Chapter

Shipping Digitalization and Automation for the Smart Port

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Abstract

Shipping, like most industries, is undergoing a digital transformation process which influences existing business models and operational practices, in a multifaceted way. Today, the shipping business context has been changing to incorporate further social demands, environmental, innovation and sustainability priorities, into fundamental shipping strategies, while taking advantage of technological advancements. In the era of Industry 4.0, which constitutes a recent evolution of advanced communications and information technologies and further promotes sustainable, human-centric, and resilient business development strategies, shipping and port entities need to embrace a broader perspective and a deeper understanding of various elemental technologies, namely: Artificial Intelligence, Blockchain, Cloud Computing, Big Data, and Physical Internet, in addition to core maritime logistics matters. This chapter proposes a descriptive framework of shipping digitalization and port automation, while providing a review of related technologies and business approaches, also international initiatives, for automation in global ports. Hence the chapter offers insights for business practitioners to steer through the current challenging global environment, also for policy makers to gain a more informed understanding of maritime logistics developments, towards necessary coordination and oversight mechanisms implementation.

Keywords: shipping, digitalization, automation, smart port, artificial intelligence, blockchain, physical internet

1. Introduction

In recent years, major ports around the world have been implementing new technologies to realize "Smart Ports," in order to enhance international competitiveness, reduce environmental impact, and improve the workplace environment. In addition to the automation and labor-saving measures that have been actively pursued so far, smart ports are nowadays expected to benefit from the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data[1], as well as more focused initiatives, in specific the Physical Internet (PI), based on the development of

[1] Big data refer to various types of data in various forms and with various characteristics. Big data consist of three V's: Volume (amount of data), Variety (types of data), and Velocity (frequency of data generation and update).

high-speed communication infrastructures, such as the fifth generation mobile communication system (5G). The robust use of the numerous digital technologies, such as the ones above-mentioned, offers substantial business innovation opportunities and requires numerous organizational adjustments [1].

In specific, the digitalization of ports is enabled by 5G networks that provide low latency, high capacity, and increased bandwidth, hence allowing the collection and intelligent processing of vast amounts of data shared over an IoT information network infrastructure. 5G is foremost supporting the PI objectives, namely the widespread adoption of interconnected, sustainable logistics systems and applications.

A smart port is realized by means of wireless devices, smart sensors, actuators, data centers, and other IoT-based systems being connected and exchanging information. The seamless communication of ships, cargoes, and waterway and shore-based facilities, based on 5G and IoT technologies, constitutes the infrastructure of the smart port and shapes the innovation potential of the emergent maritime logistics services and applications. The efficiency, security, and safety of port operations and the achievement of the highly prioritized sustainable development goals are substantially improved by automating port operations, such as vessel management, container terminal operations, and yard automation.

Competitiveness and henceforth the competitive positioning of ports being nodes of multiple, global supply chain networks are of paramount importance and are directly determined by the adopted digital strategy and infrastructures implemented in each port.

This chapter outlines the main technologies' capabilities, as well as the current status of policies and initiatives for the development and deployment of various technologies, primarily for automated terminals and automated ships in ports, as innovations for ships and various automated machinery, mainly for cargo handling, toward the realization of smart ports. Moreover, the chapter introduces a particular technological framework for creating a sustainable next-generation maritime logistics system, by applying PI to digitize maritime logistics networks and BC technology for secure information exchange to improve the overall efficiency of maritime logistics, at ports.

2. Industry 4.0: technologies for next-generation maritime logistics and shipping digitalization

How does modern maritime logistics look like in the era of Industry 4.0? The concept of Industry 4.0, first formulated by the German government, mainly refers to the automation and digitization of manufacturing processes. Industry 4.0 encompasses cyber-physical systems[2], AI[3], IoT[4], cloud computing[5], cognitive computing[6], smart

[2] A Cyber Physical System is a system in which cyber space and physical space are more closely linked, in which information from reality (physical) is taken into a virtual space (cyber) by a computer, and the analysis results of the computer's computational power are fed back to derive optimal results in the real world. It is a system in which cyber space and physical space are more closely linked.

[3] AI, short name of Artificial Intelligence, is a branch of computer science that studies "intelligence" using the concept of "computation" and the tool of "computers."

[4] IoT, or Internet of Things, is a system in which various things (devices) are connected to the Internet to fully utilize the information those devices carried.

[5] Cloud computing is a form of usage in which computer resources are provided in the form of services via a computer network such as the Internet. It is sometimes referred to as cloud for short.

[6] Cognitive computing is a system in which computers not only process instructions given by humans, but also think and learn on their own like humans, and support decision-making.

factories[7], and digital twin[8]. Industry 4.0 has been implemented in many countries besides Germany, including the US, France, the UK, China, Japan, Korea, and Thailand. Particularly in the supply chain area, digitalization, integration of AI and IoT, sharing economy[9], and BC are playing an important role in addition to these core technologies. Logistics has not been associated with high technology for a long time since it was recognized as an industry in the mid of nineteenth century. The situation is changing with the increase of Logistics 4.0 efforts, where innovative technologies such as AI, IoT, and BC are increasingly being implemented in the logistics industry, in parallel with similar efforts to many other industries, presenting even more efficient sustainability and human-centric approaches. However, despite the numerous regional initiatives, there are no adequate frameworks existing for companies in the logistics industry to embrace those technologies to the largest extent. There is a need for guidelines to implement new technologies in the logistics industry for the common good of the entire industry and eventually society as a whole.

Against this background, a closely related development, namely the Physical Internet (PI), has drawn attention from various parties as one of the most effective measures to improve logistics efficiency and reduce greenhouse gas emissions. The features of PI include interoperability, modularity, and standard interfaces and protocols. In order to take advantage of these features, technology to share data while maintaining confidentiality, such as Blockchain (BC) technology, is essential. This technology, also known as a distributed ledger, is difficult to tamper with, requires no administrator, and allows execution of smart contracts. The use of BC technology in PI is expected to dramatically accelerate the construction of a sustainable logistics network. In the following sections, we will present, in more detail, the potential of applying BC technology in the PI network context.

2.1 AI

Artificial Intelligence (AI) is a field of computer science that uses the concept of "computation" and the tool of "computers" to study and implement "intelligence."

