

Digital standards: from fragmentation to interoperability

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Digitalization

Automation, Big Data, Ports

The transport sector faces a critical digitalization gap despite rapid technological advances in other industries. While automation and connectivity have transformed many economic sectors, transport and logistics continue to rely heavily on paper documents, telephone calls and fragmented systems. This disconnect is particularly evident in ports, where the absence of common standards has created an uneven technological landscape that varies dramatically according to region and investment capacity.

In response to this challenge, international organizations and industry leaders have stepped forward to promote standardization and digital transformation. Initiatives such as the Digital Container Shipping Association (DCSA), the European Union's Digital Transport and Logistics Forum and the Terminal Industry Committee 4.0 (TIC4.0) are working to establish common frameworks that enable seamless data exchange and interoperability in the maritime-port sector.

This analysis examines the current state of standardization in transport and explores how these diverse initiatives can collaborate to address the challenge of digitalization. By understanding the landscape of existing efforts and their potential synergies, stakeholders can better position themselves to participate in and benefit from the ongoing digital transformation of the sector.

With the arrival of **information technology**, the economy found a key ally for **management, control** and **process automation**. Activities that previously required long execution times came to be completed in a few hours, with much higher precision than that achieved by a human operator. Moreover, the emergence of **the Internet** opened a new range of possibilities by enabling **real-time data transmission** from the devices themselves, transforming the way organizations operate and make decisions.

Despite these advances, compared to other sectors, the **transport** sector shows a lower degree in terms of **levels of technological adoption**. To this day, it is still common to find printed documents, telephone calls or radio transmissions to make requests, procedures or control of goods.

If we focus on **ports**, despite the rise of **automated terminals**, we find a very uneven implementation that tends to depend largely on the **level of local development**. As a result, a highly **fragmented** landscape has emerged, in which the absence of **standards** becomes the general norm.

In this context, both the **industries** and the **institutions** have decided to step forward. To pioneers such as **Electronic Data Interchange for Administration, Commerce and Transport** (UN/EDIFACT) or the barcode have been joined by initiatives such as the **Digital Container Shipping Association** (DCSA), the **Digital Transport and Logistics Forum of the European Union** (DTLF), the **Open Logistics Foundation** (OLF) or the **Terminal Industry Committee 4.0**. Although they all cover different areas, they share the same **objective**: to promote the **creation** and **adoption** of standards and common **regulations** that facilitate the implementation of **digital standards** in the **logistics sector** and **transport**.

This analysis aims to shed light on the current landscape of **standardization** in **transport** and on how the different initiatives can collaborate with each other to face the major challenge of the **digitalization** in the maritime-port sector.

Analysis

Currently, **technological advances** make it possible to hold natural and fluid conversations, generate images and automate tasks using **artificial intelligence** through almost any medium. However, the **transport** sector still presents a limited degree of **digitalization** compared to other areas. Indeed, even today, in many environments, reliance continues to be placed on telephone calls, radio communications, email exchanges or even paper documents are still relied upon to convey information about routes, goods or service reservations.

Furthermore, the implementation of **digital systems** has proceeded at a very uneven pace, usually driven by **investments** in large **port facilities** or **terminal operators**, which have acted as an "incentive" for the adoption of these systems by other **modes of transport**. According to the joint study by Boston Consulting Group and TIC 4.0 (2025),

those **ports** that have reached a critical mass in terminal capacity or ecosystem "have a significantly more mature degree of **digitalization**" (Parlongue *et al.* 2025).

Within the **port** context, the adoption of technologies such as the **Internet of Things (IoT)**, **artificial intelligence**, **big data**, **blockchain** and **high-speed networks** (such as 5G) enables more efficient management of **resources**, greater **traceability of goods flow** and the **optimization** of **operational processes**. These innovations contribute to reducing waiting times, streamlining cargo handling and minimizing internal congestion, which translates into a substantial improvement in **productivity** and in the experience of all actors in the **logistics chain**. In addition, **digitalization** promotes **environmental sustainability** by enabling the monitoring and control of emissions.

