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Research Paper

The impact of Artificial Intelligence in the Shipping sector and the role of Total Quality Management

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ABSTRACT: *Artificial Intelligence (AI) has been integrated into various sectors of the economy, such as transport and supply chain, helping to reduce costs and increase profit margins. Particularly in the shipping industry, AI has helped manage large volumes of information to make more rational and quality decisions. These issues are raising the interest of researchers and have sparked debates worldwide as the impact of AI is significant. This article aims to contribute to the understanding of the impact that AI has had on the maritime industry and the catalytic role of Total Quality Management. Its contribution lies in shedding light on aspects that are useful to stakeholders and businesses in the shipping industry. The findings of the research showed that some of the benefits of AI in the shipping industry include faster data processing and analysis, quality and accuracy in decision-making, automation of various processes, and optimization of routes and transport, with safer operational performance.*

KEYWORDS: *Artificial Intelligence, Shipping, Smart ports, Autonomous ships, Total Quality Management (TQM)*

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I. INTRODUCTION

Researchers around the world report that Industry 4.0 has resulted in the rapid integration of technology and digitalization in various industries such as shipping with the transformation of traditional ports into smart ports.

Cutting-edge technologies such as Artificial Intelligence (AI), Internet of Things (IoT), Digital Twins, Blockchain, and 5G today are key elements that are redefining port operations to enhance efficiency, security, and sustainability (Du et al., 2023).

At the same time, the development of smart ports creates a new challenge to have smarter, more efficient and economical ports that can adapt more quickly and smoothly to today's global changes in the shipping industry.

The maritime industry is experiencing a new era of digital transformation, with multifaceted challenges to which it is required to cope effectively while maintaining a high level of Total Quality Management principles for maritime businesses and related organizations and stakeholders (Sofranac and Stefanovic, 2025).

In addition, all these challenges as a whole effect not only the financial resources of shipping but in a broader context the operations, energy, safety, and human resources associated with this industry.

In recent years, the presence of the Internet of Things (IoT) has become significant and is considered a major technological revolution related to smart cities, smart homes, smart factories, and smart port applications (Bouhlal, Aitabdelouahid and Marzak, 2022).

Ports in particular are fiercely competing to gain a sufficient market share and provide a more efficient and secure flow of goods globally. This is as high-performing ports usually adopt and implement smarter technologies to better manage operations that meet the new challenges in terms of maintaining safe and energy efficient facilities that are able to reduce environmental impacts (Battino and Muñoz, 2022).

However, interest is also extending to autonomous and drone ships through the development of sensor technology, through connectivity with specialized decision support software.

It is now a fact that automation is part of the maritime industry with the presence of unmanned ships or even remote-controlled by land-based virtual bridges in order to achieve optimization of operations (Botti et al., 2017; Belmoukari, Audy and Forget, 2023).

It is noteworthy that, there are various issues even for cyber security which is a modern challenge through the threat of sensitive personal data.

All these crucial issues can as a whole be manageable if there is strategic planning, policies, proper implementation of total quality management of shipping industry operations, and effective application of artificial intelligence to have a clearer and quality workflow (Shoushtari, Ghafourian and Talebi, 2021).

However, the effectiveness of artificial intelligence is based on accurate and large amounts of data, where managing it is complicated using algorithms and relatively costly, but with simultaneous human judgment and supervision it is easier to run efficient and quality operations (Gao et al., 2022).

The global shipping map is now shifting towards a more holistic approach that combines AI with human supervision, which is becoming highly necessary to highlight its potential and reduce the risks associated with its implementation and the ethical issues that it is associated with.

In line with the above-mentioned, the present research must contribute to identify and highlight critical points that contribute to the improvement and effectiveness of the shipping industry in the light of artificial intelligence and how it affects Total Quality Management.

The second section discusses AI, the third is how it has created smart ports, and the fourth presents autonomous ships and how they have been influenced by technology and AI. Then in the fifth section, the role of Total Quality Management in the field under consideration is analyzed, followed in the sixth section by the conclusions and the literature used in this research.

II. ARTIFICIAL INTELLIGENCE

Artificial intelligence refers to computer systems that simulate human intelligence processes using various techniques, such as machine learning, natural language processing, robotics and others. AI essentially aims to provide systems that can perform tasks and solve problems that usually require human intelligence (Rane, 2023).

