Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 62 (2022) 832–839

Transportation Research Procedia

www.elsevier.com/locate/procedia

24th EURO Working Group on Transportation Meeting, EWGT 2021, 8-10 September 2021, Aveiro, Portugal

Communication platform concept for virtual testing of novel applications for railway traffic management systems

Gabriele Cecchetti[a], Anna Lina Ruscelli[a] *, Piero Castoldi, Cristian Ulianov[b], Paul Hyde[b], Luca Oneto[c], Peter Márton[d]

[a]*Sant'Anna School of Advanced Studies – Pisa, Piazza Martiri della Libertà, 33, 56127 Pisa, Italy*
[b]*Newcastle University, Newcastle upon Tyne NE1 7RU, United Kingdom*
[c]*University of Genoa, Via Opera Pia 11a, 16145 Genova, Italy*
[d]*University of Žilina, Univerzitná 8215/1, 01026 Žilina, Slovakia*

Abstract

In recent years, the railway system has been facing the various challenges of the "digital age". To increase its attractiveness, capacity, sustainability, and security, it needs to improve its' everyday operational and planning process. This can be enabled using new generation digitised and automated Traffic Management Systems (TMS). Nowadays, railway dispatchers need a TMS that offers precise and real-time traffic information as fundamental condition for effective traffic management, and whose performance can be further improved by increasing availability and diversity of sources and data, for which an effective data management platform is required. The EU-funded OPTIMA project is designing and developing a communication platform to manage the connection between several services supporting TMS applications, also enabling their testing. It represents one of the steps required for the development and implementation of a new generation of TMS. This paper describes the concept for the OPTIMA platform which will link TMS applications used by railway dispatchers with infrastructure systems such as signalling and interlocking systems, maintenance, and energy management, as well as with data services (such a weather information) with the aim of providing standardised interfaces and common data structures as basis of a common and standardised communication.

Keywords: Railway; Railway Traffic Management Systems; Communication platform; Conceptual Data Model.

* Corresponding author. Tel.: +39 050 882016.
E-mail address: annalina.ruscelli@santannapisa.it

2352-1465 © 2022 The Authors. Published by ELSEVIER B.V.

10.1016/j.trpro.2022.02.103

1. Introduction

The Shift2Rail (S2R) Joint Undertaking (JU) is supported by the European Commission within the H2020 programme to create a cost efficient, high-performing, sustainable European railway transport mode toward a Single European Railway Area, by promoting research and innovations actions both for S2R members and non-members, with focus on specific topics organised in five Innovation Programmes (IP) and Cross-Cutting Activities (CCA).

A particular goal of the S2R Multi-Annual Action Plan (2015) within its Innovation Program IP2 is to develop and implement new technologies for Traffic Management Systems (TMS). The Technical Demonstrator (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, that aims at significant higher Integration of status information of the wayside infrastructure, trains, and maintenance services together with management of energy and other resources." Furthermore, the implementation of TD2.9 includes the "Task 2.9.7 Integrated Demonstrator", where: "To proof and validate the targeted achievements of the new TMS with integration of status information from different services a platform will be established".

