International Journal of Combinatorial Optimization Problems and Informatics, 16(1), Jan-April 2025, 49-54. ISSN: 2007-1558.
https://doi.org/10.61467/2007.1558.2025.v16i1.946

www.editada.org

Maritime Technology from the 16th Century to Artificial Intelligence

Alejandro Fuentes-Penna, Adriana Espinoza Saucedo
El Colegio de Morelos
alejandrofuentes@elcolegiodemorelos.edu.mx, adriana.espinoza@elcolegiodemorelos.edu.mx

Abstract. Maritime technology has evolved significantly since the 16th century when navigation relied on sails and tools such as the astrolabe and sextant. In the 19th century, the Industrial Revolution introduced steam propulsion and iron structures, improving the strength and efficiency of ships. In the 20th century, combustion engines, radars, and GPS revolutionized maritime safety and navigation. In the 21st century, artificial intelligence has optimized traffic management, predictive maintenance, and autonomous navigation, reduced costs, and improved safety. This article reviews the technological advances in maritime technology and its evolution towards a sustainable future.
Keywords: Artificial Intelligence, Maritime Technology, technological advances, Artificial Intelligence.

Article Info
Received Feb 26, 2025
Accepted March 01, 2025

1 Introduction

Since the 16th century, humanity has demonstrated a drive to explore and understand the oceans that cover our planet. In turn, the need to seek better living conditions has led to technological innovations in the maritime field, aimed at overcoming the challenges presented by navigation and facilitating expansion into new horizons.

At the dawn of the Modern Age, navigation faced significant limitations due to the lack of precise instruments and detailed geographic knowledge. The introduction of the compass and astrolabe revolutionized the ability of sailors to orient themselves on the high seas, allowing for safer and more efficient voyages. These instruments were fundamental to developing deep-sea navigation, making possible transoceanic voyages that were previously unthinkable (Universidad Católica de Chile, n.d.)

During the 16th century, Spain and Portugal led a revolution in shipbuilding. The shipyards of the Cantabrian Sea, Cuba, Panama, and Veracruz became nerve centers where the ships destined for the Carrera de Indias were built. During this period, improvements were implemented such as the reinforcement of the inner lining of the vessels and the application of lead plates on the bottoms to protect the hull. In addition, the preservation bitumen was used to prolong the useful life of the ships.

The need to transport larger loads and make longer voyages led to the development of larger and more robust ships. The galleon, which appeared in the mid-16th century, is a clear example of this evolution. This type of vessel combined greater load capacity with a reinforced structure, adapting to both the demands of trade and the military needs of the time (Reyes García, 2018).

Throughout the 17th and 18th centuries, astronomical navigation experienced significant advances. The transition from the "art of navigation" to more scientific techniques allowed sailors to more accurately calculate their geographical position, determining latitude and longitude on the high seas. This progress was essential for the expansion of trade routes and the exploration of new territories.

With the arrival of the Industrial Revolution in the 19th century, steam propulsion gradually replaced sail, marking a milestone in maritime history. This innovation allowed ships to maintain constant speeds regardless of wind conditions, reducing voyage times and increasing the reliability of trade routes. The construction of iron and, later, steel ships improved the strength and capacity of vessels, making it easier to transport larger volumes of cargo over longer distances.

In the 20th century, automation and the introduction of electronic systems once again transformed navigation. The incorporation of radar, global positioning systems (GPS), and other electronic technologies improved safety and efficiency at sea, allowing for constant monitoring of maritime conditions and more precise navigation.

Today, the integration of Artificial Intelligence (AI) into maritime navigation represents the culmination of this evolutionary process. AI is used to optimize routes based on variables such as weather, sea conditions, and maritime traffic, reducing delivery times and minimizing operational costs. In addition, AI-based systems can constantly monitor sea conditions and other potential obstacles, offering real-time solutions to avoid collisions and improve safety.

The implementation of AI has also led to the development of autonomous vessels capable of planning and executing navigation routes without direct human intervention. These ships can recognize objects and obstacles in their environment, adjusting their trajectory to avoid collisions and optimize their route. Furthermore, AI enables continuous monitoring and early detection of technical problems on vessels, facilitating preventive interventions that ensure the safety of crews and cargo.

This paper explores maritime technologies from the 16th century to the present day, highlighting the key milestones that have allowed humanity to conquer the seas and adapt to the challenges of each era. From the first navigation instruments to the incorporation of artificial intelligence, it analyses how each advance has contributed to transforming maritime navigation and expanding the horizons of human knowledge.

