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FACILITATION OF TRANSPORT AND TRADE IN LATIN AMERICA AND THE CARIBBEAN

Digitization in ports: application of digital twins to complex logistics

Background

Digital technologies are a new frontier in the modernization of ports and a means of facing the challenges of the sector, including the need to manage increasingly limited physical space, extreme weather events, and growing changes in consumer spending habits. They also reduce costs and toxic emissions that are harmful to the environment and improve the reliability of port services.

This *FAL Bulletin* forms part of ECLAC reflections on disruptive technologies in transport. This issue explores the opportunities and challenges involved in the implementation of digital twins in logistics and port operations and the potential impact of this new technology on competitiveness.

This issue also highlights the importance of digital twins as a new key technology for the development of logistics and urban infrastructure, and the important benefits which its application could bring to Latin American and Caribbean countries. Digital twins could optimize operations in the region's ports, which are paramount to the region's participation in international trade and global value chains.

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In this context, one tool that is beginning to revolutionize many sectors is digital twinning. Digital twins are virtual representations of objects or processes that, among many potential uses, facilitate decision making by digitally testing different scenarios without real risks. The technology makes it possible to create a 'twin' of a machine, a building, a factory, a city or a port. Research is also underway to create digital twins of patients to explore therapies for the treatment of diseases. Industry 4.0, ports and logistics management, and interaction between industries and communities are other areas in which this new technology can feasibly be applied. Digital twins could also represent a means of achieving the Sustainable Development Goals of the United Nations 2030 Agenda in the areas of inclusion, security, resilience and sustainability (Morales and others, 2021).

In terms of port operations, digital twin systems can be used to create impact assessment models of activities in logistics chains and the community. These systems can predict better long-term alternatives with immediate impact, not only for the development of specific actions but for the role played by ports in logistics activities as well. They therefore offer advantages in the restructuring of processes to adopt what is known as a 'smart logistics' approach.

However, recent ECLAC studies, in line with the analyses conducted by the World Economic Forum,[1] point to the risks posed by the exponential technologies driving the fourth industrial revolution. One such risk is an increased gap between countries that have the economic and strategic resources to adopt technologies such as artificial intelligence, the Internet of Things (IoT), blockchain and 5G communications in their processes, and those that are excluded from these opportunities. Port activities have historically been and remain of central importance to communities in Latin America and particularly the Caribbean, for example, and the role of port authorities is key to the wellbeing and sustainable development of these communities.

This bulletin presents the technology of digital twins and analyses its potential in different applications, along with the benefits and challenges it represents for the countries of Latin America and the Caribbean. The document is divided into five sections. Section one introduces the concept of digital twinning in the context of today's new technologies. Section two describes the role of this tool in the technological development seen in Industry 4.0. Section three presents the potential of developing the use of digital twins in port logistics and supply chains. Section four looks at the possible effects on society of advances in digital technologies. Section five proposes a series of recommendations on how to best incorporate digital twin technology into port infrastructure. The annex contains a case study on the digital twin of Singapore.

[1] See World Economic Forum (2016).

I. Digital twins and new technologies

Digital twins are becoming a major technology in a variety of sectors owing to their potential to improve systems, processes and services through monitoring, remote management and the simulation of any type of asset. While companies had already begun investing in this technology prior to the coronavirus disease (COVID-19) pandemic, the health crisis has made digital transformation and the ability to make quick decisions not only sources of strategic advantage but necessities to ensure a company's future. The pandemic taught us this lesson and accelerated the implementation of sensor- and automation-based information technology that enables smart data analysis and the monitoring of systems to prevent problems before they occur, prevent downtime and customize production, in addition to other possibilities.

Digital twin technology, which draws on various forms of know-how and applied sciences, becomes possible once these advances have matured sufficiently to be applied at the industrial level. The healthcare and pharmaceutical industries, accelerated by the pandemic, are driving this growth and adoption. It is estimated that approximately 13% of companies in these two sectors already use digital twins, and another 62% are in the process of adopting the technology (Morales and others, 2021).

While attention is focused primarily on system development, digital twins are frequently used for design and measurement validation tasks. Use of digital twins in state-of-the-art engineering applications usually takes the form of simulation models that replicate the properties or behaviour of a given system. The term "digital twin" emphasizes that the model accurately replicates the system, covers various aspects and provides detailed answers to questions concerning specific issues or the system in general. This feature sets twin technology apart from traditional approaches such as systems simulation.