Regarding **terminal automation** and according to Drewry (2024), in the year 2024, only 72 **container terminals** out of the 850 that exist throughout the world were fully or partially automated (Port Economics, Management and Policy 2024). Besides being costly, the automation of a **port facility**, whether new construction or adaptation, involves the deployment of **software** and hardware solutions to "weave" the communication network between machines and operators. With good implementation, the latter can use the data generated to evaluate the performance of the facilities.

However, there is great diversity in the solutions adopted, since these usually depend on the nature of the **investment**: the fact of whether the investment is in *brown- or greenfield*¹, the manufacturer of the machinery, country of implementation, company are important conditioning factors, in addition to the type of **systems** used by the **port authorities**. However, the transition to **digital systems** is not without challenges.

One of the main hurdles is the high **initial implementation cost**, which can be a barrier especially for **ports** of smaller size or regions with fewer resources. Investment in **digital infrastructure**, **IoT sensors**, **5G networks** and **automated systems** requires **solid financial planning** and sometimes public-private partnerships or green financing instruments. Finally, there are also **cultural** and **organizational barriers**: many organizations in the **logistics-port sector** are accustomed to traditional processes and require a transformation of mindset, staff training and change management to fully adopt digital technologies. This human aspect is as important as technological investment; without the active participation of key actors for decision-making and proper training, **advanced systems** will not be able to deploy their full potential.

Fortunately the industry has responded by driving advances in the **regulatory framework** and promoting international collaboration initiatives around **digitalization** and **common standards**. In this area, the **International Maritime Organization (IMO 2022)** is promoting the **adoption of digital standards**, whose technical deployment and alignment are

¹ "Brownfield": operation executed on already existing infrastructure.

"Greenfield": operation executed "from scratch", without pre-existing infrastructure.

reinforced by the standards registry of the International Association of Marine Aids to Navigation and Lighthouse Authorities (**IALA**), which facilitates their coherent implementation by **maritime authorities, ports** and **technology providers**.

Beyond the port, the **digitalization** of **transport** as a whole –from road to rail– drives a more **transparent** and **efficient logistics chain**. These strategies connect different modes of transport, facilitate the **synchronization** of **data** in real time and open **new opportunities** for **efficient** and **sustainable multimodal trips**. The aim is to reduce congestion, increase road safety and reduce emissions, while generating a more accessible and competitive environment for users and operators.

At the political level, the **European Union (EU)** is promoting the **homogenization** of **procedures** and the **mutual recognition** of **documents**; as evidenced by initiatives such as the European Maritime Single Window Environment (EMSWe) and the Electronic Freight Transport Information (eFTI). In this context, the **Digital Transport and Logistics Forum (DTLF)** has been created, an expert group established by the European Commission whose mission is to **advise** and **support** the **digitalization** of **transport** and **logistics** throughout the EU. More specifically:

- The DTLF brings together public and private representatives from different modes of transport and links in **the logistics chain** with the aim of facilitating dialogue, coordinating technical aspects and promoting the adoption of **interoperable technologies**. As part of this task, the Forum works together with the European Commission to identify barriers to digitalization and propose solutions that promote harmonization and data exchange between countries and operators. Additionally, it plays a key role in the implementation of projects such as eFTI and EMSWe, ensuring that regulatory frameworks translate into practical tools that benefit the entire sector.
- The eFTI regulation seeks to **eliminate** the **obligation** to carry **paper documents** in freight transport through the adoption of **digital equivalents** with the same **legal validity**. In practice, this allows carriers, freight forwarders and authorities to access freight information electronically, thus reducing bureaucratic burden, streamlining control procedures and improving traceability. By favoring data exchange through **certified platforms**, eFTI aims to eliminate redundancies, strengthen regulatory **compliance** and facilitate the **seamless flow** of goods and vehicles across borders within the European Union.
- **EMSWe** constitutes a **digital platform** that centralizes and **standardizes** the **submission** of information related to ships, cargo and passengers arriving at or leaving **European ports**. This initiative seeks to simplify the reporting of maritime transport operations, eliminating the need to provide repetitive data to different authorities or **Port Community Systems**. By integrating multiple national systems into a single European digital window, **transparency, efficiency** and **compliance** with

regulations are increased, while promoting **interoperability** between member states and **optimizing** administrative processes.