Artificial intelligence can automate repetitive tasks that will thus improve the overall performance of whatever is being used. Large volumes of data (Big Data) can also be processed and streamlined through AI algorithms to provide predictive analytics that can help determine future events such as market trends (Abduljabbar, 2019; Kottara and Zaridis, 2024).

Another key advantage of AI is its ability to assist in decision-making by providing people with insight and recommendations. These techniques can be applied to the port industry in various ways (Cui and van Esh, 2023).

Ports around the world can optimize their entire service offering, from order management to logistics and inventory management, through the use of AI. For example, AI can be used to optimize operations and fleet management of vessels. One of the most interesting examples of the application of AI in ports is the development of autonomous ships that can navigate, dock, and make decisions on their own.

III. SMART PORTS

In the period 2020 to 2023, the top ten shipping hubs in the world were Singapore, London, Shanghai, Hong Kong, while the eighth place was occupied by Athens with the port of Piraeus and Tokyo.

Ranking	2020	2021	2022	2023
1.	Singapore	Singapore	Singapore	Singapore
2.	London	London	London	London
3.	Shanghai	Shanghai	Shanghai	Shanghai
4.	Hong Kong	Hong Kong	Hong Kong	Hong Kong
5.	Dubai	Dubai	Dubai	Dubai
6.	Rotterdam	Rotterdam	Rotterdam	Rotterdam
7.	Hamburg	Hamburg	Hamburg	Hamburg
8.	Athens/Piraeus	Athens/Piraeus	New York/ New Jersey	Athens/Piraeus
9.	New York/New Jersey	New York/New Jersey	Athens/Piraeus	Ningbo zhoushan
10.	Tokyo	Ningbo zhoushan	Ningbo zhoushan	New York/New Jersey

Graph (1) Top 10 shipping hubs in the world (2020-2023)

Source: Xinhua-Baltic International Shipping Centre Development Index Report, 2023

The use of technology in traditional ports has contributed to their efficiency while creating strategies to improve their performance and transparency.

The improvements brought about by automated processes in ports have had a multiplier effect on all stakeholders such as logistics, transport, and terminal operators.

The era of "port 4.0" is a fact with the emergence of "smart ports" which are governed by a high degree of automation, providing advanced services for the seamless flow of transport networks.

The digital transformation and the trend of the digital ecosystem (DE) are now a reality that often leads to the success of organizations and businesses related to this sector.

The pillar of the port industry is constantly growing and contributing to the international economy through the upgrading of international trade.

Relevant research with participants from various ports in Europe, the United States, China, the Middle East, and Singapore revealed that automated ports have a particular potential and the future of automated ports. In addition, it was identified that costs during the operation of a green automated terminal are reduced by 25%, while productivity is increased by 30% (Douaioui, Fri and Mabrouki, 2018).

Yang et al., (2018) focus on the competitive aspect of ports worldwide, as they represent a significant share of the market and a good flow of goods. High-performance ports in particular have adopted several smart technologies to manage operations more efficiently. In particular, ensuring higher quality and more energy efficient facilities in addition to reducing operating costs promote sustainability as there is a reduction in environmental impact.

Each port needs to be tailored to cope with daily operations such as cranes on the docks, and automated vehicles to help handle containers and other routine operations.

However, all these tasks through automation and the use of artificial intelligence are becoming easier and more efficient, reducing the time and costs that were previously required.

Molavi, Lim, and Race, (2020), highlighted the issue of port resilience and sustainability by focusing on key performance indicators (KPIs) which focus on the areas of environment, energy, and safety.

In this research, it becomes clear that smart port initiatives must be critical as they are governed by different systems around the world, and for this reason, government policies should be considered with great care and even take into account ethical and moral issues that may arise with the onslaught of cybersecurity and artificial intelligence.

Although studies on smart ports have been carried out in recent years, however, due to the constant technological and economic changes that exist on a global scale, there are several research gaps regarding performance indicators and future development trends.

It is crucial to conduct more studies to identify the strengths and weaknesses that underlie most of the smart port development (Li et al., 2023).