Secondly, the tool is used during the operation and servicing of a system. The digital twin acts as a virtual equivalent of a real system —the real twin— helping users operate and maintain that physical system. National Aeronautics and Space Administration (NASA) used the term in its roadmaps to describe technology objectives and to develop digital satellite twins for space missions.

Most systems that are based on multiple levels of control and automation generate data using embedded sensors and/or software. Connectivity via wireless communication technologies and standards for devices and ubiquitous computing are technical drivers of trends such as the Internet of Things (IoT), Industry 4.0 and the Industrial Internet of Things (IIoT).

Many applications in these areas are based on data collection and analysis, combined with artificial intelligence. These developments escalate the importance of the digital twin approach. Data from the actual, physical system can be used to continuously synchronize the digital twin, ensuring that the real-time, virtual representation always reflects the current state of the real system. Applications can be used in the digital twin to predict system behaviour, assess operational scenarios and improve system performance.

Digitization is changing the world and creating new opportunities to interconnect complex systems and make them intelligent. It will help advance mechatronics, control and automation, bionic engineering, biomedical engineering, as well as traditional engineering fields such as mechanics and power engineering (Aquino and others, 2020).

II. Digital twins and Industry 4.0

The fourth industrial revolution, a concept widely developed in literature, and specifically by ECLAC in recent documents, is changing the world of production processes forever. Tomorrow's logistics systems will be based on the interconnectivity of information and the optimization of time and resources, along with significant investment and innovation to maintain competitiveness (Barleta, Pérez y Sánchez, 2020).

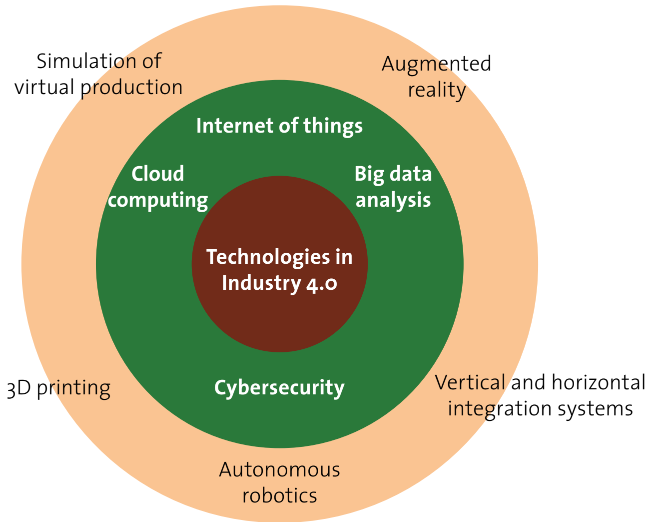
At the same time, the notion of creating a virtual model of any production process is not new. Performance, however, only became guaranteed with the arrival of data analysis capacity, connectivity infrastructure, the development of storage technologies and information processing.

Digital twin technology developed on the same basis as Industry 4.0: the digitization of factories and processes to gain efficiency in production. Both processes, like everything related to innovation, are part of a single ecosystem that includes several complementary tools. As a result, more and more factories are adopting this technology and achieving tangible results, despite sometimes exaggerated expectations and models that remain experimental (see diagram 1).

Many applications in these fields are based on data collection and analysis and driven by artificial intelligence. These developments increase the importance of the digital twin approach because they enable the creation of dynamic digital replicas of the real-time state of a physical system. This protected and safe environment for experimentation makes it possible to detect problems, plan maintenance tasks, avoid unexpected downtime and develop new, more efficient operating scenarios without risking heavy investments in new infrastructure or prototypes.

A prerequisite for the construction of a digital twin is the availability of all data. This requires the use of big data technologies to efficiently manage real-time data, combined with historical and contingent information that connects activities such as logistics, sales, warehouse operations and maintenance. The construction of the predictive model that underlies a digital twin, for example, requires the application of cutting-edge techniques in the field of machine learning. Incorporating both disciplines is essential to create a digital twin that provides accurate simulations of current, past and future operations.

Diagram 1
Industry 4.0 and new technologies



Source: Prepared by the authors.

A digital twin is built on a significant layer of powerful software that includes:

- Digital simulation: a model that defines the system.
- Intelligent automation and sensors connected to the Internet of Things (IoT) to link the real system to the model.
- Data analytics and artificial intelligence.
- An advanced human-machine interface.
- Virtual reality and augmented reality (VR/AR).
- 3D computer-assisted design (CAD).