2 Instruments and methods in maritime technology (XVI - XVIII century)

La Casa de la Contratación of Seville was constituted as an intermediary and administrative authority in charge of controlling trade and fleets coming from the Indies, although we know the great importance of this corporation we have been interested in the sense of navigation, because since 1503 the Spanish nautical and cartographic activity was organized in the Casa (Sánchez Martínez, 2010: 613) where its official members taught navigation classes, design of instruments and construction of maps.

The implantation of the main pilot to the Casa seems the germ of the first European technical school, where the development and application of scientific knowledge was directed to the improvements of the navigation of height or oceanic, since that applied the correct use of the sea charts, locating the points in it, mainly the courses, lands and ports. At the time of the explorations, if cartography possessed the virtue of opening the windows of the Spanish empire, navigation constituted the real eye of the kingdom.

In that sense, navigation and cartography had the impulse of new intellectual disciplines and those who practiced it extended the meaning that the trade harbored in the social status and morality of the officers for the advancement of their knowledge (Sánchez Martínez, 2010: 610) The political and scientific officialdom that took charge of the chief pilot not only favored the specialization of the officers, but also the development of their knowledge.

Alonso de Chaves, as a senior pilot, obtained the first scientific post in the Casa de Contratación. Towards the beginning of the 16th century, the monarch's concern arose that those who wanted to become pilots in the navigation of the islands and land in the Indies and the Ocean Sea should be instructed in the quadrant and the astrolabe. One of his outstanding tasks resided in the creation of an original chart or model map called “Padrón Real” that reflected all the lines of lands and islands discovered up to that moment, recognized and described by route (estimation or calculation) or height (latitude fixed through the vision of the stars) (Sánchez Martínez, 2010: 612).

The figure of the cosmographer was, likewise, one of the highest scientific positions to which any sailor could aspire; elaboration of sea charts and navigational instruments, which were in turn reviewed by the chief pilot. In 1552, given the organizational and academic needs due to the massive arrival of geographic information in the Casa de Contratación, the Chair of Cosmography was created.

The elaboration of manuals was one of the resources for the “men of the sea”, in that tenor, the basic rule for a navigator who lost his route or was disoriented, could retake the way employing the sun or by the north, about they mention in these manuscripts the use of the astrolabe; instrument par excellence of the astronomy. However, the navigators used the simple astrolabe to take the altitude of the sun or the North Star, building it out of metal or wood. Another of the instruments needed was the crossbow or astronomical staff to measure the altitude of the North Star and to measure any height or distance. This instrument used the zone to measure the depth of the water and the hourglass to always recognize the time.

The development of navigation, instruments, and, in short, the knowledge of the sea, allowed the Hispanic Monarchy and its captains, soldiers, sailors, and other men of trade to continue with the expeditions. The idea of reaching Asia was consolidated with Legazpi, then, a trade would begin between the four parts of the world, although headed between New Spain and the Philippines. This regular trade was possible through the Manila galleon, Nao de China, or Acapulco galleon (Adano Bernasconi, 2017; 62), which began its formal activity in 1573, however, the idea of accessing goods from China and the East, motivated the Crown to authorize direct and free traffic between the archipelago and Mexico on April 14, 1579 (Bonialian, 2014;35).

According to Selles Garcia, three stages can be identified in the history of Western navigation: navigation to esteem, based on the knowledge of the course followed and the distance traveled by it, specifically dominated by the Mediterranean; in the second, the determination of latitude was introduced and where the Atlantic is the protagonist through the Portuguese and then the Spanish; finally, the possibility of directly knowing the longitude opened the extensive region of the Pacific (2005; 523). Two observations after the above, the route of the Manila galleon reveals the maritime development that spanned three centuries, from the sixteenth to the eighteenth the Spanish navigation manuals continued to be in force during this period. Although, in the middle of the XVIII century, navigation charts were not printed due to the fear that other nations would exercise piracy and smuggling; secrecy continued to be an element of power. At the same time, new methods appeared to measure the longitude at sea, and with this, navigations were safer, in that sense, the preparation of more accurate charts with the recognition and mapping of the coasts was achieved through the observation of Jupiter's satellites and the use of marine chronometers, the above in the last third of the century (Selles García, 2005; 523).

3 Emergent technologies and the maritime sector

The maritime sector faces new challenges that have redefined the industry and its operation in the 21st century. These challenges are complex and cover various areas, from environmental sustainability to technology and safety.

