8-30-2022

Weather routing for the refined management of passage

Guobao Gong

WORLD MARITIME UNIVERSITY

Dalian, China

WEATHER ROUTING FOR THE REFINED MANAGEMENT OF PASSAGE

By

GONG GUOBAO

The People's Republic of China

A dissertation submitted to the World Maritime University in partial

Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

In

MARITIME AFFAIRS

(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)

2022

DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

Signature: …… GONG GUOBAO…….

Date: ……2022.6.28……..…….

Supervised by:……..…Wang Jun…….

Supervisor’s affiliation:……..……Dalian Maritime University……

ACKNOWLEDGEMENT

As a member of Maritime Safety and Environmental Management 2022, I want to say thank you to all professors, teachers, and students in this programme. I would like to acknowledge and extend my sincere appreciation to the following persons without whom this dissertation can not be completed.

I would like to express my sincere gratitude to my supervisor, Professor Wang Jun, from Dalian Maritime University. He is not only my supervisor in my master period, but also teaches me a considerable number of knowledge in transportation sector. Without his recognition, care and careful guidance, I could not successfully complete this dissertation and even this programme.

Same thanks also to my director Professor Tian Bai Jun from Maritime Cargo Operation section in Dalian Maritime University, who selflessly provides me with relevant references related to my topic from his rich working experience and spares no effort to help me complete this dissertation.

I would also like to express my sincere gratitude to Mrs. Zhao Lu, from Dalian Maritime University, providing a reasonable and high-standard study environment, strict management system and happy campus life for us.

To my family, classmates and friends, thank you for your company, patience and support. Especially my wife, if without whom I cannot be engaged in study with few distractions.

ABSTRACT

Title of Dissertation: **Weather routing for the refined management of passage**

Degree: **Master of Science**

Weather routing has been used for shipping since the early 1950s, the first generation of weather routing methods were thought only to optimize time, the fuel consumption, basically no consideration of the effect of the weather routing selection on the passage performances during the entire voyage. In recent years, under the guidance of the national policy of "One Belt and One Road", in particular, the development and implementation of the national strategy of "21st Century Maritime Silk Road" has put forward an urgent demand for Marine meteorological support services not only in offshore waters, but also in the ocean areas and even around the world. The optimized voyage was approached in a wide sense, not only taking into account the ship running performances, but also the operational cost. This paper overviews the operation and development of domestic and foreign marine weather routing service, compared several routing service companies, find the existing problems, analysis and research the weather routing with diversified platforms and products gradually developing under the background of informationization, the weather routing service in China is striving to innovate and good progress has been made. Through the refined management of weather routing, shipping owners and charterer achieve safety, efficiency and maximum benefit voyage.

KEYWORDS: Weather routing; Energy efficiency; Operation cost; Safety; Optimization.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AWT	Applied Weather Technology
CMA	China Meteorological Administration
CCTV	Closed Circuit Television
ECDIS	Electronic charts and display system
ECWMF	European Centre for Medium-Range Weather Forecasting
ENS	Ensemble Forecasts
ETA	Expected time of Arrival
EEXI	Energy Efficiency Existing Ship Index
GFS	Global Forecast System
GHG	Greenhouse Gas
GX	Global Xpress
HRES	High Resolution Forecasts
IMO	International Maritime Organization
Inmarsat	International Maritime Satellite Organization
IoT	Internet of Things
MEPC	Marine Environment Protection Committee
NOAA	National Oceanic and Atmospheric Administration
NOR	Notice of readiness

PA	Press Association
PSSA	Particularly Sensitive Sea Area
RPM	Revolutions per Minute
SEEMP	Ship Energy Efficiency Management Plan
SG	Storm Geo
SPOS	Ship Performance Optimization System
USB	Universal Serial Bus
TNM	True North Marine
WNI	Weathernew Inc
WR	Weather routing

CHAPTER 1 INTRODUCTION

1.1 Background

Nowadays, with the boom of global economic world system, safe and efficient transportation systems connect global supply chains are the driving force for economic development and prosperity. Sea transport accounts for a large proportion of world's total trade. According to statistics, 90% of world's trade is carried through sea transport (IMO. 2021a). As a trade driving force, shipping plays a huge role in the global economy, and its importance is self-evident. With the influence of human activities and carbon emission rising, the global climate is changing constantly, and the frequency of extreme weather is gradually increasing. Marine accidents caused by meteorological factors occurred from time to time, and the huge economic lost and environmental pollution caused by them have attracted more and more attention (Xue-feng Yang. 2018).

