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Railway system Digital Twin: a tool for extended enterprises to perform multimodal transportation in a decarbonization context

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Abstract: To achieve our long-term goal of doubling the modal share of freight transport by rail and develop multi-modality in transports in France, a fine control over the railway network management is required to better synchronize rail transport with other modes of transport e.g., cars, trucks, trams. The Digital Twin (DT) of the railway system and the extended enterprise are central concepts in our approach to answer this problem. Our method aims at giving access to our railway system’s Digital Twin through a Service Oriented Architecture (SOA). This architectural choice facilitates seamless communication and interaction with our partners, fostering a dynamic exchange of information critical for effective multimodal transportation planning. This article describes our approach with a successful implementation of an initial version of our infrastructure Digital Twin, complemented by services designed to meet the diverse expectations of users. This milestone underscores our commitment to leveraging cutting-edge technology and collaborative frameworks to enhance railway management, promote sustainable transportation practices, and contribute significantly to the reduction of GHG (Greenhouse Gas) emissions. As we continue to refine and expand our Digital Twin capabilities, we remain dedicated to advancing the future of intelligent and eco-friendly transportation systems.

Keywords: *Digital Twin; Decarbonization; Railway system; multi-modality of transport; Extended enterprise; Shared digital representation.*

1 Introduction

Transport accounted for 25% of EU greenhouse gas (GHG) emissions in 2018. The emissions of this sector come primarily from road transport (72%), while marine transport

and aviation represent shares of 14% and 13% of emissions, respectively, and rail a share of 0.4% (emissions by diesel trains only) [9]. Apart from their direct contribution to global

warming and air pollution, emissions that take place during the production, transmission and distribution of energy used by trains and aircraft are also considered. Transportation also leads to non-exhaust emissions of air pollutants, such as those generated by the wear and tear of brakes, wheels, tires, and railway tracks.

In the light of the above, it appears that rail transportation has less impact on the environment compared to other modes of transport in terms of GHG emissions (diesel locomotives represented only 0.4% of EU transportation GHG emissions in 2018). Unfortunately, the modal share of rail transport is yet currently the least important compared to all the other means of transport. This could be explained by the complexity of the railway network, which embraces current struggles to manage issues such as network aging, optimization in the use of assets.

The aim of the paper is to present a possible way of performing multimodal transportation in the framework of an extended enter-

prise using the concept of DT. This DT is a facilitator for managing and monitoring the railway system, which includes for instance: transportation plan, planned train scheduling and related real-time adjustments, network requirements, network physical assets, the supply chain and maintenance data. The DT also facilitates collaborations between partners, which is crucial in our context, since multimodality of transports entails a diversity of stakeholders working together e.g., Infrastructure Managers, Operating and Logistics companies. In this short paper, our objective is to describe the implementation of our DT, which natively supports an extended enterprise model required for data exchanges between all partners. In section 2, we will start by giving an overview of transport multimodality. We will then explain in section 3 our DT architecture in details. Finally, in section 4, we will discuss the different kinds of services that the DT can deliver to stakeholders involved in multimodality of transports.

2 Multi-modality of transport (rail transportation)

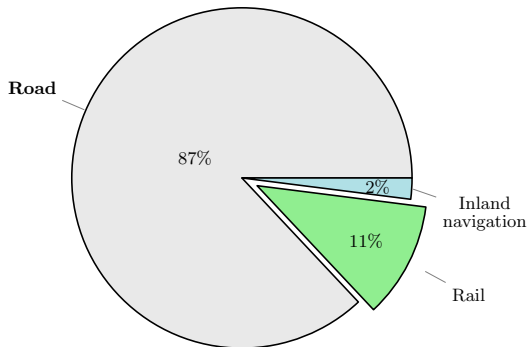


Figure 1: Modal split of different modes of transport in France [5].

In France, the various modes of transport are responsible for 28.7% of national GHG emissions, equivalent to 113.6 million tons of CO₂ [1]. Among the various modes of transport, rail transport has the lowest emissions (e.g., 0.4 Mt CO₂-eq vs. 28.6 Mt CO₂-eq for heavy goods vehicles).

To reduce these emissions, European authorities have already begun to work on de-

carbonization strategies and programs. For example, the French government has set up a national strategy for the development of rail freight. This strategy is a roadmap for rail transport but can also be applied to other modes of transport [11]. The expansion of the rail network in France must be carried out in close collaboration with managers of other modes of transport. Although road transport today emits an enormous quantity of greenhouse gases, it is still the most widely used mode of transport in France, because the distribution between the different modes of transport favors it and as it is accessible everywhere in the country (see Figure 1). To promote decarbonization of the various modes of transport, it's clear that managers of the different modes of transport at national, European, and even international level need to work together to put in place a global strategy to meet these environmental challenges. According to [11] and [6], the transport mode

that emits the fewest greenhouse gases is rail transport, which is why it is so important to favor rail transport over other modes of transport, in the interests of decarbonization. For the industry, it is essential to be more efficient in terms of the services it delivers to its customers, whether passengers or freight. In the context of rail transport in France, we have set

ourselves the goal of doubling the modal share of rail transport by 2030 [10]. The development of this mode of transport must be based on three essential pillars: (1) the optimization of the existing network, (2) the regeneration and modernization of the network, and (3) the provision of customer services tailored to their needs.