AI can be classified into general-purpose AI and specialized AI. General-purpose AI is also referred to as strong AI. It is an AI that is not limited to a specific task but is capable of general-purpose processing; that is, it has the same intelligence as humans. Some examples of general-purpose AI are Doraemon and Astro Boy. None of them exist in the real world yet. Specialized AI is also called weak AI. It is an AI that specializes in performing a specific task. Image recognition, chess, Go, automated driving, human conversation, etc., are all examples of specialized AI.

In a broader sense, AI includes rule-based AI and machine-learning AI. Rule-based AI refers to making decisions according to rules described by humans. It also automates tasks that require hardware and human judgment. It can be described

[7] A smart factory is a highly productive and efficient factory that utilizes digital technologies such as AI and IoT.

[8] Digital twin is a technology that reproduces various data collected from the real world on a computer, as if they were twins. Based on the huge amount of data collected, the computer can perform physical simulations that are as close to reality as possible, which is an effective way to improve the manufacturing process of your products and services. Digital twin ship is a recognized prospect in shipping sector that helps optimize fleet management and enhance port and terminal operations.

[9] The sharing economy is a new economic movement in the form of renting, buying, selling, and offering among individuals via an Internet platform.

as an office robot. In contrast, machine-learning AI generally does not require a human to write the rules. It has algorithms for self-learning in machine-learning models, and it behaves intelligently based on those algorithms, building the models automatically. Compared with machine-learning AI, rule-based AI has advantages such as faster to automate tasks, a human can train AI, and lower cost. On the other hand, it also has disadvantages such as unable to learn independently, unable to train AI unless it is explicit knowledge, and unable to make decisions on matters it has not been trained on.

Machine learning can be divided into supervised learning, unsupervised learning, and reinforcement learning in general (**Figure 1**).

2.1.1 Supervised learning

Supervised learning is the process of preparing training data with a set of inputs and correct outputs in advance, and having the computer learn to produce correct outputs when given a certain input. Supervised learning methods are mainly used for prediction and classification (labeling). Examples include image classification. Supervised learning can be applied to forecasting sales and predicting the tendency of customers' churns, etc.

2.1.2 Unsupervised learning

Unsupervised learning is often referred to as self-supervised learning these days. It is used to grasp the inherent structure of data from the input data supplied Unsupervised learning mainly uses clustering techniques to classify data. Examples of applications include product recommendation, customer segmentation, target marketing, etc., based on customer purchase history.

2.1.3 Reinforcement learning

Reinforcement learning is a model that learns to maximize future value instead of giving the correct answer. In other words, it learns to act in a way that maximizes value through trial and error. The problem setting is similar to that of

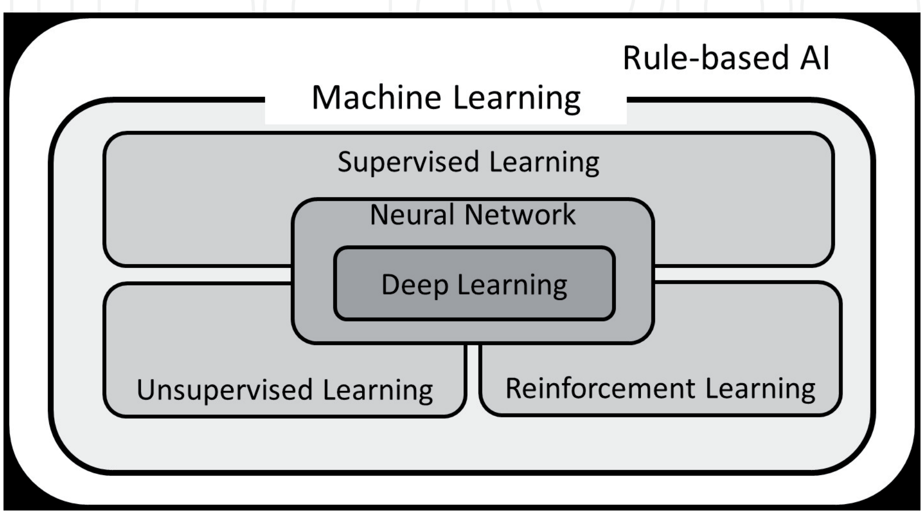

Figure 1.
AI and machine learning relationship diagram.

supervised learning, but it is not enough to learn the output of the given correct answer as it is, but it is necessary to learn the behavior that maximizes value in a broader sense.

Tetris game is a good example to understand the scheme of reinforcement learning. When playing a game of Tetris, the problem of getting the highest possible score can be considered in the framework of reinforcement learning. The best way to score at that point is to play in such a way that even a single row can be eliminated immediately, but in the longer term, the score will be higher if you accumulate as much as possible and then eliminate many rows at once.

AlphaGo, which defeated a human player, also incorporates reinforcement learning in some parts of its games. As in the case of Go, it can learn even when humans do not necessarily know the correct answer, so it is expected to acquire the ability to surpass humans.

2.1.4 Artificial neural network

A neural network is a mathematical model inspired by the function of nerve cells (neurons) and their connections, or neural networks in the human brain, called artificial neurons. When the neural network model is properly constructed according to the problem to be solved, it can make a variety of decisions (i.e., outputs), such as the following:

First, image recognition and binary classification. For example, it answers questions such as: Is the object in front of me a ship or a train?

Second, natural language processing, multi-level classification. For example: which is "Emma Maersk" among various images of vessels online?

2.1.5 Deep learning

Deep Learning is a method of machine learning in which neural networks are combined in multiple layers to enhance their representation and learning capabilities. Currently, it is the most commonly used algorithm for AI.

Deep learning, on the other hand, is often used when complex unstructured data is available and is applied in fields such as speech recognition, image recognition, and natural language processing.

There are many cases where conventional machine-learning methods do not work well for classification and regression without complex function approximation, and deep-learning methods are increasingly being used for such problems. In some cases, deep-learning methods have dramatically improved recognition accuracy compared with conventional methods, and deep learning is currently attracting a great deal of attention in the world. Recently, it has been used in a wide range of fields such as recommendation and automated driving.