This multi-platform technology is revolutionizing processes along the entire value chain, allowing individual phases to be seamlessly linked using a virtual representation of a product or production process. This translates into greater efficiency, which minimizes failure rates, shortens development cycles, and generates new business opportunities, leading to increased business competitiveness.

The advantages of connecting the physical and virtual via digital twins include:

- The design of products and processes that increase productivity more than traditional methods.
- Reduced time to market for new products and reduced costs for its introduction into the market.
- Reliability and predictive maintenance.
- Scenario planning.
- Reduced downtime, increased efficiency, and cost savings.
- overall improvement in the quality of processes and products.

Economic digitization can enhance the use of the circular economy insofar as it entails a relative increase in the use of intangible consumer goods, prolongs their life span thanks to collaborative consumption platforms, enables the optimization of production processes and increases the degree of corporate social responsibility in companies.

III. Smart ports: innovation and digitization in port logistics

In logistics, digital twins can be used in a wide variety of applications across the value chain, including container fleet management, shipment monitoring and the design of large-scale logistics systems. IoT sensors in individual containers, for example, display their location and monitor issues such as damage or contamination caused by their transport. These data flow into a digital twin of the container network, which uses machine learning to aid decision-making for operational efficiency.

Digital twins can be mobilized not only for individual assets, but also for entire networks and ecosystems, such as warehouses, combining a 3D model of a facility with real-time, networked tracking of inventory and operational data. The system can provide an overview of equipment status and product availability, as well as predict outcomes and even make decisions about stock or deliveries autonomously. The digital twin technology market is expected to grow by more than 38% annually, exceeding $26 billion by 2025 (Technavio, 2022). This approach offers unprecedented capabilities to track, monitor and diagnose assets. It could radically change supply chains, bring a wide range of options to facilitate collaborative environments and data-driven decision making, thereby simplifying business processes and creating new business models (C de Comunicación, 2019).

In the case of maritime operations, the flow of data generated by smart containers provides a wealth of information for the optimization of transport and, as a result, land logistics of loading and unloading, and internal port logistics. The greater the connection between devices and data generated by various uses (e.g., transit time, detour alerts, and infrastructure use in conjunction with container movements and operations), the more opportunities digital data streams provide for real-time representation and simulation of actual situations (Naucher Global, 2020). In this context, modelling with digital twins makes it possible to anticipate situations and leads to significant benefits in costs and operational capacity.

In addition, digital connectivity improves decision making for shipping lines, port operators and other players in the transportation ecosystem and navigation. It also facilitates the development of standards that support both the integration of transportation supply chains and the development of digital twinning for improved operations and strategic planning (Naucher Global, 2020).

Three domains in the maritime sector that could particularly benefit from the digital twin technology are: (i) the optimization of fleets, ports and terminals, (ii) increased situational awareness of key stakeholders, and (iii) end-to-end supply chain optimization (Lind and others, 2020).

Regarding the optimization of fleets, ports and terminals, it is important to note that shipping companies may use different carriers simultaneously. This diverse range of stakeholders makes the exchange of data essential to maintain and increase competitiveness and optimize the operation of vessels and their transport capacity. Logistics operations can be analysed using a digital twin, based on the history, current status and projections of business transactions, to plan and anticipate activities.

Efficiency in port operations is contingent on balancing supply and demand in a flexible manner and on integration across the transportation ecosystem. Such a model can study the number of berths needed for the port to meet timeliness targets and provide the yard space needed by customers to store cargo as it moves between shipping services, marine or otherwise. The data streams generated by smart containers provide valuable information for fleet, port and terminal optimization and are a source of data for digital twins (Lind and others, 2020).

Knowledge of the situation of the different parties involved in logistics processes is also fundamental to boosting competitiveness in the maritime and port sector. Cargo owners, freight buyers and end customers seek greater visibility and predictability of the status of freight as it moves from origin to destination. To improve the situational awareness of these stakeholders, one feasible option is to connect relevant digital twins in tandem so that the repercussions of a delay at a given stage can be fully assessed and adjustments made. In this context, connected digital twins hold obvious potential for the investigation of the coordinated development of infrastructure investments through a network of ports that interact frequently so that key stakeholders also gain long-term situational awareness (Lind and others, 2020).

In addition, containers pass through numerous transportation hubs and are sometimes managed by different carriers in the end-to-end supply chain. This means that the information generated by connected containers is a valuable source of data for digital twins, whether retrieved from a data source or handled in real time as a data stream (Panaggio, 2020). By using digital twin technology in supply chain optimization, buyers and transport coordinators can choose the transport methods and routes that best suit their customers. The information can also serve to optimize the flow of empty containers.