Today, all major railway Infrastructure Managers (IMs) are using TMS, along with systems for energy management described by Ruscelli et al. (2017), maintenance management and advanced signalling. TMSs are used by dispatchers in the operation control centres acting on traffic, energy, and detector remote control, ERTMS (European Rail Traffic Management System) central point, video surveillance system. Such systems have been originated and introduced progressively in the railway environment, according to the needs deriving from the increase of traffic demands and for modernisation and replacement of existing systems, and according to the solutions that technological developments have put at the disposal of the relevant parties. Due to the progressive evolution, TMSs are different in each EU country and, even a single IM may have even different TMS for different areas. They are usually not fully interconnected so the maximum potential gains in operational efficiency cannot be achieved. Signalling is a typical example: the incompatibility between the systems adopted by different IMs has become a limiting factor for the competitiveness of railway compared to other transport modes. However, the development of European Rail Traffic Management System (ERTMS) shows how standardised interfaces (i.e. data structure and format, communication protocols and bearers) play an essential role in enabling the uninterrupted movement of train across the whole EU network. Based on ERTMS, there is a drive towards increasing the level of automation of trains on national and international railway networks, which would be most effectively achieved if implemented in a standardised and interoperable way as discussed by Ruscelli et al. (2019). The levels of automation in train operation are various, with the trend being from none, through automatic train control with the automated systems tacking the roles of the driver, and fully Automatic Train Operation (ATO), where the driver is mainly supervising and acting as a backup to the automated systems and, ultimately, to fully autonomous operation without human attendance. These levels of high automation require a high level of standardisation of data and communication procedures and would benefit from a new model of TMS. This new TMS model relies on the digitalisation of all its the inputs and outputs to enable the implementation of new features, such as advanced automated decision making and optimisation of traffic management, based on processing of large amounts of data from numerous sources as illustrated by Ruscelli et al. (2016). Moreover, TMS, energy management, maintenance management, signalling systems, are currently not yet interconnected in a complete and efficient way since they are normally based on non-standardised interfaces. For instance, interconnection with the maintenance system increases the efficiency of TMS; in particular, regarding cross border traffic, sharing maintenance information related to rolling stock is of vital importance to minimise disruptions and to ensure safety in a more efficient way. Furthermore, the existing interfaces of the TMS were not developed considering the scalability of the system and were generally limited to the core TMS as discussed by Kršák (2010). Therefore, the integration of new interfaces with additional rail business and information services will require a duplication of ICT resources and large recurrent expenditures. Another disadvantage of the current TMS is the lack of standardisation in their interfaces which does not allow for the potential advantages of interoperability of TMSs to be benefited from.

The main goal of the OPTIMA (cOmmunication Platform for TraffIc ManAgement Demonstrator) project, which started on December 2019, is to specify and design a communication platform using standardised data structures and processes to manage the communication/data exchange between the TMS and different services/clients and applications supporting the TMS, as well as connecting it to other operational systems. Consequently, OPTIMA is closely linked to TD2.9 and its communication 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 (2019) and FINE-2 (2019). In particular, the technical objectives of OPTIMA, in accordance with TD2.9, are:

- Support seamless and dynamic data exchange between the various rail services and for the information related to these, being permanently available on one common layer that will enable the improvement of the efficiency of the decision-making processes to achieve the targets for capacity growth, improved reliability, increased resilience, and cost reduction;
- enable new applications for Traffic Management and Traffic Control, including enabling the integration of new functionalities developed within S2R into the rail operation processes, allowing the optimisation of traffic flow and the decision making related to service delivery whilst minimising delays;
- integration of new technologies/functionalities, such as those developed under the S2R programme (ATO, Moving Block, Data provision/exchange for new advanced Maintenance Strategies, Freight Transport, and Passenger Information services);
- standardising of constituents and workflows inside a Control Centre: standardised Operators Workstation and a framework with “Plug & Play” features will enable increased efficiency and reduced costs with regards to control centres, and easy installation and operation of Applications;
- specify a Conceptual Data Model that will be used to define a “S2R” Data Model to enable the integration of legacy and future applications into one communication data structure.

2. The OPTIMA project methodology

The strategic objective of the OPTIMA concept is to develop a new communication platform that harmonises Traffic Management, Traffic Control, Asset Management, Maintenance operations, Energy (Grid) Control Systems, signalling field infrastructure and vehicles for signalling purposes (ETCS). The communication platform also provides a gateway for external clients such as Weather Forecast, Passenger Information System (PIS), and Freight logistics information systems, which will connect through Web Interfaces. It will also allow the integration of Freight applications in line with the scope of S2R CCA WA4.2.

The new reference architecture proposed by OPTIMA for the communication platform is in line with the architecture proposed in TD2.9, as illustrated in Fig. 1. It has been conceived as a system working as a middleware that provides all the functional blocks required for a seamless and standardised communication and data exchange between TMS services, from one side, and Rail Business Services and External Services, on the other side. The main components of OPTIMA communication platform are the Integration Layer (IL), the Application Framework (AF), the Databases (DBs) for the persistence layer (containing the data used), and the standardised Operator Workstations (OW) to be installed in the Control Centres.

The core component is the Integration Layer; it allows integrated and automated data exchange process and permanent real-time availability, supports multiple clients and allows seamless and dynamic exchanges between the various services. It also provides a gateway for the communication with external clients and services, like Weather Forecast and Passenger Information Services, by using web-interfaces (web-if). In particular, it can integrate existing functionalities of legacy service applications via adaptors, it can connect existing signalling infrastructure by the means of dedicated software (SW) clients connected to the IL through interface services, and it enables access to be granted to external clients and services to pre-determined relevant information available in the system via webservices.

