Communication platform for testing of novel technologies for railway traffic management systems

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Abstract

New generation Traffic Management Systems (TMS) aim to face off the lack of interoperable data structures and standardized communication interfaces of legacy systems addressing the interoperability, multimodality, scalability, and sustainability issues of the railway sector. The H2020 Shift2Rail OPTIMA project develops and validates a communication platform demonstrator (TRL 6/7) for the testing and validation of new technologies developed by industry for the new TMS generation. The OPTIMA communication platform offers to Rail Business Services and external services a seamless access to persistent data from heterogeneous data sources with automated data exchange process, real-time availability, and configurable levels of quality of services.

In this paper, a detailed description of the OPTIMA platform architecture is provided, focusing on the functionalities of its components. In particular, the Integration Layer, its main constituent, which deals with the seamless exchange of data between rail business services and external services and TMS applications, is presented, with focus on its implementation details. Furthermore, the paper presents the methodology used for establishing a Common Data Model to ensure the interoperability between different systems and processes and to provide a fully standardized data representation, along with its relationship with the Platform Independent Model to ensure a fully compatibility with the Platform Specific Models developed in other Shift2rail complimentary projects.

Keywords: Railway Traffic Management Systems, Communication Platform, Integration Layer, Common Data Model, Signalling and communication railway systems.

1. Introduction

Nowadays, all major railway Infrastructure Managers (IMs) are using Traffic Management Systems (TMS) for train operations together with energy management, maintenance management and advanced signalling systems, which have been progressively introduced according to traffic demands and based on different technological solutions at the disposal of the relevant parties. However, over the last decades, Infrastructure Managers have deployed TMSs not considering their scalability, neither the standardisation of the interfaces towards the related subsystems as Rail Business Services (RBS) and external services, as well the TMS specific applications. Furthermore, data exchange between systems belonging to the same IM and between IMs are done through non-standardised interfaces. The progressive integration created a heterogeneous map of solutions at European level not fully interconnected, so limiting the maximum efficiency of exploitation and cross border interoperability. This increases the investment needed for the integration of new Rail Business services and applications and jeopardizes TMSs interoperability.

As there are economical and practical reasons for not proceeding with a complete substitution of existing TMSs and Rail management systems, in the context of the Shif2Rail (S2R) Joint Undertaking activities promoting the development and the implementation of new technologies for railway TMSs, the H2020 OPTIMA (cOmmunication Platform for TraffIc ManAgement demonstrator) project [1] proposes a novel and first of a kind TMS communication platform. This communication platform is based on specific harmonised architecture, standardised interfaces, and data models to interconnect the existing systems without stopping their activities, while serving

as a basis for the validation and deployment of new applications and services. In particular, the OPTIMA platform is closely linked to the S2R Technical Demonstrator (TD) 2.9 that aims "to specify and design a new TMS based on standardised frameworks, data structures, real-time data management, messaging, and communication infrastructure including interfaces for internal and external communication between different subsystems, applications and clients. It aims at significant higher integration of status information of the wayside infrastructure, trains, and maintenance services together with management of energy and other resources" [2]. Furthermore, the platform for the Traffic Management demonstrator will be used to facilitate the testing and validation of the prototypes developed by the S2R complementary projects X2Rail-4 [3] and FINE-2 [4].
The paper is organized as follows. In Section 2 the OPTIMA project, the architecture of its communication platform, and the derivation of the Common Data Model are described. In Section 3 its core component, the Integration Layer (IL), a middleware that ensures a seamless data exchange with the different internal and external services and the several TMS applications is illustrated. Its functionalities will be illustrated, along with the design solutions and the interactions at the basis of the data exchange. In Section 4 some conclusions will be drawn.