2.2 Blockchain

BC is an open distributed ledger technology (DLT) based on a peer-to-peer (P2P) approach that allows transactions to be recorded on thousands of servers simultaneously. On the efficient, verifiable, and immutable BC platform, anyone can see the transactions of others in near real time, making it difficult for one user to manipulate the records and control the network [2]. Applying these features, BC facilitates the digitization of traditional economic, legal, and political systems.

Consensus	PoW (Proof of Work)	PoS (Proof of Stake)	PoI (Proof of Importance)	PoC (Proof of Consensus)	PBFT (Practical Byzantine Fault Tolerance)
Evaluation method	(one's) workload	Workload and coin holdings	Overall evaluation of coin holdings, transaction volume, transaction frequency, etc.	Designated agency	Consensus of two-thirds or more
Benefits	Resistant to transaction tampering	No wasted power consumption	Low power consumption	Fast remittance speed	High speed compared to other methods
Weakness	High-power consumption	How the rich get richer.	Participation is impossible without a certain amount of coins.	centralized	A block will not be created unless a two-thirds majority is agreed.
Representative example	Bitcoin (BTC)	Ethereum (ETH)	Nem (NEM)	Ripple (XRP)	Permitted type consortium type

Table 1.
Typical consensus algorithms.

In BC, cryptography is used to store records (hash values[10]) of transactions that occur in the network in blocks of records called blocks. In each block, it contains three values, the first is the hash value of the previously generated block, the second is the record of the transaction in the current block, and the third is a new hash value generated by a disposable random value called a nonce. The three values are passed to the next block and the accumulated blocks form a chain of blocks in time series. The name BC comes from this data structure.

BC can be divided into public BC, which allows anonymous participation, and permitted BC, which requires permission to participate. Public BC is mainly applied to cryptocurrencies. Since the permitted type of BC is faster than the public type in handling transactions, it has been applied to various business fields such as supply chain and intellectual property management [3].

There have been five main types of algorithms for consensus building in BC (**Table 1**). In public BC, PoW and PoS are mainstream; in the PoW consensus, rewards are evaluated by the amount of work done. In PoW consensus, the reward is evaluated by the amount of work done; in other words, the network participant who performs the appropriate computation the fastest receives the reward. In the PoS consensus, rewards are based on both the amount of work and the amount of cryptocurrencies held. In PoS consensus, rewards are based on both the amount of work done and the amount of cryptocurrencies held, easing the fierce competition in PoWs and saving electricity consumption, it suffers the problem that the rich get richer. On the other hand, in permitted BC, PBFT is the mainstream method. PBFT is faster than other consensus methods but has the disadvantage that blocks will not be created if two-thirds or more of the consensus is not obtained.

[10] A hash value is a fixed length of data created using a hash function. It is unidirectional and is difficult if not impossible to restore the original data from a hash value.

In the maritime industry, many players from different industries, usually in several countries, are involved in currently operating blockchain platforms. This complexity leads to a lack of transparency in the entire supply chain. In addition, the industry has the disadvantage of high transaction costs for information exchange, the possibility of fraud and theft, and vulnerability to the risk of cyber-attacks. BC offers the possibility to solve these problems [3]. To maximize the capacity and productivity of the digital information space, traditional authentication methods and data structures need to be reformed and modern technologies such as BC need to be actively applied.

2.3 Physical internet (PI)

PI was initially proposed by Montreuil in 2010 [4]. He defined PI as an open, global logistics network that efficiently and sustainably interconnects all elements of the logistics process. The PI includes the complete supply chain including storage, movement, supply, and delivery of goods, and the PI network is composed of various logistic providers. The goal of PI is to create a global logistics system based on the interconnection of existing logistic networks. To achieve this, a standardized set of protocols, modular containers, and smart interfaces are combined modular containers, called PI containers (**Figure 2**), which come in various sizes and can be combined and loaded to reduce waste. In addition to modular containers, PI-stores, PI-movers, PI-conveyors, and PI-gateways have also been proposed.

The characteristics of PI include interoperability, modularity, and standard interfaces and protocols. In order to take advantage of these features, technologies to share data while protecting confidentiality, such as BC technology, are essential.

Although it is not difficult to understand the usefulness of PI and BC, specific application measures have not been fully studied. In this chapter, we make a proposal for planning measures to build a BC network in PI, and discuss issues and measures for practical application. Specifically, the next sections also aim to clarify the following two points. First, to clarify the scope of application of BC in PI. Second, we propose a framework for implementing PI and BC technologies.

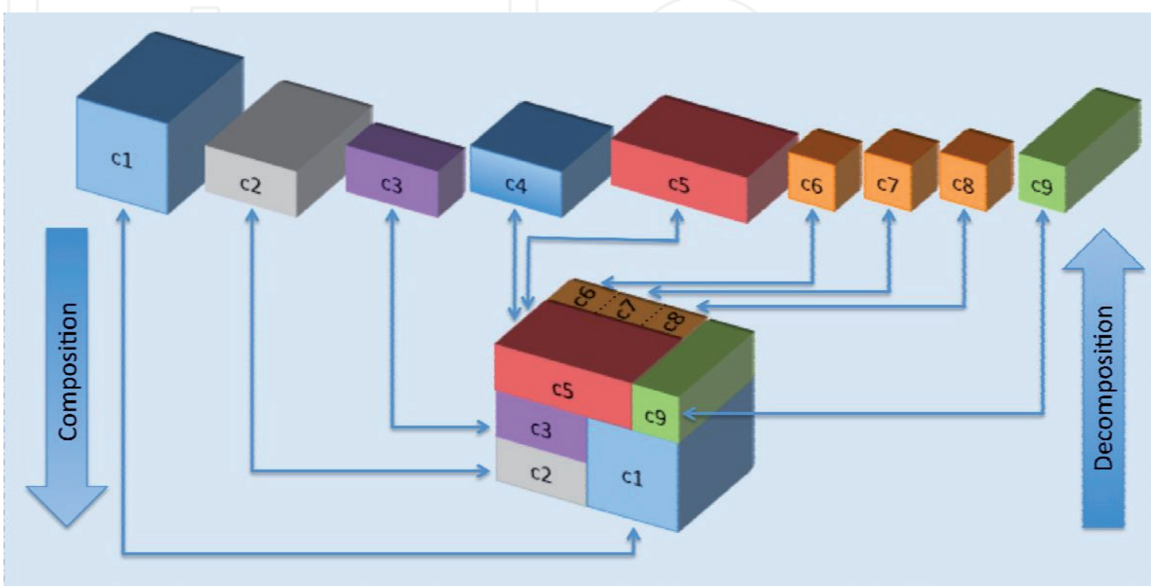

Figure 2.
An example of PI container combination. Source: Montreuil et al., 2010 [4].