This is achieved by using a communication infrastructure based on a real time messaging system utilising a publish-subscribe model with standardised topics and interfaces for internal and external communication between different subsystems, applications, and clients. The standardised and scalable system architectures, data structures, and process are based on the Conceptual Data Model (CDM) that is derived from the outcomes of Lighthouse project In2Rail (2019), and Shift2Rail projects X2RAIL-2 (2017) and Linx4RAIL (2019). In this way, the interoperability is guaranteed and the use of a common CDM allows the integration of legacy and future applications into one communication structure to be secured, and current and future interfaces to be managed. By cleanly separating the data model from the data storage implementation and enforcing a data storage structuring driven by the data model, it is possible to simplify the business processes, enabling rapid and cost-effective engineering and deployment as well

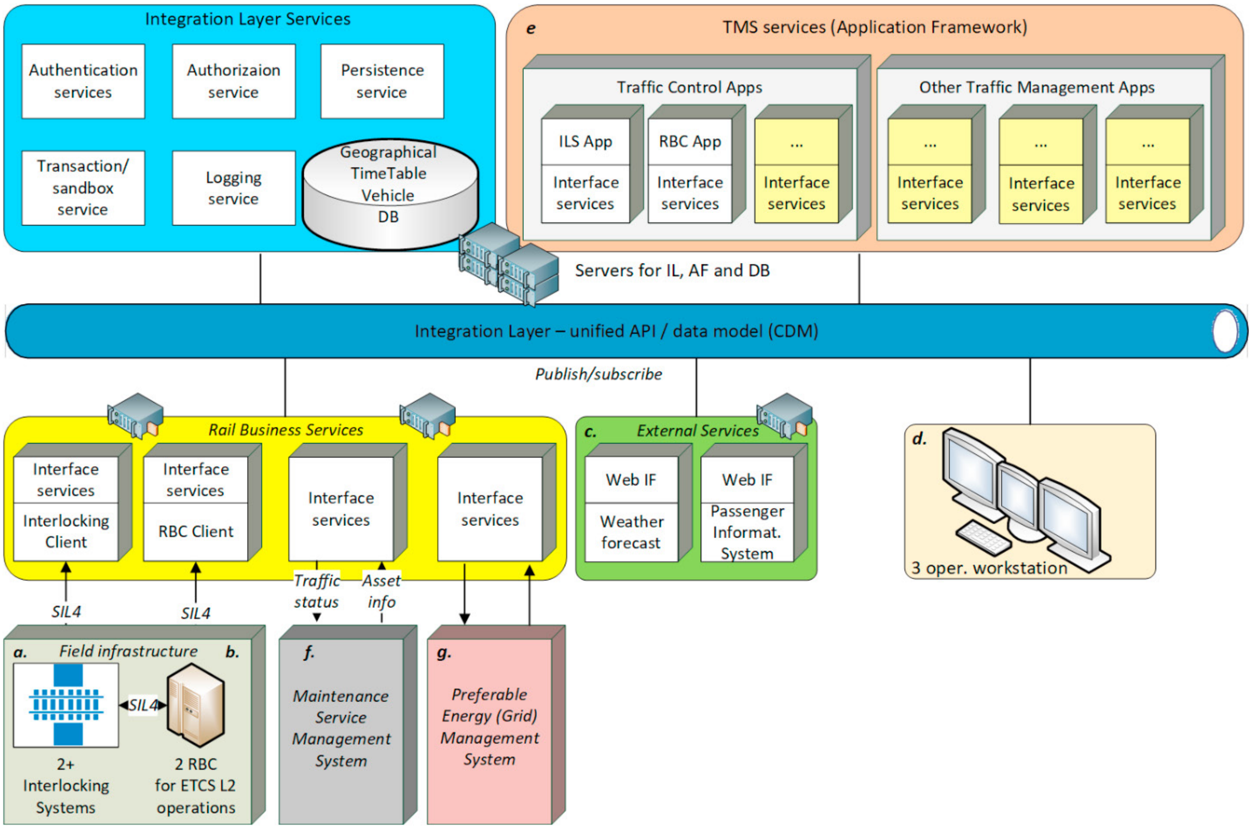

Fig. 1. General architecture of the OPTIMA new communication platform for TMS

as improved interoperability in line with improved upgradeability, scalability, and maintenance of the overall TMS and other rail services. Data definition, hence, depends only on business requirements; it is also usable by all software solution providers, no matter the technology they use. Moreover, the DBs provide the persistence layer to the collected data about geographical infrastructure, timetables and vehicles.