The risk of sea transport is greater than other modes of transport. The frequent occurrence of marine perils at sea is mainly relating with the bad weather. The survey results show that since the 1990s, the number of ships and the gross tonnage of ships damaged due to the wind and wave environment reached 33%, ranking the top of all kinds of ship total loss (Leng Jiaohang. 2010). Especially in bad weather, strong winds, waves and other severe weather, is the main factor of capsizing ships. Therefore, for the safety and economic benefits of ship navigation, the concept of Weather routing(WR) was first proposed by the US Navy in the early 1950s (Chong Pan. Zhanshuo Zhang. Weikang Sun. Jun Shi. Hongbo Wang. 2021).

1.1.1 Weather routing is the special agencies to advise the vessels applying for passage on the best route and continue to provide tracking services during the

voyage. It is characterized by taking wave, swell, wind, current and other factors into full consideration, reducing the impact of wind and wave area, making the shortest sailing time and the best economic benefit under the condition of ensuring navigation safety (Guang-wen Ma. 2005). Mariners can utilize extensive weather forecasting services and their own expertise to identify and assess potentially hazardous conditions (Andrew Rawson, Mario Brito, Zoheir Sabeur, Long Tran-Thanh. 2021). In addition, a number of commercial routing packages assist the navigator in this regard using pre-set limits of wind or wave conditions to plot the optimal route to avoid the worst of the weather (StormGeo, 2020).

1.1.2 Shipping companies want to gain more market profits, it needs both safe and economic routes. In the maritime transportation, ship safety and energy efficiency are two of the most important topics to make a ship's operation more competitive and sustainable (Helong Wang, Wengang Mao, Leif Eriksson. 2019). The application of marine weather routing technology solves these problems initially. Weather routing can make the navigation of ships safer, avoid bad weather sea conditions and reduce the economic loss caused by ship damage and cargo damage. With its more and more extensive application, weather routing has gradually become an important guarantee of maritime navigation safety. Moreover, combining the concepts of voyage planning and weather routing is also regarded by the shipping industries as an effective measure to ensure ship navigation safety, obtains more economic benefits and reduces negative impact on the environment (DNVGL, 2015).Weather routing is developing very rapidly, but also because of this, coupled with the navigation seafarer shortage, most of the Weather routing company internal staffs have no actual sea experience, the weather routing quality is uneven, the recommended

routes of unrealistic would happen sometimes, resulting in ships suffered unnecessary storm, ice, and deviation (Liu, G. 2012).

In addition, due to the mechanism of weather routing itself, weather routing agencies on the shore are relatively limited in understanding of ship performance. Real time course correction, flexibility, and real-time performance are obviously insufficient, sometimes lack of privacy while making the ship itself and requires certain economic cost (Qiao qianfang. 2013), and therefore this way of weather routing does not meet the needs of all maritime shipping routes for meteorological.

1.1.3 In the actual sailing process of the ship, the captain can make analysis and decision for the ship route. According to the trading ports of the navigation area of the ship, the captain can use the marine hydrometeorological data on board, such as the Ocean passage for the world, World climate map, Routing charts, Sailing directions, Mariner’s handbook and other publications, combined with the captain's own sea experience, choose a relatively safe and economic route. Its advantages are that the captain is in control of the ship at any time, more flexible and initiative in the command of the ship, and can save communication and weather routing costs; however, the disadvantages are also obvious. This method relies too much on the navigational knowledge, navigational experience and command ability of the captain, and the scientific decision support is insufficient. Due to lack of sufficient weather data supporting and a lot of data calculating, the captain could not forecast the weather as accurate and efficient as the shore based weather routing organizations. Sometimes, a wrong meteorological analysis could cause a ship to sail into a high wind and rough wave area, what’s more, leading to a catastrophe.

1.1.4 Depending on the rapid development of information technology and the progress of ship communication means, weather routing can analyze and forecast the ocean weather and typhoon tracking (Zhang Xiaochuan, Cui Jianhui & Rong Lei. 2014), such as shown in FIGURE 1.

