Retrospective on the Digital Twin concept and perspectives for railways: the case of SNCF Réseau

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1 Introduction

Digital Twins (DTs) represent high potential solutions to answer digital transformation questions in organizations such as companies. DTs could indeed perform monitoring, simulation, computer-aided decision and optimization regarding a given system of interest through a digital system that mirrors this system of interest. In this short paper, we propose a twenty-year retrospective on the DT concept before stating remaining questions: (1) there is yet no consensus on the DT definition neither in industry nor in the field of research dedicated to DTs [7, 9]; (2) a DT implies digital models but hardly any generic frameworks, methods or norms exist yet regarding a model-based standardized production of DTs [7, 9, 2]. Then, we briefly share our vision of the DT concept in the railway context along with the methods we used to produce our DT as part of our information system at SNCF Réseau.

2 A retrospective on the Digital Twin concept

According to Barricelli et al. [1], Madni et al. [5], Kritzinger et al. [4] and Zhang et al. [9], the first signs of the DT concept appeared in the early 2000s with Michael Grieves' contributions to Product Lifecycle Management (PLM). First, we have elements in his presentation "Conceptual Ideal for PLM" then secondly, his white paper described the three main aspects of a DT: a real space, a virtual space, and a data flow that connects the two spaces together [3]. Still according to [1], a decade later NASA also attempted to define the concept of DT focusing on aerospace industry needs. Twenty years after the first signs of this concept, DTs are now emerging in manufacturing, aviation and healthcare [1]. Indeed, DTs allow to performing monitoring, simulations, predictions and optimization of systems.

Following these achievements, what is the situation about the DT concept definition to date? Barricelli et al. conducted a survey about DTs with a part dedicated to DTs definitions. According to their results, among the

seventy-five papers reviewed in their study, thirty-one provide a definition of the DT concept. The authors of the study classified these definitions in the following topics: (1) "*Integrated system*" (2) "*Clone, counterpart*" (3) "*Ties, links*" (4) "*Description, construct, information*" (5) "*Simulation, test, prediction*" (6) "*Virtual, mirror, replica*" [1]. As for Kritzinger et al., they defined the concepts of *digital model*, *digital shadow* and *digital twin*, depending on the integration level of a physical system with its related virtual twin i.e., disconnected, one-way or both-way automated information flow [4]. In addition, Wright and Davidson highlighted the difference between a model and a DT [8].

We have summarized DT characteristics recurrently found in definitions within the three following aspects:

Digital representation of a system: Users might want to *represent* a given system digitally. According to Madni et al. a DT could be considered as a "*precise and up-to-date representation of a physical twin that also reflects the operational context of the physical twin*" [5]. These latter authors state: "*the digital twin represents an instance*", in other words a specific system, "*while virtual models tend to be generic representations* of such systems [5].

Information flow: (between a system and its corresponding digital representation) Users might either want to *monitor* a given system and therefore, data should be collected from sensors placed on this actual system in order to process information about its state at a given point in time. Thanks to the potential of the *Internet of Things* (IoT), it is easily possible to remotely acquire data from sensors. Tao and Qi highlight that it could be difficult to "*aggregate data from thousands of sensors that track vibration, temperature, force, speed and power, for example*" considering that "*data can be spread among many owners and be held in various formats*" [7].

Simulation of a system, predictions and decisions: Users might also want to *anticipate the behavior* of a given system. In order to do so, simulations could be conducted thanks to digital models. In addition, statistics and artificial intelligence algorithms may be useful to obtain likely future statuses with simulations based on the current knowledge of the system. The goal is then to use predictive analytics to anticipate major unplanned changings (e.g., failures) by taking informed decisions [1].

3 Remaining questions according to our analysis

First, it appears that there is no consensus on the definition of the concept of DT, neither in industry nor in academic research [9, 2]. As stated by Tao and Qi: "*Even the definition of digital twin is not settled*" [7]. In fact, we conjecture that multiple definitions of the DT concept exist because stakeholders define it depending on the applications they aim to realize with this DT e.g., monitoring, simulations, predictions. The definitions reviewed in section 2 illustrate well this problem: the concept of the DT is approached with use cases and not by defining its very nature. By the way, Barricelli et al. state "*literature works have never described in detail the characteristics of a generic DT. Indeed, each state-of-the-art paper concentrates on the development of few components of DTs*" [1].

Secondly, the cornerstone of any DT is a generic digital model and consequently a semantic model; to quote Tao and Qi: "*To build a digital twin of an object or system, researchers must model its parts*" [7]. Models bring the required semantics regarding the system of interest. Semantics are crucial to shape the DT: these are necessary to logically store and access the data related to the represented system in the DT.

However, there is here an underlying problem: to the best of our knowledge, no generic framework or methods exist yet to produce a model-based DT except [9]. This has already been pointed by Tao and Qi: "*Each model is built from scratch: there are no common methods, standards or norms*" [7].

4 Insights of the SNCF Réseau industrial case

In order to establish a *railway system* DT at SNCF Réseau, we first proposed to define the Digital Twin as a *digital representation of system* i.e., the railway system in our case. Furthermore, this digital representation has to be *shared* among all stakeholders working in collaboration with the railway system. Thanks to our definition, we produced our DT as a *shared digital representation of the railway system*, which is part of the information system of the company. Our DT is both manually and automatically updated by end-users, data managers and IoT. It is produced according to object-oriented principles, following a class-instance relationship. From an implementation perspective, our DT could be considered as a *set of instances generated from a global and systemic class model*, stored in repositories and accessible through *services* (i.e., RESTful web-services developed according to a Service-Oriented Architecture). These services process personalized and easily interpretable high-value information for end-users. At SNCF Réseau, this global and systemic class model is named "ARIANE" and is produced using the systemic and the object-oriented approaches with Model-Driven Engineering techniques. "ARIANE" is a reference model for railways that is now embraced by the International Union of Railways standard called "Rail System Model" [6].

5 Conclusion

The lack of consensus about the definition of the DT concept is causing sensitive issues for concrete industrial applications. As a result, we proposed a definition valid in our railway context, which we hope as generic and reusable as possible. In addition, the production of a DT necessarily implies a model to be based on. However hardly any generic framework or methods exist yet to produce a model-based DT. To pave the way of the establishment of such generic framework, we mentioned insights from our industrial case at SNCF Réseau focusing on the production of the railway system DT. We employed systemic and object-oriented approaches, utilizing Model-Driven Engineering techniques.

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