The AF connected to the IL forms a new communication environment allowing flexibility, easy installation ("Plug-and-Play") and administration of functional service application modules, Business Software Modules, Applications for TMS services, and Applications for Traffic Control and automated data exchange between them. These modules can be application or information systems running inside virtual machines or containers.

The OW will address the issue of having controls and operations deployed on multiple different machines, by offering a standardised desk with a large overview screen and a touch screen connected to the communication platform letting the operator to use any TMS application they are authorised to access.

In order to ensure the achievement of the planned OPTIMA project outcomes and the alignment with S2R, the project methodology and work strategy of OPTIMA defines three phases:(i) the preparation of the physical constituent components of the demonstrator;(ii) the development and implementation of the demonstrator;(iii) the validation of the demonstrator. The three phases of the project are as follows:

First phase: preparation of the constituents of the demonstrator. This phase consisted of a) analysis of requirements already outlined in the deliverables of previous related projects, i.e., In2Rail and X2Rail-2, b) generating the specification for the SW, HW and functionality to be developed, and c) procurement of tools & equipment (HW and SW).

All the three IMs involved within this consortium, ADIF (Spain), RFI (Italy), SZDC (Czech Republic), are actively performing Traffic Management and Traffic Control in dedicated Control Centres. They are providing real data relating to network infrastructure and trains. The network infrastructure data includes at least two sets of interlocking, two Radio Block Centres (RBCs) for ETCS Level 2 operation, the Maintenance Service Management System, and the Preferable Energy (Grid) Management Control System. Having three IMs, ensures a broader perspective with regard to interoperability between rail business services and the IL, as it provides a broader knowledge base of the field infrastructure interfaces needing to be connected to the IL, rather than just focusing on a single case.

Following the definition of the requirements and specifications, and preparation of the hardware (HW) and software (SW) tools required for the implementation of the Communication platform, the project is currently in the phase of demonstrator development.

Second phase: design and development of the demonstrator. During this phase, several simultaneous design and development activities are carried out:

a) Development of IL middleware, with its Applications Program Interfaces (API), services and interfaces to support the rail business services, the external sources (Web-If), the DBs, the CDM, the AF, the OWs and all specified communication and data management processes.
b) CDM implementation relevant to the exchanged data, which is setup according to the requirement analysis and delivered as a set of UML packages. It will be made available as XML files.
c) Structuring and definition of DBs that will follow CDM model and are responsible for the persistence of data within of the IL. To avoid the redefinition of the DBs each time that the CDM is adjusted, the mapping from the model to the DBs will be automated. One of the main requirements identified for the mapping design of the DBs is the prevention of loss of stored data during their evolution.
d) Development of Rail Business services development, composed by SW clients connected to field elements, and IL. SW clients could be developed by using emulators, software tools, network clients and log files depending on specific IMs requirements.
e) Provision of OWs linked with Integration Layer and Application Framework. The OWs will be used to visualize information, interact, and manage the Traffic Management and Traffic Control applications and prototypes hosted in the AF, or hosted remotely and connected to the IL.
f) AF development, which is linked with the Integration Layer and the OWs. It will host prototypes for Traffic Management and Traffic Control provided by complementary projects.

Third phase: validation of the demonstrator. The validation of the communication platform demonstrator consists of the internal validation of the platform, and the validation of the platform with the complementary projects' modules integrated on it. OPTIMA will provide support to the external activities of the complementary projects to facilitate the integration of their modules. The main activities of this third phase are listed below:

a) Develop a test programme to validate the functionality of the IL developed in previous steps and the integration of the single TMS modules, external services, and DBs, i.e. to verify that the IL is managing and exchanging data between itself and the modules and services.
b) Provide support, during the installation, commissioning, and testing phase of the X2RAIL-2, X2RAIL4 and FINE-2 prototypes.
c) Develop a test programme and test the Integration Layer and the traffic management demonstrator platform, with Traffic Management and Traffic Control modules developed by members of S2R integrated into the system; the test programme considers the performance indicators for the modules under test. Thereby providing a demonstration platform for those modules, and a further validation of the Integration Layer and traffic management demonstrator platform.