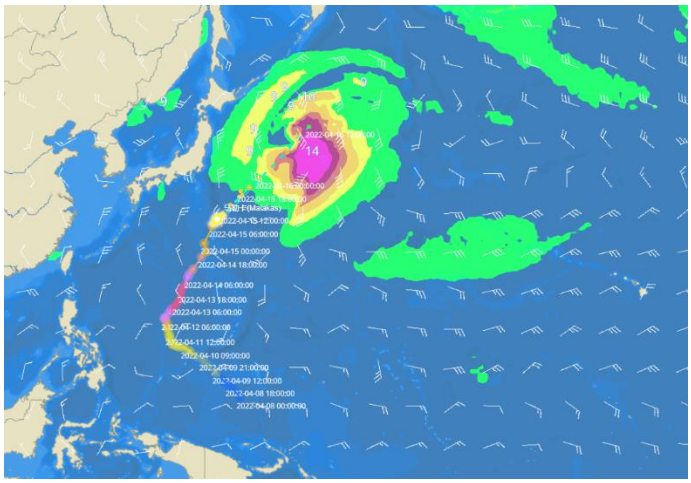


FIGURE 1 – Unitedmeteo forecast ocean weather

The routing takes full account of the future weather process on the route, overcomes the limitations of the climate route, and can be based on the ship and the day real-time monitoring of the weather system, timely adjustment of the route, so that the ship can reduce the impact of wind and waves in advance, minimize the effect of bad weather and ship construction & strength damage, for the safety of the ship to provide the greatest help, and ultimately achieve the shortest sailing time, the least fuel consumption, the ship highest operating efficiency and maximum economic benefit. Using advanced ship to shore communication system, shore based weather routing service company can release timely and accurate digital weather forecast information and navigation reference information, to make navigation safer, sea transport more efficient, scientific expeditions smoother, and military action more proactive (Yu He Shu, Xu Xiao Feng, Liu You Qi. 1995).

The routing service provides the recommendations on transportation routes prior to and during ship sailing in various navigation constraints under global weather forecasts. According to the forecast of ship sailing environment factors, combined with the cargo of ship voyage and ship performance conditions, the weather routing company applies the best control theory to select the best route for the ship, and provides the most economical and efficient route planning guidance for the ship on the premise of guaranteeing the safety of ship sailing, thus improving the economic benefits of ship operation. Safe ship handling provides the recommendations on vessel position, orientation and speed conditions that should execute at the previously recommended route (with safe navigation conditions) under local weather conditions (Lokukaluge P. Perera & C. Guedes Soares. 2016). Weather routing agencies use computers to continuously carry out tracking and navigation services for the weather routing service contract listed ships. Routing services are carried out according to the constantly updated and highly accurate short and medium term marine environment forecast and the position of the ship. In case of adverse weather and sea conditions in the sea area ahead of the route, the service company can timely remind and warn to the ship regarding the coming deteriorate weather, and revise or change the initial recommendation route if necessary, so as to avoid the adverse marine environment in time.

In this respect, even if the route selection is entrusted to the ship master, the adaptive weather routing can provide a significant support to the decision making process, to ensure the proper balancing between the safety of navigation and the related economic impact, in terms of voyage duration and fuel savings (Silvia Pennino, Salvatore Gaglione, Anna Innac, Vincenzo Piscopo and Antonio Scamardella. 2020).

1.1.5 Some shipping routes are usually drawn up by shipping companies according to their historical navigation experience. Or a meteorological route, that is, to be drawn up by a weather routing company on shore based information provided by the ship; Sometimes also according to the great circle route calculation results, and then with the experience of the navigation personnel for manual editing. The empirical route design method lacks sufficient scientific basis and has great randomness. Although weather routing navigation has played a significant role in the safe and economic navigation of ships, there are still obvious limitations and deficiencies.

1.2 Significance and objectives

For the recent few years, with the growing number of maritime transport vessels, shipping industry forms a dense and complex traffic situation, which brought great challenges to the shipping industry of all countries around the world. With the development of logistics supply chain, the cost and efficiency of maritime transportation put forward higher requirements, coupled with complex and changing meteorological conditions, leading to maritime transportation in the safety, efficiency and energy saving on each other formed a contradiction, resulting in maritime traffic accidents still continue to occur. Safety at sea is becoming an increasingly important issue, as the safety of maritime traffic is a matter of life for the crew and cargo.

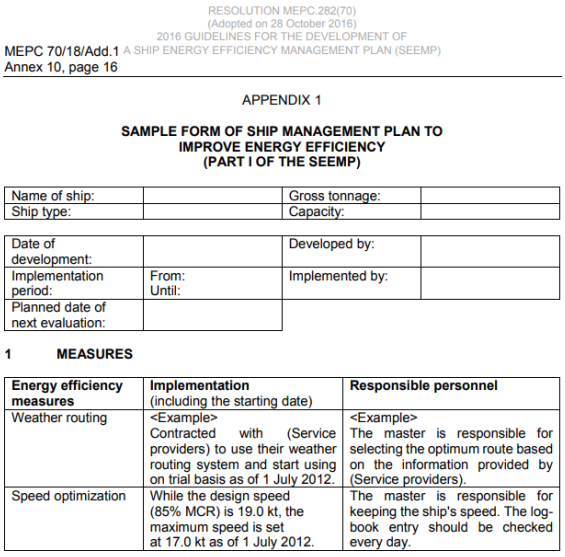
Nowadays, increasing attention has been paid to the role of ship navigation technology in improving the efficiency, economy and safety of shipping. Developments in maritime technology have not only greatly improved the economy of navigation, but also the safety of ships during ocean going passages. As an important aspect of navigation technology, weather routing has always occupied a

