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# Toward new generation railway Traffic Management Systems: the contribution of the OPTIMA project

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**Abstract**

Legacy Traffic Management Systems (TMS) lack interoperable data structures and standardized communication interfaces. The H2020 Shift2Rail OPTIMA project is developing a demonstrator of a communication platform for a new generation of TMS with advanced functionalities for improving the efficiency, effectiveness, and resilience of railway operations, as well as improved interoperability, modularity, and scalability. In this paper, this platform is described, along with its main components that provide seamless access to persistent and real-time data from heterogeneous data sources. A Common Data Model supports the automated data exchange process by means of a fully standardized structure for representing the data. Furthermore, the testing and validation of the OPTIMA platform and of connected TMS services when it is set up as a testing environment are illustrated.



*Keywords:* Railway Traffic Management Systems; Integration Layer; Common Data Model; Technological Demonstrator; Integration of networks and services.;

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## 1. Main text

The railway sector is undergoing a process of transformation driven by social changes, including greater inclusiveness and environmental emergency. The progressive digitalization and the availability of new ICT technologies are some of the enabling factors for this transformation by enabling the increase of the railway sector's efficiency, the effectiveness, and the attractiveness to passengers, and as a mode of freight transport, as described by Ruscelli et al. (2019) and Ruscelli et al. (2016).

**Nomenclature**

| | | | |
|---|---|---|---|
| AF | Application Framework | OVT | One Virtual Track |
| API | Application Program Interface | OW | Operator Workstation |
| CDM | Common Data Model | PIS | Passenger Information System |
| CPD | Communication Platform Demonstrator | RBC | Radio Block Center |
| IL | Integration Layer | RBS | Rail Business Services |
| ICT | Internet and Communication Technology | S2R | Shift2Rail |
| IM | Infrastructure Manager | TD | Technical Demonstrator |
| JSON | JavaScript Object Notation | TMS | Traffic Management System |
| KPI | Key Performance Indicator | | |

New generation railway TMS can provide an answer to some of the more compelling issues related to interoperability, multimodality, scalability, and sustainability. Indeed, the operation control centres currently adopt legacy TMS to monitor and manage their RBS like traffic, maintenance and energy systems, and external services like the weather forecast and the PIS. The absence of standardized communication interfaces and the lack of interoperable data structures require a lot of effort to be expended on keeping the systems updated, require duplicate development efforts to implement applications for different systems, and it prevents the connection of different types of TMSs. Consequently, the S2R Joint Undertaking [1] is promoting the development and the implementation of new technologies for railway TMSs. The S2R TD 2.9 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 for significantly higher integration of status information of the wayside infrastructure, trains, and maintenance services together with management of energy and other resources" (Shift2Rail JU, 2019). The development of the communication protocols and infrastructure, along with a testing environment where TMS applications can be tested are key milestones on the roadmap towards implementation of future TMSs. The testing environment needs to be remote from operational railway systems but should be able to use communication inputs that are representative of

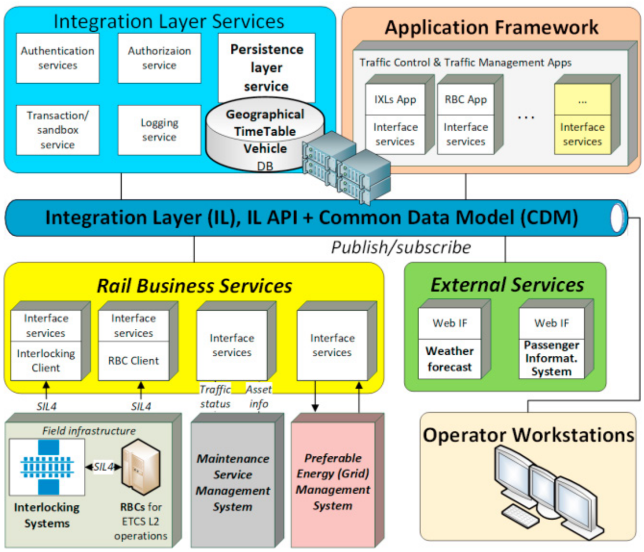


Figure 1 - General architecture of Communication Platform Demonstrator.

