Digital twins for the maritime sector

by Mikael Lind, Research Institutes of Sweden (RISE), Hanane Becha, UN/CEFACT,
Richard T. Watson, University of Georgia, Norbert Kouwenhoven, IBM, and
Phanthian Zuesongdham and Ulrich Baldauf, Hamburg Port Authority

A digital twin is a dynamic digital representation of an object or a system. It uniquely describes in a binary format a person, product, or environment's key characteristics and properties and can be rendered in one or more physical or digital spaces.

Decision making options

Decision making is the central activity of all organisations, and decision makers use explanatory or causal models either implicitly or explicitly. They decide based on the anticipated effects of their intervention.

Decision making is typically improved by open sharing of decision models with colleagues and calibrating them with data. The value of a decision model is often determined by the quality and breadth of data used for creation and calibration. The vast and growing Internet of Things (IoT) will be a key source of real-time data for model building and reality assessment.

The simplest and most common decision model is based on a measured association among variables in a data set. Methods such as regression and machine learning fit this mould.

A more advanced approach is to test interventions prior to implementation, such as with pilot studies and experiments, aimed to validate a causal model before scaling to a larger population. Randomized field experiments have been applied to test key economic principles, and the key proponents were awarded the 2019 Nobel prize in economics.

The problem with interventions is that some don't work and might harm the subjects, such as when testing new drugs, or jeopardize financial sustainability, such as infrastructural investments for a port that are below the intended return. The most rigorous approach to decision making is to build a hi-fidelity mathematical or biochemical model, or digital twin, of the environment of concern and simulate a possible range of interventions. This enables the exploration of counterfactuals, such as what if we did x instead of y.

Such models do not physically harm humans or nature and provide a conceptual foundation for decision-making for future sustainable business operations. You can distinguish these three approaches, respectively, as building a theory from data, testing a theory in one or more real settings through interventions, or testing a theory many times using a digital twin to simulate many possible settings. The latter is the least risky and likely to be the most successful.

Digital twins require the construction of a precise set of equations for each component in the model and the interaction among the components. They also need data for their calibration and operation. As the digital transformation of the maritime sector proceeds, it can also create the data required to calibrate digital twins of the various components of a ship, a port, and other elements of the transport infrastructure such as the goods being transported (as e.g. dry and reefer containers). In many industries, included shipping, there are "emerging opportunities to digitally represent *and* simulate objects and events prior to decision making".[1] As more devices become connected, such as a smart

[1] Pigni, F., Watson, R. T., & Piccoli, G. (202). Digital Twins: Representing the Future. *Working paper*. University of Georgia.

container with data generated by diverse use cases (e.g., executed transit time, deviations alerts, and infrastructure utilization associated to container movements and operations),[2] digital data streams built upon standardized data sharing provide opportunities for real-time representation and simulation of authentic situations. Digital twins will displace simulation models because of the order of magnitude increase in the fidelity of representation of the physical world and their continual recalibration via digital data streams to local conditions and changed circumstances.

In this article, we elaborate on the key fundamentals of digital twinning followed by how it may improve the decision making of shipping companies, port operators and others in the transport and shipping ecosystem, as well as in developing standards, that support both the integration of transport supply chain operations and the development of digital twins for operational enhancement and strategic planning.

Digital twins

A digital twin is a dynamic digital representation of an object or a system describing its characteristics and properties as a set of equations. Complex processes involving a multitude of actors are often difficult decision-making environments that are best modelled digitally prior to action. A digital twin includes both the hardware to acquire and process data and the software to represent and manipulate these data. Digital twins are more powerful than models and simulations because they leverage digital data streams to bridge the barrier between the physical entity and its representation. This means that digital twin analytics relies on historical data (e.g., a data lake), and real-time digital data streams (e.g., IoT generated data), to analyze possible outcomes (Figure 1). A digital twin is a generic model of a situation that can be tailored to a specific situation by specifying relevant parameters to provide answers to "what happens if …" or "what happens if this does not …" to support decision-making.