3 Description of the railway system Digital Twin at SNCF Réseau

In this section, we first present the technical architecture we used at SNCF Réseau to implement our Digital Twin; we detail why the latter addresses questions of Data Governance and multi-stakeholder access. Secondly, we state the principles we selected to create

a shared digital representation of the railway system, stored as data within the DT. Lastly, we mention how to create adapted services, also as part of the DT, to fulfil the expectations of each stakeholder in terms of information about the railway system.

3.1 Proposal of a Digital Twin architecture in the context of an extended enterprise

At SNCF Réseau, the Digital Twin is becoming the cornerstone of the Information System: the DT gathers, into a unique source of information, all company's data regarding the entire lifecycle of the railway system. The purpose of this unique source of information is to guarantee both the unicity and the accuracy of each datum, which are two quality characteristics essential related to data governance. Data Governance is however not part of the scope in this paper, it is still important to mention it since its principles led to the establishment of the DT as a unique source of information at SNCF Réseau. Furthermore, the latter is a prerequisite to implement a digital continuity as a founding principle for exchanges of data flows within the company (e.g., between several entities in the company, several digital tools), as well as

exchanges between SNCF Réseau and other companies (e.g., partners, suppliers, operating and logistics companies). Therefore, the DT represents an asset for stakeholders ensuring activities at SNCF Réseau or in relationship with our company. Multimodal transportation requires several companies exchanging data together, such as in an extended enterprise. In our case, stakeholders access the DT according to a Service-Oriented Architecture (SOA) and more specifically a Representational State Transfer (REST) Architecture [2], [12]. Clients request data stored in the repository of the DT through web-services, as shown in Figure 2. Moreover, depending on the profile of the client, the data access could be restricted to a given scope or limited to reading only, if necessary.

3.2 Production of a shared digital representation of the railway system

To produce this previously mentioned shared digital representation of the railway system,

contained within our DT (i.e., precisely in the set of the DT repositories), we need a

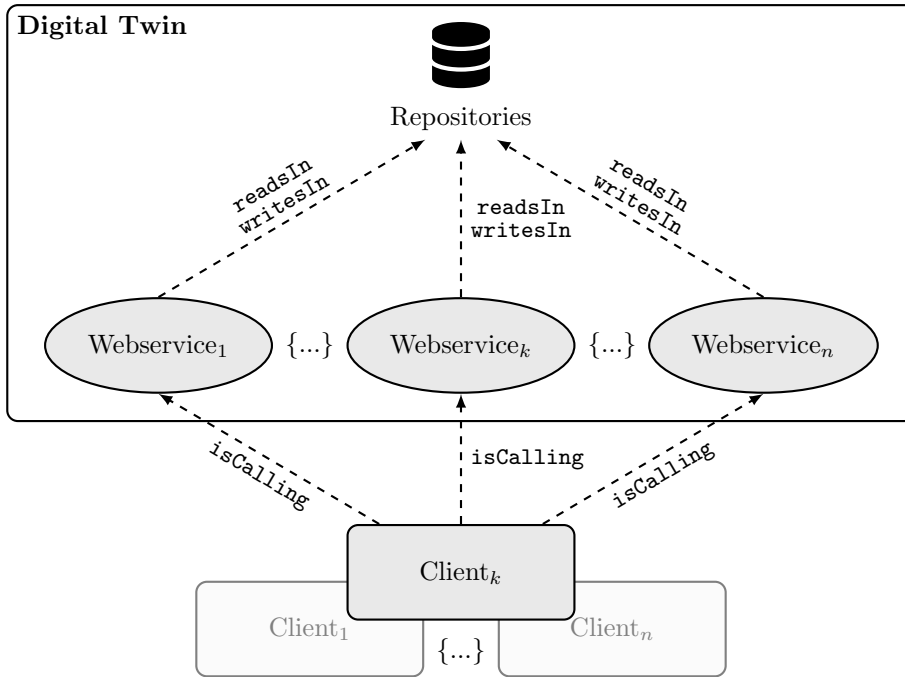


Figure 2: Diagram of the technical architecture of the railway system DT at SNCF Réseau.

global model which describes all the concepts and relationships involved in this representation. At SNCF Réseau, this global model is named “ARIANE” [14]. It is made up of UML classes and is produced using the systemic and object-oriented approaches [13], [8]. Particularly, the shared digital representation

is instantiated from “ARIANE” following the class – instance relationship in object-oriented programming [7] as shown in Figures 3 and 4. In addition, the production of “ARIANE” lies in the application of the Object Management Group (OMG) modelling standard called Model-Driven Architecture (MDA).

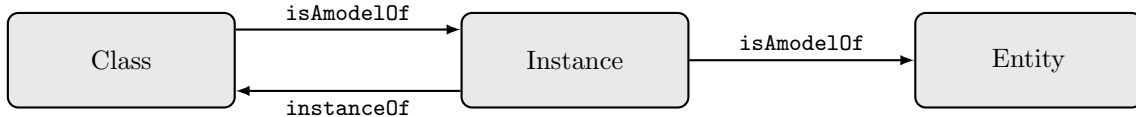


Figure 3: Metamodel representing the instantiation/representation relationships between the different concepts that we use to handle the actual railway system along with related models.