The validation activities will be carried out with respect to all relevant requirements identified from pre-existing standards, interoperability regulation, conventions for the TMS modules, external services and DBs and other sources (e.g., stakeholders practice, complementary projects, etc.). These requirements will determine the criteria and performance indicators for the validation of the Communication Platform, as well as the scenarios and use cases that will be designed to provide data for the validation of the system with respect to these criteria. This methodology will be used to set up the demonstrator platform with generic TMS test and associated clients/services and implement a test programme designed to verify functionality and performance of the system. In particular, if the system functionality and performance reach or exceed the validation criteria, then the development, integration into a functional TMS, and performance of the Communication Platform will be considered as validated. Furthermore, if the system is functional with the integration of the TMS elements from other S2R projects, such that those elements can be tested, the Integration Layer/Communication Layer and demonstrator platform will be considered further validated with respect to the requirement of being able to host external elements for testing. The validation of the Integration Layer/Communication Layer and demonstrator platform will exclude consideration of the performance of the system related to the characteristics of the external elements, as long as the system can support their operation, it will meet the requirements set for it.

3. Expected impacts and possible future research

OPTIMA will contribute to a change of paradigm regarding the ability of the Traffic Control System to cope with increasing demand of services, improve the efficiency, and contribute to railway modernization and digitalization. The expected impacts that OPTIMA will generate on railway ecosystem are as follows:

Train Traffic control: today's Traffic Control systems are designed to support the operations personnel's capacity to react to disturbances, and to solve problems and conflicts when they occur. The proposed AF will enable innovative business applications for Traffic Management and Traffic Control. Using the new communication environment, they will enable advanced processes and automated data processing to optimize the flow of traffic and the decision making to deliver the production timetable with fewer and less significant delays. This will increase the line capacity and improve the resilience of services to disruptions.

Operator/dispatcher workstation: which usually consists of several separated information systems, that allow only a limited sharing between different TMS applications and rarely form an effective collaborative working environment. The goals of OPTIMA are to provide a standardised OW from which an operator profile can be accessed, and any business client application can access to the whole data available in the system DBs that the application or operator is authorised to access. In this way the cost of the OW will be reduced both in terms of HW and SW, it will also reduce the training time for the operators and allow greater flexibility of the staff within the Control Centre.

Automation and predictive models: currently automatic support systems and predictive models are not predictable enough from the dispatchers' point of view and, in case of disturbances, the operator takes control over the situation, often having the automated system working against his/her mental plan. In some instances, the situation exists where the operator inhibits all the automatic functions in the affected area and solves disturbances manually, which increases exponentially the workload. The OPTIMA IL will realize the concept of a multi-skilled team working together on solving a problem, sharing data and responsibilities, as well as enabling automated systems making optimal decisions based on larger and more disparate data sets than a human operator could consider, or allowing a combination of human and automated responses to be developed. The AF will host innovative applications for Business Clients. To fully exploit their potential, the application will have access to, and be capable of analysing all the data stored in DBs thanks to the innovative CDM created by OPTIMA. Moreover, the distribution of traffic status fore-cast to asset management services will allow much better scheduling of preventive service & maintenance activities and increase the overall availability and reliability of infrastructure assets.

Passenger information: currently, this information is mostly provided at stations and is related to train schedules, rarely it is available on board and in case of disturbances information on the revised service plan arrives with significant delays, if at all. OPTIMA is integrating the PIS through the IL, for which purpose a CDM specific Business service will be created. The data available through the IL also offers the potential for freight customer information services, both in terms of offering and planning services, and providing real time service and logistics information, both for the customer and for the traffic control system to consider as an input to its' decisions.

System Integration: traditionally, a Control Centre for Traffic Management and signalling application is physically separated from non-critical management systems (Maintenance, SCADA, CCTV) as well as from external systems. The OPTIMA AF will be compatible with critical and non-critical business services: all the applications will potentially be accessible from any Workstation with the correct authorisations, with access controlled with appropriate login and key management. Moreover, seamless updated status information of all the rail infrastructure assets and vehicles will allow automated and optimized decision processes for traffic regulation applications to deliver the production timetable with fewer and less significant delays.