Crane manufacturers, port infrastructure and ship designers need to develop or advise on the creation of a standard model. Standardized digital systems across all components of the shipping industry are the next target if the industry is to achieve higher levels of capital productivity through analytics-driven operational and strategic decision making (Naucher Global, 2020).

IV. Social impacts of digitization and technological development

Implicit in the concept of digital transformation is the disruption of business strategies and business models. Digitalizing strategies is not the same as adapting to the digital environment. In other words, the reach of digital transformation extends to cultural, strategic and operational changes within an organization in order to compete in the new digital environment.

One of the main drawbacks associated with this new and changing digitized world is "technological unemployment": if factories incorporate more and more intelligent equipment, autonomous processes and robots into their operations that can perform the tasks of workers, the need for human capital is likely to diminish. Employees are not alone in their concern: many businesses worry about 'digital Darwinism', in which those who do not manage to adapt have little chance of surviving.

To quantify the true magnitude of this possible impact, the first factor to consider is the level of digitization of society as a gauge of how prepared it is to face the phenomenon. This assessment should be based on five indicators:

(i) Connectivity: fixed broadband, mobile broadband and pricing.

(ii) Human capital: basic and advanced digital skills.

(iii) Internet use: citizen use of online content, communications and transactions.

(iv) Adoption of digital technology: digitization of companies and online shopping.

(v) Digital public services: e-government and e-health.

The second factor is the significant impact on the labour market of companies' efforts to adapt to technological change and new forms of production, along with a growing demand for qualified professionals. In this regard, certain functions are tending to disappear while other new jobs are emerging, some of which are already consolidated, and others growing and directly related to new technologies. The negative effects of this ongoing process can be minimized by deploying the skills required to focus on activities that are difficult to automate—those that emphasize creativity, manual dexterity and interpersonal relationships, for example.

One career option that tends to face little competition, offers good opportunities and is connected to innovation and technology is that of data scientist. A data scientist is a data processing expert who 'mines' and transmits recommendations to their company's business managers based on data from multiple sources (usually big data). Other consolidated employment opportunities which continue to grow include:

- Cybersecurity specialist.
- Agile scrum methodology specialist.

- Robotics specialist.
- User experience specialist.

Only some of the job functions involved are mentioned here: the list of jobs that are linked, in one way or another, to the fourth industrial revolution is more extensive and elaborate (Del Bosque Peón, C., 2019).

Other persistent, fundamental barriers for companies include the difficulty of digitizing plant systems, as most of their traditional architecture is difficult to transform into digital sensors, and the processing and management of large volumes of real-time data that digital twin technology requires. The solution lies in big data, but not all companies can afford its cost (Del Bosque Peón, C., 2019).

As a result, the implementation and use of digital twins could be restricted to large companies only, which have more resources than smaller ones for the necessary investments. This suggests that small and medium-sized enterprises (SMEs) may be left out of the race.

In this context, it is important to note the development of several projects designed for compatibility with any plant or sector, which provide access to Industry 4.0 to companies that would otherwise run the risk of disappearing from the market. The Spanish company Semantic Systems, for example, is developing a digital twin capable of replicating any type of industrial process and adapting to any type of plant, with less investment than is currently required for this type of technology. The objective is to enable industrial SMEs to become more efficient and competitive (Samaniego, 2018).

Societies and economies are becoming increasingly digitized. To meet the challenges of this dynamic environment and the pace of change, most companies are adapting, with new strategies and business models and progressively implementing new management and control tools, all of which has led to significant savings in time and costs. This need to adapt was already reflected in 2013 by Nobel Prize-winning economist Robert J. Shiller: "You cannot wait until a house burns down to buy fire insurance on it. We cannot wait until there are massive dislocations in our society to prepare for the Fourth Industrial Revolution." (World Economic Forum, 2016).

V. Recommendations and final considerations

As supply chains become increasingly complex and environmental standards and regulations are tightened, along with security in and around port areas, ports today face a host of challenges. Ports have become service providers and an active part of the supply chain. They deliver services to numerous stakeholders, including the coordination of port calls, environmental management, ship-to-shore operations, as well as commercial and industrial property management.

In their traditional role, the size and capacity of ports were key to the success of this industry. Now, with the transformation of supply chains, efficiency takes precedence, and ports must become smart. This became apparent with the onset of the current COVID-19 pandemic, as many ports grappled with how to manage the impact of the economic crisis.