According to Kuo, Huang, and Chen, (2022) the Internet of Things (IoT) is on the rise and has not left shipping and smart ports unaffected. As a whole, it comprises a set of modern technologies with extremely large amounts of information where through sensors and devices information is exchanged and transmitted.

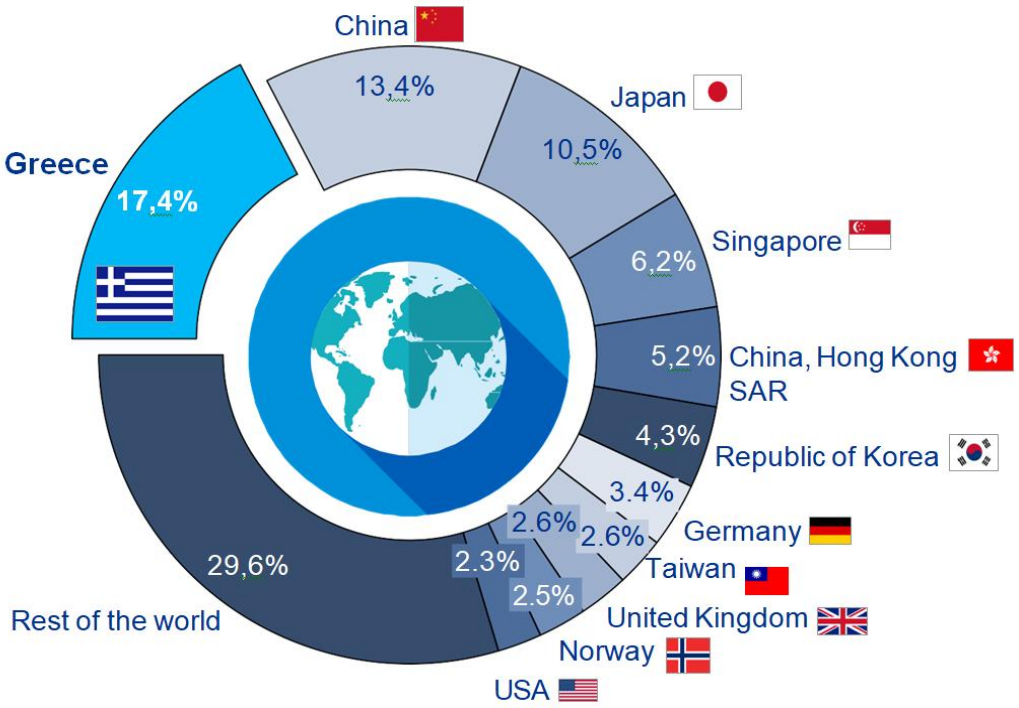
At the same time, instructions are fed and commands are issued to the device, which in turn conducts the prediction and decision-making by artificial intelligence (AI). This overall process is carried out after analyzing a large amount of data, which is called the AI of Things (AIoT) system, with the help of artificial intelligence.

Today, the post-industrial 4.0 revolution has been a major factor in terms of demand for seaports, setting new foundations with a set of challenges involving concerns about their operational capabilities, competitiveness, and sustainability of the industry's businesses.

Smart ports are of major importance; intelligent hubs in the supply chain.

