Application of Digital Twins in Port System

Haiyuan Yao1,2*, Dachuan Wang1, Mengchao Su1 and Yue Qi1,2

1Division of Waterway Planning, Transport Planning and Research Institute, Ministry of Transport, Beijing 100028, China
2School of Civil Engineering, Tianjin University, Tianjin 300072, China
*Correspondence: Building 2, 6A Shuguangxili Chaoyang District, Beijing, China
Zip Code: 100028
Tel: (8610) 59629166
Mobile: 18001313445
E-mail: yaohy@tpri.org.cn

Abstract. This article reviewed the concept, development history, technical characteristics, and application directions of the digital twin, concluding the port’s characteristics as an international trade hub window, and the construction decision-making problems faced by the government in management, and proposed the application of digital twins in the field of port construction and operation, which should focus on the needs of port digitization and integrated management, especially set up the research on infrastructure construction, data integration, information model construction, application service platform expansion, etc., then established a spatiotemporal correlation index system for infrastructure, simulate port construction and operation processes, to realize port’ infrastructure elements virtualized, real-time monitoring, and management collaborated. The full scene visualizes the port development process and ability to ensure the adaptation, thereby promoting the cost reduction and efficiency improvement of the entire logistics chain and value chain.

1. Introduction
As a hub window for international trade, ports play an important role in the global logistics chain system. However, how to grasp the pace and timing of port construction is always of great concern to the China government’ management. Scientific, intuitive, and real-time monitoring of port operations, on the one hand, can ensure that ports have sufficient transport capacity; on the other hand, can avoid the occurrence of inter-port synchronization, qualitatively waste of resources such as vicious competition and redundant construction. With the digital economy is becoming a hot spot for global economic development, the United States, the United Kingdom, the European Union and other countries had successively proposed to vigorously develop the digital economy, and promote the deep integration of new technologies such as digital twins with all kinds of industries, and promoted the digitalization, networking and intelligence of various industries. Therefore, the proposal of the digital twin technology system can provide a solution and framework for solving the problems above. By forming a port development model combining virtual reality and twin interaction, the whole life cycle management and project construction decision-making of the port can be realized, and then the intelligent port with optimized resource
allocation and intelligent logistics scheduling can be built, so as to promote the modernization of national governance capacity and the cost reduction of the whole logistics chain.

2. The concept of digital twins

The term “Digital Twin” was first proposed by Professor Michael Grieves of the University of Michigan in the speech when “PLM Development Alliance” was established, which was called "Conceptual Ideal for PLM (Product Lifecycle Management)", as shown in Figure 1. The concept became known to the public around 2010, and was gradually applied to the aerospace and industrial fields. NASA defined an example of digital twins for future aircraft in 2010, and the US Air Force Research Laboratory also proposed the concept of "Airframe Digital Twins" in 2011, as to solve the problem of fighter body maintenance [1]. In 2014, Professor Michael Grieves gave a more detailed explanation of digital twins and laid the basic connotation of digital twins [2]. After 2014, more well-known industrial software companies such as PTC, ESI, ANSYS, etc. have all used the term "Digital Twin" in their marketing promotions, and have successively done a lot of in-depth research and expansion in terms of technology construction.

![Figure 1. Schematic diagram of the concept in PLM.](image)

There is no industry-recognized standard definition of “digital twin”, and the concept is still developing and evolving. Some universities and technology companies in the world believe that digital twins make full use of data such as physical models, sensor updates, and operating history to integrate multi-disciplinary, multi-physical, and multi-scale simulation processes to complete the mapping of physical entities in virtual space to reflect the whole life cycle process of a physical entity. For example, ANSYS believed that the digital twin is to establish a simulation model in the digital world which was completely consistent with the operating performance of the real-world system and can realize real-time simulation. The sensor data installed on the real system was used as the boundary condition of the simulation model to realize the synchronous operation of the real-world system and the digital world system. GE also proposed that “digital twins” were a software which representations of assets and processes used to understand, predict, and optimize performance to achieve improved business results. The “digital twin” consisted of three parts: a data model, a set of analysis or algorithms, and knowledge. Alam K, Rosenr, Vassiliev A and others believed that “digital twins” were three-dimensional models of physical entities, emphasizing the interaction between virtual and real, and realizing real-time update and dynamic evolution through simulation and other methods [3-5].

Many scholars in China have also carried out extensive research on digital twins. For example, Liu Yawei believed that “digital twins” were essentially a digital mirror image of physical entities or processes. The process of creating “digital twins” integrates artificial intelligence, machine learning and sensor data. In order to establish a real-time update, a strong sense of the "real" model, used to support the decision-making of various activities of the physical product life cycle [6]. Tao Fei and others researched and proposed “digital twin workshop” [7], “digital twin five-dimensional model and application and standard system framework” [8,9], “digital twin enabling technology and tool system” [10]. At the same time, Tao Fei et al. also used Scopus' advanced search function to calculate that the number of publications of “digital twins” had entered a period of rapid growth since 2016. In 2019, the number of articles published on digital twins exceeded 600, accounting for more than 50% of the total
number of papers published annually, of which the total number of published papers in three countries
including Germany, the United States and China ranks in the top three. The statistical results reflect that
these countries have a relatively high level of science and technology and a certain information
foundation, which provides a supporting environment for the research, development and application of
“digital twins” [11,12].

