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Research Article

Analysis of Transportation Network Scheduling of Maritime Silk Road and International Digital Trade Potential Based on Improved Genetic Algorithm under Digital Trade Barriers

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The purpose is to improve the ship scheduling capability of the Maritime Silk Road transportation network and advance the international digital trade capabilities along China's Maritime Silk Road. The optimization process of ship network scheduling based on a simulated annealing- (SA-) improved genetic algorithm (GA) is studied. Then, according to the time-varying stochastic frontier gravity model, the potential of international digital trade between China and the countries on the western route of the Maritime Silk Road is analyzed. The model is simulated and verified. The results reveal that the improved GA has obvious advantages over other algorithms in the message delivery rate of the high-speed and low-speed TT Controller Area Network (TTCAN) protocol for ship control. Regardless of the external environment and the number of message nodes, the message delivery rate is above 95%, showing a high delivery rate and the best network scheduling effect. The total volume and proportion of trade between China and the countries along the western route of the Maritime Silk Road can represent a good growth trend over time, and the proportion of digital trade exports has increased from 9.75% in 2009 to 45.12% in 2020. China has great potential for the development of the countries along the Silk Road as a whole. The main contribution of the research is to construct the ship network scheduling optimization process of the GA improved by the SA and use the time-varying stochastic frontier gravity model to study the digital trade potential between China and the countries along the Maritime Silk Road. The data information management system for network dispatching of marine ships has been improved, and the optimal dispatching efficiency has been enhanced.

1. Introduction

As a new type of trade, digital trade has become an important focus for promoting China's opening up and economic progress. The development of the Maritime Silk Road plays a vital role in strengthening international regional economic cooperation [1]. Therefore, exploring the trade competition and trade potential between China and the countries along the Maritime Silk Road has momentous practical significance for promoting China's economic growth and regional economic cooperation among countries along the route [2]. In the process of sailing at sea, the ship faces a complex and changeable marine environment. Only by properly scheduling the ship network and realizing the manipulation of the overall control system can the stable sailing of the ship be ensured [3]. At the same time, affected by digital trade barriers, there are certain obstacles to global trade. Research on reducing obstacles and improving ship network scheduling plays a significant role in the development of international trade construction [4].

At present, some scholars have made some studies on maritime transportation network scheduling. Yang et al. [5] conducted a detailed study on the resource management scheduling of maritime networks by using a deep learning (DL) algorithm combined with the optimal link selection scheme of Markov Decision Processes (MDPs) [5]. Zhang et al. [6–8] proposed a new intelligent and effective method based on an improved Ant Colony Optimization (ACO) to solve the optimization problem of the path of multiobjective ships [6]. Shang et al. [9] proposed a DL-based energy optimization scheduling method for ship power systems, and through simulation experiments, the effectiveness and superiority of the optimal scheduling method were verified [9]. Peng et al. [10] studied the coordination and dispatch of emergency materials according to the characteristics of emergencies at sea, constructing a maritime emergency material dispatching architecture including three layers of onshore supply layer, assembly layer, and accident layer and two processes of onshore transportation and maritime maneuver rescue [10]. In the application of genetic algorithm (GA), Wang and Gao [11] established a mathematical model for the judgment of logistics distribution demand points and transfer points and used GA to solve the path planning model of logistics distribution and conducted a simplified study of the model [11]. By summarizing the above literature, scholars have done research on marine network resources, ship route optimization, power system energy, and emergency supply optimization. Taking the Maritime Silk Road as the background, there are few studies using GA to study ship network scheduling. In response to digital trade barriers, in terms of international digital trade, Liu et al. [12] conducted an empirical study on the export potential and influencing factors of digital trade in countries along the "Belt and Road Initiative" [12]. Shang et al. [13] made a detailed review and exploration of the obstacles and barriers in the development of the digital service trade. The research literature found that there are many related studies on the qualitative analysis of the interpretation and evaluation of the "Belt and Road" policy and the analysis of factors affecting trade. The research on the transportation network scheduling and trade potential analysis of the Maritime Silk Road is relatively scarce, and there are even fewer studies on the implementation of models to carry out data statistics and potential estimation of trading partners. It is easy to fall into the optimal solution prematurely with a single GA, resulting in an unsatisfactory optimization scheduling effect. A single simulated annealing algorithm (SAA) optimization efficiency is relatively poor and cannot fully meet the requirements of network scheduling optimization. SAA is used to improve the GA, which can suppress the premature convergence of the GA. In ship network scheduling, the communication quality of the ship network can be improved, and better optimization results of network scheduling can be obtained [14].

On account of the above theories, this research takes the Maritime Silk Road and digital trade barriers as the background. Firstly, the ship network structure of the high-speed Controller Area Network (CAN) protocol is designed and studied. Secondly, the traditional GA is improved by using SAA, and an optimization process for ship network scheduling with improved GA is constructed. The reason for improving the GA is that the minimum value of the message transmission jitter of the matrix period of the shipping network can be obtained, the search efficiency of the GA can be improved, and the optimal results of the ship network scheduling can be obtained. Finally, the test of the message delivery rate of the ship in the TTCAN protocol is analyzed. Meanwhile, by constructing the time-varying stochastic frontier gravity model, a detailed comparison of the international digital trade potential between China and the countries along the western route of the Maritime Silk Road is carried out. The innovation of this research lies in constructing the optimization process of the ship network scheduling of the Maritime Silk Road based on the improved GA of SAA, and the time-varying stochastic frontier gravity model is used to analyze the trade potential. It is aimed at providing a reference for the research on international digital trade and maritime transportation networks between China and countries along the Maritime Silk Road.

2. Research on Theoretical Basis and Model Method

2.1. Maritime Silk Road and the Theory of Digital Trade Barriers. The "Maritime Silk Road of the 21st Century" includes two parts: the first part is westward, from China's coastal ports to the South China Sea, then to the Indian Ocean, and finally extending to Europe. The second part is southward, from China's coastal ports to the South China Sea and then to the South Pacific. In terms of international trade, the western route already has a foundation for cooperation, and many large-scale projects have been implemented. The countries on the western route have responded positively to the policy, and the political mutual trust between the two sides is relatively high [7]. To analyze the scale of digital trade exports, 21 countries along the Silk Road are selected and divided into four regions according to the traditional geography, as shown in Figure 1.

In Figure 1, Southeast Asia includes Singapore and Malaysia. Central Asia includes Kyrgyzstan. West Asia and North Africa cover Turkey, Israel, Azerbaijan, Cyprus, and Greece. Eastern Europe involves Russia, Bulgaria, Belarus, Hungary, Croatia, Poland, Serbia, Lithuania, Estonia, Slovenia, Latvia, Czech Republic, and Slovakia [15].

2.2. International Digital Trade. Digital trade is driven by globalization, new technologies, new demands, and new rules of global trade governance. With the help of Internet platforms, intellectual property-intensive products and services are used as trade objects. With the continuous development of technologies such as big data and cloud computing, the forms of digital trade are gradually enriched. Figure 2 indicates the connotation of digital trade from three dimensions: mode, content, and the subject of trade [16].

In Figure 2, from the perspective of trade mode, digital trade is divided into digital ordering, digital delivery, and platform support. From the viewpoint of trade mode, digital trade covers split into goods, information, and services. From the point of the trade subject, digital trade involves three levels: enterprise, individual, and government.