As for **initiatives** that promote **cooperation**, in the maritime domain DCSA and IPCSA (2023) stand out. Unlike TIC 4.0, whose approach will be described below, DCSA focuses particularly on the documentation of the port and cargo process, such as the Electronic Bill of Lading, as well as on the **modelling of maritime processes**. For its part, IPCSA brings together port operators, single window managers, port authorities and even airport authorities, with the aim of promoting, advising on, and facilitating the **electronic exchange** of information among the various actors in the **logistics chain**.

TIC 4.0

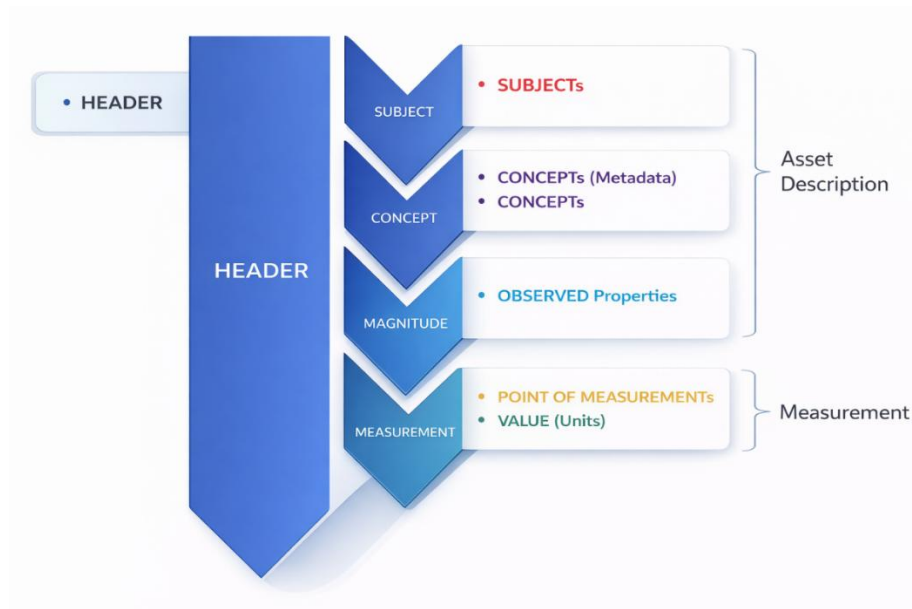
TIC 4.0 is an international non-profit association with a presence on all continents. Its origins date back to 2018, when the **Federation of European Private Port Companies and Terminals** (FEPORT) and the **Port Equipment Manufacturers Association** (PEMA) decided to establish it in order to respond to the **challenges** posed by the adoption of **new technologies** in the **port domain**. Both organizations conceived it with the aim of creating **unified digital standards** oriented towards the **adoption** of Industry 4.0 **technologies** by the **port community**. In this way, it seeks to bridge the technological gap existing in the port sector in order to introduce these advanced solutions. It currently has 70 active members, including **major terminal operators** such as DP World, APM Terminals or TiL, machinery manufacturers like Konecranes or Kalmar, and service providers such as Kaleris or DSP. Thanks to this diversity of members, TIC 4.0 is able to bring together the vision of all actors involved in the **port logistics chain**, providing its **standards** with a high level of quality and relevance.

Similar to the functioning of **international standardization committees** such as ISO or CEN, experts designated by companies meet in working groups that address different topics such as **terminal automation**, **digital twins**, or **machinery maintenance**, among many others. Since its inception, TIC 4.0 has continuously published new versions of its standard; to date, it has compiled hundreds of definitions of key concepts across 18 publications. All of these are available for download on the Internet, while, in a key milestone for the Association, the standard is set to acquire the status of "Publicly Available Specification" (PAS) by the British Standards Institute. This recognition represents a preliminary step towards its transformation into an official international standard by ISO, a goal set for the year 2029.