3. Digitalization and automation for smart ports

3.1 Smart port initiatives in major countries

Various information systems have been introduced in maritime and port-related operations, such as Terminal Operating System (TOS) for internal terminal operations, Port Community System (PCS) for port logistics, Automatic Identification System (AIS), and the Transport Management System (TMS) for land-side operations such as trucking [5]. A smart port is an initiative that aims to improve the efficiency and safety of the port as a whole and to reduce the environmental impact of the port by integrating these systems through innovations in automation and new digital technologies such as IoT, AI, and 5G. Currently, the Port of Rotterdam (Smart Port Initiative) and the Port of Hamburg (smart port) in Europe, Japan (PORT2030), Korea (Smart Maritime Logistics) and Singapore (Sense-making Analytics For maritime Event Recognition: SAFER) and other major ports around the world are working on various initiatives.

The Port of Rotterdam in the Netherlands has a vision of being the "smartest port in the world" and is working on digitalization, energy transformation, and innovation to become carbon neutral. They have identified four levels of "digital maturity" for a port cargo community as shown in **Table 2** [8]. The Smart Port Initiative is a roadmap that includes projects in energy and industry like recycling, electrification, renewable energy, logistics like BD, automated driving and BC, port infrastructure like quays, dredging, maritime traffic management, and innovation. The Port Call Optimization (PMO) project is underway as part of Port Collaborative Decision Making (PortCDM), an initiative aimed at optimizing the timing of vessel arrival and departure [9]. PortXChange (formerly Pronto), a real-time information sharing platform for PMO between shipping companies, shipping agents, terminals, and other stakeholders, has been in operation since 2018. In the past, about 75% of shipping companies, including major operators such as Maersk and ONE, have participated in

Level	Name	Overview
1	Digitization of individual activities in the port	The individual organizations operating in the port digitize their processes so that they work more efficiently.
2	Integrated systems in a port community	The digital exchange of information within the port community leads to reliable, efficient, and paperless dataflows, resulting in more efficient port operations. The focus at this level is related to securely sharing data. Cybersecurity and cyber resilience are key.
3	Logistics chain integrated with hinterland	The hinterland four players (importers, exporters, logistics hubs, and domestic transporters) are involved in digital communication with the port community. This integration promotes sharing of real-time information on freight and vessel movements, facilitating better planning.
4	Connected ports in the global logistics chain	The port and its hinterland connections are extended to other ports around the world, forming a global network of interconnected ports. This network will allow further reductions of inefficiencies in the global logistics chains by optimizing the use of port capacities and achieving shorter, more reliable transit times.

Source: Buck et al. 2019 [6] and ADB2020 [7].

Table 2.
Definition of maturity levels of smart ports.

the experiment, and the results have shown that PortXChange is effective in reducing the waiting time of ships, especially for departures.

In Japan, one of the main measures in the mid-to long-term port policy "PORT2030" announced in July 2018 is to make ports smarter and more resilient by using information and communication technologies. In addition to the complete computerization of ports, which will be called "Cyber Port" through the construction of a port-related data linkage infrastructure, the policy aims to create container terminals with the world's highest level of productivity and a good working environment (AI terminals) by combining AI, IoT, and automation technologies. In the container terminal field, the introduction of remote-controlled cargo handling machinery and automated gate handling is being promoted, terminal operations are being streamlined and optimized using AI and other technologies, automated vessels, and remote-controlled tugboats are being operated, automated guided vehicles are being introduced, and automated trucks are being driven in convoys. In addition, the next generation high standard unit load terminal will be developed. Furthermore, in the next generation of high standard unit load terminals, the use of automatic driving technology for cross-carriage transport and the linkage with automatic navigation and navigation support technology for ships are mentioned.

3.2 Research and development for the realization of the automated ship

Various efforts have been made by shipping companies to develop navigation support technologies to improve the safety and efficiency of ship operations using IoT and big data. In this context, Maritime Autonomous Surface Ships (MASS) have been attracting attention rapidly in recent years. The term MASS generally describes a ship that is highly automated or remotely controlled to perform some or all of the following shipboard tasks: external situational awareness (watchkeeping), monitoring of equipment status, ship operation, engine control, cargo management, and loading/unloading, take-off and landing, and other shipboard tasks by using the latest technologies such as IoT, ICT, and data analysis technologies, various sensors, and land-based monitoring and control centers connected by broadband communications.

A number of projects are underway, mainly in Europe, with the aim of realizing MASS. In December 2018, Rolls-Royce and FinnFerry successfully demonstrated the world's first fully automated ferry. As an example of an international project, One Sea, a consortium launched in Finland in 2016, is developing a roadmap for practical application and discussing the necessary safety standards and international standardization in order to create an environment for MASS operation by 2025.

There is an ongoing international discussion on the legislative framework for safety standards for MASS. With regard to classification societies' certification systems, in February 2017, the British classification society Lloyd's Register published the LR Unmanned Marine Systems Code, which sets out the performance requirements for automated ships. The International Maritime Organization (IMO) has been considering the regulatory aspects of automated ships since May 2018 and has presented a provisional proposal, as shown in **Table 3**, and is discussing the necessary amendments to IMO rules and new developments. For demonstration tests, the provisional guidelines for safe and efficient demonstration tests of automated ships, jointly proposed by Japan and Norway, have been approved in June 2019. In May 2021, IMO has completed a regulatory scoping exercise on MASS that was designed to assess existing IMO instruments to see how they might apply to ships with varying degrees of automation.