[1] https://shift2rail.org

operating railways and should allow the responses of the TMS to be monitored; in this way, the concepts and technologies developed can be tested and refined before trial implementations. The H2020 S2R OPTIMA (cOmmunication Platform for TraffIc ManAgement demonstrator) project (OPTIMA, 2019-2023) main goal is to address the S2R aims and it is closely linked to TD2.9. OPTIMA aims to design, implement and validate a demonstrator of a communication platform for the testing and validation of new industry solutions for new generation TMSs, as described by Cecchetti et al. (2022). OPTIMA provides a standardized communication system by means of an IL, which uses standardised and interoperable data structures and processes based on the definition of a CDM for the data exchange between different RBS and external services. The requirements' analysis of the related S2R projects (In2Rail, 2015-2018; X2Rail-2, 2017-2021), allowed the definition of the architecture of the OPTIMA CPD as shown in the Figure 1. This architecture is composed of the following main building blocks: the CDM, the IL, the RBS, the AF, and the OWs of the control rooms.

The core components of the OPTIMA architecture are the CDM and the IL. The former is responsible for providing standardized topics and interfaces for each subsystem involved in the communication process to ensure their interoperability and allows the extension of TMS with new functionalities (see Section 2.1). The latter is a communication system based on a publish/subscribe mechanism which offers seamless access to persistent data and real-time status data from heterogeneous sources with automated data exchange process, real time availability and configurable Quality of Service (QoS) levels. The IL uses standardised and interoperable data structures and processes based on the definition of a CDM for the data exchange between different RBS (such as field information from interlocking, RBC, maintenance services, energy stations), and external services (such as Passenger Information Systems, weather forecast services). An AF, connected through the IL to the rest of TMS components, offers a uniform deployment environment with a plug-and-play approach to deploy the various TMS services and traffic control applications into virtual machines or containers. The TMS system can be managed by means of standardized Operator Workstations which allow the operators to use any TMS application they are authorised to access on a single machine to monitor and control operations. A testing and validation phase using specific KPI derived from the requirements of the systems and of the OPTIMA complimentary projects, X2Rail-4 (2019-2023) and FINE-2 (2019-2023), is planned for the assessment of the OPTIMA Communication Platform Demonstrator and the TMS and services connected to the platform when it is set up as a testing environment.

The rest of the paper is organized as follow. In Section 2 the OPTIMA communication platform is described detailing its main components: the CDM (Section 2.1), the IL (Section 2. 2), the RBS (Section. 2.3) and the AF (Section 2.4). Then Section 3 describes the testing and validation activities. Finally, Section 4 concludes the paper.

## 2. OPTIMA Communication Platform

In this section the main components of the OPTIMA CPD will be described along with their functionalities.

### *2.1. The Common Data Model*

The proposed novel TMS hinges upon an Integration Layer (main outcome of OPTIMA), which in turn relies on a "data model" that provides a structure for the information exchanged. The development of such data models has been a long standing endeavour of the S2R Joint Research Undertaking, giving rise to successive versions of data models, lastly under the projects X2RAIL-2 and X2RAIL-4. Simultaneously, many efforts were expended by other organisations to develop models with different technical scopes (infrastructure only versus comprehensive railway system), phases (construction or operations) or business capability levels (traffic management or commercial operations). The overall trend is towards open models (public licenses) that can be used for purposes that are not restricted to the uses cases initially envisaged by their authors. The objective of LinX4Rail (2019-2022), an ongoing S2R project, is "to develop and promote a common Functional Rail System Architecture for the Rail sector, as requested by the European Commission. It will be supported by a widely adopted S2R CDM that will, with the commitment of the S2R members, establish the standard for interactions between legacy and new systems, thus ensuring sustainable interoperability between systems".