Although digital trade has great potential for development, because digital trade covers information and data in various industries such as communications, public services, and finance, and involves personal privacy and national security, there are still many digital trade barriers in various countries to a certain extent. Trade barriers are restrictions

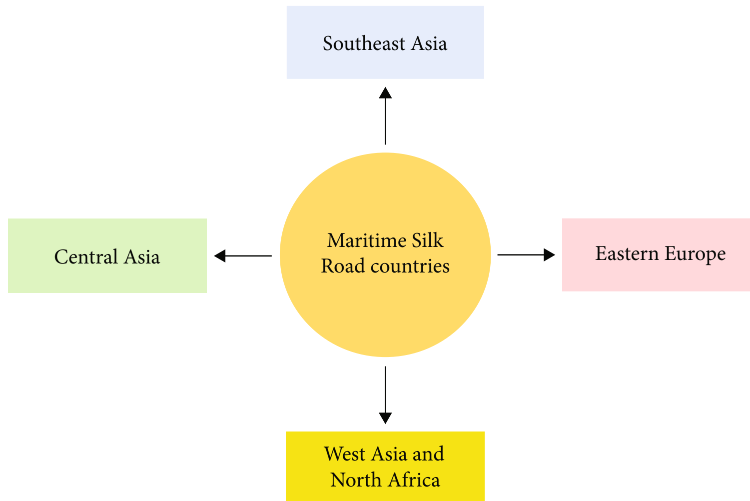


Figure 1: Four regions of countries along the "Belt and Road Initiative."

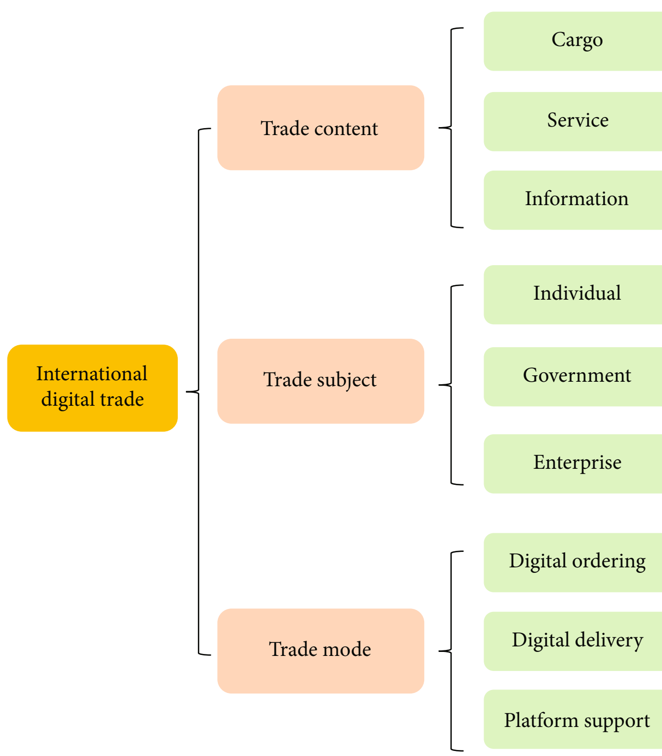


Figure 2: Analysis of digital trade dimensions.

on the importation of goods and services. Digital trade barriers mainly manage and control information and data [17]. Digital trade barriers manifest in different forms, as expressed in Figure 3.

As portrayed in Figure 3, the first is for the localization requirements of enterprises. Enterprises need to store and manage data in their own countries. The second is market access control; mainly, the government regulates the inflow of foreign companies into the domestic market. The third is the personal information protection policy. The government uses a series of means to improve the level of information security and effectively supervise and manage data. The fourth is the issue of intellectual property rights, mainly the issues of patents and related intellectual property rights involved in digital trade. The fifth is the uncertainty of legal liability, which makes it easy to cause disputes over tortious acts. The sixth is censorship measures. The government will use effective censorship measures to restrict online information inquiries. The seventh is customs measures, which means that the relevant measures of the customs are unclear and complex [8].

2.3. The Process of GA. GA incorporates the theory of "survival of the fittest" and has the characteristics of self-

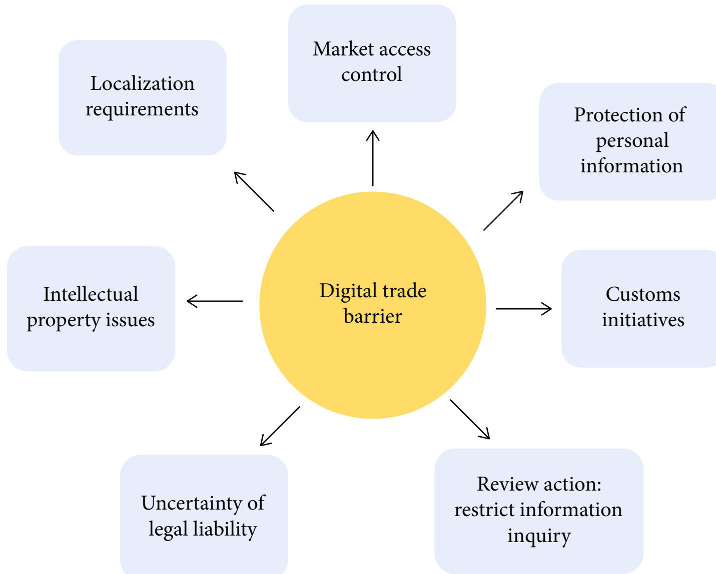


Figure 3: Measurement framework for international digital trade.

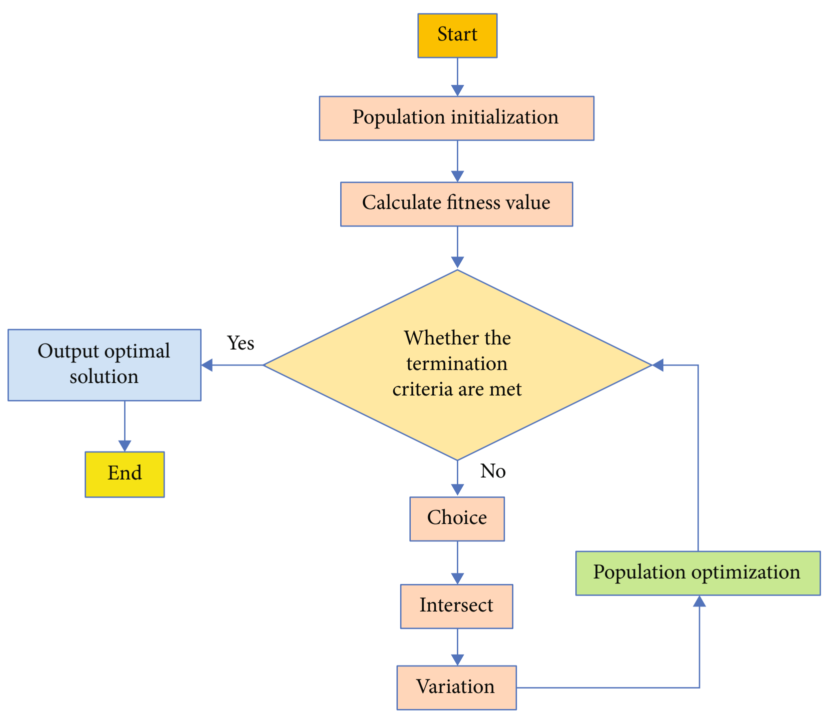


Figure 4: The flow of GA.

adaptation, randomness, and high parallelism [18]. The GA uses the evolution process of "chromosome" survival of the fittest to simulate the process of problem-solving. With the iteration of the population, the chromosomes are evaluated for pros and cons. After many iterations, the optimal solution to the problem is finally obtained [19]. The process of GA is exhibited in Figure 4.

