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THE ECONOMIC IMPACT OF DIGITALIZATION IN MARITIME LOGISTICS

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Abstract: The maritime transport sector is undergoing profound transformations driven by digitalization, transitioning modern ports from simple freight transit points into smart logistics hubs. This paper aims to analyse the extent to which digital technologies—specifically Artificial Intelligence (AI), Blockchain, and the Internet of Things (IoT)—have contributed to the economic performance of the Port of Constanța. Based on statistical data from the 2020-2025 period, the research methodology evaluates traffic variations, capacity efficiency, and applies economic formulas to determine the Compound Annual Growth Rate (CAGR) and estimated cost savings. The results reveal that the existing digital infrastructure enabled the port to successfully absorb severe geopolitical shocks and immense volume fluctuations, achieving a structural growth CAGR of 2.28% per year and generating estimated operational savings of 443.9 million euros over the analysed timeframe. In conclusion, digitalization fundamentally restructures maritime logistics and generates quantifiable economic benefits. To maintain competitiveness and align with strict European regulatory frameworks, the Port of Constanța must urgently accelerate investments in cybersecurity, integrated digital ecosystems, and skilled workforce training to fully capitalize on its potential as a leading European digital hub.

Key words: Artificial Intelligence, Blockchain, Digitalization, Economic impact, Maritime logistics, Port of Constanța.

1. INTRODUCTION

In the context of the rapid transformations brought about by digitalisation, the maritime transport sector is going through a period of profound change, with significant economic implications at global, European and national level. Modern ports have gone from freight transit points into smart logistics hubs, where digital technologies are redefining operational efficiency and cost structure.

The Port of Constanța is the largest port with access to the Black Sea and one of the most important ports of the European Union, and represents a relevant and current case study for the analysis of these transformations. It has had a spectacular evolution in recent years, with a significant increase from 75.5 million tons in 2022 to the historical record of 92.6 million tons in 2023 [38], [57]. The drop to 67.5 million tons in 2025 shows both the huge potential of digitalization and the vulnerabilities of a system still in transition.

This paper aims to analyse, based on statistical data from the period 2020-2025, the extent to which digitalization has contributed to the economic performance in the Port of Constanța, while presenting the challenges and opportunities for the next period. The digital technologies analysed will be: artificial intelligence, blockchain and IoT systems.

2. DIGITAL TECHNOLOGIES IN MARITIME LOGISTICS

2.1 Artificial Intelligence (AI)

Artificial intelligence is a technology that has transformed the maritime sector in recent years, developing it very rapidly. A report by Lloyd's Register [5] states that the maritime AI market has grown rapidly, reaching a value of $4.13 billion in 2024, Growing almost three times compared to the previous year, with an annual growth rate of 23% projected for the next five years. This rapid development shows the concrete usefulness of AI in solving certain operational problems of the maritime sector. More than 70% of shipping companies will integrate AI technologies by 2025, to drive efficiency and innovation and to navigate the challenges of a dynamic global market.

Optimizing shipping routes is the most practical application of AI in shipping. With the help of AI route optimization systems, fuel consumption can be reduced by up to 10-15% [6], [7]. These systems are based in particular on choosing more energy-efficient routes,

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minimising downtime and avoiding adverse weather conditions. In January 2025, HD Hyundai Marine Solution launched OceanWise, a carbon emission management and navigation optimization platform through big data algorithms to significantly reduce fuel consumption and greenhouse gas emissions. This system monitors emissions, optimizes routes according to the weather and uses digital twin technology to simulate the behaviour of the real ship in different conditions; it has also saved an average of 5.3% of fuel.

Predictive maintenance is another AI-powered system in the maritime sector. Companies such as Rolls-Royce and Wärtsilä have developed autonomous systems capable of short uncrewed voyages, based on sensors, LIDAR, radar and satellite data that create a virtual environment for autonomous navigation [8], [27]. According to UNCTAD [2], more than 80% of global trade is carried out at sea; increasing pressures to optimize operations, reduce costs and minimize environmental impact make AI an indispensable technology for maritime authorities and regulators.