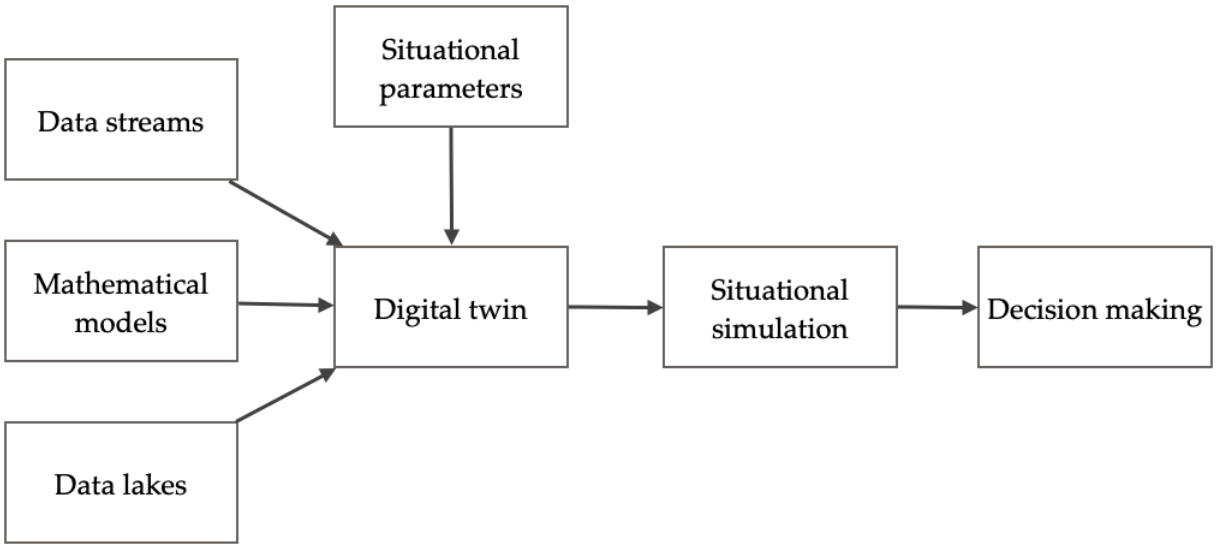

Figure 1: The components of a digital twin

[2] UNECE (2020) Trade Facilitation White Paper on Smart Containers: Real-time Smart Container data for supply chain excellence, Geneva

A digital twin can be continually calibrated through its entire lifecycle by integrating real time digital data streams.[3] This also means that a model can be continuously refined to so that it converges to a very high-fidelity model of reality.

Standards to support digital twins

Traditionally, we have used data modelling to surface that core component within a standard and to ensure compatibility across standards. This has been followed by efforts of defining standardised interfaces for communication, so-called APIs (Application Protocol Interfaces). Now, we need to recognize that data have a dual role: *transaction processing* and *data analytics*, such as that facilitated by a digital twin. Thus, a digital twin is another use case that needs to be supported by standardized digital data streams using standardised APIs. We need to redesign business processes to support the generation of IoT derived data necessary for digital twin creation and operation, so that they become powerful tools for risk management analysis and mitigation, as well as effective decision making aids To prepare for the era of digital twins, standardisation bodies, such as UN/CEFACT, GS1, WCO, and DCSA have developed various building blocks in support of the digital twin concept, namely the UN/CEFACT Smart Container data model and the DCSA IoT connectivity infrastructure. Extra standards are still needed to build and deploy fully the digital twins. Standards need to serve both the transactions of today and the digital twins of the future. Three areas of operations are now discussed for which maritime sector digital twins would serve as an important foundation for strategic and operational decision-making to enable ecological and financial sustainable maritime transport.

Examples of digital twin use cases for the maritime sector

Digital twinning is an acknowledged opportunity for maritime sector improvement. "There is no doubt that the digital twin is the future. Being able to predict potential dangers and create the optimum design, will enhance safety and operation greatly. With the element of the unknown significantly limited, the digital twin concept can help the shipping industry make better use of digitalization and move to a new era".[4] Three areas that will likely benefit from digital twins are fleet optimisation, port optimisation, end-to-end supply chain optimisation and increasing key stakeholders' situational awareness, which we now elaborate upon.

