Efficiency and Sustainability in International Maritime Logistics: The Role of Artificial Intelligence

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Abstract. Artificial Intelligence (AI) is rapidly advancing and has become synonymous with high-tech innovation. As international shipping, a traditionally established industry, evolves within this era of technological progress, it is increasingly embracing intelligent and sustainable practices. A growing number of researchers and practitioners are exploring the integration of AI into the shipping industry, leading to significant advancements in recent years. Notable examples include the application of PLC technology in port cranes, the development of visual management systems for port energy consumption, the implementation of AI in port horizontal transport systems, and the introduction of intelligent berthing and de-berthing assistance systems. This paper outlines the structure, operational models, and sustainable development concepts of the international shipping industry. By reviewing current research and practical applications of AI in this field, it highlights emerging trends, identifies research gaps, and offers recommendations for researchers and shipping companies to guide future developments in the industry.

1 Introduction

Today's international logistics is developing rapidly, and shipping is favoured by companies and wholesalers from all over the world as the most affordable mode of transport. This also leads to higher demands on the efficiency and safety of shipping. International shipping consists of three segments: loading at the port, sailing, and unloading at the port. Therefore, there are two working scenarios, port and ship. The operational efficiency of ports and environmental issues are of great concern; while sailing also requires seafarers to work 24h shifts for navigational decision-making, emergency response and collision avoidance operations, and in the process of sailing, seafarers often suffer from decision-making errors due to insufficient rest.

Artificial Intelligence is a new technological science that researches and develops theories, methods, technologies and application systems that can simulate, extend and expand human intelligence. AI's primary goal is to build an intelligent machine. The second goal is to find out about the nature of intelligence [1]. The term "automation" describes autonomous robots as intelligent agents collaborating with humans at the same time, in the same workspace.

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Trust and reliability between these two parties will achieve promising efficiency, flawless production, minimum waste, and customizable manufacturing. By doing so, it will bring more people back to the workplace and improve the process efficiency [2]. Machine-assisted decision-making or operations for harbour managers and seafarers can be achieved through deep learning with AI. In the era of Industry 4.0 and 5.0, the collaboration between machines and people is getting closer and better, and nowadays there are many examples of deep learning assisting seafarers and port personnel in decision-making and manoeuvring: prediction of ship trajectory, visualisation of port energy management system and the research and development and put into use of automated container terminal process system [3].

International maritime transport can be divided into two primary stages: port operations, including loading and unloading, and the ocean voyage itself, which includes the storage and transport of goods. Ensuring sustainability in this context requires balancing efficiency with energy conservation. This paper will explore the role of AI in enhancing sustainability across both stages of maritime transport. It will summarize the current applications of AI in ports and shipping, identify research gaps from the perspectives of seafarers, port managers, and port workers, and offer insights into the future potential of AI for promoting sustainable practices in international shipping.

2 Port

2.1 The operation mode of ports

The port is a meeting place where goods and passengers from the Mainland are transported overseas, or where ships dock to deliver passengers and freight to local or inland locations, and its scope includes both water and land. Ports in this study refer to cargo ports in the above definition.

The operation mode of ports is characterised by process and aggregation. The ports involved in the use of artificial intelligence temporarily include container terminals and bulk carrier terminals. The operation process of these two types of ports is similar. Taking the container port as an example, the operation process of the port is divided into loading and unloading. In the ship loading process, containers are first transported from the yard to the ship's side and then moved from the ship's side to the designated bay. During unloading, the containers are first moved from the designated bay on the ship to the ship's side and then transported from the ship's side to the container yard.

Port operation units are also very simple, that is, the port bridge crane, container trucks and forklift trucks in the port. Still, take the container port as an example, the port bridge crane is responsible for loading and unloading containers on containers. That is, by the stowage plan, the containers on the container ship will be unloaded and placed on the in-port transporter, or the containers on the in-port transporter will be transferred and placed in the designated bay of the container by the crane. The in-port transporter is responsible for transporting the unloaded containers to the designated container yard, or transporting the target containers in the yard to the bridge crane, while most of the bulk carrier terminals use the conveyor belt to complete the transport of goods between the yard and the ship. These three units work in coordination to become a closed loop whole.