The pandemic revealed how dependent companies and countries are on resilient, efficient and fully visible supply chains in air, sea and road transportation. A lack of information can result in considerable delays that can compromise or, in the worst case, decrease or even obliterate the value of shipped goods. According to a report by Trelleborg, a Swedish multinational engineering company, 41% of those who book hold on ships lose their space more than 20% of the time; another 20% say they experience average delays of over six hours in facilities (Trelleborg, 2020). These multiple delays not only impact each stakeholder; they can also cause bottlenecks that affect the entire supply chain and increase operating costs (Hellenic Shipping News, 2020a).

For this reason, the emphasis on efficiency should increase the digitization and automation of the maritime port industry. Data-driven insights will allow ports to simulate in advance and estimate exact arrival times of ships for planning purposes. This will also allow stakeholders (sales and operations departments, for example) to adjust their resources and operations. A combination of connectivity and growth will enable the change needed in the industry, with a view to the following:

- Provide services to vessels and freight services.
- Act as an interface between maritime and terrestrial environments.
- Develop a productive environment.
- Embrace major trends in logistics.
- Act as strategic points in the production, transportation and world trade system.

The current role played by ports in the world economy is the result of a process developed alongside world trade. Despite doubts, a market report by Markets and Markets projects that the market for digital solutions for smart ports will reach US$ 5.3 billion by 2024 with a compound annual growth rate (CAGR) of 25% as of 2019 (Markets and Markets, 2020), suggesting that smart ports are on the rise (Hellenic Shipping News, 2020a).

These trends are already felt in the port community. Last year, the Port of Valencia launched iTerminals 4.0, a project funded by the European Commission's Connecting Europe Facility (CEF) programme aimed at digitizing port operations and adopting new technologies. In the last two years, other seaports in Europe, America and Asia initiated digital projects, e.g., Rotterdam, Antwerp, Hamburg, Los Angeles, Cartagena and Singapore (Hellenic Shipping News, 2020b).

In addition, the suitable degree of maturity of new technologies such as IoT, AI (artificial intelligence), big data and machine learning has enabled the emergence of digital twin technology as a versatile design tool in multiple fields. The scale of implementation is broad, and the high levels of complexity, given the number and variability of components as is the case of projects to develop or expand cities and ports, produces benefits for all parties and related stakeholders, involved in a climate of mutual support.

In that regard, the use of digital twins provides advantages in terms of reducing costs through predictive maintenance as well as detecting bottlenecks and capacity imbalances, making it possible to avoid segments or nodes that could otherwise be harmful to the ecosystems or logistics processes considered. Versatility is evident in the possibility of customizing products by adapting them to the needs and preferences of projects, thus indirectly addressing the idiosyncrasies and cultural preferences of the communities involved.

Modern port-cities are the product of the successful merger between one of our oldest ways of life —the city— and one of the most far-reaching activities in society — commerce. As the world's population has grown, trade has become a primary catalyst of globalization.

Increased trade has imposed new standards and requirements on loading and transportation methods, as well as on ports themselves. In the last 50 years, the cargo capacity of ships has increased by 1,200% (Alfaro, 2016). These patterns of growth have major implications for ports, including an increased need for space, energy, logistical capacity and staff, which have complicated port-city relationships.

Should it continue, this expansion could give rise to a stage of disengagement in which a fracture appears between the city and the port. This conflict stems from the sharp contrast between the social conditions of a city and the economic opportunities provided by its port. The goal is to harmonize relations between the port and the city and to foster collaboration and coexistence.

Given the complexity of this context, there is a need to incorporate digital twin technology, with all its components and interfaces, from the design phase through to day-to-day operations. Progress in this direction demonstrates the feasibility of applying digital simulation concepts that naturally impact hubs of human activity.

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VII. Annex
Case study: Singapore's digital twin

A major example of the development and practical application of digital twins is the project involving the island city-state of Singapore, known as Virtual Singapore. The model, one of the most ambitious digital twin projects in the world, consists of a dynamic three-dimensional (3D) representation of the city on a collaborative data platform. The project is a joint venture of the National Research Foundation (NRF), the Singapore Land Authority (SLA), which provides topographic map data for the 3D model, and the Singapore Government Technology Agency (GovTech), which provides information, technology and communications.