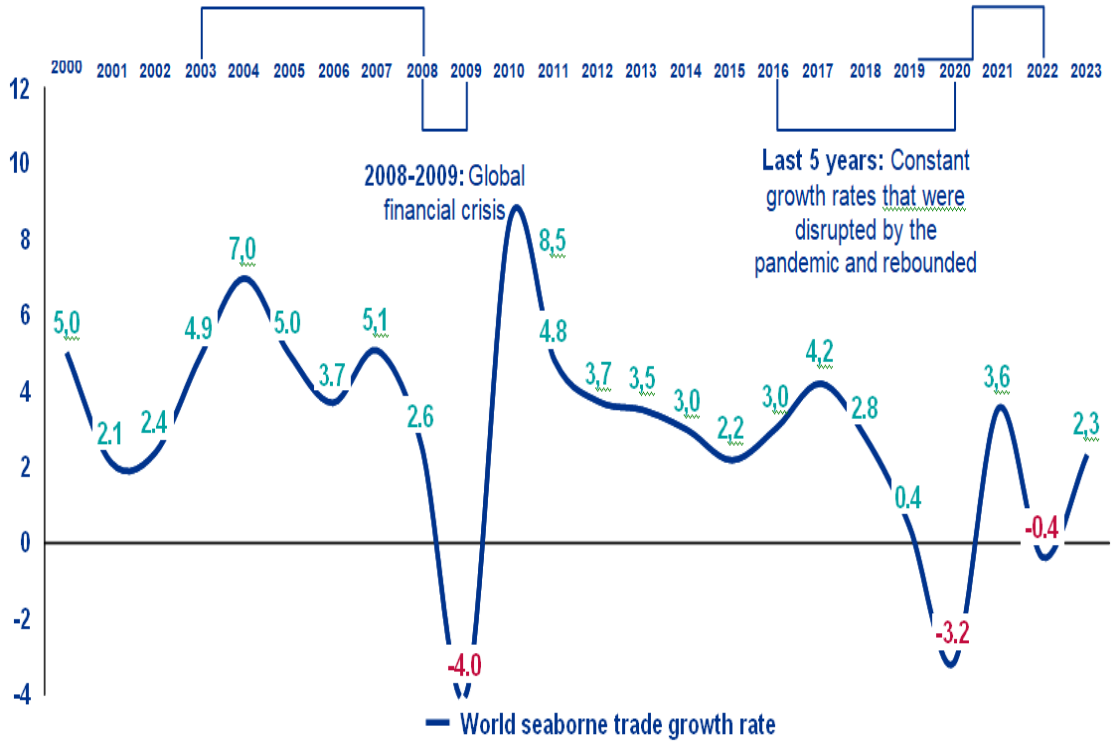
The extraordinary impact of digital transformation and the use of technology is increasingly shaping a new context that shifts to the need to create a more evenly distributed across different geographical locations development of smart ports to quantify the intelligence provided in recent years using artificial intelligence for a more sustainable future (Bakhsh, Fiori and de Luca, 2024).

The country ranks 1st globally in ownership of merchandise vessels, presenting a 17.8% increase in owned capacity the last five years. Country’s average vessel’s size is almost double compared to global average of 39k tons, a fact which indicates that Greek ship-owners mostly operate in high-volume markets. In terms of flagship, Greece rank 9th with 2.6% of global fleet (in capacity terms) to be registered in the Greek register.



Graph (2) UNCTAD –Review of Maritime Transport 2023

Shipping represents up to 90% of global trade in terms of capacity. Sector's historical growth is strongly related to the global economy as major political, economic and social events/ periods affected directly the demand for shipping services.



Graph (3) UNCTAD - Sector's size and historical growth

IV. AUTONOMOUS SHIPS

Indicatively, in countries such as Finland, Japan, the USA, and Singapore, there has been an effort for a more advanced development of autonomous ships and the introduction of unmanned shipping. The overriding reasons are to highlight the benefits as their use reduces human error and costs. In addition, increased life safety is observed, with more efficient use of space in ship design (Askari and Hossain, 2022).

There are governments that have identified all these advantages to create the next generation of advanced ships. Collaboration between universities, ship designers, equipment manufacturers, and classification societies to consider socio-economic, legal, regulatory, and technological factors is constantly improving autonomous ships with a more holistic qualitative approach.

AI offers new possibilities for the sustainability of diverse maritime activities, providing more flexible and safer operations that will be able to reduce environmental impacts through user-friendly applications that will further deepen the cooperation between ships and shore-based facilities (Negenborn et al., 2023).

Dominant applications of artificial intelligence are the organization and planning of container shipping. More specifically, through predictive analytics, shipping companies are enabled to create safety nets and better quality in terms of scheduling their vessels using port call data.

This data can be reported on destinations, arrivals, departures, and voyage duration to have a more efficient management (Martelli, et al., 2021).

AI even gives predictive data as well as better organization in container placement through the use of appropriate AI-powered machines.

In terms of creating a more sustainable environment, AI-based solutions make it easier to reduce the ship's carbon footprint, as it is easier to predict a route that includes factors of less fuel consumption.