2. The OPTIMA project

OPTIMA is a European funded project within the framework of the Shift2Rail programme, which aims to design, implement, and test a prototype of a TRL 6/7 communication platform that uses standardised data structures and processes to manage the data exchange between different services/clients [5]. OPTIMA demonstrator enables new applications for Traffic Management and Traffic Control, including the integration of new functionalities developed within the S2R program into the rail operation processes along with their testing and validation [6]. Such demonstrators include Automatic Train Operation (ATO), Moving Block, Decision Support System, Connected Driver Advisory System, Data provision/exchange for new advanced Maintenance Strategies, Freight Transport, and Passenger Information services, etc.
The main expected result of the project is the first of a kind TMS communication platform capable to integrate TMS applications, which harmonises Rail Business Services and provides a gateway for the connections with external clients. Its outcome is a key element for the validation and further exploitation of the future TMS solutions, as it feeds directly into the testing and validation process of novel technology currently developed by industry. Therefore, OPTIMA communication platform is an enabler for the implementation and market uptake of the new generation of TMS solutions and has good chances for its own implementation in the context of novel TMS becoming operational.
OPTIMA platform is the first of its kind, no similar research or uptake of previous R&I activity was identified. Indeed, although the TMS communication platform requirement specification was addressed in previous projects In2Rail [7], X2RAIL-2 [8] and IMPACT-2 [9], the design, implementation and validation of a demonstrator was not tackled before. The new TMS communication platform demonstrator developed in OPTIMA overcomes all the disadvantages due to the lack of standardized interfaces and data in current TMSs previously mentioned and brings additional benefits through: i) implementation of future standardized interfaces; ii) the Integration Layer (IL) component that allows a seamless communication based on publish subscribe model; iii) a Common Data Model (CDM) used to provide interoperable data structure and access methods iv) modularity of its components; v) a dedicated Application Framework (AF) to host the Traffic Control and Management (TCM) applications.

2.1 The Communication platform architecture

OPTIMA's major contribution to the efficiency of TMS is the development of the IL, an essential constituent for interconnecting TCM applications with the railway/external subsystems interfaces, using a standard platform and harmonised data structures.
The architecture of the Communication platform of OPTIMA, shown in Figure 1, was conceived on the basis on an analysis of requirements outlined by related S2R projects (In2Rail [7] and X2RAIL-2 [8]). Furthermore, a review of the resources available at the three Infrastructure Managers participating in the OPTIMA consortium, (RFI - Italy, ADIF - Spain, and SZDC – Czech Republic), has been performed to know the type of railway data available for the experimentation. Going into detail, RFI provides the field information coming from two Radio Block

Centre and all the interlockings along the track chosen for the experimentation, SZDC provides the status of the maintenance operations like closures and restriction to the railway traffic, and the status of the energy grid (e.g., energy segments, stations, substations, etc.), and ADIF provides weather data. As no direct connection to IMs' production systems can be allowed due to cyber security policies and national public transport legislation, IMs had to collect live log files from their field equipment and TMS and had to store them into OPTIMA servers, replaying all the registered events by the means of ad-hoc developed software appliance. On the other hand, the involvement of three IMs ensures a broader perspective regarding interoperability between Rail Business Services and IL, as it provides the knowledge of a broader set of field infrastructure interfaces that need to be connected to the IL, rather than focusing on just a single case.