In Figure 4, the parameters are input first, and the number of iterations is set to 0. A set of chromosomes is randomly generated as the initial population, and the fitness values of all chromosomes in the population are calculated. Then, it is determined whether the termination criterion is met. If it is satisfied, the calculation is stopped to output the optimal result, then the solution process ends; if not, the next step is executed. According to the preset crossover probability, the selection and crossover operation are performed. The mutation operation is carried out by the mutation probability to generate a mutation population, and the criterion judgment is continued.

2.4. Ship Network Structure by Using High-Speed TTCAN Protocol. The studied ship network is a high-speed TTCAN

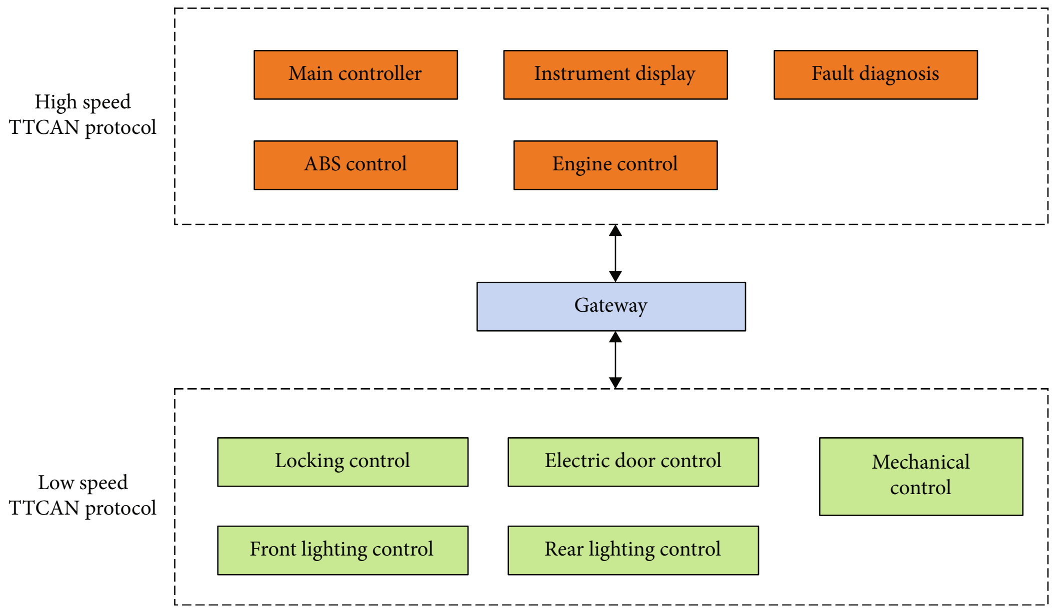


Figure 5: The topological structure of the ship control network.

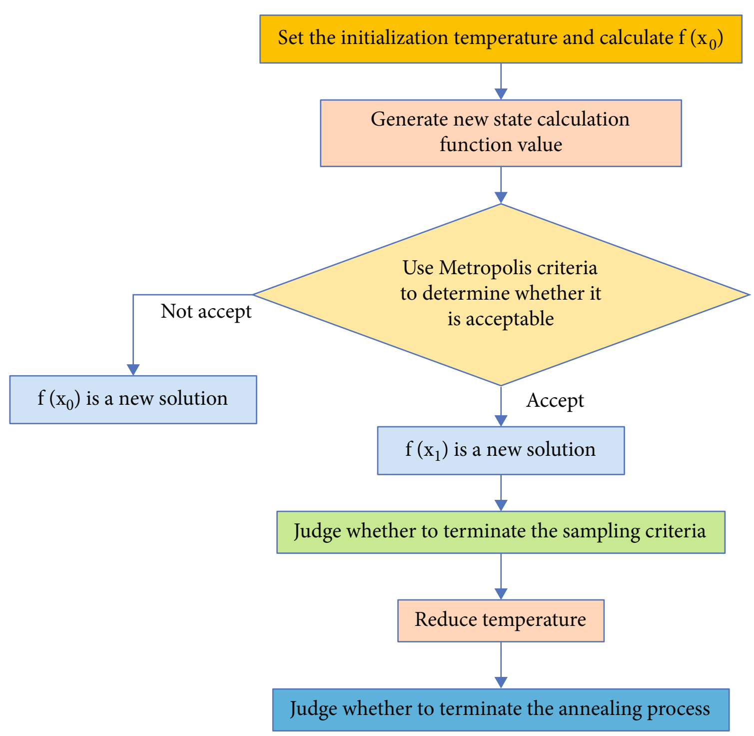


Figure 6: Process of SAA.

protocol, and it communicates all CAN information. Data transfer in the network requires a specific time window while managing and predicting the information on the network. Taking time as the judgment basis, there is a master node on TTCAN, which uses a counter to realize the complete storage of the node time copy, and the counter accumulates 1 point every 1 unit [20]. The composition structure of TTCAN includes a time slot and time window, and a single message can complete the transmission of nodes in the network through the time window. There is a matrix period in TTCAN, which determines the future development of scheduling in the network, and the optimal scheduling results are applicable to the ship network. The normal operation of the ship requires the support of multiple control networks to realize the navigation control of the ship. Once the command is issued, the relevant equipment must respond within the specified time; otherwise, the normal navigation of the ship will be affected. Therefore, the study of the ship network structure plays an important role in normal navigation [21]. Figure 5 presents the topological structure of the ship control network.

Figure 5 refers that in the ship control network, different nodes have different requirements for message transmission timeliness. From this perspective, two TTCAN protocols, high speed and low speed, are selected to construct the topology of the entire ship control network [22]. The high-speed TTCAN protocol comprises the main controller, instrument display, fault diagnosis, Antilock Brake System (ABS) control, and engine control. The low-speed TTCAN protocol includes locking control, electric door control, mechanical control, and lighting control [23].

The matrix period in the ship control TTCAN network is divided into two types of message information: node transmission period and aperiodic. There are differences between them. This difference is called message transmission jitter in the optimization process of ship network scheduling. It is represented by the following equations.

$$j_{i,k} = t_{ai,k} - t_{ei,k}, \quad (1)$$

$$t_{e,i,k} = kM_i + t_{0i}. \quad (2)$$

M_i means the transmission period of the ith message, $i = 1, 2, 3, \cdots, n.t_{0i}$ shows the start of the transmission time of the 0th instance message. $t_{ai,k}$ and $t_{ei,k}$ express the actual and expected start transmission times of the ith and kth instances, respectively.

Equation (1) is analyzed, describing the overall message transmission jitter in the ship control network, as shown in the following equation.

$$J_{OS} = \sum_{i=1}^{n} \sum_{k=1}^{M_i} j_{i,k}. \quad (3)$$

2.5. Specific Process of SAA Optimizing GA. SAA is an algorithm inspired by the physical annealing process in life and an algorithm designed after combinatorial optimization problems find commonality. The flow chart of the SAA operation is indicated in Figure 6.

In Figure 6, the first step is to set the initialization temperature, chain length, cooling rate, and termination temperature and calculate the function value $f(x_0)$. The second step uses the state function to generate a new state to calculate the function value $f(x_1)$. The third step: if $f(x_1) \le f(x_0)$, $f(x_1)$ is accepted to generate a new solution, and if $f(x_0) \le f(x_1)$, the metropolis criterion is used to judge whether to accept. If accepted, $f(x_1)$ is a new solution; if not, $f(x_0)$ is a new solution. The fourth step is to judge whether to terminate the sampling criterion, and the fifth step is to cool down. The sixth step is to judge whether to terminate the annealing process, and finally, the optimal solution is outputted. SAA has strong local search ability and simple operation. However, each optimization process of SAA is aimed at a single solution in this space, resulting in the low efficiency of the algorithm [24].