The OPTIMA project can be seen as a testbed for some concepts underpinning the CDM as explained in Magnien et al. (2022). The apparent ambiguity of letter "C" (Common or Conceptual) is no mistake: the CDM, in order to become "common", is assembled from an open set of shared models. The step from "shared" to "federated" implies model responsibility allocation and governance rules to be endorsed by all model owners: these aspects are outside the scope of OPTIMA. To become fit for many sorts of usages, rather than a limited set of use cases, the CDM must also be true to the other meaning of "C", namely "conceptual", by isolating concepts at the finest practicable level. Concept isolation applies to systems and their components on one hand, and to their specified, observed, or predicted properties on the other hand. Consequently, OPTIMA borrows from LinX4Rail the same set of shared models, including EULYNX, RSM, X2RAIL-4, TRANSMODEL, and IFC Rail. The X2Rail-4 model has a special status due to its distinct purpose and the formats adopted. It supports two serialisation formats, namely a human-readable format (JSON) and a binary format (Protobuf), which can be used interchangeably via API. Serving TMS use cases requires coverage of topics such as weather forecasts and train operations management, that are not (or not completely) covered by the shared models. Several strategies were experimented with and implemented for extending the CDM scope:

- *transforming ontologies into Unified Modeling Language (UML) packages and class diagrams*: weather phenomena description and forecasting benefited from such a transformation. The sources were the Climate and Forecast terminology, and the cff and cfm ontologies derived from that terminology. The transformation was performed "manually": opposite to ontology extractions so from UML to Web Ontology Language (OWL). The automated path from OWL to UML is not well explored, and OPTIMA is not the right framework for such experiments.
- *reverse-engineering existing data exchange formats*: the Telematics Applications for Freight/Passenger services (TAF) Technical Specification for Interoperability (TSI) managed by the European Railway Agency mandates an XML schema definition for messages concerning, inter alia, train traffic management. OPTIMA project promotes "eurocompatibility" of its CDM by extracting key concepts from the TAF XSD, to populate its own Operations package. For that purpose, the extensive documentation provided by the Railway Undertakings/Infrastructure Managers Telematics Joint Sector Group was put to use[2], in cooperation with their authors.

Considering the significant re-use of previous TMS developments, OPTIMA opted to use the X2RAIL-4 model for the Integration Layer. The pre-existing X2RAIL-4 model was extended according to the OPTIMA requirements. A pre-requisite was to leave the "legacy" schema unaltered. Two strategies were adopted for the extension:

- extension designed at conceptual model level (in UML), then manual transposition into the X2RAIL-4 JSON schema defining the X2RAIL-4 model;
- formalization of OPTIMA requirements, using a context-free grammar developed for that purpose, followed by semi-automated extension of the original JSON schema, and automated schema verification, as detailed in Magnien et al. (2022).

"Semi-automated" results from the tedious identification of requirements already satisfied. Such identification relies on lexical searches (coinciding class and property names) that easily fail (false positives as well as false negatives), in the absence of a shared dictionary of concepts. Such a shared dictionary is the aim of LinX4Rail Work Package 2 and is being developed under the UIC Ontorail project[3].

### *2.2. The Integration Layer*

The IL has been developed by using RTI Connext software framework (RTI), a commercial enhanced implementation of the Object Management Group (OMG) Data Distribution Service (DDS) – a middleware protocol and API standard for data-centric connectivity – and it includes the DDS API and network interoperability protocol. This product satisfies over 92% of the IL requirements set out in the In2Rail and X2Rail-2 project and partially satisfies the remaining ones. In this architecture the data producers can publish to the IL by using the provided service API based on DDS and a CDM which allow the interoperability of exchanged data. The IL software as developed, is composed of different components and layers:

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[2] http://taf-jsg.info/?page_id=32

[3] http://ontorail.brainz.ai:5000/ontorail

- *the IL-API "Core"*, which oversees all aspects of communication through the DDS API, and provides all low-level services for accessing to items (write, read, asynchronous read, lock, etc.) of the real-time database. It is the foundation of the IL API, on which the "IL-API command" layer is based, as well as all the higher-level application modules. All programs, wishing to use the OPTIMA CPD, need to interface with the IL API;
- *the IL-API "command"*, which provides services and operations for the command concept. It also offers a set of "native" agents that support several functions, such as management of the real-time database, management of commands (queries) involving the real-time database, and centralized processing of locking orders;
- *the CDM-API*, which provides all services for serialization/deserialization (encoding/decoding) of data item.