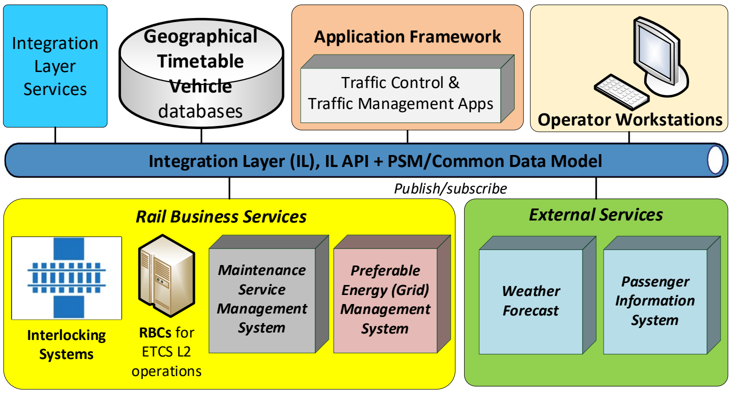

Figure 1: OPTIMA Communication platform architecture

Moreover, to offer a homogeneous access to the different sources of information, the data coming from the three IMs has been mapped into One Virtual Track (OVT). The railway line of Ventimiglia-Albenga (west coast of Liguria region in Italy) controlled by RFI was chosen as reference rail track where the different data sources have been coherently mapped. A software layer, named "OVT mapper", takes care of this task (see Figure 2).

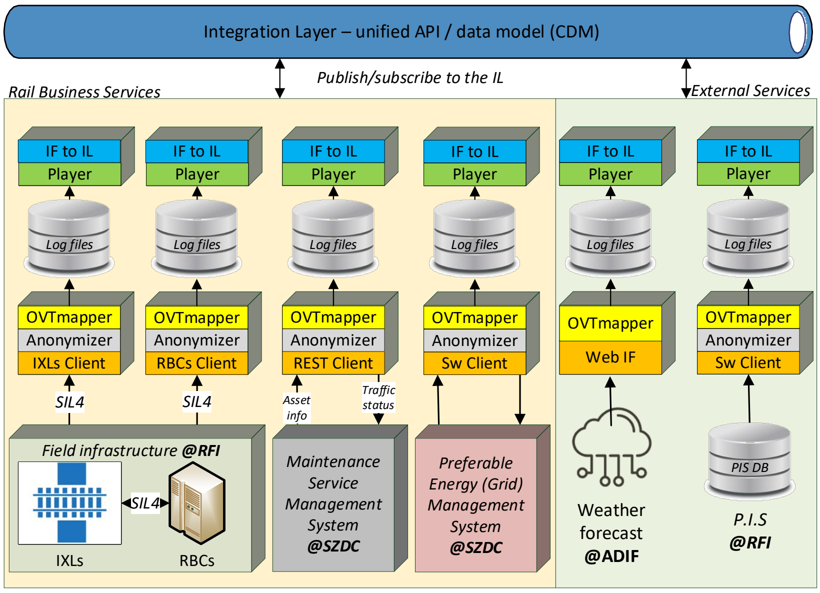

Figure 2: Rail Business Services and External Services implementation design.

Then the data and events collected from the RBS are anonymized and stored in log files, along with the information stored into the persistence layer about the railway network elements, vehicles, assets, and timetables. Finally, the software player timely publishes the information to the IL by using the IL-API and the agreed Platform Specific Model (PSM) obtained from the Platform Independent Model (PIM) which is the CDM[1]. In this way, the IL can connect the existing signalling infrastructure by means of dedicated SW clients connected to the IL via

[1] This process is described in the next section

interface services, and also allows external services to publish their information available in the system via web services connected to the IL.
On the other side, TMS applications connected to the IL can subscribe the relevant topics to get the needed information. These applications can be hosted into the AF, a new environment where to deploy the TCM applications connected through the IL to the services provided by the platform. The AF eases applications' installation ("Plug-and-Play") and administrates service application modules and automated data exchange. Some of these applications have been developed by OPTIMA (e.g., monitoring the trains circulations, interacting with Rail Business Services, showing the Passenger Information Systems for each station, etc) while others are external prototypes developed by the X2Rail-4 partners (e.g., conflict detection and resolution, ATO, etc).
Finally, new standardized Control Centre Operators Workstations for the human intervention in train operations and connected to the IL enable the allocation of tasks to different workstations, benefitting from the availability of the different data on an integrated network provided by the IL.