GA has a very strong search ability, and it is easy to enter the optimal solution in advance, which affects the search efficiency. SAA is used to improve the GA, which can suppress the premature convergence of the GA and improve the efficiency of the search. The optimized GA can optimize the matrix period in the TTCAN, ensure that the message signal in the ship network has the lowest transmission jitter, obtain the minimum value of the message transmission jitter, and improve the communication quality of the ship network [25]. The detailed steps are as follows:

Step 1: the algorithm parameters are given, the annealing initial temperature T_i is set to a large enough number, and the evolutionary algebra i is set to 0.

Step 2: the initial population is randomly generated and set to G_i.

Step 3: crossover and mutation operators are executed. The purpose is to suppress premature convergence. With the change of the fitness value, the crossover probability P_c and the mutation probability P_m will change. If trapped in a local extremum, the part of the individual with a larger fitness value will also have an increase in these two probabilities, so that the suppression of premature convergence can be achieved [26]. P_c and P_m are calculated as equations (4) and (5), respectively.

$$P_c = \begin{cases} c_1 * \left[\dfrac{f_{\max} - f}{f_{\max} - f_{\min}}\right], & f \ge \bar{f}, \\ c_2, \quad f < \bar{f}, \end{cases} \quad (4)$$

$$P_m = \begin{cases} c_3 * \left[\dfrac{f_{\max} - ff}{f_{\max} - f_{\min}}\right], & ff \ge \bar{f}, \\ c_4, ff < \bar{f}. \end{cases} \quad (5)$$

$f_{\max}$ and $f_{\min}$ are used to represent the maximum and minimum fitness values, respectively, and $\bar{f}$ and f are used to express the average fitness value and the larger fitness of the crossed individuals, respectively. c_1, c_2, c_3, and c_4 all belong to $(0, 1)$, and ff describes the mutation fitness value. $f_{\max} - f_{\min}$ represents the stability of the population.

Step 4: the fitness function is calculated, as illustrated in the following equation.

$$\text{fitness}\,(f(x)) = \begin{cases} f(x), \\ -f(x). \end{cases} \quad (6)$$

Step 5: calculation of annealing increments. It can be written in the following equation.

$$\Delta F = F(G_i) - F\left(G_i'\right). \quad (7)$$

$F(G_i)$ refers to the fitness function of the original population, and $F(G_i')$ stands for the fitness function of the next-generation population.

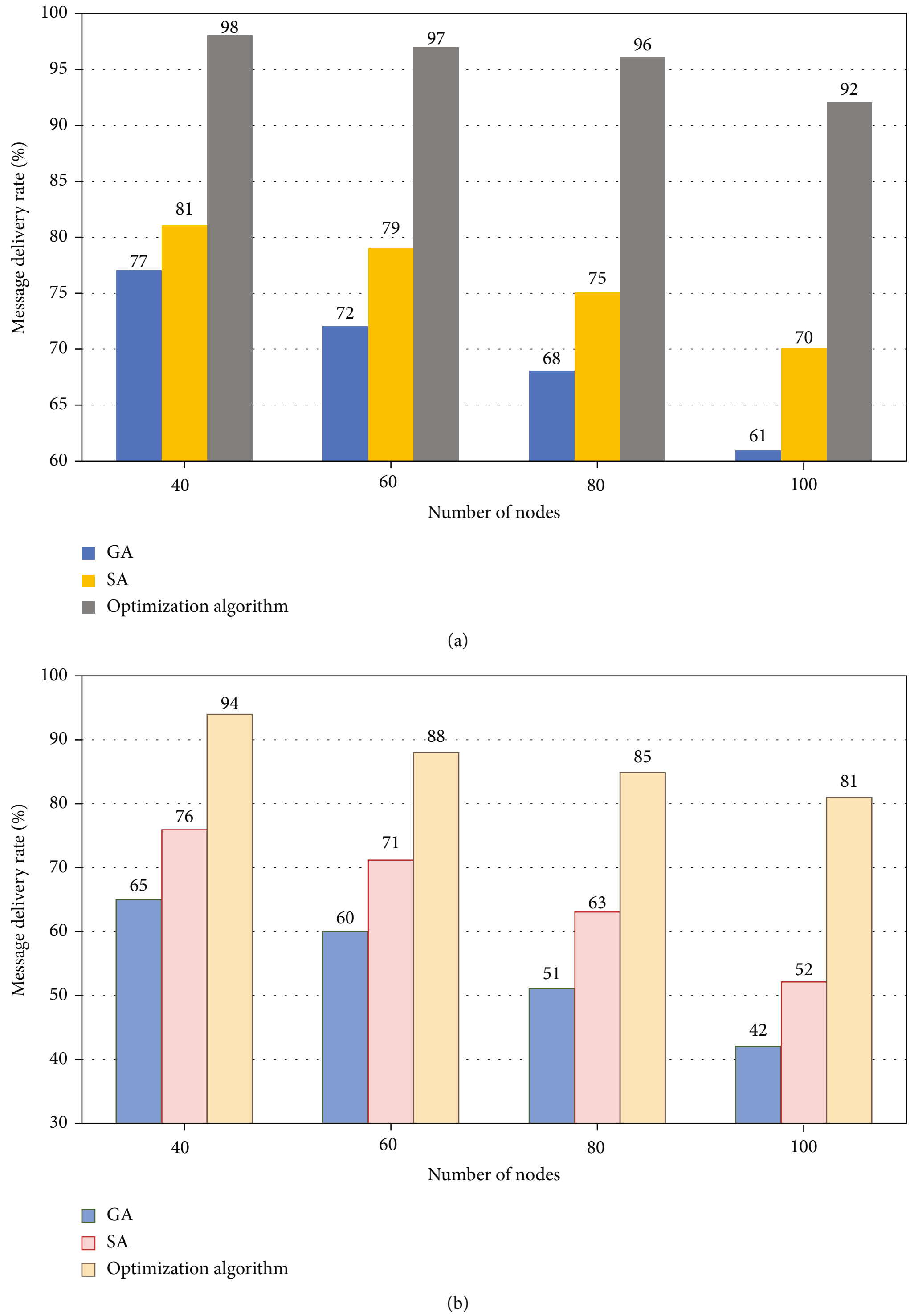


FIGURE 7: Comparison of message delivery rate of different algorithms at high speed. (a) The message delivery rate in sunny weather; (b) the message delivery rate in extreme weather.

Step 6: cool down. The specific expression is as follows.

$$\&T_{i+1} = \lambda T_i, \quad 0 < \lambda < 1, \\ \&G_i = G_i', \\ \&i = i + 1. \tag{8}$$

Step 7: the end conditions of the evolution are judged. If the end conditions are met, the optimal individual can be outputted. If not, step 3 needs to be performed again.