Standard interfaces and data structure: nowadays the TMS systems are developed by different suppliers according to the needs of an individual IM, and built over proprietary solutions, not compatible with other systems, except for some communication interfaces and standardized applications (e.g. SCADA). OPTIMA aims to provide a solution suitable for any railway operation, thus saving time-to-market costs and assuring interoperability. The standardization of the frameworks, data structures and interfaces will deliver a reduction of the investment for new integrated installations linking several functional rail services such as Traffic Management, Maintenance Management and Energy Supply. Moreover, it allows an IM greater independence of the technological suppliers, resulting in a reduction in implementation and maintenance costs.

The ability to concentrate all the railway related data will be a fundamental enabler of the development of state-of-the-art technologies for storing historical information and exploiting it to be able to extract new actionable information. Furthermore, their application suggests further directions of investigation, for instance in the context of Machine Learning and Data Mining (ML&DM) techniques and Big Data Collection, Management, and Fruition Systems (BDCMS). Indeed, recent technologies for BDCMS allow the collection, storage and accessing of huge amounts of data from different and heterogeneous sources. Software frameworks for distributed data storage and processing like Hadoop by Shvachko et al. (2010) and Spark by Zaharia et al. (2012) and their ecosystems allow to easily access data in different formats from different sources, to create and to process big data sources with reference to the phenomenon under examination. Moreover, recent advances in ML&DM have remarkably improved our ability to extract meaningful and actionable information from them. Deep by Goodfellow et al. (2016), Multi- Task by Evgeniou (2004), Transfer by Pan and Yang (2010), Semi-Supervised by Chapelle et al. (2006) learning algorithms together with rigorous statistical inference procedures by Oneto (2020) allow us to transform huge amounts of distributed and hard-to-interpret pieces of information into meaningful, easy to interpret and actionable information. Moreover, recent advances in the field by Dwork (2008) showed that it is possible to learn from data while maintaining the privacy of the data itself.

Contemporarily, computer applications in industries have undergone a drastic change, solving complex problems to support the human decision-making processes, or to fully automate them. Model Based Reasoning proved to be an effective tool for solving hard optimization problems – see, e.g., Dodaro et al. (2016), Leone and Ricca (2015) – by encoding an application problem as a logical specification evaluated by a general-purpose solver, whose answers can be mapped back to solutions of the initial application problem by Russel and Norvig (2010), Baral (2010), Brewka et al. (2011).

All these technologies can be employed to improve many railway aspects: from maintenance to circulation, from conflict resolution to crew scheduling, from energy optimization to users confront improvements.

4. Conclusions

In this paper a new European project, OPTIMA, which started in December 2019 under the Shif2Rail programme, is presented, describing its aims and highlighting its main expected contributions to the railway domain. OPTIMA, operating in coordination with other S2R projects with the aim of boosting European railway transportation, will contribute to a significant improvement of the efficiency of TMS; it will propose the specification and design of an innovative Communication Platform. Standardized data structures and processes will enable the management of the Communication/Data exchange between different services/clients and to support TMS applications connected to other multimodal operational systems. A Conceptual Data Model will be used to define the data structures and to secure the integration of legacy and future applications into one communication structure.

This approach makes possible cross border interconnections, efficiently supporting the uninterrupted movement of trains, and the implementation of user-friendly interfaces and access point for railway customers with enhanced functionality.

The improvement facilitated by OPTIMA will rely on the interconnection of different kinds of systems, belonging to different Infrastructure Managers, through a standard platform and harmonised data structures. Indeed, the new interconnection platform must be able to integrate all different technical and operational systems into a single unit, offering increased performance. The interconnection will also put in place standard interfaces external to the railway system but accessible for customers, offering increased performance, friendliness of use, respecting as much as possible the current methodologies.

OPTIMA will develop a traffic management demonstrator platform and generate experience of operating it both with TMS test elements and TMS elements developed by other Shif2Ral projects. The experience and demonstrator platform technology will be placed at the disposal of other TMS developers with access to the outputs of the project to enable them to learn from the experience obtained in the project, enabling them to develop, and have a testing platform for, advanced automated TMS of the future.

Acknowledgements

This work has been supported by OPTIMA H2020 Shift2Rail European project (Grant Agreement n. 881777).