decisive position. How to solve the problem of safety, efficiency and energy saving of shipping has become the focus of global shipping enterprises. The old concept is that weather routing only for avoiding bad weather. However, combined with digital technology and artificial intelligence, weather routing not only can reduce the weather impact, but also can play a key role in ship operation and port management that helps managers make better decisions, minimize fuel consumption and greenhouse gas emissions from ships. This paper mainly discusses about how to achieve safety, efficiency and max benefit passage through weather routing of refined management.

1.2.1 Ship route design and optimization has been a great concern in foreign countries. Within specified limits of weather and sea conditions, the term optimum is used to mean maximum safety and crew comfort, minimum fuel consumption, minimum time underway, or any desired combination of these factors. The core element of such a voyage planning (ship weather routing optimization) system is a proper voyage planning algorithm, which generates optimal navigation path based on the ship operational capabilities, ship molded lines characteristics and ocean weather forecast conditions around the ship's sailing areas, as well as some particular constraints for the voyage optimization (Simonsen, Martin & Larsson, Erik & Mao, Wengang & Ringsberg, Jonas. 2015). However, the purpose of route optimization ten years ago was to focus on the navigation efficiency and safety of ships. In recent years, many shipping enterprises have found that choosing a reasonable weather route is not only helpful to improve ship efficiency and reduce operational risks, but also accurately predict ship expected time of arrival (ETA), make port operation, ship maintenance and repair plan more reliable, and reduce demurrage costs and unnecessary expenses. Meanwhile, Artificial intelligence is used as a key

ingredient in planning the route for ships. Artificial intelligence uses operational and weather data to create a detailed, reliable and optimized route, minimizing the fuel consumption.

1.2.2 IMO have adopted [2016 Guidelines for The Development of a Ship Energy Efficiency Management Plan (SEEMP)] on 28 Oct 2016. The plan has listed some measures for normal cargo ships to improve ship energy efficiency management. Identified energy saving measures which have been undertaken and their effectiveness depend on what measures can be adopted for further improve the energy efficiency of the ship (FIGURE-2). Weather routing has a high potential for efficiency savings on specific routes. It is commercially available for all types of ship and for many trade areas (IMO. 2016).



RESOLUTION MEPC.282(70)
(Adopted on 28 October 2016)
2016 GUIDELINES FOR THE DEVELOPMENT OF
MEPC 70/18/Add.1 A SHIP ENERGY EFFICIENCY MANAGEMENT PLAN (SEEMP)
Annex 10, page 16

APPENDIX 1

SAMPLE FORM OF SHIP MANAGEMENT PLAN TO IMPROVE ENERGY EFFICIENCY (PART I OF THE SEEMP)

Name of ship:		Gross tonnage:	
Ship type:		Capacity:	

Date of development:		Developed by:	
Implementation period:	From: Until:	Implemented by:	
Planned date of next evaluation:			

1 MEASURES

Energy efficiency measures	**Implementation** (including the starting date)	**Responsible personnel**
Weather routing	<Example> Contracted with (Service providers) to use their weather routing system and start using on trial basis as of 1 July 2012.	<Example> The master is responsible for selecting the optimum route based on the information provided by (Service providers).
Speed optimization	While the design speed (85% MCR) is 19.0 kt, the maximum speed is set at 17.0 kt as of 1 July 2012.	The master is responsible for keeping the ship's speed. The log-book entry should be checked every day.

Figure 2- SEEMP FORM

1.2.3 Weather routing for the refined management of passage is based on the future meteorological and hydrological conditions, combined with ship technology and operation, through artificial intelligence algorithms to collect information such as metrological data and maritime traffic, and find modes that suggests

optimum route for the voyage saving time and fuel. It considers relevant data of natural environment that the ship is expected to encounter through the entire voyage, ship motion performance curve, as well as the loading condition, some special requirements and other constraint conditions, then use computer to calculate optimization algorithm, to find the best weather routes, minimize the resistance affected by wind & swell, reduce the possibility of stall phenomenon and ship hull damage, recommend optimal routes for ocean-going vessels, and provide vessel tracking, voyage evaluation, speed and operation requirements.