2.6. Research on the Potential of International Digital Trade Based on the Time-Varying Stochastic Frontier Gravity Model. The time-varying stochastic frontier gravity model

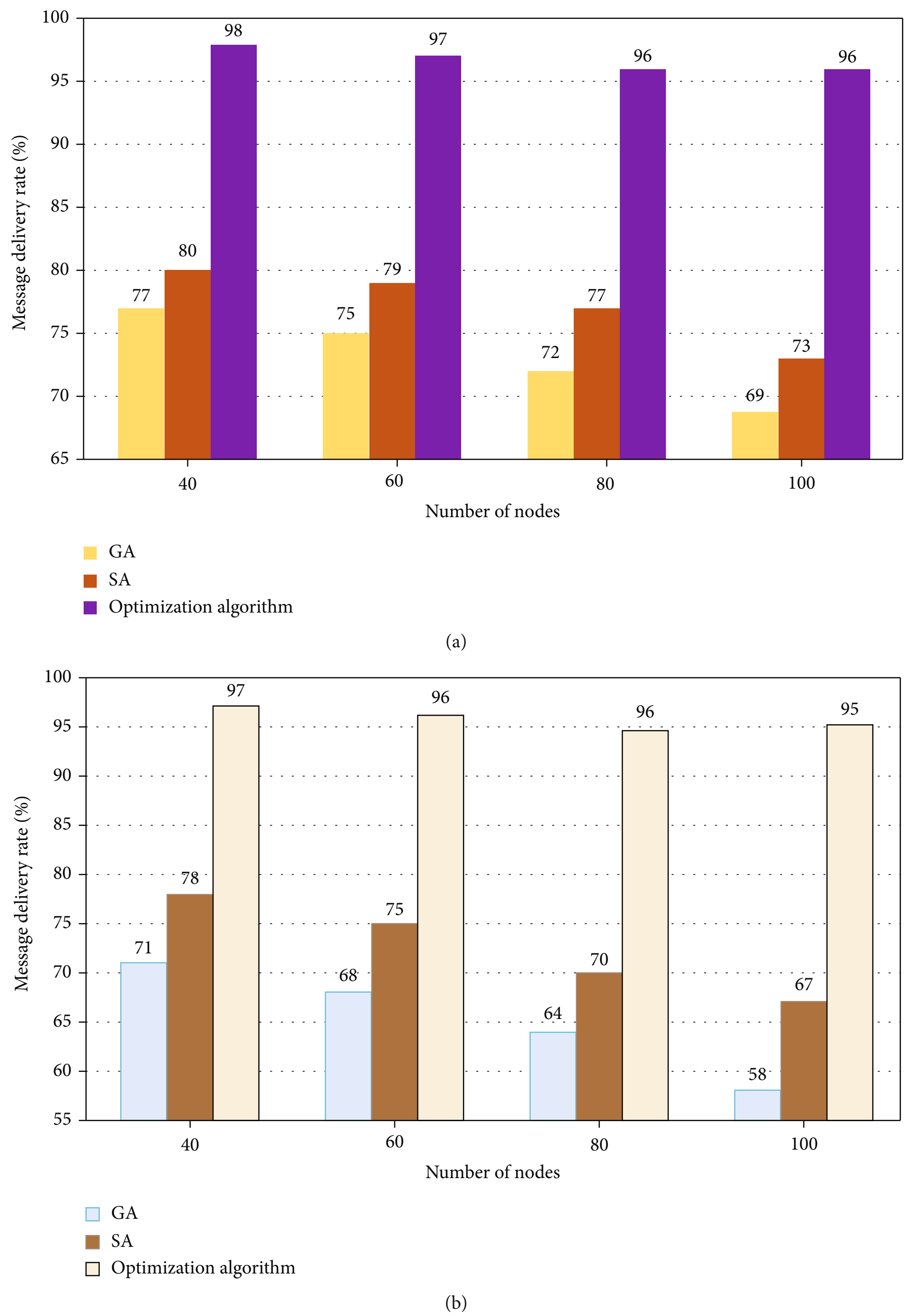


FIGURE 8: Comparison of message delivery rate of different algorithms at low speed. (a) The message delivery rate in sunny weather; (b) the message delivery rate in extreme weather.

is used to analyze the potential of international digital trade [27]. In this model, the expression that determines the actual trade volume is demonstrated in the following equation.

$$Y_{ijt} = f\left(x_{ijt}, \alpha\right) \exp\left(v_{ijt}\right) \exp\left(-u_{ijt}\right), \quad u_{ijt} \geq 0. \tag{9}$$

The logarithm is taken on both sides of the equation, and the result is as follows.

$$lnY_{ijt} = lnf\left(x_{ijt}, \alpha\right) + v_{ijt} - u_{ijt}, \quad u_{ijt} \geq 0. \tag{10}$$

Y_{ijt} is the actual trade volume between country i and

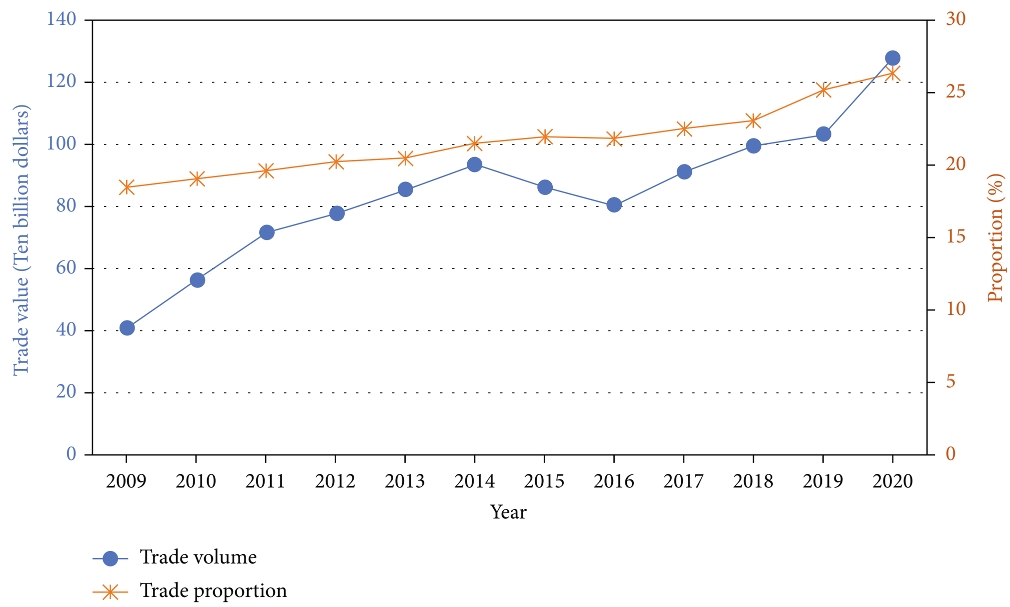


Figure 9: Trade volume and trade proportion between China and the countries on the western route of the Maritime Silk Road.

country j in the time period t; x_{ijt} indicates the natural factor affecting the trade volume and is also the core variable affecting the gravity model; α means the parameter to be estimated; v_{ijt} represents a random factor that obeys a normal distribution with zero mean; u_{ijt} denotes the trade resistance ignored by the traditional gravity model and is the trade inefficiency term in the model. There is no artificial trade resistance; that is, when the nonefficiency term u_{ijt} of trade is zero, the expression of the potential maximum trade volume is displayed in the following equation.

$$Y_{ijt}^{*} = f\left(x_{ijt}, \alpha\right) \exp\left(v_{ijt}\right). \tag{11}$$

Y_{ijt}^{*} demonstrates the trade potential. At this time, equation (12) expresses the trade efficiency.

$$TE_{ijt} = \frac{Y_{ijt}}{Y_{ijt}^{*}} = \exp\left(-u_{ijt}\right). \tag{12}$$

According to the characteristics of whether the trade inefficiency term changes with time, the stochastic frontier gravity model can be divided into two types: the time-varying and the time-invariant model [28]. Equation (13) signifies the basic form of the time-varying model.

$$u_{ijt} = u_{ij} \exp\left(-\eta(t-T)\right). \tag{13}$$

u_{ijt} is the trade inefficiency term, which obeys the truncated normal distribution; η refers to the parameter to be estimated. If $\eta = 0$, it means that the trade inefficiency does not change with time, and a time-invariant model should be adopted. If $\eta \neq 0$, it means that it changes with time, and a time-varying model should be adopted. Among them, if $\eta > 0$, it indicates that the trade resistance decreases with time, and if $\eta < 0$, illustrating that it increases with time.