Publishing the data to the IL requires a two steps process: 1) call the codec library API to define the structure for the data to transmit, and then 2) proceed with the real connection to the IL by calling the IL-API. An example is offered by the RBS which will serialize the raw data coming from the field by calling the codec library with the appropriate Protobuf schema, as defined by the Platform Specific Model, and then they will publish the data through the IL API.

### *2.3. Rail Business Services and external services*

The OPTIMA CPD includes the following Rail Business Services: i) the interlocking systems, ii) two Radio Block Center enabled for ETCS level 2 operations, iii) the Maintenance Service Management System which provides information about maintenance operations and closures along the track, iv) the Energy Management System which interacts with Energy system and sub-stations which power trains on the track and the related subsystems. There are also two external services linked: the web interface to the service providing the current weather conditions and the weather forecast, and the Passenger Information System which offers information about the number of passengers on-board at each time/station, the capacity of the train, and the train connections. The original intention in the project was for each RBS to be linked to real field equipment at the Infrastructure Managers (IMs) premises. However, due to cybersecurity, safety policies and national public transport laws, no direct connection can be allowed to the IMs' ICT systems. This issue was mitigated by the following actions: i) collect 24 hours live log files from the field equipment and from the TMS; ii) anonymize the data; iii) upload the log files to the CPD; iv) develop a software layer named "Event player" which parses and filters the log files and then replays "as-live" all the events and information previously registered by the real system by publishing them to the IL at the correct time intervals as if the field equipment was connected directly to the IL (see Figure 2). As a side effect, only a one-way flow of data, from RBS through the IL to the TMS services, AF and other services can be achieved. Each one of the three IMs of OPTIMA consortium provides a set of data about different RBS: i) RFI (Italy) contributes the topology of the chosen representative line from Ventimiglia to Albenga (west coast of Italian Liguria region), the One Virtual Track (OVT), the timetables, the passenger information, and the information coming from the interlocking and RBC subsystem; ii) ADIF (Spain) contributes the information about, and data from, the Weather Forecast subsystem; iii) SZCZ (Czech Republic) gathers the data about the maintenance and energy subsystem. The data sourced from different IMs relates to different railway networks, therefore, an additional software layer, named "One Virtual Track", was added to each RBS: it coherently maps the data coming from ADIF and SZCZ to the geographical locations of the selected RFI railway track. The participating of three IMs ensures that interoperability between rail business services is considered throughout the development process.

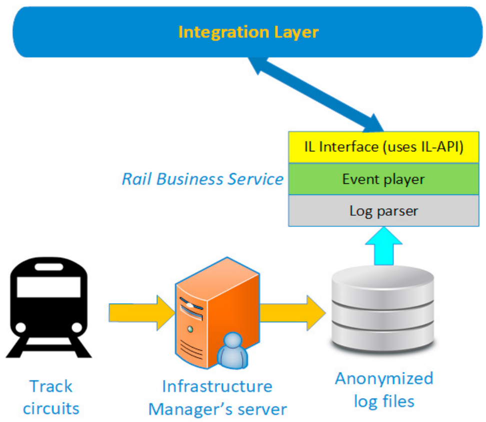


Figure 2 - A typical Rail Business Service architecture.