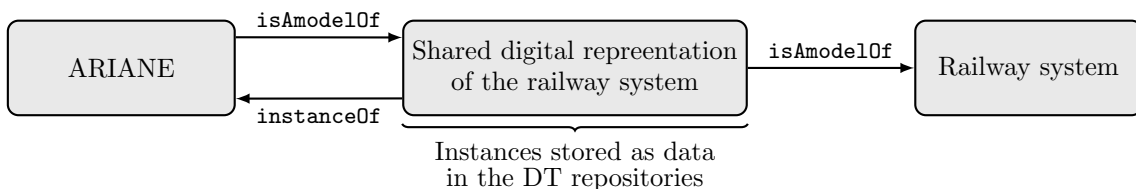


Figure 4: Shared digital representation of the railway system, produced with “ARIANE”, in conformity to the upper metamodel.

3.3 Views upon the shared digital representation of the railway system

Web-services could process personalized, filtered and easily interpretable high-value information: based on data contained in the shared digital representation of the railway system, services could offer to each stakeholder a dedicated “view” on the railway system that fits its specific needs and use-cases, by containing

all the necessary pieces of information in the required format. This is possible thanks to the Model View Controller pattern, described in [3]; several views can be constructed upon the same shared digital representation of the railway system.

4 Digital Twin for supporting multi-modality of transport

In this section, we will be using digital twin technologies to meet the challenge of multi-modal transport, known as combined transport. Combined transport involves using rail or ship to transport goods in containers, which are then transported by truck for the last few kilometers. Intermodal transport offers an energy-efficient logistical solution for modal shift. It is particularly relevant over long distances [6].

The digital twin provides a real-time representation of the state of the railway infrastructure [4]. From this representation, the railway infrastructure manager can know exactly how much capacity is available to run trains. This information is based on a combi-

nation of different sources of information, and therefore on the processing of heterogeneous data. Using diverse data sources, the Railway Infrastructure Manager can collaborate with managers of other transportation modes to extend coverage to areas not currently served by rail transport. To achieve this, we can share the necessary data with other transportation mode managers to facilitate coordination regarding the most suitable mode for passenger or freight transport, taking into consideration the previously mentioned criteria such as CO₂ emissions e.g., a single train emits three tons of CO₂, which is equivalent to the amount of emission generated by forty-five trucks [9].

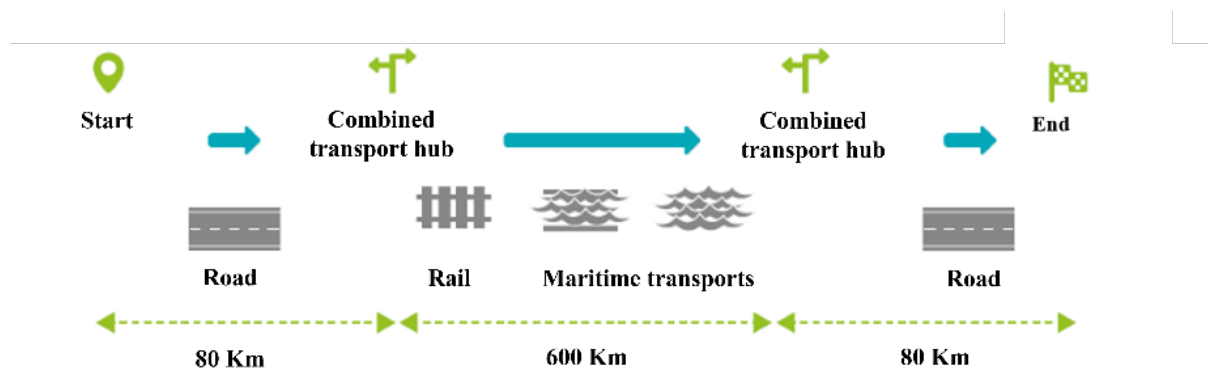


Figure 5: Example of combined transport involving rail, maritime, road modes [9].

5 Conclusion

In this paper, we highlight the pressing necessity to reduce greenhouse gas (GHG) emissions within the transportation sector, accounting for a quarter of the GHG emissions of the European Union in 2018. Rail transportation is a sustainable eco-friendly option for reducing GHGs in transportation, but it has not yet surpassed road transportation in terms of its usage. Using a multimodal transportation approach, which combines long-distance rail with road transport for the final kilometers, seems to offer an efficient solution for environmentally friendly door-to-door trans-

portation with reduced GHG emissions. Multimodal transportation entails multiple companies and stakeholders working together following an extended enterprise model. Therefore, these stakeholders must exchange accurate and up-to-date data about the railway system. To address this question, we introduced a Railway System Digital Twin solution to centralize all data related to the railway system at SNCF Réseau. The data of this Digital Twin will be accessed through services that can be utilized by stakeholders who contribute to multimodal transportation.

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