Level	Name	Overview
1	Ship with automated processes and decision support	Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
2	Remotely controlled ship with seafarers on board	The ship is controlled and operated from another location. Seafarers are available onboard to take control and to operate the shipboard systems and functions.
3	Remotely controlled ship without seafarers on board	The ship is controlled and operated from another location. There are no seafarers on board.
4	Fully autonomous ship	The operating system of the ship is able to make decisions and determine actions by itself.

Source: IMO [10].

Table 3.
Definition of automation levels for MASS.

In Japan, industry, government, and academia have been collaborating since FY2017 to develop technologies, develop infrastructure and systems, and study business models for the realization of MASS through demonstration projects of automatic ship operation, remote ship operation, and automatic docking and unloading functions in order to improve the environment, including the formulation of safety requirements. The ClassNK has been working on the development of the technology through demonstration projects. In January 2020, the ClassNK established requirements and procedures for the functional verification of automation and remote-control systems used on ships and remote-control facilities, from the perspective of ensuring safety at each stage of development and design, ship installation, and operation [11]. The Ship Data Centre was established in December 2015 as a platform for the use of ship big data, with the participation of shipping companies, shipbuilders, marine industry operators, and meteorological information companies. The Ship Data Center was established in December 2015 as a foundation for the use of ship big data, with the participation of shipping companies, shipbuilders, marine industry companies, meteorological information companies, etc. Rules for fair and equitable data use have been established to promote the distribution and use of ship big data, and the effective use of accumulated big data is being promoted.

Based on the results of the economic evaluation of the MASS operation system, efforts are being made to commercialize a manned automated ship operation system (corresponding to automation level 1 in **Table 3**), which is more feasible in the short term. In NYK line, research has been conducted on an action planning system for the decision-making required to execute ship operations, and the world's first demonstration of a manned automated ship based on the provisional guidelines set by the IMO was conducted in September 2019 [12]. Future projections for unmanned automated ships (corresponding to automation level 3 or higher in **Table 3**) for domestic ships suggest that if 50% of ships are replaced by unmanned automated ships in 2040, the annual economic impact will be approximately 1 trillion yen [13]. In June 2020, the Foundation selected five projects for MEGURI 2040, which aims to realize unmanned automated ships by 2025, by conducting the world's first demonstrations in waters with high vessel traffic, long-distance navigation, and using large vessels.

3.3 Deployment of automated terminals at ports

The unmanned and automated handling of cargo at container terminals is expected to increase productivity per worker, improve the working environment and safety, and reduce the effects of weather conditions such as fog and wind. On the other hand, the introduction of the system is not without its challenges, such as high initial investment costs, maintenance costs (e.g., power consumption), and coordination with trade unions. At the ECT Delta Terminal in the Port of Rotterdam, the world's first automated terminal, an Automated Guided Vehicle (AGV) and an Automated Stacking Crane (ASC) were introduced in 1993. However, the introduction of these systems did not proceed due to technical and economic problems and difficulties in coordinating with labor unions, and there were only a few cases until the mid-2000s. However, since the mid-2000s, and especially since the 2010s, the number of automated terminals has been increasing rapidly, with nearly 60 terminals worldwide having installed the system so far. The number of automated terminals has increased rapidly since the mid-2000s, especially in the last decade. **Table 4** summarizes the status of the introduction of automated terminals, focusing on the level of automation. The symbols in the table indicate: ◎: mainstream status with many cases of introduction, ○: diffusion stage with several cases of introduction, and △: early stage with limited cases of introduction. In the case of marshaling yards and land-side container handling, remote control and automation are the basic systems. On the other hand, the manned operation is the mainstream for quay cranes, and full automation has been introduced only recently in a limited number of cases. In the case of horizontal transport within the premises, although there is a high degree of automation, various types of cargo handling machines have been introduced, and the level of automation differs greatly between ports.

In Japan, AGVs and remote-controlled ASCs were introduced at the south side container terminal of Tobishima Pier in the port of Nagoya in December 2005, which

Type	Activities	Typical cargo handling machine	Manned	Unmanned	
				Remote control	Automation
Waterside transport	Moving containers from ship to shore	STS (Ship To Shore Container Crane)/ QC (Quayside Conatiner Crane)	◎	○	△
Horizontal transport	Moving containers between the quayside and yard storage blocks	AGV (Automated Guided Vehicle), SC (Straddle Carrier), ShC (Shuttle Carrier), Chassis	◎	—	○
Marshaling yard	Moving containers at yard storage blocks	ASC (Automated Stacking Crane), ShC	—	○	◎
Landside transport	Moving containers from the terminal truck gate or intermodal railhead to the marshaling yard	ASC, ShC	—	◎	○

Source: Takahashi 2018 [7] and PEMA 2016 [14, 15].

Table 4.
The introduction of automated terminals with the level of automation.

is a relatively early stage in international perspective, but it is the only automated terminal in Japan at present. Currently, efforts are being made to promote the introduction of remote-controlled ASCs, mainly at strategic international container ports, and to improve the efficiency and optimization of terminal operations by using AI-based on container cargo information.

4. A case study of PI and blockchain technology for smart ports

In the following, a specific case study of a blockchain technology application, in a Logistics 4.0 Physical Internet environment, is explicated, as a representative system implementation for innovative, digital maritime logistics environments, with automated ships and terminals constituting flagship applications of Industry 4.0.

Three recent representative studies on the application of PI and BC in the supply chain are available [16–18]. Meyer et al. [16] proposed a conceptual framework for the exchange of value and physical assets in logistics networks that proposed a BC-based conceptual framework and provides a solution to the fundamental barrier of PI. As the main contribution, they identified barriers to transforming current logistics systems into PI networks through case studies. The key barriers included the creation of a network with equal participation, robustness of the framework, assurance of integrity and resilience, rewards in the operational process, and reliable data exchange. By further describing the key features of the technology, they discussed how the BC would address the barriers to PI adoption. They proposed Ethereum BC, implemented smart contracts based on the ERC721 standards[11], and evaluated the transport process in PIs. The authors conclude that BC technology can solve the barriers in PI because it enables a reliable and secure exchange of value in an untrustworthy environment. The authors propose a PoS based BC environment in order to save computational resources. In the case of small-scale PIs, the proposed solution already works, but the scalability[12] problem as a whole needs to be solved before PIs can be widely adopted.