### *2.4. The Application Framework*

The AF provides an operating environment where TMS services and traffic control and management applications can be deployed. The objectives for the AF are: i) providing resource management to ensure high availability, ii) providing central monitoring and configuration to allow one "system" view on the deployed components, and iii) allowing separation of big monolithic applications into many fine-grained micro-services taking over the responsibility for fail-over, controlling, and monitoring of them. Due to the fact that the AF needs to be integrated with the OPTIMA CPD through the IL, it's necessary to develop a software wrapper around commercial off-the-shelf software. Moreover, because the new TMS paradigm requires that each service shall have its own runtime environment, and shall use specific deployment and testing procedures, an AF is needed to hide the complexity of service management from the user and to provide standardized runtime environments for running and management of containerized applications (services) covering the following lifecycle (main) functions: i) deployment, ii) monitoring (e.g., to detect a HW/SW failure), iii) start, stop, failover (e.g., restart a service on spare hardware), and iv) removal. The integration pattern for AF is based on i) the integration of Virtual Machines (VMs), where each TMS Service can be enclosed and isolated into a VM, and on ii) the integration of "Containers" where a TMS service is developed to be deployed within a container and the isolation of the process is implemented by the host Operating System (possibly even a hosting VM). Both of the integration patterns need an orchestration. In OPTIMA, the VMs are managed by VMware vSphere and vRealize Suite, which is the standard de facto for VM orchestration and deployment in the enterprise field.

OPTIMA also enables the deployment of the service using containers because there are already railways applications based on containers Ďuračík et al. (2019). A container is a unit of software that packages up code and all its dependencies, so the application runs regardless of the computing environment. The main advantage of containers over VMs is their lower resource requirements. Containers share the kernel of the operating system on which they run. However, the technology itself allows complete isolation of individual applications. To manage multiple containers simultaneously it was necessary to integrate the container orchestrator. Among the different alternatives available, Kubernetes, OpenShitft, and Docker swarm, the later was selected for this task. Docker swarm consists of two types of nodes, Master nodes which manages clusters, and Worker nodes which perform tasks (runs services). Docker swarm uses `yml` files called docker-compose to describe and configure services. To make the implementation compliant with the requirements of the OPTIMA project, basic services were configured and operated that enable the management of containers in AF: i) Docker image registry where images of OPTIMA TMS services are stored, ii) Portainer GUI management tool to administer and update or rollback services without downtime, and iii) IL Connector which provides basic information about the containers / services running and using the IL service.

## 3. Testing and Validation of the OPTIMA Communications Platform Demonstrator

The testing and validation process within the OPTIMA project consists of two main stages, i.e., (1) the testing of the OPTIMA CPD itself, and (2) the testing of novel traffic management systems and other services developed by industry within the complementary S2R projects. The second stage involves two aspects: one is validating the functionalities of the OPTIMA CPD as a communications platform and testing environment, the other is the validation of the systems and modules from other projects under test. Successful completion of both stages of the validation process will ensure the performance of OPTIMA CPD and its sub-systems satisfies the aims and objectives of the project and its potential end users, including that it is functional as a testing environment for TMS and services which are compatible with, and require, a unified communications platform to operate. The general testing and validation process adopted in the OPTIMA project is listed below, see Liu et al. (2021):

- *Requirement analysis*: analyses the requirements of the system and generates the KPIs that would be used for assessing the test results;
- *Validation planning*: organises and prioritises future validation activities, which will map the requirements and KPIs of the whole system into an ordered series of tests and validation targets;
- *Generation of test scenarios*: generates the test scenarios that establish the test conditions and processes, which will generate the data related to the KPIs and other data required assess the behaviour of the system against the requirements;
- *Test setup*: creates, provides and configures all essential data, interfaces, connections, power-supply, software, hardware, etc. to support the tests to be executed;
- *Test execution*: executes the tests with respect to the planning document and saves essential log files;

- *Evaluation of test outputs*: analyses and evaluates test results. If the KPIs for the system or component/module under test are not satisfied, the tested entity and its test results shall feedback to developers for revisions and updates;
- *Validation closure*: completion of all the tests and a full validation report.