2.2 The Common Data Model and Platform Specific Model

The TMS as a central controlling instance requires data from almost all railway domains, including infrastructure, interlocking, energy system, timetables, etc. To ensure the interoperability between different data sources, systems applications, and process and to allow evolutionary extension of TMS with new functionalities, a common platform independent data model (the CDM) and a common communication architecture (the IL) were specified as planned by the Shift2Rail guidelines. The common data model, is the sole source of data semantics and structure, allows the integration of legacy and future applications to be secured into one communication structure, and current and future interfaces to be managed.
The CDM has been defined by analysing the business requirements of the railway constituents and elements. It is composed by UML, XML and Excel files, and has been developed during several Shift2Rail projects dedicated to TMSs starting in 2015 and reached its current version in the X2Rail-4 project: it's continuously improved and updated.
Then a Platform Specific Model has been generated by using software code and configuration generation tool. The PSM supports two serialisation formats, namely a human-readable format (JSON) and a binary format (Protobuf), which can be used interchangeably via a defined API. Any application linked to the IL have to use them. It is noteworthy that a change in the PIM (the CDM) requires to recompile and to release a new version of the PSM. For this reason, CDM modifications must be limited, based on well-defined rules, and carefully evaluated and checked before application because they can affect dependent projects.
The PSM was mainly produced by X2Rail-4 project, and since the collaboration between OPTIMA and X2Rail-4, further integrations and improvements were provided by OPTIMA.

3. The Integration Layer

The IL is a real-time messaging system based on publish/subscribe mechanism with standardised topics and interfaces for internal and external communication between different subsystems, applications, and clients. It supports multiple clients, integrated and automated data exchange process, real-time availability, configurable QoS levels' service. It has been developed by using RTI Connext software framework, a commercial variant of OpenDDS with enhanced features, and attention to security aspects. The IL has been enclosed in a software wrapper that adapts it to the OPTIMA requirements, and then an IL-API was developed to provide seamless and dynamic data exchanges between the various services and OPTIMA components.
Figure 3 depicts the two steps process to publish or subscribe a topic by using the IL: the first step consolidates the data structure and the second one proceeds with the real connection to the Integration Layer. A data exchange between TMS and external system via the IL requires that the data type and the relations between data are defined within the CDM. An application or service with some data ready to be published calls a function of the "Codec library" which formats and serializes the data, compliant to the PSM by selecting the Protobuf schema corresponding to the used data type. In other words, the Protobuf schema is the data structure containing the raw data coming from the field. The serialized data is now ready to be published to the IL by means of a specific call to the IL-API. In Figure 3 the "Initialization & Import/Export DB" refers to the static data used to

initialize the database containing information about railway topology, IMs' assets, and Train Timetables. The initialization of these databases can be executed by some dedicated TMS applications, external or running into the AF. The Rail Business Services and the external services also publish their data through the IL API, by using Protobuf schema as generated from the generation tool.

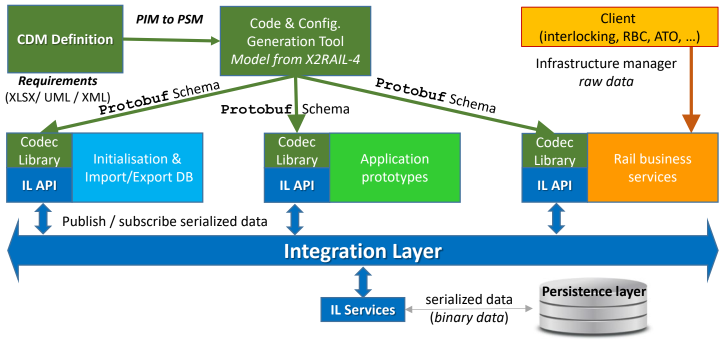

Figure 3: OPTIMA Integration Layer and its relations with model, rail business services and applications