Hassan et al. [17] presented a permitted BC architecture suitable for the integration of BC technology with PI. They discussed how to take advantage of the interoperability[13] between two permitted BCs. They demonstrated the applicability and practicality of the PI architecture to be built on top of a permitted BC and presented a case study of its application. The authors pointed out the scalability of both BC and PI networks as an issue to be solved.

Tan et al. [18] presented a framework of green logistics based on BC to realize sustainable logistics by integrating IoT and big data. The authors propose a framework with seven layers: physical layer, perception layer, network layer, blockchain layer, management layer, application layer, and user layer. The authors pointed out three issues: data storage and transmission, implementation cost, and risk. Then, for future research, the authors suggested to focus on the following: (1) developing a way to effectively connect the physical and perceptual layers to collect logistics data, and

[11] ERC721 is a common standard for smart contracts proposed by Ethereum. The feature of ERC721 is that nonfungible tokens (NFTs) can be handled in smart contracts. By using the ERC721 standard, the ownership and transaction history of NFTs will be able to be recorded on Ethereum BC.

[12] Scalability is the possibility of expanding the functionality of a system, even if it is small at first.

[13] Interoperability refers to the ability to collaborate and interoperability between different BC platforms.

(2) designing an incentive mechanism to encourage logistics companies to participate in the BC platform.

In contrast to the various advantages of BC, this technology requires a transformation of digital systems. First, existing processes need to be digitized. Currently, there are many tasks in logistic operations that are done by hand on paper or on computers that are not connected to a network. In order to effectively accumulate and utilize data in these tasks, it is necessary to digitize the tasks themselves or use AI (e.g., Optical Character Reader) services to digitize them.

Next, in order to work with platforms such as BC, existing systems need to have a mechanism to use APIs[14]. In the logistics field, many existing systems are still based on EDI[15], which supports only batch sending and receiving, while APIs support real-time sending and receiving. In the logistics sector, there are still many existing EDI-based systems; EDI supports only batch sending and receiving, while APIs support real-time sending and receiving, and the development cost is higher than APIs [3]. Making EDI-based core systems API compatible is an important task. The issue of standardization is important in the diffusion of APIs. At present, there is a bunch of standards at the level of international organizations, governments, and industries. Some of the standards conflict with each other. These standards need to be unified. Organizations like Digital Container Shipping Association (DCSA) help to expedite the process. DCSA aims to develop digital standards for the containership industry and has compiled and published electronic standards such as vessel schedules, port operations, and electronic B/Ls. The PoV should follow the standards and protocols published by DCSA. In addition, the API is an architectural style that can be easily manipulated and can flexibly respond to the unique standards of countries and industries, for example, 10-ft container, low floor chassis.

Munim et al. [19] identified the main challenges in the practical application of BC in the maritime sector as lack of standardization of data elements, lack of interoperability and scalability between systems, delay in legislation, lack of understanding of the technology, and lack of training facilities and materials. PiChain is facing the same challenges as it uses BC technology. In addition, it is necessary to solve the issues of attracting participating logistics companies and infrastructure development in the implementation of PI. The search for solutions to these issues remains a future task.

These previous studies pointed out the issues of scalability after conducting small-scale demonstrations. In this study, we propose a framework for building innovative Logistics 4.0 systems and applications to solve these issues.

4.1 Scope of application

We propose the following scope of application of BC technology in PI. PI contains three flows, namely physical (logistics) flow, information flow, and financial flow. BC technology is indispensable for two of the three flows: information flow and financial flow (**Figure 3**).

[14] API is an abbreviation for Application Programming Interface, which is a data exchange specification used by software components to exchange information with each other in real time.

[15] An abbreviation for Electronic Data Interchange, also known as "electronic data interchange," a technology that emerged in the 1970s and is mainly used for information interchange for electronic commerce between companies.

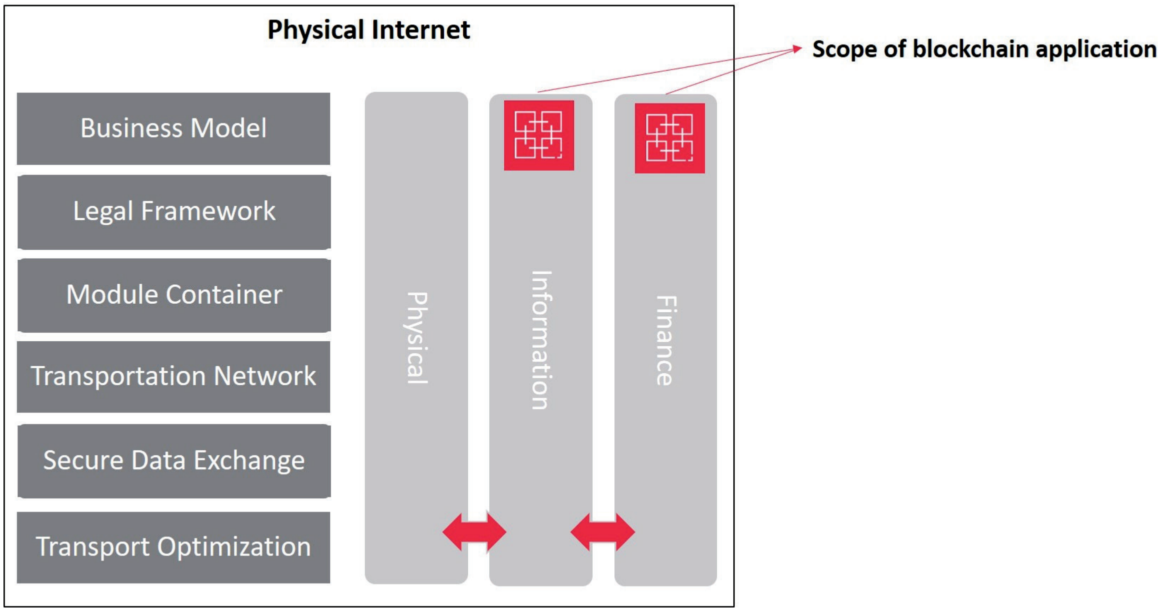

Figure 3.
The scope of BC technology application in PI.