2.2 Examples of application

2.2.1 Design and visualization of energy management system for smart ports

This part focuses on the application of AI to enhance the efficiency and sustainability of operations at the Manglang Lake bulk carrier terminal. The primary goal is to achieve a green and efficient terminal operation. The system is designed with several key functions to support this objective. The home page provides comprehensive energy consumption statistics, including electricity usage for the day, a weekly analysis of process energy consumption, a statistical analysis of energy usage by ship berths, and equipment energy consumption for the day. The power monitoring function tracks and manages the terminal's overall energy consumption. Process management is linked to relevant operating equipment and provides statistics on operational processes, power consumption, and trends in process energy consumption. Equipment management focuses on analyzing the energy consumption trends based on the operation of various terminal equipment. Ship management allows for the analysis of energy consumption trends according to specific parameters such as time, berth, and ship type. Finally, the summary function compiles electricity consumption data for shift operations, categorizing it by shifts and providing statistics on daily, monthly, and yearly energy usage [1].

2.2.2 PLC technology in the use of harbour cranes

PLC technology, i.e. electrical automation, is essentially a combination of traditional control technology and electronic computer technology [4]. This can ensure the stability of the gantry crane in the operation process so that this machine and equipment can be used flexibly over and over again, PLC can provide a certain degree of convenience for the workers [5]. PLC technology is used in port container cranes, It can ensure the working stability of the cranes and can store fault history information to prevent the repeat fault. It collects the statistics related to the working process of the equipment, such as the number of braking operations, mechanism running time, the number of times the spreader opens and closes, the number of times the contactor moves, etc., which helps the staff to obtain timely information on the operating conditions of the equipment to ensure efficient operation [5].

2.2.3 Artificial Intelligence used in Port Horizontal Transport System

The horizontal transport system is a transport system that transports containers between the shore bridge operation area and the yard bridge operation area and consists of a road network and horizontal transport equipment. In traditional container terminals, the equipment that performs the horizontal transport of containers is mainly container trucks and straddle trucks, etc., and the driver needs to receive instructions to perform the relevant tasks. AGVs are the most commonly used transport equipment in automated terminals, they can achieve intelligent navigation, unmanned driving, precise positioning, path optimisation and other intelligent functions, and are generally available in two types: 20ft and 40ft. According to different functions, AGVs can be divided into ordinary AGVs and lifting-type AGVs. Lifting-type AGVs can independently put and take containers in the cache area without waiting for the shore bridge, yard bridge and other equipment, which can effectively improve the working efficiency of the transport system [6].

2.3 Vacancy of Artificial Intelligence in the use of ports

The above research deals with the use of artificial intelligence in coordinating port operations, remote control to command the work of port transport trucks and bridge cranes and the automation of port transport trucks and bridge cranes. This part concluded that there is still no significant progress in the research of AI in the automation of forklift trucks operating in container terminal yards. The reason for this is that the size and colour of the containers in the container yard in the port cannot be uniform and the stacks of containers in the yard cannot reach a regular shape. This causes a great disturbance to the machine to recognize the target container, and it is not easy to solve this problem by machine learning methods.

3 Ocean voyage

3.1 The main problem of ocean-going voyages nowadays

Navigation is an activity that a human sailing on the sea, across the ocean, from one side of the land to the other side of the land. From unberthing out of the harbour, inshore voyage, open seas, inshore voyage, into the harbour, berthing. The process of anchoring and drifting in the anchorage may be involved in ocean-going voyages. In the course of the ocean-going voyage, the third officer, second officer and chief officer take turns to be on watch duty, and the master participates in the voyage when necessary.

Fatigue is the main problem of ocean-going voyages nowadays. The third officer, second officer and chief officer need to complete the designated work in addition to the navigational watch, such as the second officer needs to complete the voyage planning, the maintenance of the navigational equipment on the bridge and the updating of the chart. The tedious work will lead to insufficient rest time for the crew, resulting in fatigue driving during the voyage. Due to the problem of a food reserve, the quality of the crew's food often declines in the middle and late stages of a voyage, resulting in an unscientific nutritional supply, which leads to the crew becoming fatigued easily. The crew's rest is affected by the bad weather during the voyage, which will also lead to fatigue driving.

3.2 Examples of the use of Artificial Intelligence in navigation

3.2.1 Monitoring of ship navigation

Fujitsu Research Institute develops artificial intelligence technology (Fujitsu Human Centric AI Zinrai) that combines radar and automatic identification system (AIS) consulting to extract traffic data information and analyse ship operations to detect the risk of ship collisions in the Tokyo Bay area [7]. This technology is capable of flagging potential risks approximately 10 minutes before a possible incident, which can provide VTS watchstanders with approximately 5 minutes of lead time to perform warning and command tasks for the target vessel and surrounding vessels, such as providing navigational advice to sailors.