TIC 4.0 **digital standards** employ **common semantics**, derived from the Resource Description Framework, which emulates the structure of human language (subject → predicate → object). Through this, the user can model "any reality" that needs to be represented in a digital environment, even beyond port terminals, thanks to its flexibility; the generated data model is merely a "basic structure" that only acquires meaning once the user applies the "dictionary" of their field. As an example, in the European FOR-FREIGHT project, an experimental application was successfully carried out in the field of air transport, modelling the

movement of a cargo between the terminal of the Port of Piraeus (Athens) and Athens Airport.

Figure 1| TIC 4.0 semantics structure



Source: Terminal Industry Committee 4.0

Although the **implementation of a unified digital standard** may seem distant, it is already a reality in several locations. Ports such as Malta or Hamburg have effectively implemented this standard. In the former case, a **monitoring system** has been deployed that allows, on the one hand, real-time supervision of machinery movements and status and, on the other, the generation of a database for the analysis of the **terminal's operational performance**.

TIC 4.0 is also part of the **official ISO "Ports and Terminals"** subcommittee as an associated entity. Founded in 2025 at the direct initiative of China, this body promotes the creation of **global standards** in the field of **port logistics**. In addition to TIC 4.0, the official **standardization** bodies of countries such as the United States, Germany, Norway, France, Saudi Arabia, Korea, Japan, or Azerbaijan participate, reinforcing its authority and universality.

Finally, the Association is also active in the **European innovation ecosystem**, where it has participated in the FOR-FREIGHT, SEAMLESS, and MISSION projects and has been accepted into Waterborne, the European innovation platform for the maritime and inland waterway transport sector.

Conclusions

The **digitalization of transport** offers clear advantages in terms of **efficiency, competitiveness, and sustainability**. The use of real-time data, information exchange platforms, and

interoperable systems makes it possible to **optimise routes, reduce waiting times**, improve the **traceability** of goods, and facilitate coordination among the different actors in the **logistics chain**. All of this translates into lower operational costs, greater reliability in operations, and better planning capabilities for operators, shippers, and public authorities alike. Furthermore, digitalization is a key enabler for advancing environmental objectives, by reducing emissions through more efficient transport management and better multi-modal integration.

However, this **transformation** faces significant structural challenges. The **transport sector** is **highly fragmented**, with a large number of small and medium-sized enterprises that have limited financial capacity and human resources to bear the costs of technology investment, system adaptation, or staff training. Added to this is the **coexistence** of **legacy systems** that are **poorly compatible** with each other, which hinders **interoperability** and reduces the real impact of digital solutions when they are not applied in a coordinated manner across the entire chain.

Another relevant challenge is the **business culture of the sector**, traditionally highly oriented towards day-to-day operations and with **little room** for **strategic innovation**. In many cases, a certain **resistance to change** persists, driven by the perception that digitalization entails greater administrative complexity or an increased workload in the short term. Without adequate change management, accompanied by clear incentives and tangible benefits, there is a risk that digital tools will not be fully used or will become mere formal requirements.

In addition to the **internal transformation** of transport companies, European **digital initiatives** are a **decisive factor** in overcoming the **sector's structural challenges**. Projects and frameworks such as the EU eFTI are laying the foundations for replacing paperwork with **standardized** and secure electronic data exchanges between operators and authorities, which will reduce administrative costs and facilitate cross-border and multimodal interoperability. In this effort, the DTLF also plays a key role, coordinating public and private stakeholders to promote **data interoperability** and the technical implementation of these frameworks. Beyond regulatory projects, **cooperation platforms** such as **TIC 4.0**, which bring together innovative industry companies and service providers, help to transfer advanced solutions (e.g. IoT, data analytics, **automation**) to the core of logistics and transport. This not only makes digitalization accessible to organisations with lower economic capacity, but also fosters **collaborative ecosystems** that **reduce** market **fragmentation** and facilitate the cultural transition towards more **efficient, resilient, and sustainable** transport models.

Finally, **digitalization** raises cross-cutting **challenges** such as **cybersecurity, data governance**, and the need for **common standards**, especially in **multimodal** and **cross-border** environments. Overcoming these obstacles requires not only technological investment, but also **public-private coordination, clear regulatory frameworks**, and a shared vision at the European level, so that the digitalization of transport becomes a true driver of **competitiveness** and **resilience**, rather than an additional source of fragmentation.

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