When implementing a stochastic frontier gravitational model, natural factors that will not change in the short term are introduced as explanatory variables, including economic scale, population, and distance, etc. [29], as exhibited in the following equation.

$$\begin{aligned} \&\ln \mathrm{EXP}_{ijt} = \beta_0 + \beta_1 \ln \mathrm{GDP}_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln \mathrm{POP}_{it} \\ + \beta_4 \ln \mathrm{POP}_{jt} + \beta_5 \ln \mathrm{DIS}_{ij} \& + \beta_6 \mathrm{CB}_{ij} \\ + \beta_7 \mathrm{LANGB}_{ij} + V_{ijt} - U_{ijt}. \end{aligned} \tag{14}$$

EXP_{ijt} represents the actual total value of China's digital trade exports to the country j in period t, GDP_{it} means China's gross domestic product in period t, and GDP_{jt} signifies the gross domestic product of country j in this period. POP_{it} refers to the total population of China in period t, POP_{jt} implies the total population of the country j in that period. DIS_{ij} represents the distance between China and the capital of the country j in period t, and CB_{ij} and LANGB_{ij} are dummy variables.

Equation (15) implies the trade inefficiency model.

$$\begin{aligned} U_{ijt} = \alpha_0 + \alpha_1 N_t + \alpha_2 \mathrm{FTA}_{ijt} + \alpha_3 \mathrm{FB}_{tj} + + \alpha_4 \mathrm{FT}_{jt} + \alpha_5 \mathrm{LPI}_{jt} \\ + \alpha_6 \mathrm{IT}_{jt} + \alpha_7 \mathrm{TX}_{jt}. \end{aligned} \tag{15}$$

N_t and FTA_{ijt} express dummy variables, FB_{tj} indicates the fixed broadband penetration rate in country jt, FT_{jt} denotes this country's fixed telephone penetration rate in this period, LPI_{jt} displays its logistics performance index, I

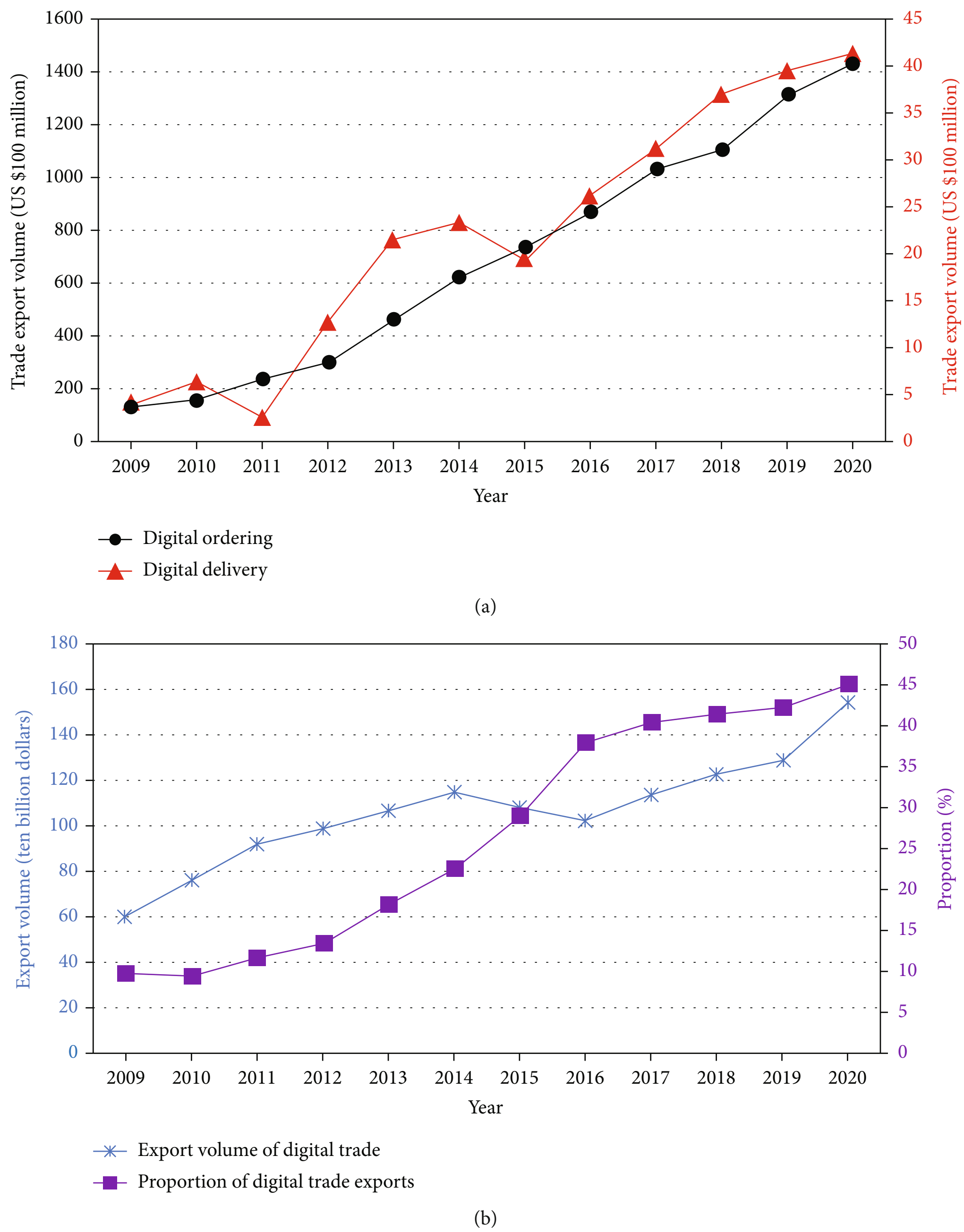


FIGURE 10: The scale and growth rate of China's digital trade exports to the countries on the western side of the Maritime Silk Road. (a) Analysis of export value of digital order and digital delivery trade; (b) analysis of the proportion of digital trade exports to total trade exports.

T_{jt} stands for its security servers per million, and TX_{jt} demonstrates its share of high-tech exports [30].

2.7. Simulation Experiment of Optimization of Transportation Network Scheduling of the Maritime Silk Road for Improved GA. Taking China's self-built large ship as the research object, the ship has a length of 322.6 m, a hull height of 73.2 m, and the maximum draft and speed are 8.65 m and 22.7kn/h, respectively. The relevant data parameters of the ship control network are collected, and 255 kbit/s is set as the message transmission rate. The performance of the method is verified by conducting simulation experiments with these data using a simulation test platform. To test the time-varying stochastic frontier gravity model, there are 251 observations, and the data from 2009 to 2020 of 21 countries along the route are selected as samples. The data are mainly from the service website of China (Shanghai) Pilot Free Trade Zone and the World Bank Development Indicators Database. Data related to trade export value come from the UN Comtrade database.

3. Data Test Analysis and Result Discussion

3.1. Optimal Analysis of Transportation Network Scheduling by Improved GA for Maritime Silk Road

3.1.1. Test of Message Delivery Rate in High-Speed TTCAN Network for Ship Control. In the simulation test platform, the change in the message delivery rate of different algorithms is simulated under sunny weather and extreme weather environments of the ship. The results are displayed in Figure 7.