3.2.2 Berthing and de-berthing assistance

Intelligent berthing and de-berthing assistance system used in Zhoushan Plain Mountain Port Are [8]. The system mainly uses artificial intelligence (AI) and 5G communication and other technical means to realize visual situation sensing, ship berthing assistance, visible real-time interoperability between ship and shore, ship dynamic monitoring and other functions. During the berthing operation, the sailor can view the video monitoring and berthing data during the berthing period through the mobile terminal, and read in real time the berthing speed of the vessel, the distance from the quay and the berthing angle between the vessel and the quay, as well as the visibility on the sea, the wind speed and the wind direction, the flow velocity and the flow direction, and other meteorological and hydrological information. For the safety risks that may exist during berthing and de-berthing, the system will also automatically compare the data parameters of berthing and de-berthing with the berthing data under the recommended practices of berthing and de-berthing at the terminal, to provide early warning services for the sailors promptly when there is an over-limit of the relevant safety data. At the same time, the quayside can also realize real-time monitoring of ship dynamics through the intelligent berthing assistance system.

3.2.3 Green Shipping

Since the Green Shipping Monitoring System was installed on board COSCO Shipping Passenger Company Limited's "Longxingdao" in October 2022, the company has completed the deployment of ship-to-shore communication gateway for more than 20 vessels [9]. Based on real-time data, the cloud-based service program of the green shipping monitoring system constructs a green shipping indicator system by extracting, processing, summarising and organising data, and generates a series of intuitive and mineable green shipping data analysis products according to actual business and decision-making orientation. Taking the statistics of shore power equipment usage as an example, the previous way of manual data collection and manual report filling took at least 2d times to complete one statistic, after adopting the green shipping monitoring system, the management of the company can log in the system at any time to check the multi-dimensional automatic report, which provides data support for the statistics of energy-saving and carbon-reducing utility.

3.3 Vacancy in the application of artificial intelligence in ocean navigation.

Nowadays, the application of artificial intelligence in ocean navigation still stays in the stage of near-shore navigation, that is, the above-mentioned berthing and berthing and VTS near-shore navigation supervision. As for the automatic ocean-going navigation, due to the complexity and multi-objective of the ship encounter situation, as well as the diversity of the ship's navigation environment, such as the influence of wind currents, the machine learning for the ship's movement has become extremely complex. Therefore, the research and application of artificial intelligence in automatic ship navigation is still in a very early stage.

4 Storage

Artificial intelligence is now involved in cold chain warehousing. In intelligent logistics, the core algorithm of cold chain logistics mainly includes.

Real-time monitoring algorithm. Real-time monitoring algorithm is mainly used for real-time monitoring of environmental parameters in cold chain logistics, such as temperature, humidity, oxygen content and so on. These parameters can be monitored through sensors and other devices, and data transmission through IOT (Internet of Things) technology. The core principle of the real-time monitoring algorithm is to obtain the values of environmental parameters in real-time using sampling, filtering and prediction, and to analyse and process them in real-time [10].

Prediction and optimisation algorithms. Prediction and optimisation algorithms are mainly used to predict and optimise various factors in the process of cold chain logistics, such as logistics time, logistics cost, logistics risk and so on. These factors can be predicted and optimised through big data analysis and artificial intelligence algorithms. The core principle of prediction and optimisation algorithms is to achieve prediction and optimisation in the logistics process using model building, parameter estimation and optimisation solutions [10].

Automation control algorithm. The automation control algorithm is mainly used to realise automatic adjustment and control in the process of cold chain logistics, such as temperature adjustment, humidity adjustment, oxygen adjustment and so on. The core principle of the automation control algorithm is to realise automatic regulation and control in the logistics process using control system design, control strategy design and control execution [10].

5 Conclusion

This study has examined the role of AI in improving the efficiency and sustainability of international maritime logistics, with a particular focus on its applications in port operations, ocean voyages, and cold chain storage. AI technologies, such as energy management systems in ports and automated monitoring in logistics, have begun to revolutionize the maritime industry by enhancing operational efficiency and reducing environmental impact. Despite these advancements, challenges remain, especially in areas like automated ocean navigation and the integration of AI in container terminal operations. Continued research and innovation are essential to overcoming these hurdles. The future of sustainable international shipping depends on the further development and adoption of AI, which holds the promise of making global maritime logistics more efficient and environmentally friendly.

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