To build an easy-to-navigate virtual city, NRF is also collaborating with French software company Dassault Systèmes, which specializes in 3D design software (Govtech, 2017). The digital twin will allow users from different sectors to use simulation models to optimize logistics operations, develop sophisticated tools and applications for planning and decision making, as well as conduct research into new technologies.

The 3D model includes detailed information such as texture, representations of geometric objects, terrain mapping, water bodies, vegetation, transportation infrastructure, etc. Building models encode the geometry as well as the features of a structure, including walls, floors and ceilings, down to its fine details like the composition of granite, sand and stone in a building material. The system makes it possible to measure temperature, pressure, air moisture, lights, noise levels, infrared temperature, as well as motion and step counting (NRF, 2021).

In addition, the system will enable virtual test-bedding —the use of a testing platform to validate service delivery, for example, with crowd control models to establish evacuation procedures during an emergency. Virtual Singapore will also offer a rich data environment for planning and decision making to analyse transportation flows and patterns in pedestrian flows (NRF, 2021), which, in the context of logistics, will yield significant benefits.

Source: National Research Foundation (NRF), "Virtual Singapore", February 2021 [online] https://www.nrf.gov.sg/programmes/virtual-singapore.

Potential applications and benefits for stakeholders

With appropriate security and privacy safeguards, Virtual Singapore will enable public agencies, the academic and research community, the private sector and the community to harness the system's information and capabilities in a variety of ways. Geo-visualization and 3D data will provide a realistic virtual platform to connect, create awareness and services that enrich the community (NRF, 2021).

Companies, for example, can leverage the vast amount of data and information in the digital twin for business analytics, resource planning and management, as well as specialized services. Virtual Singapore's capabilities are driving innovation and the development of technologies for public-private partnerships. By leveraging the big data environment and aggregating public and private sector information, the tool allows different agencies to share and review plans and designs for different projects in a single environment.

Furthermore, Virtual Singapore is convenient for citizens, who can view updates on their assets and provide timely feedback to relevant agencies. As an accurate representation of a physical landscape, it can be used to identify and display barrier-free routes for the disabled and elderly, who can easily find the most accessible and convenient route, and even protected paths, to bus stops or underground transport stations. The platform can also be used to visualize the park connector network and plan cycling routes.

For urban planning, information is available on variations in ambient temperature and levels of sunlight throughout the day. Urban planners and engineers can visualize the effects of the construction of new buildings or facilities on temperature and light intensity. They can also overlay heat and noise maps for simulation, which can help create a more comfortable and cooler living environment for residents. A semi-automated planning process is also supported in which buildings of interest can be quickly filtered based on pre-set parameters (NRF, 2021).

In the area of energy planning and use, data such as building height, roof surface area and levels of sunlight are available in Virtual Singapore. This allows urban planners to analyse which buildings have the greatest potential for solar energy production and are therefore best suited for the installation of solar panels. More detailed analysis allows planners to estimate how much solar energy can be generated on a typical day, as well as energy and cost savings. It has been shown that cross-referencing with historical data collected from neighbouring buildings makes it possible for analysis to be validated and seasonally adjusted to reflect even more accurate and granular projections (NRF, 2021).

All these examples enable better urban planning through the analysis and testing of different scenarios. Digital twin technology is therefore also an important and innovative solution for urban planning that can be used in several ways, both for day-to-day activities in cities and activities in ports and logistics operations.

VIII. Publications of interest

FAL Bulletin No. 375

Industry 4.0 and the emergence of Logistics 4.0

Eliana Barleta
Gabriel Pérez
Ricardo J. Sánchez

The fourth industrial revolution is bringing about a series of disruptive changes in both business models and the production chains that support them. Logistics, which is a fundamental element of these processes, is inevitably affected by these significant changes. This fourth industrial revolution is characterized by its speed, magnitude and depth. The changes are so dramatic that they will alter the way we live, work and relate to one other, affecting countries, companies, industries and society as a whole. Therefore, the logistics system of the future must aim for interconnected information and optimized time and resources, with significant investment in innovation and development to maintain competitiveness.

Available in: Spanish English

FAL Bulletin No. 382

Cybersecurity in the time of COVID-19 and the transition to cyberimmunity

Rodrigo Mariano Díaz

This *FAL Bulletin* forms part of the Reflections on Disruptive Technologies in Transport that often appear in Economic Commission for Latin America and the Caribbean (ECLAC) publications. On this occasion, it examines the importance of cybersecurity from a logistical standpoint, especially in the current context of a pandemic.

Available in: Spanish English