Different challenges have been identified based on current needs related to climate change and national and international regulations in terms of developing a sustainable industry. The maritime industry must address the challenge of reducing greenhouse gas emissions and with this, the International Maritime Organization (IMO) has established ambitious decarbonization goals, however, a high percentage of the world fleet depends on fossil fuels.

A second challenge facing the maritime sector is migration towards the use of emerging technologies such as AI, IoT, and big data, among others that will allow this sector to evolve. However, it is necessary to consider the negative effects of these technologies, such as the increased vulnerability to cyber-attacks. At the same time, with these recent technologies, the goal has been to develop autonomous ships and smart ports to reduce operating costs and improve security. To this end, the International Chamber of Shipping (ICS) has identified the need to develop a regulatory framework to integrate these recent technologies safely and effectively (ICS, 2024).

Furthermore, the dynamics of global trade are changing due to factors such as the trade war between the United States and China, Brexit, and the COVID-19 pandemic. These changes affect trade routes and the flow of goods, requiring greater flexibility and adaptability on the part of shipping companies (UNCTAD, 2024). Another important aspect in the development of the maritime sector is innovation in Port Infrastructure, with the modernization of ports being an obligation, given that, currently, a large amount of data from different transactions is handled, this includes investment in physical infrastructure and advanced technologies to improve efficiency and reduce waiting times (UNCTAD, 2024).

Finally, even today we are still seeing the impact of the COVID-19 Pandemic, which has caused significant disruptions, affecting both trade and crew mobility. The industry must adapt to these new realities, including the implementation of stricter health protocols and improved contingency planning (ICS, 2024).

Artificial intelligence (AI) has become a key technology in the maritime sector, as it provides real-time information on fuel consumption, speed, hull condition, energy consumption, and trim of a vessel, among other aspects that are relevant to optimizing the resources used in navigation.

The applications of AI in the maritime sector are diverse:

- Optimization of maritime routes
- Autonomous navigation
- Management of preventive and corrective maintenance.
- Remote monitoring
- Detecting the operability of equipment and sensors.
- Analyzing security data in conjunction with other technologies such as big data and digitalization
- Long-term cost reduction

- Among others

AI has been a key tool in talent management, from candidate selection, training, and data analysis in decision-making, to the simulation of scenarios.

Currently, the systems in the maritime sector take advantage of the use of technology to offer faster and more efficient solutions in different fields of action. AI-based systems in this sector provide real-time information on fuel consumption, speed, hull status, energy consumption, and trim of a vessel.

With these recent technologies and the need to know the conditions based on changing climates and global warming, smart ports have been developed, since multiple administrative and logistical operations are conducted in them to supply the movement of people and goods. Smart ports are known as ports that apply advanced technologies to optimize resources and services, as well as autonomous loading and unloading. From 1993 to the present, there has been a slow but steady pace of continuous improvement in automation, from the East Container Delta Terminal in Maasvlakte, Rotterdam to the current Yangshan in China, which in 2017 became the largest automated container terminal in the world (Gómez, 2018).

For example, Blockchain and Artificial Intelligence can be applied to a smart port, where it can be represented as a set of nodes $N = \{n_1, n_2, \ldots, n_k\}$, where each node represents an entity participating in the supply chain, such as cargo terminals, cranes, warehouses, shipping companies, customs, etc. With this description, each Transaction (ti) conducted within the port such as container unloading, customs inspection, ..., is presented as a set $T = \{t_1, t_2, \ldots, t_k\}$ and for each transaction, it can be represented as in equation 1.

$$t_i = (ID_i, D_i, O_i, F_i, D_i, \tau_i) \quad (1)$$

Where:

- IDi: Unique transaction identifier
- Di: Transaction data (type of cargo, weight, ...)
- 0i: Origin Node (sender)
- Fi: End Node (receiver)
- τi: Timestamp

In turn, the set of chained blocks is defined as equation 2, where each block is represented as bm which belongs to the set of blocks B. In turn, each block bj contains a set of transactions, having a representation in equation 3.

$$B = \{b_1, b_2, \ldots, b_m\} \quad (2)$$
$$b_j = (H_{j-1}, T_j, H_j) \quad (3)$$

Where:

- H_{j-1}: Hash of the previous block
- T_j: Set of transactions in block j
- $H_j = H(H_{j-1} \| T_j)$: Current hash, calculated with cryptographic function H (·)

Finally, the Artificial Intelligence model is integrated, whose function is to analyze the data in the optimal time, based on the optimal use of resources (equation 4).

$$y = Model_{IA}(X) \quad (4)$$

Where:

- X: Set of features to be optimized
- y: Prediction of optimal resource use

The mathematical model combines the immutable and decentralized structure of the Blockchain with the predictive and optimization capabilities of AI, generating an efficient, transparent, and secure system for the management of smart ports. With this proposal for the integration of Blockchain and AI, it can be applied in different contexts of a smart port:

- Container Registration: Every container entering the port is recorded as a transaction on the blockchain, ensuring full traceability.
- Route Optimization: AI analyzes port traffic in real-time and assigns optimal routes for cranes and autonomous vehicles, based on congestion predictions.