<u>Fleet optimisation</u>

Typically, a shipping company serves multiple clients at the same time, and clients may use different shipping companies simultaneously. Thus, a shipping company needs to maintain and gain in competitiveness by optimizing its fleet in terms of ships and their cargo carrying capacity. This need for sensitivity analysis could be served by a digital twin based on historical, ongoing, and predictions of business transactions. This digital twin could form the basis of strategic decision-making by testing a variety of scenarios for trade patterns and shipping fleets.

Furthermore, a digital twin for fleet optimisation could also enhance operational decision-making under diverse contextual factors, such as weather conditions that create atypical situations, and various options need to be rapidly reviewed.

<u>Port and terminal optimisation</u>

[3] Pigni, F., Watson, R. T., & Piccoli, G. (202). Digital Twins: Representing the Future. *Working paper*. University of Georgia.

[4] https://safety4sea.com/cm-the-digital-twin-concept-explained/

Port efficiency relies on balancing demand and supply in a flexible way and integration within the entire transport system.[5] A port is dependent of a continuous inbound and outbound flow of cargo and passengers arriving and departing from the port by different means of transport. For strategic planning, a port and its partners need to capture historical, ongoing, and predicted future trade in a digital twin. Such a model should incorporate the different parameters and relationships that port decision-makers should include in their strategic decisions, such as investment in infrastructure, port design, and terminal capacity. Typically, questions that such a model should address are how many berths are needed for the port need to meet punctuality goals, or how much yard space is needed to allow for different customers to store their cargo as it moves between transport services, either shipping or other modes.

A digital twin, fed by multiple data streams of real-time data and historical databases, is also an operational planning tool for the coordination and synchronization of port operations.[6] It could be an essential foundation for virtual arrival processes and green steaming[7] and for the hinterland window to support efficient use of trucks, trains, and infrastructure for diverse needs.

Situational awareness: short and long term

Cargo owners, transport buyers, and end-customers seek enhanced visibility and predictability on the state of the transport of goods in their movement from origin to destination. To enhance situational awareness for these groups, it is feasible to consider a parallel linking of relevant digital twins so that the repercussions of a delay in one stage can be thoroughly analysed, adjustments made, and situational awareness updated. In addition, connected digital twins are a tool for investigating the coordinated development of infrastructure investments across a web of ports that frequently interact so that key stakeholders also gain long-term situational awareness. This allows them to collaboratively make decision to serve the common goals of the eco-system like minimizing emission in ports. Understanding a complex interacting world is increasingly beyond the cognitive capabilities of humans, and we must build and use high-fidelity models of that world that enable them to perceive the state of the present and the future.

Optimization of container flows in the end-to-end supply chain

Recently, smart containers supporting IoT connectivity standards for have been introduced.[8] There are numerous use cases for smart containers that overcome some of the pain points that the transport industry experiences. The data streams generated by smart containers are a valuable input for fleet optimization, port and terminal optimization, and situational awareness as elaborated previously. Containers pass through many transport hubs and are managed by different carriers (of the same and different type) in the end-to-end supply chain. As a result, data generated by connected containers is a very valuable source for data for digital twins, whether retrieved from a data lake or handled real-time as a data stream.

---

[5] Becha H., Lind M., Simha A., Bottin F. (2020) Smart ports: On the move to becoming global logistics information exchange hubs, Smart Maritime Network, 20/4-2020 (https://smartmaritimenetwork.com/2020/04/20/smart-ports-on-the-move-to-become-global-logistics-information-exchange-hubs/)

[6] Lind M., Bjørn-Andersen N., Ward R., Watson R.T., Bergmann M., Andersen T. (2018) Synchronization for Port Effectiveness, Ed. 79, pp. 82-84, Port Technology Journal (http://www.porttechnology.org)

[7] Watson R.T., Holm H., Lind M. (2015) Green Steaming: A Methodology for Estimating Carbon Emissions Avoided, Thirty Sixth International Conference on Information Systems, Fort Worth 2015

[8] https://dcsa.org/dcsa-establishes-iot-standards-for-container-connectivity/

A digital twin for supply chain optimization will provide transport buyers and coordinators opportunities to optimize the choice of transport mode and route for serving their clients. This should strengthen their strategic relationship to transport producers, such as carriers and transshipment hubs. Furthermore, a digital twin will be a basis for optimizing the flow of empty containers. Connected containers are an electronic necessity for "smart" supply chains[9] and an essential building block for digital twins of supply chains.