In Figure 7(a), as the number of message nodes increases, the message delivery rate gradually decreases, the number of nodes increases from 40 to 100, and the message delivery rate of the optimized algorithm decreases from 98% to 92%. Compared with GA and SAA alone, the optimization algorithm reduces the rate slowly, and the delivery rate of the optimization algorithm is more advantageous under the same node condition. In Figure 7(b), in extreme weather, the message delivery rate decreases, but the optimization algorithm decreases slowly, and the delivery rate drops from 94% to 81%. The delivery rates of other algorithms are generally lower than 80%. Affected by bad weather, the ship control network needs to constantly replace the operation instructions, resulting in a drop in the delivery rate. However, the message delivery rate of this optimization algorithm is significantly higher than that of other methods, and a good delivery rate can be maintained under extreme conditions.

3.1.2. Test of Message Delivery Rate in Low-Speed TTCAN Network for Ship Control. In the low-speed TTCAN, the variation in the message delivery rate of different algorithms is simulated for ships in sunny weather and extreme weather environments, and the results are demonstrated in Figure 8.

Figure 8(a) manifests that in sunny weather, with the increase of the number of message nodes, the message delivery rates of GA and SA gradually decrease, and the reduction range is small. The rate of the optimization algorithm decreases from 98% to 96%, with the smallest change, which can maintain a higher message delivery rate. In the case of the same nodes, the optimization method is more advantageous. The low-speed TTCAN network has lower requirements on the timeliness of message transmission, and the message transmission has a buffer time. Figure 8(b) displays that in extreme weather, the optimization algorithm can still maintain a high delivery rate, the delivery rate is reduced from 97% to 95%, the message can be transmitted stably, and the delivery rate remains above 95%. After using the optimization algorithm to optimize and schedule the ship network, the stable navigation of the ship can be guaranteed regardless of the navigation conditions.

3.2. Analysis of the Potential of International Digital Trade between China and the Countries on the Western Route of the Maritime Silk Road

3.2.1. Analysis of Trade Volume and Trade Proportion. The scale of China's digital trade exports to the countries on the western route of the Maritime Silk Road from 2009 to 2020 is analyzed, and the results are expressed in Figure 9.

In Figure 9, from 2009 to 2020, except for 2016, the overall trade volume showed a growth trend, and the trade volume and trade growth rate in the rest of the years increased significantly. The decline in trade volumes in 2016 was mainly due to the financial and debt crisis. The proportion of trade volume in China's total foreign trade is also increasing year by year, from 18.48% in 2009 to 26.31% in 2020. It illustrates that China's export to its trade is developing well.

3.2.2. Analysis on the Scale and Growth Rate of Digital Trade Exports. Figure 10 implies the results of the analysis of the scale and growth rate of China's digital trade exports to the countries along the western side of the Maritime Silk Road from 2009 to 2020.

As plotted in Figure 10, during the 12-year period from 2009 to 2020, the value of digital trade exports increased from $12.75 billion to more than $140 billion, an increase of more than 10 times. The export scale of digital order trade presents a trend of increasing year by year, far ahead of the export value of digital delivery trade. It indicates that although the scale of digital delivery trade exports is small, the proportion of exports has increased from 9.75% in 2009 to 45.12% in 2020. The value of digital trade exports is growing at a faster rate every year.

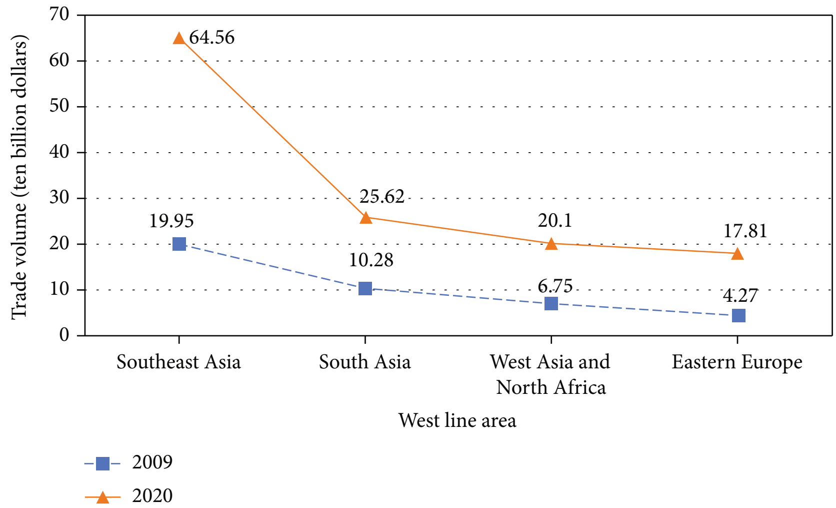
3.2.3. A Comparative Analysis of the Trade Volume between China and the Four Regions along the Western Route of the Maritime Silk Road. A comparison of trade volumes between China and the four western regions of the "21st Century Maritime Silk Road" in 2009 and 2020 is made (data source: UN Trade Database). Figure 11 demonstrates the results.

In Figure 11, the entire west route covers a wide range of areas and can be divided into four regions: Southeast Asia, South Asia, West Asia, and East and North Africa according to geographical traditions. In 2009, the trade volume was relatively small, and after more than 10 years, it changed greatly. In particular, the trade volume of Southeast Asian countries increased from 19.95% to 64.56%. The proportion of trade in the four regions has increased, but the increase is not very obvious, and the proportion of the entire trade volume maintains a stable trend.

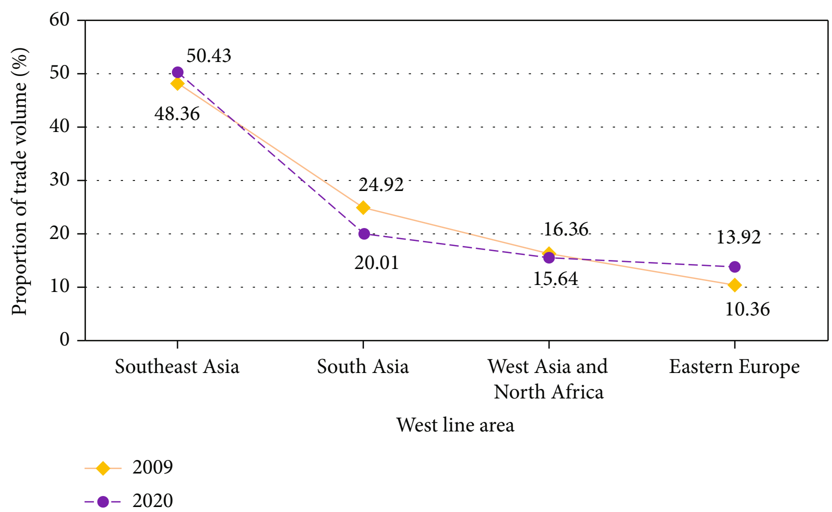
3.3. Empirical Analysis of China's Digital Trade Export Potential to Countries along the Maritime Silk Road

3.3.1. Rationality and Applicability Test of the Time-Varying Stochastic Frontier Gravity Model. Before the regression of the model, the rationality and applicability of the constructed model are tested, and the likelihood ratio (LR) test is performed on the setting form of the model in the early stage to test whether it has a trade inefficiency term. If there is, it is reasonable to use the stochastic frontier gravity model. If not, the model is unreasonable. It is tested whether the trade inefficiency term in the model changes over time. If the test result is rejected, the time-invariant model is adopted. Table 1 represents the results of testing by using Frontier4.1 software.

Table 1 details that trade inefficiency exists, which indicates that the stochastic frontier gravity model is reasonable. The inefficiency term varies with time, illustrating that the finalized time-varying stochastic frontier gravity model is reasonable and applicable.