Meanwhile, the total operation cost will be calculated according to the entire passage, including ship crew cost, fuel consumption cost, cargo cost, and chartering cost, then give feedback to the weather routing service team whether the speed and route for the intended voyage are workable or not. All the intended voyage can be simulated prior to the voyage by simulating and analyzing for ship cost and cost of the voyages, then make the final decision to choose the route which could achieve the best benefit.

1.2.4 The traditional weather routing service mainly lies in the following aspects. First, it can improve the safety of ship navigation. The use of marine weather routing can make the ship avoid bad weather areas as far as possible and reduce the damage of wind and waves to the hull. Second, it can improve the economic benefits of ship operation. Using marine weather routing can avoid bad weather and sea conditions as far as possible, make full use of favorable environment field, shorten sailing time, save fuel cost and other cost. Third, weather routing assessment data will serve as important evidence for resolving disputes over speed and fuel consumption (Zhang zenghai, Liu Tao, Cao Yuenan, Yang Zhenglong & Guo Yiying. 2020). The weather routing company estimates the weather coefficient and ocean current coefficient according to its own

meteorological data and captain's report, revises the actual speed, obtains the performance speed, and then compares it with the speed stipulated in the charter to judge whether it meets the requirements of the charter party (Wang Hui & Bai Chunjiang. 2018).

Compare with the normal weather routing service, the weather routing refined management is an integrated service through all big data from meteorology, ship owners and charters. It can provide weather routing service with real time online update of global weather and ocean numerical forecast query and API data interface through the Unitemeteo platform to directly show the real time route monitoring, weather forecasting, oil consumption, operation and other safety matters. It constructs a ship energy efficiency management big data system based on ship shore collaboration, establish a fleet energy efficiency management service system, explore the potential value of ship data, and promote the development of smart ships. The refined management based on real time data of ship shore collaboration, ship and fleet navigation analysis, fuel consumption monitoring, energy efficiency analysis, decision-making assistance, speed optimization monitoring, and weather monitoring to put forward early warning, optimize the allocation of ship and shore resources, more efficient serves users.

1.3 Structure

The first chapter states the background, significance and objectives of this dissertation.

The second chapter illustrates the historical evolution of weather routing service companies in China and abroad, the different companies' different services in different periods. The existing problems of weather service now.

The third chapter elaborates the sector of weather routing services for the refined management of passage. The significant differences from traditional weather routing services are highlighted.

The fourth chapter introduces the mode of integrated weather routing refined management service with its successful cases, through weather routing of refined management to achieve safe, efficient and economic passage.

The fifth chapter gives the conclusion of this dissertation.

CHAPTER 2 ANALYTICAL REVIEW OF CURRENT WEATHER ROUTING SERVICE

2.1 Historical evolution of Weather Routing Service

The development of the marine navigation industry cannot be separated from the application of weather routing navigation. In Chinese history, from the early Tang Dynasty (753) when Jian Zhen crossed to the East, to the Ming Dynasty (1405) when Zheng He went to the West; in European history, Columbus discovered the New World (1492) to Magellan's first voyage around the world (1522). None of these were possible without their application of the laws of weather (monsoons, currents, etc.). The correct use of weather patterns (monsoon winds, currents, etc.) allowed ships to sail safely. This was an early manifestation of the use of weather routing navigation (Zhang Yongning. 2008).

2.1.1 The beginning of weather routing navigation was the establishment of the British Meteorological Office in 1885. It was the world's first meteorological organization, at that time was able to produce marine weather forecasts and analysis them at the same time, and then send the results in the form of messages to the target ships. However, due to the limited conditions, the outdated communication technology and meteorological detection technology could not guarantee the forecast, and this makes it difficult to navigate a ship based on weather conditions.

2.1.2 After the Second World War, the development of science and high technology is very rapid. The collection and processing of maritime hydrometeorological data are carried out by computers. Long-term forecasts technology has made

great progress and greatly promoted the research of scholars on meteorological routes. The US Navy recognized that the use of weather routing technology could ensure the safety of ship navigation and, in view of the severe attrition of warships in the Pacific at the time, formally adopted weather navigation to alleviate this problem. From 1948 onwards, the US Weather Bureau began to make extensive use of radio communication technology to transmit weather station forecasts, including short-term weather and sea conditions in the relevant areas etc. Hydrographic bureau G.J.Haltiner and other scholars spent two years recommending 1000 optimized routes to Military Sea Transportation Service based on the forecast information of wind, wave and current on the sea, which effectively guaranteed the safety of ships, goods and personnel and achieved an annual saving of more than 2 million dollars and an average saving of 14 hours of sailing time (Hanssen, G.L. 1960).

