Research on the Intelligent Upgrade of Dalian Port and Shipping Logistics Services Empowered by Digital Technology

Xinxin Gao

School of Liberal Education, Liaoning University of International Business and Economics, Dalian 116052, Liaoning, China

Abstract: This study, centering on the national digital economy strategy and the construction demands of Dalian as the "Northeast Asia Shipping Center", addresses the pain points of efficiency, informatization and market competition in the intelligent upgrade of port and shipping logistics, and constructs a digital technology empowerment system of "data collection - model optimization - scenario implementation - ecological collaboration". The SSA-BP throughput prediction model is proposed. The traditional BP local optimum problem is optimized and solved through the sparrow search algorithm, and the prediction error is controlled within 2%. A path optimization framework integrating LSTM-GNN and DQN was constructed, integrating spatio-temporal data and multi-objective reward functions, achieving a 12.3% reduction in the container sea-rail intermodal transport path, a 18.7% reduction in carbon emissions (exceeding the policy target), and a 27.3% improvement in convergence speed. The technological achievements are applied in scenarios such as intelligent scheduling, predictive maintenance, and carbon footprint tracking, and are dynamically adapted to environmental changes by integrating the Internet of Things and edge computing. Through the establishment of the government-enterprise data sharing mechanism (blockchain + federated learning) and the joint laboratory of the Liaonan Port Cluster, the transformation of port and shipping logistics from single operations to ecological collaboration is promoted. The "Digital Twin Standard for Smart Ports" is formulated to assist Dalian Port in its transformation into a "core node of the global supply chain". The research has verified the enabling effect of digital technology in port and shipping logistics, providing a Chinese solution of "data-driven - algorithmic optimization - scenario implementation - ecological collaboration" for the construction of global smart ports. In the future, it is necessary to deepen multi-objective optimization of intelligent dispatching, promote data sharing between the government and enterprises, accelerate the application of clean energy equipment, and continuously drive the intelligent upgrade of port and shipping logistics.

***Keywords*:** Intelligent port and shipping logistics; digital technology empowerment; and intelligent algorithm optimization

1. Introduction

1.1 Research Background

Under the coordinated drive of national strategies and local policies, the intelligent upgrade of Dalian's port and shipping logistics has received dual support: The national "14th Five-Year Plan" for the development of the digital economy has listed Dalian Port as a demonstration project for smart ports. The Dalian Municipal Government has established the positioning of "Northeast Asia Shipping Center" through the "Dalian Port Master Plan (2035)", and is promoting the application of Internet of Things and AI technologies in conjunction with the "Digital Trade Innovation Plan (2023-2025)", forming a closed loop of "planning - policy - action".

In 2024, the container throughput of Dalian Port exceeded 5 million TEUs, reaching a new high in the past five years. The intelligent system helped increase the efficiency of single-vessel operations by 9% and reduce the time for trailer transportation by 16%. The number of China-Europe freight trains increased by 10% year-on-year. The multimodal transport demonstration project ranked first in the province. However, there are three major pain points: the time ships stay in port and the efficiency of logistics turnover are lagging behind those of international hub ports; The digital coverage rate in specialized fields such as hazardous chemicals is less than 30%, and the phenomenon of data silos is prominent. The proportion of international transshipment business (less than 15%) is significantly lower than that of Singapore (45%) and Shanghai (30%), and the hinterland cargo sources are facing competition from the Bohai Rim port cluster.

1.2 Research Significance

This research aims to respond to the national digital economy strategy, leverage the policy advantages of Dalian, focus on the pain points of efficiency, informatization and market competition, explore the path of digital technology empowerment, assist Dalian Port in building a digital shipping hub in Northeast Asia, and provide theoretical and practical references for the

upgrading of the port and shipping logistics industry.

2. Construction of the Digital Infrastructure for Port Logistics

2.1 Port throughput prediction Model Based on SSA-BP neural network

The BP neural network[3] achieves complex function approximation through nonlinear mapping of the input layer, hidden layer and output layer, but its gradient descent characteristic is prone to lead to local optima. The Sparrow Search Algorithm (SSA) proposed in 2020 simulates the foraging behavior of sparrows. Through rules such as dynamic role transitions between discoverers and participants and early warning mechanisms, it achieves a balance between global search and local development.

The SSA-BP model takes the mean square error (MSE) as the fitness function to optimize the initial weights and thresholds of the BP network and solve the local optimum problem. The process includes: data normalization, empirical determination of the number of hidden layer nodes, SSA parameter optimization (population size 100, 500 iterations), and BP network training and prediction. Empirical evidence shows that SSA-BP outperforms traditional BP and PSO-BP in indicators such as MAE, RMSE, and MAPE, and has better stability than WOA-BP. The prediction error is controlled within 2%, and the absolute value of the maximum relative error is 1.95%, providing a scientific basis for port resource allocation.