References

Baral, C., 2010. Knowledge Representation, Reasoning and Declarative Problem Solving. Cambridge Univ. Press.

Brewka, G., Eiter, T., and Truszczynski, M.,.2011. Answer set programming at a glance. C. ACM, 54(12):92–103.Chapelle, O., Scho ̈lkopf, B., and Zien, A., 2006. Semi-supervised learning. MIT press Cambridge.

Dodaro, C., Gasteiger, P., Leone, N., Musitsch, B., Ricca, F., and Schekotihin, K., 2016. Combining answer set programming and domain heuristics for solving hard industrial problems (application paper). TPLP, 16(5-6):653–669.

Dwork, C. 2008. Differential privacy: A survey of results. In Theory and applications of models of computation.

European Commission White Paper on Transport, 2011. https://ec.europa.eu/transport/sites/transport/files/themes/strategies/doc/2011_white_paper/white-paper-illustrated-brochure_en.pdf

Evgeniou, T., Pontil, M., 2004. Regularized multi–task learning. In: International conference on Knowledge discovery and data mining, Seattle, Washington, USA, 109-117.

Goodfellow, I., Bengio, Y., Courville, A., 2016. Deep learning. Vol. 1. Cambridge: MIT press.

In2Rail, 2015, Innovative Intelligent Rail, https://cordis.europa.eu/project/id/635900

Kršák, E., Bachratý, H., Polach, V., 2010. GTN – Information system supporting the dispatcher and remote tracks control. Communications 3A/2010, 64-74.

Leone, N. and Ricca, F., 2015. Answer set programming: A tour from the basics to advanced development tools and industrial applications. In Reasoning Web.

Linx4RAIL, 2019. System architecture and Conceptual Data Model for railway, common data dictionary and global system modelling specifications, https://cordis.europa.eu/project/id/881826

Oneto, L., 2020. Model Selection and Error Estimation in a Nutshell, Springer.

Pan, S. J., Yang, Q., 2010. A survey on transfer learning. Knowledge and Data Engineering, IEEE Transactions on, 22(10):1345–1359.

Ruscelli, A.L., Cecchetti, G., Castoldi, P., 2016. Cloud Networks for ERTMS Railways Systems (Short Paper), 5th IEEE International Conference on Cloud Networking (Cloudnet), Pisa, Italy, pp. 238-241, doi: 10.1109/CloudNet.2016.33.

Ruscelli, A.L., Cecchetti, G., Castoldi, P., 2017. Energy harvesting for on-board railway systems, IEEE 5th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), Naples, Italy, 397-402.

Ruscelli, A.L., Fichera, S., Paolucci, F., Giorgetti, A., Castoldi, P., Cugini, F., 2019. Introducing Network Softwarization in Next-Generation Railway Control Systems, 6th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), Kraków, Poland, pp. 1-7, doi: 10.1109/MTITS.2019.8883348.

Russell, D. J., and Norvig, N., 2010. Artificial Intelligence - A Modern Approach 3rd edition. Pearson Education.

Shift2Rail Joint Undertaking Multi-Annual Action Plan, 2015. https://shift2rail.org/wp-content/uploads/2013/07/MAAP-final_final.pdf

Shvachko, K., Kuang, H., Radia, S., Chansler, R., 2010. The hadoop distributed file system. In: 2010 IEEE 26th Symposium on Mass Storage Systems and Technologies (MSST), Incline Village, NV, 1-10.

FINE-2, 2019. Furthering Improvements in Integrated Mobility Management (I2M), Noise and Vibration, and Energy in Shift2Rail, https://cordis.europa.eu/project/id/881791

X2RAIL-2, 2017. Enhancing railway signalling systems based on train satellite positioning, on-board safe train integrity, formal methods approach and standard interfaces, enhancing Traffic Management System functions, https://cordis.europa.eu/project/id/777465

X2RAIL-4, 2019. Advanced signalling and automation system - Completion of activities for enhanced automation systems, train integrity, traffic management evolution and smart object controllers, https://cordis.europa.eu/project/id/881806

Zaharia, M., Chowdhury, M., Das, T., Dave, A., Ma, J., McCauley, M., Franklin, M. J., Shenker, S., Stoica. I., 2012. Resilient distributed datasets: A fault-tolerant abstraction for in-memory cluster computing. In: USENIX Conference on Networked Systems Design and Implementation. San Jose, CA, 2.