Final words: Standardizing for digital twinning

A digital twin is constructed by generic mathematical representations of many components (e.g., a container crane, a container, the machine of a ship, and a bollard) and their relationship with other components (e.g., a container crane unloading a container ship, the utilisation of a berth for a visiting ships).

These generic representations are parameterized so they can be tailored to specific circumstances, such as the unloading speed of a crane given its position, the position of a container on a ship, and the prediction of berth slots occupied by visiting ships.

Those groups with deep knowledge of each component, such as crane manufacturers, port infrastructure designers, and ship designers, need to develop, or advise on development of, a standard model of their component. Standardized digital models of all components in the shipping industry is the next wave of standardization if the industry is to achieve higher levels of capital productivity through analytics based operational and strategic decision making. The physical instances of all components need to have embedded sensors that generate standardized data stream to calibrate their associated digital model. Current operation and future needs can be both guided by digital twins provided the maritime industry cooperates to standardize digital data streams and models of digital components.

About the authors

Mikael Lind is Associate Professor and Senior strategic research advisor at RISE, has initiated and headed several open innovation initiatives related to ICT for sustainable transport of people and goods. Lind is also the co-founder of Maritime Informatics, has a part-time employment at Chalmers University of Technology, Sweden, and serves as an expert for World Economic Forum, Europe's Digital Transport Logistic Forum (DTLF), and UN/CEFACT. More information about RISE.

Hanane Becha is currently the DCSA IoT program Project lead. She is also the UN/CEFACT vice chair for transport and Logistics. Hanane has a solid background from the IoT provider perspective, having worked at TRAXENS for many years. Hanane has received a Ph.D. and an M.Sc. in Computer Sciences from the University of Ottawa, Canada. More information about DCSA

Dr Richard T. Watson is a Regents Professor and the J. Rex Fuqua Distinguished Chair for Internet Strategy at the University of Georgia. He has written books on *Data Management; Electronic Commerce, Internet Strategy, Energy Informatics,* and *Capital, Systems, and Objects and* published nearly 200 journal articles.

Norbert Kouwenhoven is employee of IBM NL, Authorities Leader in the (IBM/Maersk) TradeLens Organisation, as well as Solutions Leader for IBM EU in the area of Customs, Immigration and Border

[9] Becha H., Frazier T., Voorspuij J, and Schröder M., (2020) Standardized Container IoT is Key for "Smart" Supply Chains, The Maritime Executive, 27/05-2020 https://www.maritime-executive.com/editorials/standardized-iot-for-containers-is-the-key-for-smart-supply-chains-1

Management. Norbert is focused on the implementation of digitisation projects and platforms world wide in supply chains, specializing on their relevance for Government Organisations. As member of EU's Digital Transport Logistic Forum Norbert helps shaping the future of Europe's logistic system. More information on TradeLens.

Phanthian Zuesongdham is Head of Digital and Business Transformation and Head of smartPORT Program at the Hamburg Port Authority (HPA). She specializes in international transport management as well as process management, organizational development and innovation in the port and maritime logistics industry. Since 2010 she has been shaping the HPA with process orientation, digital strategy and policy as well as the business transformation. Zuesongdham represents the HPA as experts in various international working groups for digital issues like Europe's Digital and Transport Logistics Forum (DTLF), IMO, ESPO and IPCSA. More information on Hamburg Port Authority.

Ulrich Baldauf is a graduated computer scientist and Head of IT-Innovation at the Hamburg Port Authority (HPA). Since the beginning of the smartPORT initiative in 2013 Ulrich is responsible for its IT architecture and the integration of new technologies. He has already brought many new technologies into production, i.e control center software, multi touch tables and virtual and augmented reality. He is always looking for new use cases and new technologies which will lead the HPA into the future. These days he is also responsible for the development and implementation of (Connected) Digital Port Twins.