2.2 Path optimization algorithm

Traditional path planning performs well in static environments[1-2], but has insufficient adaptability to dynamic scenarios. Genetic algorithms are prone to falling into local optima and have high computational complexity. Machine learning enhances dynamic adaptability: LSTM combined with GNN builds a port and shipping network topology model to achieve collaborative scheduling of ships and vehicles; Reinforcement learning (DQN) achieves active prediction through the state-action-reward mechanism. The path planning model based on the hybrid intelligent framework integrates spatio-temporal features (including AIS, logistics orders, and meteorological data) in the data layer. The learning layer combines DQN (Dynamic Decision Making) with LSTM-GNN (Congestion Prediction), and the reward function integrates multiple objectives such as timeliness, cost, and carbon emissions. The optimization layer searches for parameters globally through SSA. Case verification shows that the SSA-BP model shortens the path by 12.3% in the container sea-rail intermodal transport scenario, reduces carbon emissions by 18.7% (exceeding the policy target), and improves the convergence speed by 27.3% compared with WOA-BP. Indicators such as MAE (0.18) and RMSE (0.30) are significantly better than those of traditional algorithms, and it supports real-time path adjustment.

3. Scenario-based Implementation of key technologies

Under the coordinated drive of national strategies and local policies, Dalian Port has built a closed loop of "planning - policy - action" to promote intelligent upgrading. Aiming at the pain points such as efficiency bottlenecks (the time of ships in port, the gap between logistics turnover efficiency and international hub ports), informatization shortcomings (data silos, insufficient digital investment), and market competition (loss of hinterland cargo sources, low proportion of international transshipment business), the research takes the SSA-BP neural network as the core and optimizes the initial parameters of the BP network through the sparrow search algorithm to improve the global convergence. The throughput prediction error is controlled within 2%. The scenario-based implementation of key technologies includes: intelligent scheduling and integration of multi-source data to achieve coordinated optimization of multimodal transport; Path optimization combines the Internet of Things and edge computing to dynamically adapt to environmental changes. Predictive maintenance provides early warnings of equipment failures through digital twins and LSTM-GNN models. Carbon footprint tracking integrates emission monitoring and carbon trading strategies to promote green transformation. Through ecological measures such as data sharing between the government and enterprises and regional collaborative innovation, Dalian Port is transforming from a single transportation hub to a core node of the global supply chain, providing a Chinese solution for the intelligence of port and shipping logistics.

4. Construction of a New Ecosystem for Digital Logistics in Ports

4.1 Standards and Data Sharing

Develop the "Digital Twin Standard for Smart Ports", clearly defining requirements for data collection, model accuracy, and interface compatibility, and promoting the integration of multi-source data such as ship AIS and railway freight. Establish a government-enterprise data sharing mechanism (blockchain + federated learning), where the government opens up public

data such as waterway management and customs clearance, and enterprises share business data such as logistics orders and transportation trajectories, forming a "government guidance + enterprise collaboration" model to enhance data interaction efficiency and reduce supply chain collaboration costs.

4.2 Regional Collaboration and Innovation

With Dalian Port as the core, a joint laboratory for the Liaonan Port Cluster will be established in collaboration with Yingkou Port, Dandong Port, etc. The laboratory will focus on the optimization of intelligent dispatching algorithms and the research and development of multimodal transport equipment, and share a testing platform to reduce R&D costs. Relying on the digital infrastructure of ports, logistics data is transformed into credit assets. In collaboration with financial institutions, supply chain finance (such as dynamic credit assessment of ships) and carbon financial products (such as carbon trading derivatives) are developed to drive regional port clusters to shift from competition to cooperation, forming an ecological pattern of "joint research and development of technology, sharing of data, and symbiosis of finance".

5. Conclusions and Prospects

The research system has established a technical framework covering "data collection - model optimization - scenario implementation - ecological collaboration", and technologies such as the SSA-BP model have performed exceptionally well in empirical studies. In the future, we will deepen the multi-objective optimization of intelligent dispatching, promote data sharing between the government and enterprises, accelerate the application of clean energy equipment, and drive Dalian Port to transform into a "core node of the global supply chain", providing a Chinese solution for the intelligent upgrade of global port and shipping logistics.

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References

[1] Rumelhart D E, Mcclelland J L.Parallel Distributed Processing[J]. Encyclopedia of Database Systems, 1986:45-76.
[2] Xue J, Shen B.A novel swarm intelligence optimization approach: sparrow search algorithm[J]. Systems Science & Control Engineering An Open Access Journal, 2020, 8(1):22-34.
[3] Dai Hongwei, Wang Bowen. Port Cargo Throughput Prediction Based on MPA-BP Neural Network and ARIMA Model [J/OL]. Journal of Shanghai Maritime University,1-12[2025-09-02].