2.1.3 After the 1960s, weather routing has become the research hotspot of many foreign experts and researchers. Because the international oil price rose at that time, the influence of fuel consumption control on ship navigation is more and more big, the weather routing business is also gradually prosperous. The first generation of weather routing methods were thought only to optimize time, guided by the pioneer works of James (1957) and Zoppoli (1972). The more recent concerns on energy efficiency and reduction of emissions (IMO. 2009) and the increasingly competitiveness in maritime trades pressured researches into multi-objective optimization and integrated energy efficiency approaches (Roberto Vettor & C. Guedes Soares. 2016)

2.1.4 After entering the 21st century, technology develops rapidly, especially the development of computer technology and the collection and processing technology of hydrometeorological data has gradually become a means to

solve the problem of route optimization. The standardization and accuracy of meteorological and hydrological data, as well as the development of computer software and hardware platforms, have given weather routing industry a better chance to flourish. At the same time, a variety of control and optimization theory route planning algorithms have emerged, and weather navigation has gradually begun to flourish. By collecting navigation data such as velocity, wind speed, swell height and water depth, and navigation status data such as ship speed, course, longitude and latitude, ship navigation energy consumption data, the dynamic response model between ship energy efficiency and navigable environment is established through digital weather routing, so as to optimize ship speed and improve energy efficiency.

2.2 Weather routing Service abroad

There are many shipping weather routing companies in the world now, among which WNI, SG-AWT, TNM and Meteo Group are outstanding.

2.2.1 Weathernew Inc (WNI) was founded in Tokyo, as a weather content maker for the purpose of serving all the weather markets in 1986. Seven years later, in 1993, WNI acquired the original parent company, Oceanroutes of the United States, and became the world's largest private weather service company. It was listed on NASDAQ Japan in 2000 and Tokyo stock exchange in 2003. WNI launched the Polar Orbiting Monitoring satellite WNISAT-1 in November 2013 and WNISAT-R in July 2017.

WNI is the world's largest weather service company, service covers aviation, navigation, highway, logistics, tourism, energy, sports and so on. An ecological empire of meteorological services covering the whole process of meteorological observation, data analysis, forecast and service. WNI is also the

largest shipping weather routing company with 32 offices in 21 countries, 7 service and operation centers. As of May 2021, the company has 1101 employees, a total consolidated sales of 18843 million yen, and more than 6,000 ships are in service at any one time (WNI.2021).

2.2.2 SG-AWT (Applied Weather Technology), founded in 1993, After Ocean routes was acquired and disbanded by WNI of Japan, and AWT was founded by the remaining employees. In 2014, it was acquired by STORM GEO of Norway and renamed as SG-AWT (STORM Geo-Applied Weather Technology, website: https://www.Stormgeo.com). AWT provides professional weather services to customers involved in land, marine and aviation. Over 70% of AWT's business is offshore. The navigation business employs over 400 people in 27 locations in 15 countries.

As a global expert in weather information and decision support, Storm Geo has been providing innovative solutions to shipping, oil, gas, renewable energy utilities, cross-industry media and aviation. For more than 12,000 ships using Storm Geo voyage planning route optimization and fleet efficiency management services, as well as more than 65,000 annual weather routing services.

2.2.3 TNM (True North Marine, https://tnmservices.com/) Headquartered in Montreal, Canada, with marketing offices in Shanghai, India and Greece, TNM is committed to help ship operators achieve the safest and most efficient voyages and reducing costs through weather navigation services. The services provided by the company mainly include weather routing service, ship performance monitoring service and post-voyage analysis service, serving ship owners and time chartering customers, and providing shipping route advice service, daily route review and correction service, scheduled route forecast

service, speed analysis, fuel consumption analysis, voyage evaluation service and other TNM services. Although it has a small share in the Marine Weather Routing industry, it is the third largest weather routing company after WNI and AWT (Zhang zenghai, et al. 2020).

2.2.4 Meteo Group was founded in 1986 as Meteo Consult, headquartered in Berlin, and was the first commercial weather company in Europe. In the early 1990s, the company quickly taking over major European markets through joint ventures with local weather companies before branching out into the world in 2010. In May 2005, Press Association (PA) Group acquired a majority interest in Meteo Consult. The acquisition further expands PA Group's portfolio of diversified information services for international markets and enables Meteo Group to accelerate growth in new markets. General Atlantic, the private equity firm, paid €160m for Meteo Group in 2013. The acquisition gives Meteo Group another boost to its international profile, with better exposure to the European and American markets.