- Document Validation: Documents such as cargo manifests or customs certificates are recorded on the blockchain and automatically validated by the system.
- Security and Audit: Any alteration in the data is detected due to the immutability of the blockchain, improving security against fraud or errors.

In this example, new complementary alternatives can be defined for the optimization of transactions conducted in the maritime sector, as in the case of Torres Manrique (2022), which proposes the following technologies:

- Drones
- Autonomous ships
- iBubble (underwater and autonomous drones)
- Devices interconnected through the Internet of Things
- Specific cases in the maritime sector such as the VHF Data Exchange System (VDES) and the Global Maritime Distress and Safety System (GMDSS)
- Among others

Conclusions

Throughout history, maritime technology has been the driving force behind exploration, trade, and cultural expansion from the 16th century to the modern era. The quest to discover new worlds and optimize navigation has led to momentous innovations, from the first navigation instruments, such as the compass and astrolabe, to the automated and digital systems that dominate the maritime industry today. Each advance responded to the needs of its time, overcoming the challenges of navigation, and allowing humanity to broaden its horizons.

In the current context, the convergence between artificial intelligence (AI) and disruptive technologies such as blockchain, IoT, and big data, among others, redefines maritime management, optimizing port operations, strengthening security, and improving the traceability of logistics chains. This evolution not only reflects technical progress but also the maritime industry's ability to adapt to new global challenges, such as energy efficiency, sustainability, and advanced automation.

Just as in the 16th century, the need to explore and trade drove decisive innovations, today it is the search for efficiency, safety, and sustainability that guides technological development. This historical journey shows that maritime evolution is not only a story of technical advances but also human resilience and creativity in the face of environmental challenges.

References

Bernasconi, M. A. (2017). Barcos novohispanos en la búsqueda de la especiería. En J. Olveda (Ed.), *Relaciones intercoloniales: Nueva España y Filipinas*. El Colegio de Jalisco.

Bonialian, M. (2014). *China en la América colonial: bienes, mercados, comercio y cultura del consumo desde México hasta Buenos Aires*. Biblos-Instituto Mora.

Gómez, C. (2018, enero). Los puertos del futuro se llaman Smart Ports. Recuperado el 18 de abril de 2020, de https://www.sertrans.es/transporte-maritimo/los-puertos-del-futuro-se-llaman-smart-ports

Hermelo, R. R. (2006). Las nuevas tecnologías en la navegación. *Boletín del Centro Naval, (815)*, Septiembre/diciembre 2006. https://www.centronaval.org.ar/boletin/BCN815/815hermelo-b.pdf

International Chamber of Shipping. (2024). *Barometer report 2023–2024*. ICS Shipping Report. https://www.ics-shipping.org/resource/ics-maritime-barometer-report-2023-2024-2/

Reyes García, J. A. (2018). Tecnología y globalización en el transporte marítimo. *CITAS: Ciencia, innovación, tecnología, ambiente y sociedad*, *4*(1), 6.

Sánchez Martínez, A. (2010). Los artífices del Plus Ultra: pilotos, cartógrafos y cosmógrafos en la Casa de la Contratación de Sevilla durante el siglo XVI. *Hispania: Revista Española de Historia*, *70*(236), 607–632.

Sellés García, M. (2005). *Navegación e hidrografía. El siglo de las luces: De la ingeniería a la nueva navegación*. Real Academia de Ingeniería.

Torres Manrique, J. I. (2022). Nuevas tecnologías, inteligencia artificial, derecho internacional marítimo y derechos fundamentales. *Revista Direitos Sociais e Políticas Públicas (UNIFAFIBE), 10*(2), 902–920. https://doi.org/10.25245/rdspp.v10i2.1267

Universidad Católica de Chile. (s.f.). Los instrumentos de navegación. https://www7.uc.cl/sw_educ/historia/expansion/HTML/p2104.html

United Nations Conference on Trade and Development. (2024). *Review of maritime transport 2023*. UNCTAD. https://unctad.org/publication/review-maritime-transport-2024