4.2 Implementation framework

For implementation, this chapter proposes a new framework called PiChain, which consists of five components (**Figure 4**).

The first component is the PI that interconnects the maritime logistics networks. The second component includes networks such as LPWA that supports various types of IoT devices, and 5G and 6G that support cloud computing and edge computing. The third component consists of sensors, IoT devices, Internet of Robotic Things (IoRT), and drones. The fourth component includes big data for optimization with AI and visualization with business intelligence (BI). The top layer is the component that refers to the space optimization of business and operational processes implemented goals of logistics and sustainability goals (SDGs). All these components function on a decentralized platform that uses BCs to prevent data modification, which also support traceability and various types of payments.

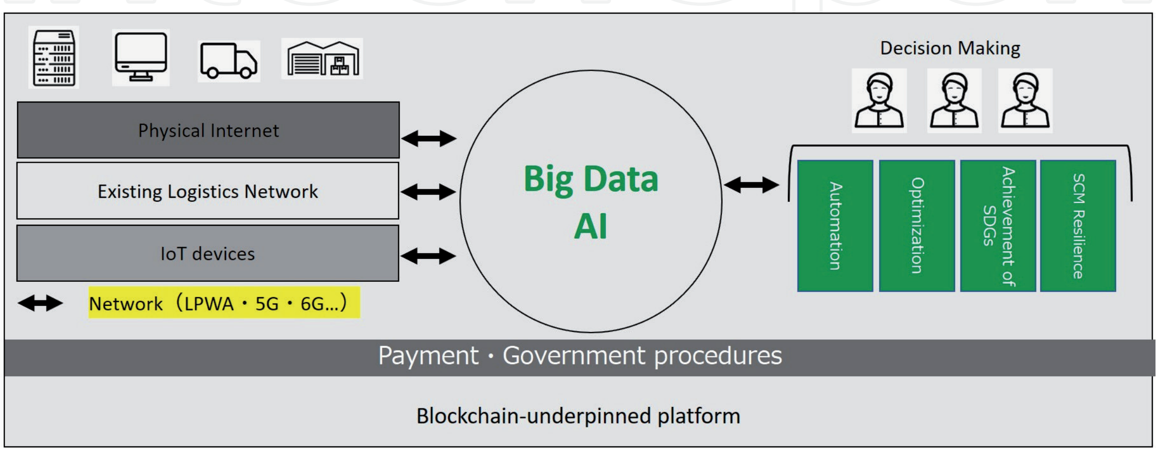

Figure 4.
Overview of the proposed framework "PiChain."

To give a better idea of how PiChain works, let us look at a few scenarios. In the future cargo transportation, upon booking information received, AI will automatically calculate the optimal transportation route and method constraints such as cargo destination, size, and weight using PI containers that match the size of the cargo. As soon as this information is finalized or updated, it is automatically sent to the shipper. In the shipper's internal system, AI uses the latest transportation information to optimize ordering, warehouse storage, and production planning. As soon as the consignee receives the shipment, the payment managed by BC's smart contract will be automatically executed.

4.3 Choosing a blockchain

To overcome the lack of scalability of BCs, as pointed out in previous studies, this study recommends the adoption of the Avalanche protocol (**Table 5**) proposed by Rocket 2019 [20].

The Avalanche protocol is one of the most promising platforms for BCs because of its scalability, ease of use, flexibility, and proper governance. Avalanche was initially built to serve the financial markets (cryptocurrency AVAX), but it is interoperable with both public and permitted BC. Therefore, it can be adopted by other industries in addition to finance. Avalanche is also capable of combining public and private BCs. Compared with the existing Classical and Nakamoto protocols, the BFT-based Avalanche protocol is very efficient and robust, and can also achieve high productivity and fast finality. While traditional protocols require any given node to communicate with all other nodes, the Avalanche protocol communicates with a small subset (validators), which dramatically reduces the latency to 1/3600 compared with Bitcoin (**Table 6**). As a result, Avalanche is able to achieve a performance of 7100 transactions per second, compared with 5 transactions per second for Bitcoin, the Nakamoto protocol equivalent.

We recommend a small-scale Proof of Value (PoV) to be executed. In the PoV, a small-scale PI network will be constructed by implementing the Avalanche protocol, which is small scale and scalable, in order to connect with the existing logistics

Protocol	**Classic (1980)**	**Nakamoto (2008)**	**Avalanche (2019)**
Typical applications	Byzantine General Problems	Bitcoin	AVAX
Robustness	✕	○	○
Low latency and quick finality[1]	○	✕	○
High processing capacity	○	✕	○
Lightweight	○	✕	○
Low power consumption	○	✕	○
51% attack resistance[2]	✕	✕	○
High scalability	✕	✕	○

[1]Finality means that the amount of money is certain to be obtained as expected. The Bank of Japan lists the following specific conditions for a finalized settlement: (1) The money received will not later be turned into scrap paper or disappear, and (2) the settlement made will never be reversed later.
[2]A 51% attack is the control of 51% (more than 50%) of the hash rate of the entire network by a malicious group or individual to perform fraudulent transactions.
Source: Prepared by the author based on Sirer 2020 [13].

Table 5.
Comparison of BC protocols.

Performance comparison	Bitcoin	AVAX
Latency	1	1/3600
Speed (transactions per second)	5	7100
Finality	Accomplished in 1 hour.	Accomplished in 1 second.
Number of simultaneous participants	About 20 people	millions of people

Source: Prepared by the authors based on Sirer 2020 [13].

Table 6.
Comparison of performance.

network and using BC technology, the collected big data will be analyzed for optimization, etc., using AI while ensuring its confidentiality. The results will be used for management decisions and environmental protection measures. This positive cycle will dramatically improve the efficiency of logistics and promote sustainable development. It will also be possible to measure and optimize the contribution of innovative technologies to the sustainable development of logistics and the SDGs. For example, it will be possible to quantify how much waste in loading and waiting for pickup is eliminated by the use of PI-containers, and how much congestion is eliminated by optimization at ports. Or how much truck driver time was saved by reducing waiting time, or how much CO_2 emissions were reduced, such measurements could be automatically recorded and measured on a reliable BC. The combination of Avalanche and PI in the logistic industry will drive logistics digitalization to a global scale.