From the other side, an application prototype installed and running into AF wanting to receive some field data via the IL, must subscribe the topic of interest by calling a specific function of the IL-API. Then when it has received the data, it must call a function of the codec library to deserialize such data. Moreover, because the PSM shall be the same in all the Shift2Rail projects, the codec library produced in each project is expected to be the same or at least very similar apart negligible differences, even if each project has developed its own coded library. All the applications and services adopt the same architecture, regardless of their role, thus ensuring some degree of commonality. Therefore, a complementary project prototype willing to use the OPTIMA communication platform only needs to know and use the IL-API. This API offers OPTIMA applications and services and allows the external prototypes to communicate and exchange data according to constraints of quality of service, which can be specific to each prototype. Most of these data are "opaque" objects for the IL-API that completely ignores their meaning. Therefore, the architecture and the design of the IL ensure the scalability and maintainability of the TMS.

Figure 4 shows an example of signalling information collected by the RBS and stored in the event log that are processed and transformed into JSON format ready to be published in the IL through a call to the IL-API.


```
---------------- ROW READED IN REGEVE XLS ----------------
DATA                                          05/02/2020
ORA                                             04:57:33
LOCALITA/TRATTA                              VENTIMIGLIA
NOME ENTE                       bloccamentodelPercorsoMS
ID ENTE                                         08aR*157
N TRENO                                              NaN
EVENTO                                             [BIT]
UTENTE/SISTEMA                                       NaN
INFORMAZIONE EVENTO/STATO             BLOCCATO uno (CTC)
Name: 4595, dtype: object
----------------------------------------------------------
-------------------- JSON INFORMATION --------------------
"Trackoccupationstatus": {
    "Timestamp": "1638193367",
    "BloccamentodelPercorso": {
        "Id": "08aR*157",
        "Name": "VENTIMIGLIA",
        "Net Elements": {
            "Net Elements": [
                {
                    "Net Elements": {
                        "Id": "08a",
                        "Length": 0
                    },
                    "OffsetFromstart": 0,
                    "OffsetToEnd": 0
                },
                {
                    "Net Elements": {
                        "Id": "157",
                        "Length": 128
                    },
                    "OffsetFromstart": 146824,
                    "OffsetToEnd": 146696
                }
            ]
        },
    "Position Switch": "Left (Reversed)"
    },
    "Observation": "BLOCCATO uno (CTC)"
}
```


Figure 4: Example of RBS data (IXL) published to the IL by using CDM/PSM.

4. Conclusions

This paper describes some of the most relevant aspects of the demonstrator of the communication platform for TMSs developed by the Shift2Rail H2020 OPTIMA project, focusing on the platform architecture and its integration Layer which lets a seamless communication between the RBS and the TM applications running into OPTIMA Application Framework or externally. The proposed architecture addresses the issues related to the interoperability, scalability, and sustainability of legacy TMSs due to lack of interoperable data structures and standardized communication interfaces. Furthermore, the derivation of a CDM suitable to ensure a standardized data format compliant with other proposed models is described. OPTIMA contributes to changing the paradigm of TCM/TMS solutions, to cope with increasing demand, improve the efficiency and contribute to Railway modernisation and digitalisation. Organisations involved in the development of high Technology Readiness Level (TRL 7) innovation will benefit of the outcomes, along with end-user rail stakeholder. In particular,

- Railway associations, by acquiring and promoting the new TMS knowledge and paradigm, can become a key participant in railways standardization groups.
- Rail suppliers, through their participation in the development of future TMS by implementing interoperable and standardized interfaces, services, and systems, will benefit of offering innovative products to IMs with a reduced time-to-market of the product, they
- Infrastructure Managers directly benefit the outcomes of flexible, proactive, standardized, and interoperable solutions resulting into more efficient traffic control model.
- Universities and research centres receive valuable feedback from the end-users' outcomes and knowledge to boost both quantity and quality future research and educational purposes, and to foster further collaborations with railways industries and organizations.

Currently, the demonstrator is under testing and validation and its performance will be evaluated against predefined Key Performance Indicators also by connecting prototypes developed by Shift2Rail X2Rail-4 complementary project.

Acknowledgment

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