2.2 Blockchain

Blockchain is a technology that addresses excessive documentary bureaucracy and lack of transparency in the supply chain. Traditional transport processes involve multiple parties and large quantities of paper documents, leading to slow transfers of information and coordination difficulties. Blockchain offers a structural solution to this problem by creating a decentralized, immutable digital ledger that is accessible to all parties involved. The cost of a blockchain-based electronic bill of lading (eBL) is on average $15, which is about 15% of the price of a traditional bill of lading delivered by international courier [9], [11].

The impact of blockchain on the operational efficiency of ports has been demonstrated through rigorous academic studies [10]. These studies showed that blockchain technology reduces the average storage time of containers in the terminal by 3-4% and decreases the maximum storage time in the port yard by up to 30%, thus increasing the utilization rate of the equipment.

2.3 Internet of Things (IoT)

IoT transforms ports and ships from relatively opaque entities into fully transparent and real-time monitored systems. IoT applications in maritime logistics are diverse and have a direct impact on costs and safety. The smart container market is on a rapid growth trajectory, projected to reach USD 13.69 billion by 2030, with a compound annual growth rate of 19.6% from 2024 to 2030, driven by the growing demand for real-time visibility, enhanced commodity security, and data-driven decision-making in global supply chains [15], [16].

According to Gartner [12], IoT-based predictive maintenance reduces unplanned downtime by up to 30%, eliminates unnecessary repairs, generating savings of 15-25% in maintenance budgets [13]. IoT sensors installed throughout the port collect large volumes of data in real time, tracking container movements, monitoring equipment status, measuring environmental conditions, and detecting vessel positions [14], [17].

3. EUROPEAN AND NATIONAL REGULATORY FRAMEWORK

The European Union has adopted in recent years an ambitious legislative framework that requires the mandatory digitalisation of the maritime transport sector, with direct implications for all Member States. The EMSWe Regulation (EU) 2019/1239 [19], [20], applicable since August 2025, creates a decentralised network of National Maritime Single Windows that function as a single point of entry for the exchange of information in each Member State [21]. The economic impact is direct: operators operating in several European ports benefit from significant reductions in administrative costs. The eFTI Regulation (EU) 2020/1056, fully applicable from July 2027, aims to completely eliminate paper documents from all European modes of transport, with estimated savings of €27 billion for operators [22]–[25]. The inclusion of maritime transport in the EU ETS from 2024 adds additional financial pressure, mandating a 40% reduction in emissions by 2030 and forcing ports to invest in green technologies and digital emission monitoring systems.

At the national level, Romania has implemented the RO e-transport system, mandatory for international transports from July 2024, with penalties between 20,000 and 100,000 lei for non-compliance [28]–[30]. The Ministry of Transport has developed the Institutional Strategic Plan 2025-2028, which explicitly recognizes the gap with European standards and prioritizes the digitization of infrastructure [31]. Through the Transport Program 2021-2027, Romania has access to significant European funds for the modernization and digitization of ports, an opportunity insufficiently capitalized so far due to limited administrative capacity [32], [47].

4. CASE STUDY: PORT OF CONSTANȚA

The Port of Constanța is the most important logistics hub of Romania and one of the most significant ports of the European Union. The Port of Constanța can process up to 120 million tons of cargo annually, being equipped with modern facilities, including specialized terminals for containers, grain, oil and other general cargo. It also has passenger and cruise ship terminals. From a European perspective, the port occupies a remarkable strategic position. The Port of Constanța recorded in 2022 the third highest percentage increase in freight traffic among the ports of the European Union [36], [39].