In 2006 all the businesses were collectively known as Meteo Group and in 2018 were acquired by DTN Weather of Switzerland (https://www.dtn.com/weather/shipping/). By 2018 Meteo Group was operating in 18 countries, with more than 20,000 weather stations, more than 120 meteorologists, the largest private weather observation network in Europe Group (DTN. 2018).

Meteo Group has worked with international energy and petrochemical companies to develop Ship Performance Optimization System (SPOS), a shipboard routing system that is now installed on more than 2,000 ships worldwide and is the undisputed market leader. In addition, it also provides solutions for transportation, hydrology, media, energy, insurance and other

industries (Weatherize.2018).

2.3 Weather routing service in China

The third session of the Technical Commission on Marine Meteorology, held in 1960, is the first time mentioned forecasting of sea state through meteorological data, and the shipping industry began to recognize the economic benefits of weather routing services. From the end of last century to the first decade of this century, the international weather routing service business has made great progress, but China had missed this development opportunity period.

2.3.1 China's Marine weather routing started in the early 1980s, when part of China's ocean-going ships used the United States weather routing company (Oceanroutes) has achieved great economic benefits in ensuring safety, saving sailing time and reducing cargo loss. In order to establish Chinese weather routing business, in 1981, Dalian Meteorological Observatory, Naval Surface Ship Academy, Dalian Ocean University, Dalian Ocean Shipping Company and Dalian Maritime University cooperated to carry out weather routing test research; at the end of 1983 and the end of 1984, two comparative experiments were carried out. In 1985, the achievements of weather routing technology were appraised, which made up the gap in China's weather routing technology (Yu He Shu, Liu You Qi. 1993). During the same period, with Shandong Ocean University (now Ocean University of China) as the scientific research base and Qingdao Ocean Shipping Company as the experimental base, the Qingdao weather routing Consortium organized six teaching and business units of navigation and marine hydrometeorology and established a relatively complete marine weather routing system after nearly three years of collaborative efforts (Zhang zenghai, et al. 2020).

In 1985, the Marine Meteorological Navigation Center of the Central Meteorological Observatory (National Meteorological Center of the China Meteorological Administration) began to carry out marine weather routing service. A global weather routing service system has been developed, and five meteorological navigation sub-centers in Dalian, Shanghai, Tianjin, Guangzhou and Qingdao have also been established. In June 1987, the National Meteorological Observatory implemented weather routing support service for China's ocean liner MV “Anping 5” crossing the Pacific Ocean for the first time. China's weather routing service took a solid first step and changed the situation of China's long-term dependence on foreign commercial meteorological navigation (Yu He Shu, Liu You Qi. 1993).

2.3.2 In 1990, the marine weather routing Center of the Central Meteorological Observatory and the China Ocean Shipping Corporation established a joint company to carry out ship to shore experiments on weather routing of the three oceans and achieved success. From 1987 to 1988, the number of navigation ships in China was less than 10 each year. In 1992, the number of navigation ships increased to 126, and in 1995, it increased to 250.

The marine weather routing center of the Central Meteorological Observatory has researched and developed new weather routing technologies, developed the global ship weather routing service system, the global meteorological ship position monitoring system, the global route calculation, tracking navigation and voyage evaluation automation technologies, and established a global maritime satellite communication link, providing services to all sea areas around the world. However, since the beginning of the 21st century, due to institutional reform and other reasons, the size of the original weather routing service business has gradually shrunk, the technical research and development

and software support have to be suspended and not been further developed.

From 2000 to the present, with the implementation of various international observation programs, especially the advancement of satellite remote sensing technology, the international trend of marine weather routing operations has started to move from the ocean to the offshore coast. The international trend in marine weather routing operations is beginning to move from the ocean to the coastal zone. The national strategies of the 18th National Congress and the national strategies such as "One Belt, One Road" have brought new development opportunities for marine weather routing services.

2.3.3 In recent years, under the guidance of the national policy of "One Belt and One Road", in particular, the development and implementation of the national strategy of "21st Century Maritime Silk Road" has put forward an urgent demand for Marine meteorological support services not only in offshore waters, but also in the ocean areas and even around the world. Some meteorological departments in coastal areas of China and some meteorological companies established in universities are basically capable of route planning and meteorological services, such as Unitedmeteo (https://www.meteochina.com/). However, they started late and their overall business scale is not large.