In some cases, formal testing of the OPTIMA CPD will not be required or needed; these cases are those where the characteristics of the system developed can be checked for compliance with the requirements directly. The requirements for OPTIMA CPD to be considered in the validation process were established from complementary projects, pre-existing standards, railway interoperability requirements, as well as conventions for railway traffic management system, railway operational rules, the communication principle of interconnected sub-systems, etc. The KPIs identified and/or defined for the OPTIMA CPD mainly quantify or/and qualify the QoS of the whole CPD by evaluating the capability and capacity of the demonstrator to receive, prioritise, deliver, and save data supporting railway traffic management systems and connected services. Some example KPIs to evaluate system QoS for the OPTIMA CPD are shown in Table 1.

Table 1. Example of KPIs to evaluate system QoS for the OPTIMA CPD.

| KPI definition | Description | Expected value |
|---|---|---|
| Time to registration | The IL should provide a mechanism for Service Registration. A client application intended to provide a service registers itself at IL. | up to 1s |
| Mean time between failure | The operating environment hosting the IL, and the middleware part of the IL itself, shall be designed to enable operation 24 hours a day, 365 days per year. | as long as possible |
| Rate of correct routing (%) | The data should be routed to correct provider/consumer. The IL shall route requests to the correct provider, and data to correct consumer: The IL shall be able to route requests and messages to the correct service provider/data source, and the responses to the correct consumer. | 100% |

The requirements and KPIs for the TMS applications and services to be tested in the second stage are based on those determined for those applications and services in the projects they originated from. In the second stage of the validation process, further data for the assessment of the OPTIMA CPD against the requirements for the system will be generated, as well as data for assessing the performance of TMS applications under test. In addition to the testing in the first stage, the second stage includes testing the specific functionalities and general performance of the OPTIMA CPD to support the validation of novel traffic management applications developed by complementary projects. In both stages of testing, the OPTIMA CPD will be set up to communicate mock and real-time data to simulate railway operations on a section of real railway network modelled in the system. This will present the TMS applications and services with data similar to real-time data on an operating railway network, to enable the responses of those applications and services to be assessed. In some scenarios in the first phase of testing, where the important factors are the speed, accuracy and capacity of communication, the mock data might be abstract data. Table 2 shows the traffic management applications and services from the X2RAIL-4 project, which will be tested within the scope of the OPTIMA project as part of the validation process of the OPTIMA CPD and that of those applications and services themselves. This contributes to the wider objective of developing systems in line with the concept of having railway operating systems and services, specifically TMSs, connected to a common communication platform, to enable the improvement of railway operations and services, and of having the communication platform operate as a testing environment for the development and validation of the connected applications and services.

Table 2. Traffic management applications and services from the X2RAIL-4 project.

| Traffic management modules | Description | Developer in X2Rail-4 |
|---|---|---|
| Automatic Train Operation (ATO) | Generate real-time train speed profile based on railway infrastructure data and make relevant train control actions. . | ALSTOM |
| Graph Viewer | Visualisation of train movement in considered network or/and platform occupation in a station. | INDRA |
| Conflict detection and resolution application | Monitor and anticipate operational conflict between trains in junction, station, single track, etc. and make real-time timetable amendment decisions. | SIEMENS |

## 4. Conclusions

This paper describes the architecture and the functionalities of the CPD of the H2020 S2R OPTIMA project, in particular its main building blocks, the IL and the CDM that provides a seamless data exchange based on standardized data structures and interfaces. The implementation of the environment for the deployment of TMS applications, the AF, based on software containers is illustrated. Furthermore, the issues related to the integration of the different data sources from the different RBS provided by the three IMs involved in the project and the adopted solution based on OVT are explained. The paper also discusses the approach and methodology on testing and validation of OPTIMA project. The validation activities of this project will be performed in two stages, i.e., validation of the OPTIMA CPD itself, and as a virtual environment to validate novel railway traffic management applications developed by the X2Rail-4 project; the second stage will, thus, support the validation process for X2Rail-4. The outcome of this validation activity will be a CPD for future railway traffic management applications that ensures seamless access to real-time updates and persistent data from heterogeneous data sources with automated data exchange processes and communication of the outputs. This demonstrator has a Technology Readiness Level of 6/7 and will be part of S2R TD2.9, which will be used as a reference for new standardized and interoperable TMSs.

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