In November 2020, at the China’s International High-tech Achievements Fair jointly organized by
the Ministry of Commerce, Ministry of Science and Technology, Ministry of Industry and Information
Technology, National Development and Reform Commission and others, the "Digital Twin Application
White Paper (2020 Edition)” was officially released, and once again gave the concept of “digital twins”,
proposing that “digital twins” are digital expressions of specific physical entities or processes with data
connections. This data connection can ensure the same rate of convergence between the physical state
and the virtual state, and provide an integrated view of the entire life cycle of the physical entity or
process, which helps to optimize the overall performance [13].

3. Technical characteristics and application directions of Digital Twins
"Digital Twins Application White Paper (2020 Edition)” summarized and proposed that digital twins
should have real-time interaction, system simulation, full traceability, closed-loop optimization and
other typical characteristics [13]. The physical objects and digital space in the digital twin model can be
mapped in two directions, dynamically interact and interact with each other. The digital virtual body in
the digital twin can be used to describe the visual model and internal mechanism of the physical entity,
so as to monitor the state data of the physical entity, analysis of the reasoning, optimization of the process
parameters and operating parameters.

The life cycle of virtual entities in digital twins includes initiation, design and development,
verification and validation, deployment, operation and monitoring, re-evaluation and decommissioning,
corresponding to the full life cycle of physical entities. Due to the development of new generation
information technologies such as the big data, cloud computing, AI and so on, digital twins have been
applied to industries such as aviation manufacturing, industrial design, power distribution, ship design,
urban management, construction, and energy mining[14-19]. Researchers and clinicians in the
healthcare sector are also exploring applications of digital twinning, including aspects of human
modeling to help doctors understand the body's structure or responses in greater detail, while reducing
the need for invasive tests. In addition, digital twinning is also being used for remote support of complex
devices, such as CT scanners that perform magnetic resonance imaging (MRI)[20,21].

4. Application of digital twin technology in the port field
As a hub window for international trade, ports play an important role in the global logistics chain system.
In the field of logistics, digital twins can act on various application scenarios in the entire logistics chain
and value chain, including container fleet management, shipment monitoring, and logistics tracking. For
example, IoT sensors deployed on individual containers can show their location and monitor cargo
damage or contamination. These operational and warehousing data will flow into a digital twin of the
container on the network, which uses machine learning to ensure that containers are deployed as
efficiently as possible. Digital twins can be applied not only to a single asset, but also to the entire
logistics network, making it easy to make predictions and autonomous decisions on inventory or
distribution [22]. Therefore, digital twin technology is very suitable for the design and deployment of
logistics hubs and logistics networks such as ports.
The application of digital twin technology in the port field can focus on port digitization and integrated management needs, based on the BIM platform, fully sort out the spatio-temporal correlation index system of anchorage, quay crane, port machinery, and gate infrastructure, and effectively integrate the sensing information of the data, use Anylogic, Simio, Arena, Transmodeler and other software to simulate the port construction and operation process, to realize the virtualization of port infrastructure elements, real-time status, scene visualization and management coordination, full scene of port development process, and integration of port’s planning, design, construction and operation. Specific application content includes the following aspects:

4.1 Infrastructure
Infrastructure such as websites, facilities and equipment for the smart port "digital twin" model should be provided, including monitoring centers, cloud computing resources, computer rooms, computer equipment, network equipment, etc., to strengthen monitoring, storage, computing, and transmission capabilities.

4.2 Data integration
Data in ports include the conventional data types such as traditional surveying and mapping data, but also the new surveying and mapping data, three-dimensional model data such as 3D GIS, BIM, oblique photography, laser point cloud, geographic location data based on the Internet, real-time perception data based on the Internet of Things, port operation production data, industry data, and unstructured videos, pictures, documents, etc.

4.3 Information model construction
By using BIM + GIS technology, image matching technology, more oblique photography, texture mapping technology, three-dimensional model storage optimization techniques such as modeling technology, the information model can be set up. The wharf apron loading and unloading zone, yard,
buildings, car parks, green space should be processed into the model as monomers, forming a quantitative monomer information model and indexes of port, whose synchronization can access many of the main functional elements of information resources, providing digital twin port from inner to outer in an structured.

IoT perception data should be quickly loaded, fused, and presented in real time on the model platform to realize real-time operation monitoring data visualization, such as real-time operation video images, air pollution index, traffic flow, pedestrian trajectory, and berth operation volume.

4.4 Application service platform construction
It is necessary to expand the application platform of port planning, construction management, operation and maintenance, public services, etc. Before each port plan and construction project, the effect and perception after its implementation should be tested in advance. Through the port model of virtual and real, every time the planning adjustments and program changes can predict the impact on the overall development pattern of the port in advance. The port status can be fully displayed during port operation, the bottleneck of port operation can be analyzed, and the efficiency and capacity can be improved.

Figure 3. ITOS virtual container port simulation system for the first phase of Shanghai Yangshan Port

5. Conclusion
Based on the basic attributes of the port as an important logistics chain node, it can be seen that digital twin technology is very suitable for the port system. Digital twin technology should be combined with the current smart port construction to carry out further exploration, and be closely linked and deeply integrated with the new generation of information technology, relying on new technologies such as big data, IoT, and AI to build a port that combines virtual and real. The digital twin model can fully explore the value of AIS data, and it is necessary to develop targeted and systematic simulation technology, to truly simulate the current operation scenarios of the port, to predict the correct direction of the port’s future development, and to effectively guarantee the transportation of important international materials, while to protect resources and develop rationally.

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