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Table 1 Constanța Port Traffic 2020-2025 (Source: authors' study)

Year	Total Traffic (mln tons)	Absolute variation (mln tons)	Percentage variation (%)	Main Context
2020	60.3	-6.3	-9.5%	COVID-19 pandemic
2021	67.4	+7.1	+11.8%	Post-pandemic recovery
2022	75.5	+8.1	+12.0%	Ukraine War
2023	92.6	+17.1	+22.6%	Historical peak
2024	77.5	-15.1	-16.3%	Resumption of Ukrainian ports
2025	67.5	-10.0	-12.9%	Traffic normalization

Annual Growth Rate (%)

$$Growth\ rate = \frac{Traffic\ year\ N - Traffic\ year\ N-1}{Traffic\ year\ N-1} \times 100 \quad (1)$$

Application: 2019-2020: -9.5% ; 2020-2021: +11.8% ; 2021-2022: +12.0% ; 2022-2023: +22.6% ; 2023-2024: -16.3% ; 2024-2025: -12.9%

Compound Annual Growth Rate (CAGR)

$$CAGR = \left(\frac{Final\ Value^{\frac{1}{N}}}{Initial\ Value} - 1\right) \times 100 \quad (2)$$

$$\text{CAGR} = \left(\frac{67{,}5^{\frac{1}{5}}}{60{,}3} - 1\right) \times 100 \Rightarrow \text{CAGR} = +2.28\%/\text{year} \quad (3)$$

Port Capacity Efficiency Index

$$\text{Capacity efficiency} = \left(\frac{\text{Real Traffic}}{\text{Maximum capacity}}\right) \times 100 \quad (4)$$

Absolute Variation from Baseline

$$\text{Absolute variation from baseline} = \left(\frac{\text{Traffic year N} - \text{Traffic 2020}}{\text{Traffic 2020}}\right) \times 100 \quad (5)$$

Estimated Economic Impact of Efficiency Gains

$$\text{Digitalization savings} = \frac{\text{Operational cost}}{\text{Ton}} \times \text{Total traffic} \times \text{Discount rate} \quad (6)$$

Table 2 Estimated Economic Impact (Source: authors' study)

Year	Traffic (mln tons)	Est. total cost (mln. EURO)	Savings 25% (mln. EURO)	Capacity Efficiency	Absolute change
2020	60.3	192.0	48.0	50.3%	0%
2021	67.4	236.3	59.1	56.2%	+11.8%
2022	75.5	302.4	75.6	62.9%	+25.2%
2023	92.6	388.5	97.1	77.2%	+53.6%
2024	77.5	345.8	86.5	64.6%	+28.5%
2025	67.5	310.5	77.6	56.3%	+11.9%

The analysis of data from the period 2020-2025 allows the identification of three distinct phases in the evolution of the Port of Constanța:

Phase 1 – Recovery (2020-2021): The port recovered from the pandemic impact, recording an increase of +11.8% in 2021. The digitization of document operations and the early adoption of digital traffic management systems have contributed to operational flexibility.

Phase 2 – Geopolitical tensions and accelerated digitalization (2022-2023): The context of the war in Ukraine has generated exceptional growth, with the port reaching 92.6 million tons in 2023. This period demonstrated that the existing digital infrastructure could absorb dramatic increases in volume without major bottlenecks.

Phase 3 – Normalization and restructuring (2024-2025): The return of Ukrainian traffic to its own ports has reduced volumes, but the port's traffic in 2025 was 11.9% higher than in 2020, confirming a real structural growth. The operating revenues of the port administration company fell by 8.6% in 2024, and for 2025 the budget provides for a further decrease of 491.6 million lei.

The Port of Constanța significantly accelerated investments in the analysed period. Investments worth over 756 million euros are underway and in preparation in the Port of Constanța, including the modernization of the electricity distribution infrastructure, the extension of the quays and the electrical connection of the ships to the quay (Cold Ironing system) [42].

A large-scale project for the Port of Constanța is the development of Piers III S – IV S, with an estimated value of over 1 billion euros. Also, the development of the artificial island is estimated at over 1.4 billion euros. The total planned investments thus exceed 3.2 billion euros, representing the largest modernization in the history of the port [41].