4.4 Summary and future prospects

In this chapter, we have overviewed the international efforts for innovation in automation and digitalization for the realization of the Smart Port, including the development of technologies and demonstration experiments for their diffusion. It is necessary not only to automate cargo handling at the terminal, but also to share information in real time regarding pre-and post-processes, such as the arrival and departure of ships and the waiting status of vehicles, in cooperation with various IoT devices, and to prepare in advance based on predictive information using AI. It is expected to establish a de facto standard on a global scale by promoting the packaging of port handling machinery combining hardware and software. On the other hand, the international standardization for automated ships is being discussed internationally mainly by initiated by IMO as de jure standard. In addition, it will be necessary to share real-time information on the movements of ships using AIS and IoT and to make comprehensive efforts in cooperation with port infrastructures, such as coordinated operation with work vessels such as tugboats and refueling vessels, and automatic mooring at the wharf. In August 2020, MASSPorts, a framework for international collaboration on the operation of Maritime Autonomous Surface Ships (MASS) in ports, will be launched to establish guidelines for demonstration operations and to study interoperability in multiple ports around the world.

From the research and development stage to the full-scale deployment of new technologies, it is necessary to consider not only the individual optimization of ports and ships but also the overall optimization involving the ocean, ports, and the inland hinterland. As the need for mutual cooperation between ports and ships increases, new infrastructures, systems, laws and regulations, and international standardization need to be discussed. In addition, it is necessary to address not only the safety and cost aspects of installation and operation, but also cyber security, environmental aspects including renewable energy and electrification, and social acceptability. In order to enhance social acceptability, it is important to build a relationship of trust so that not only the port and maritime industries but also the general public can feel secure.

Furthermore, in this chapter, we have proposed PiChain, a framework for creating a sustainable, next-generation maritime logistics system, by applying PI to digitize maritime logistics networks and BC technology for secure information exchange to improve the overall efficiency of maritime logistics, at ports. The following three effects can be expected from the adoption of PiChain.

4.4.1 Strengthening supply chain resilience

Recently, there have been many disruptions in the supply chain due to unexpected circumstances such as bad weather, cyber-attacks, and port congestion. In particular, the covid-19 pandemic that began in early 2020 led to travel restrictions and border closures in some countries, which in turn caused disruptions in sea, land, and air logistics. The disruption of logistics also resulted in stagnant production in many countries. The framework proposed in this chapter, PiChain, is useful for supply chain management during emergencies and early recovery from disasters, as the BC-based platform provides real-time information and visualization of the entire delivery process, which in return enables quick response to unexpected delays. In addition, since PI containers can be freely combined or split, switching parts of cargo to alternative modes of transportation can be done flexibly when needed. Furthermore, the application of automated delivery methods, such as drones, will make it possible to deliver even in the middle of the night or in hazardous environments. In conclusion, PiChain can strengthen the resilience of the supply chain while managing a wide range of unknown risks.

In addition, cyber-attacks in the supply chain have been dramatically increasing in recent years. With risks increasing day by day, a high level of cybersecurity is vital for supply chain resilience. The PiChain framework uses BC technology to make the entire network highly resistant to cyber-attacks. Even in the event of being attacked, the stolen data are a hash value generated by BC, so it is difficult to recover the original data from the hash value, which significantly reduces the risk of information leakage. In addition, since the data are stored in a distributed manner in the cloud, it can be recovered quickly after an attack.

4.4.2 Port sustainability

Regarding the establishment of a sustainable supply chain within the framework of PiChain, the following three points can be summarized.

First, realizing the SDG Goals. Visualizing, measuring, and optimizing GHG emissions will help to minimize their negative impact on the environment. This will contribute to the realization of SDG Goal 13: Take urgent action to combat climate change and its impacts.

Second, improvement of working conditions. In the framework of PiChain, it is expected to improve the working conditions of workers. For example, AI-guided optimal delivery routes will shorten waiting time hence reducing stress for drivers. In addition, logistics workers will be able to enjoy the benefits of advanced visibility and perform their daily work in a more independent way. This will contribute to SDG Goal 8: Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.

Third, improvement of service quality. Visible logistics management with PiChain will make just-in-time delivery easier. The deployment of drones will also make nighttime delivery possible. This will help improve the quality of logistic operations by enabling a quick response to any unforeseen circumstances that may arise.

4.4.3 Creating new business models

With the spread of innovative technologies, new business models will emerge. For example, the inspection at the yard when returning empty containers used to be done by human eyes. Now, using AI image recognition technology, AI can quickly analyze photos of containers automatically taken by surveillance cameras at the gate, and determine if the container is dirty or damaged with an accuracy of over 98%. This kind of service is already being offered in countries like China.

AI will be able to analyze the big data collected and accumulated from the IoT and other sources to realize end-to-end optimization and real-time visibility of the supply chain. New business models that provide niche services in the supply chain emerge continuously, benefiting from innovative technologies.

In addition, there will be businesses that provide training on technologies such as BC and AI. Not only corporate management but also frontline workers will acquire basic knowledge of the new technologies to work more comfortably and efficiently. Since such services are still few, demand will increase further and new businesses in this field are expected to grow considerably. With the digitization of operations and the creation of new business models, maritime logistics, and its various systems, including smart ports will evolve into the next generation, Industry 4.0 modus operandi.

5. Conclusion

As data-centric processes gain more momentum, shipping and port operations are transformed by meticulously embracing innovative business models and Industry 4.0 technologies. Reliable, secure, and efficient cross-collaboration maritime logistic processes are of paramount importance for the promotion of automated ports, as critical nodes in sustainable, digital supply chains.

A decentralized maritime logistics management system, such as a blockchain-based and IoT-aware system that is deployed over a Physical Internet reference architecture, can support and further advance the development of shipping digitalization and ports' automation. AI techniques and respective platforms can exploit real-time information on the movements of ships using AIS and IoT, also port infrastructures and machinery information, and data from vehicles and objects supporting the overall logistics flow, in road or air transport segments, respectively. In this chapter, we outline the technologies and provide a blueprint for building efficient, decentralized, scalable Logistics 4.0 systems, offering a prototype infrastructure model and immediate practice guidance to the next-generation shipping and port community.

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