners should carry out their own implementation of the SW Toolset. It would be recommended too, to finish the development of the Simulation Framework to be able to carry out an integration of all the building blocks of this project; Simulation Framework, Train Virtualisation, Communication Emulator and, the matter of this deliverable, the SW Toolset. These integration tests will provide a high-quality feedback to improve the implementation. It would be also recommended to carry out some tests in a real project for the same reason described before.

7.4 A contribution to the IEC 61375-2-8

CONNECTA collaborated with the IEC in the development of the IEC 61375-2-8 standard (ECN/ETB Conformance Testing). Three activities were carried out for this purpose. One; Information from the IEC 61375 standards related to Ethernet communications was transferred to requirements (IEC 61375-2-3, 3-4, 2-5 standards). Two; test cases were defined that will make possible the validation of the above-mentioned requirements. And three: These test cases were implemented and executed on a test bench built for the occasion.

As a result of this activity, a large part of the standard was approved and feedback was been provided to the IEC to improve or correct both the standards related to Ethernet communications mentioned above and the Conformance Testing itself.

The next steps aim at getting a company to be authorized to become an equipment certifier in compliance with the standards mentioned above.

8. HIGHLIGHTS OF WP7 – DISSEMINATION AND STANDARDISATION

8.1 GETTING STANDARDISED

The final goal of CONNECTA and its successors is to have the technologies standardised to guarantee the interoperability of products and the expected cost reduction.

Taking advantage that several CONNECTA members are respectively national experts at the main standardisation groups from CENELEC and IEC (e.g. TC9 WG43) the knowledge transfer was straightforward.

In that sense CONNECTA members participated in five meetings of the IEC TC9 WG43 in charge of the TCN standards series (i.e. IEC 61375) and provided key inputs to finalise the long awaited new train-to-ground communication standard, enabling interoperability for many important services like the energy metering (as of TSI ENE).

Another important contribution was a number of clauses for the new ECN/ETB conformance test protocols (i.e. future IEC 61375-2-8) and the implementation of some of them on a test bench, which was showcased to the IEC TC9 WG43 during a meeting.

Figure 2: Conformance Testing Demo on the WG43 meeting in Beasain, 16/05/2018

In addition, members of CONNECTA also were participating regularly to the UIC/IEC joint subgroup TRAINET for the replacement of the old UIC 556 leaflet by FOC application profiles. Several workshops took place during the CONNECTA lifetime, one in Beijing, and as a result the FOC application profile “Doors” was fully integrated in the TRAINET specification.

During CONNECTA-2 the members will continue contributing to the standardisation groups, which probably will include new revisions (e.g. IEC 61375-2-5 ETB, IEC61375-2-6 T2G, IEC61375-2-7 WLTB) and a new part (i.e. IEC 61375-2-9 Virtual Coupling).

8.2 ADVISORY BOARD

CONNECTA organised jointly with the complementary action Safe4RAIL an advisory board that was invited to two workshops. During the workshops relevant discussions based on previously shared documentation and on specific presentations were taking place. The board was composed of 10 members from different stakeholders, including the convenor of the IEC TC9 WG43, notified bodies, national safety agencies and one urban operator, to compensate the lack of them in CONNECTA.

Valuable inputs were received and doubtless reinforced the on-going activities of the project.

Figure 3: First workshop in Vienna, 5th October 2017

Figure 4: Second workshop in Munich, 6th June 2018

8.3 Dissemination Items

The members of CONNECTA were much concerned about dissemination, and during the lifetime of the project they kept the public website (http://www.s2r-connecta.eu) updated with news, events and public documents and deliverables.

The project identity was set from the beginning by designing the project logo and documents templates, together with an initial brochure, containing a general description of CONNECTA and its activities.

Figure 5: CONNECTA brochure

During the project two videos were produced and shared among the most popular platforms and media. The first one described the tests of the new wireless train backbone on a Euskotren 950 series train, during commercial service: https://vimeo.com/265966043

The second video covered the “Connected Trams” demonstrator unveiled during the Innotrans fair in Berlin. This demonstrator showcased several innovations proposed by CONNECTA, like the aforementioned wireless train backbone, the new standardised train-to-ground communication and the functional distribution framework. In addition, digitalisation services and virtual coupling completed the demonstrator: https://vimeo.com/287383330

Finally, a newsletter containing the main results of the project together with the expected next steps (i.e. within CONNECTA-2), was released before the final conference. Its 16 pages described, work package by work package, the most relevant outcome of the activities.

Newsletter September 2018

Foreword

After two years of activities and fruitful cooperation, the Shift2Rail project CONNECTA has completed its work programme, so it is the right time to provide an overview of the main results obtained, which are many and valuable. CONNECTA started with the aim of contributing to the Shift2Rail's next generation of TCMS architectures and components as well as to the next generation of electronic braking systems and I can assure now we succeeded.

The project has conducted research into new technological concepts, standard specifications and architectures for train control and monitoring, with specific applications in train-to-ground communications, safe communications, new computing concepts and high safety electronic control of brakes.

Today, the results of CONNECTA seem to be even more decisive than ever. Indeed, the future railway system looks much more autonomous, connected, digital and safer, and the new generation of TCMS and brakes will play a major role.

In the following sections, our work package leaders are presenting the said results. I wish you an enjoyable reading.

Javier Goikoetxea (CAF)

Shift2Rail IP1 Coordinator & CONNECTA Coordinator

Figure 6: Newsletter

8.4 Conferences and Congresses

The project was presented in three main conferences. First, CONNECTA was introduced to the audience during the mid-term conference of Safe4RAIL in 2017, the complementary action of the project.

In 2018, the project was selected to be presented during the Transport Research Arena in Vienna, and finally, in September 2018, the final conference was jointly organised with Safe4RAIL. Many stakeholders attended the event, rising the audience to more than 100 souls. It was well appreciated the presence of representatives of UIC, of many TCMS suppliers and even Chinese (CRRC) people.

Figure 7: Safe4RAIL mid-term conference

Figure 8: Final Conference

Showing the good collaboration with other Shift2Rail projects, both CONNECTA and X2RAIL performed a combined presentation in the ETSI workshop Developing the Future Radio for Rail

Transport hold in Sophia Antipolis, tackling the new concept for the train-to-ground communication system.

Finally, the work package leaders of CONNECTA submitted a number of abstracts to the World Congress Railway Research, whose acceptance is not yet known:

- Wireless Train Backbone for TCMS
- Interoperability tests of the new standardised train-to-ground communication
- Enabling SIL4 functions in TCMS: The drive-by-data concept
- Achieving full interoperability through the Functional Open Coupling
- Brake-by-wire
- First ECN/ETB conformance test implementation
- "Connected Trams" demonstrator: A showcase for the virtual coupling of trains

9. CONCLUSIONS

CONNECTA has been one of the most successful projects of the first call of Shift2Rail. It combined long term developments on radical innovations with quick-wins, providing already valuable inputs to the standardisation bodies.

The project has completed the first phase of the planned activities in the Multi-Annual Action Plan (MAAP) and the reached maturity will allow the implementation of the new technologies up to TRL 4/5 in CONNECTA-2.

CONNECTA has been fully integrated in the structure of IPs of Shift2Rail, sharing knowledge and expertise with other projects like X2Rail-1, X2Rail-2, Safe4RAIL, IMPACT-1 or PLASA.

The new technologies developed with CONNECTA, some prototyped in the “Connected Trams” demonstrator, reveals that they will play a key role in the future railway system, which will be much more autonomous, connected, greener, cost-efficient and safer.