5. CHALLENGES AND RISKS OF DIGITALIZATION

5.1 High implementation costs

One of the most significant barriers to maritime digitalisation is the substantial upfront investment needed to modernise existing systems. Installing digital systems on board ships costs between $0.5 million and $2 million per ship, and upgrading port terminals involves hundreds of millions of euros. Interviewing

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global industry leaders reveals common challenges: incompatible legacy systems, data sharing concerns, and IT skills gaps [48]. Resistance to change often stems from high implementation costs and managerial fear of reducing workload requirements. Trade unions frequently view digitalization with scepticism, believing that it would lead to a decrease in the demand for personnel. These challenges are particularly relevant for the Port of Constanța, which operates with infrastructure built largely during the communist period and which requires major investments to bring it up to European standards.

5.2 Skills gap and labour force

The digital transformation creates an acute demand for qualified personnel in niche technical fields, generating a significant gap with the existing supply on the labour market. The transition to digitized operations requires a proficient workforce in advanced technologies, and the labour gap in the industry is shifting from quantity to quality. At the level of the Port of Constanța, this challenge is amplified by the national context: Romania is facing a massive phenomenon of emigration of qualified labour.

5.3 Cyber vulnerabilities

Cyber risk is the most dynamic and dangerous type of risk associated with maritime digitalisation. The number of maritime cyber incidents in 2025 increased by 103% compared to 2024, with DDoS, ransomware and malware attacks accounting for the majority of them [50], [52]. An analysis based on 112 incidents from 2020-2025 reveals a 150% increase in incidents, with state-sponsored actors from Russia, China, and Iran responsible for the most high-impact attacks [51], [53], [56].

5.4 Geopolitical and external factors

The Port of Constanța has proven to be extremely vulnerable to external geopolitical factors, as illustrated by the dramatic evolution of traffic in the period 2022-2025. Global maritime trade grew modestly by 2.2% in 2024 and is projected to stagnate at just 0.5% in 2025 [54]. Traffic through the Suez Canal has fallen by 70% from the peak level, forcing ships to be rerouted on longer and more expensive routes [55]. At the local level, the resumption of activity of Ukrainian ports reduced Constanța's traffic by 25.1 million tons between 2023 and 2025, a decrease of about 27% in two years. This dependence on external factors underlines the structural vulnerability of the port and the need to diversify cargo types and trade routes through digital tools.

6. CONCLUSIONS AND RECOMMENDATIONS

The analysis of real-world data from 2020-2025 confirms that digitalisation generates quantifiable economic benefits and structurally transforms maritime logistics. The application of economic formulas on the data of the Port of Constanța demonstrated estimated savings of 443.9 million euros over the entire analysed period, a structural growth CAGR of 2.28%/year and a remarkable capacity to absorb external shocks.

The European legislative framework (EMSWe, eFTI, EU ETS, TEN-T) imposes a strict digitalisation timetable that creates financial pressures, but also ensures access to European funding and alignment with the competitive standards of Western European ports. Romania has taken concrete steps through the RO e-Transport system and the MTI Strategic Plan 2025-2028, but the pace of implementation remains insufficient compared to the needs.

- Accelerating the absorption of European funds from the 2021-2027 Transport Program and PNRR for port digitalization projects
- Urgent implementation of a cybersecurity plan aligned with the CER Directive (EU) 2022/2557 and the IACS UR E26/E27 standards
- Investing in skilled workforce training and closing the skills gap in critical areas
- Building an integrated digital ecosystem that connects all port components: terminal, customs clearance, rail logistics, electronic documentation
- Diversifying the types of goods processed to reduce dependence on Ukrainian traffic
- Partnerships with European reference ports for the transfer of best practices and the acceleration of digitalization.

The Port of Constanța is at a strategic crossroads. The announced investments of 3.2 billion euros, the European legislative framework and the privileged geographical position at the confluence of trade routes between Europe, Asia and the Middle East offer all the premises for transformation into a leading European digital logistics hub. The realization of this potential depends on a single determining factor: the speed and quality of the implementation of digitalization in all the parameters analysed in this paper.

7. CREdit authors statement

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