(a)



(b)

Figure 11: Comparative analysis of trade volume between China and the four regions. (a) Comparison of trade volume between 2009 and 2020; (b) comparison of the proportion of trade volume in the total trade volume of countries along the western route in 2009 and 2020.

Table 1: Test results of model specification.

Propose a hypothesis	There is a trade inefficiency term	The trade inefficiency term changes over time
Unconstrained model values	-379.08	-379.08
Constrained model values	-413.55	-392.23
LR statistic value	66.33	28.15
1% critical value P	10.35	8.93
Result	Accept	Accept

By regressing the time-varying stochastic frontier gravity model and using the one-step method to regress the trade inefficiency model, and using the Frontier4.1 software for calculation, the estimated value of China's digital trade export efficiency to countries along the route from 2009 to 2020 is obtained. The results are exhibited in Figure 12.

In Figure 12, the overall export efficiency of China and the countries along the route has obvious differences in the dynamic changes in the time-varying model and the nonefficiency model. In the time-varying model, the export efficiency decreases with time, indicating that trade resistance increases with time. The one-step method is used to regress the nonefficiency model. Since the artificial trade resistance factor is taken into account, the trend of export efficiency changes has no significant relationship with time. The overall export efficiency is 0.56, illustrating that China has encountered a large artificial trade resistance in its trade with the vast majority of countries along the route, resulting in low export efficiency, so that China has a huge potential for progress with the countries along the route.

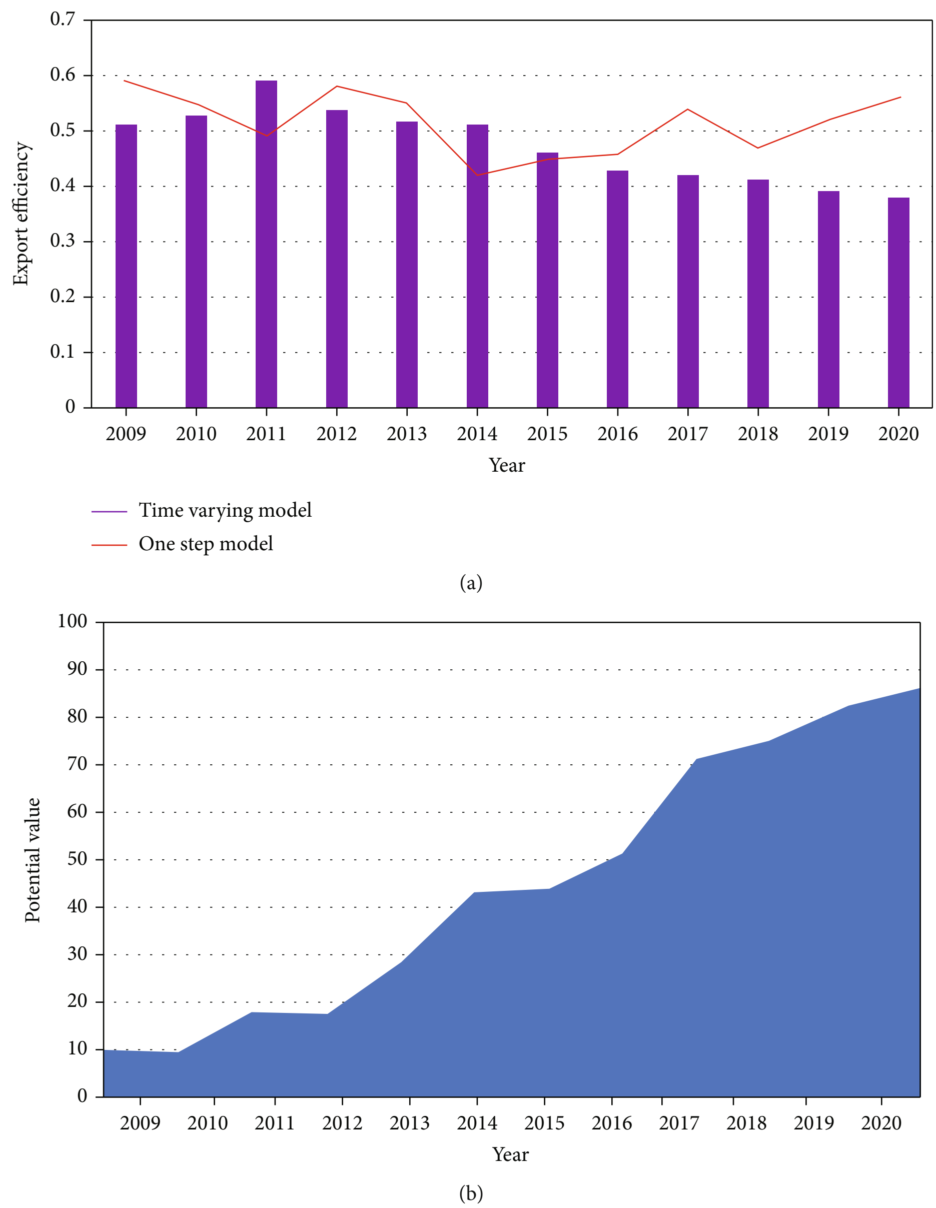


Figure 12: Changes in the overall average export efficiency and export potential of China and countries along the route from 2009 to 2020. (a) Dynamic changes in export efficiency; (b) dynamic changes in export potential.

4. Conclusion

The objective is to improve the efficiency of ship transportation network scheduling of the Maritime Silk Road, optimize the ship network scheduling, and enhance the potential of maritime international digital trade. Firstly, the Maritime Silk Road and digital trade barriers are expounded, and the ship network structure by high-level TTCAN is designed and studied. Secondly, the traditional GA is improved by using SAA, the optimization process of ship network scheduling based on improved GA is constructed, and the simulation test is carried out using the simulation test platform. Finally, the potential of maritime international digital trade is analyzed through the time-varying stochastic frontier gravity model, and the rationality and applicability of the model are tested. The results reveal that: (1) In the high-speed TTCAN of ship control, with the increase of message nodes, the optimized algorithm reduces the message delivery rate from 98% to 92% under sunny conditions; under extreme weather, the message delivery rate decreases from 94% to 81%. Compared with other algorithms, the delivery rate decreases slowly and the delivery rate is higher; the network scheduling effect is better. (2) In the low-speed TTCAN test, it is found that regardless of the weather and the number of message nodes by improved GA, the message could be transmitted stably, the delivery rate remained above 95%, and the effect of ship network scheduling is the best. (3) From 2009 to 2020, the total export volume of trade between China and the countries on the western route of the Maritime Silk Road is on the rise as a whole, and the proportion is increasing year by year, from 18.48% to 26.31%. The proportion of digital trade exports increased from 9.75% to 45.12%. The export value of digital trade is growing at a rapid rate every year, among which China has the largest proportion of trade with Southeast Asian countries, and the proportion of trade volume in the four regions has remained relatively stable. (4) Through the analysis of export efficiency and export potential, it is found that China has a huge development space for the overall potential of the countries along the Silk Road. The contributions of this research are as follows. (1) The optimization process of ship network scheduling of SAA improved GA is constructed; (2) the ship network structure of high-speed CAN protocol is optimized under different conditions; (3) the time-varying stochastic frontier gravity model is employed to study the digital trade potential between China and countries along the Maritime Silk Road. Although this research has achieved some results, it still has certain limitations. The research view of trade potential is relatively narrow, and no multiangle study has been carried out. An in-depth analysis should be performed later to expand the research area.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no competing interests.

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