Both autonomous ships and port operations have been overwhelmed by the presence of artificial intelligence which is having a significant impact. Today, algorithms can create a set of movements of more automated applications that give greater autonomy to ships, ports, companies, and the wider shipping system (Zhang et al., 2025).

V. TOTAL QUALITY MANAGEMENT

Researchers Cheng and Choy, (2013) state that, shipping companies have as one of their overriding concerns the establishment of good quality management practices. Effective management in the context of quality allows the company to become even more competitive in the shipping industry. In this research, it was evident that the development of organizational, operational, and financial performance metrics works as a catalyst for the business while engaging the top management members of a shipping company.

The creation of good practices in quality and organizational performance management in the shipping industry enhances managerial knowledge, particularly with the use of technology and the integration of artificial intelligence. More specifically, processes for implementing and managing total quality are thus developed more easily and quickly to achieve the optimal measures of organizational performance that a company sets in a modern global environment.

Pantouvakis and Psomas, (2016) focused on the factors when implementing total quality management (TQM) in shipping companies, highlighting a set of TQM practices. The data were obtained from 87 large shipping companies based in Piraeus, Greece.

In summary, it was found that there is a need to create strategies in terms of management change and leadership culture, which are aimed at improving the efficiency of shipping services and their business performance.

The shipping sector in 2021 played an important role as it accounted for over 80% of international trade and employed more than 1.5 million seafarers. For these reasons, the shipping industry, including shipbuilding and equipment manufacturing, has been classified as labor-intensive. However, both of these industries have faced rapid developments and challenges such as technological advances, the integration of artificial intelligence, and stricter environmental legislation (Kilpi, Solakivi and Kiiski, 2021).

Fadilasari et al., (2024) examined the set of needs that firms operating in the marine logistics and shipping industry have. From the data obtained, it was found that both technology and automation should be upgraded to meet not only the current needs which are related to the standards of total quality management but also the future needs which are related to the near future. A crucial point seems to be the training of all employees to cope with the integration of artificial intelligence into the daily practice of companies.

Total Quality Management (TQM) according to Industry 4.0 marks the beginning of a more holistic transformational collaboration in modern sectors of the economy, including shipping. This collaboration is important to harness all smart technologies, and good practices to improve decision-making processes in the context of promoting the core principles of TQM (Sofranac and Stefanovic, 2025).

VI. CONCLUSIONS

The dynamic trajectory of artificial intelligence has swept all sectors of the economy, affecting the shipping industry. Its applications have contributed to the creation and development of smart ports, autonomous ships, and, in a broader context, the entire economic entity of shipping companies and entities working with this industry.

In addition, AI has also had a strong impact on the internal environment of companies, bringing about significant changes even in Total Quality Management with the corresponding indicators and standards. Its use has contributed to the streamlining of back-office operations.

The sequencing of algorithms which is based on historical data, today influences business decision-making, creating a series of new processes of organizational gobbledygook, performance, and innovation.

Smart ports as a whole seek to improve overall performance, enhance capacity, ensure security, and reduce the operational costs and environmental impact of port operations.

Today more than ever, smart ports are striving to be not only sustainable but also competitive to promote the growth of global trade through the integration of advanced technology and related data-driven techniques processed by algorithms.

However, even today there is still a lack of research, which is of major importance for businesses, organizations, and maritime operators.

The footprint of globalization and the rapid impact of artificial intelligence are bringing a new normal to which stakeholders in the maritime industry are called upon to respond through strategic planning and the adoption of corresponding policies that will be sustainable in the near future.

Additionally, through this research, it is concluded that some of the benefits of applying AI in shipping are faster and safer processing and analysis of operational data, with better quality in data processing. At the same time, improvements in decision making, and process automation through standards governed by Total Quality Management principles were identified.

VII. LIMITATIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This research is secondary and like all research has limitations. In particular, it was based on reputable studies by other researchers and not on the implementation of quantitative or qualitative primary research. It is considered important to carry out more extensive scientific research to highlight new aspects that will help to understand the field under consideration. In addition, it is reasonable to compare these results with previous ones to identify any differences or even to reinforce existing findings around the world. The shipping sector is a dynamic and healthy pillar of the economy and is directly affected by the ecosystems to which it is linked and where further examination and assessment are proposed.

ABOUT THE AUTHOR

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