In 2017, the central meteorological station from the perspective of national security, to conduct marine weather routing service, after several years of construction, have modern navigation ability, can undertake marine weather routing services, marine meteorological support production and economy, the important responsibility of the meteorological safeguard national security and other professional services, have large-scale business development and commercial shipping services, the number of ships increased steadily.

On December 11 2020, the China Ocean-going Meteorological Navigation Service Consortium (hereinafter referred to as the Consortium) was formally established. On the same day, the preparatory meeting and the first general meeting of members of the Consortium were held. The meeting deliberated and approved the working rules of China Ocean-going marine weather routing service consortium and the working plan of China Ocean-going marine weather routing service consortium in 2021 (Zhang Jian lei. 2020). The consortium will focus on meteorology and enabling shipping, jointly promote the construction of joint service mechanism, establish and improve service business process, and play a positive role in strengthening joint research and development of Marine meteorological technology in coastal provinces and cities, improving Marine weather routing service capacity, and promoting the integration of meteorology and shipping industry. The Consortium will encourage meteorological departments in coastal provinces and cities to jointly promote Marine meteorological services and improve the efficiency of resource use. After the establishment of the joint consortium, it will combine the development requirements of professional meteorological services, strengthen mechanism construction and exploration, promote the joint construction and sharing of various departments, form a good division of labor and distribution mechanism, strengthen joint research and development of service technology, and jointly establish standards and norms of ocean-going meteorological navigation services (CMA, 2020).

2.4 The common problems for weather routing service

The best route is to make the route reach the best economy and comfort in a sense on the premise of ensuring the safety of ship navigation. However, the proposed weather routing has some problems.

2.4.1 In the process of environmental assessment, the accuracy of the used meteorological and hydrological data is not very high, and the obstacles involved are not comprehensive (Kenta Kurosawa, Yusuke Uchiyama, Taichi Kosako. 2020). The data source is unitary, the accuracy and forecast periods are still under improvement. Except the data from satellite monitoring stations and a few buoy stations，the marine real time meteorological monitoring data is still quite limited. Therefore, radar monitoring data are used in the offshore radar coverage area, and meteorological data from numerical weather prediction models are used to compensate for the offshore radar coverage (Li Jian, Deng Chuang, Zheng Weicai & Wei Chen. 2018). Due to the limitation of time and accuracy of marine environmental forecast, it is still impossible to give an ideal optimal route before setting sail in an ocean going voyage of more than ten days or longer, and there are still 10~12% original routes need to be corrected or modified after sailed.

The climate routes recommended in some navigation books are superior only from the perspective of climate, which is the optimal route under certain climate conditions. However, if analyzed from the actual weather and sea conditions at that time, the climate routes are not necessarily superior, or even very bad. Therefore, some experienced sea captains report that some routes recommended in nautical books are sometimes impossible to implement in practice, because the hydrometeorological conditions are too harsh to achieve safe and economic results by using this route. On the contrary, some of the sea areas considered unsuitable for navigation by the climatic data are at certain times accompanied by favorable weather conditions for navigation, which is the limitation of the climatic route and its inability to meet the needs of modern navigation (Li zhihua, Gao Chao & Wu Jinchao. 2000).

2.4.2 The best optimized route is changeable, needs to be calculated by computers with integrated information. Due to weather variations and port operation uncertainty, the minimum consumption route, the maximum benefit route and the minimum consumption for on time arrival route are difficult to be defined. Weather routing services are designing the optimized route according to port operation schedule and weather forecast. Some weather routing services will monitor the route, update and modify the course and speed according to short and medium term marine environment forecast with high accuracy and ship location navigation, to avoid strong wind and rough sea condition. Due to the limitation of the timeliness and accuracy of marine environmental forecast, it is very difficult to give an ideal optimal route before sailing in long voyage of more than ten days or longer.

As economies in many parts of the world recover from the pandemic, demand for commodities and goods has rebounded rapidly worldwide, leading to congestion at many ports and continuing strains on the global shipping supply chain. On time delivery is very important for a global liner shipping company as delayed cargo carries a high cost by customers and key clients. Nevertheless, the negative effects of miss-connections or delaying a key clients merchandise can be hard to measure against a concrete cost of for example bunker (Berit D. Brouer, Jakob Dirksen, David Pisinger, Christian E.M. Plum, Bo Vaaben. 2013). A common scenario for recovery planned schedule progress is to either increase speed at the expense of significantly increasing fuel consumption or to delay delivering cargoes and decreased the company's punctuality rate. Some shipping companies choose the recovery options by skipping one or two ports, and transfer cargoes in other adjacent convenient ports. While some other liner companies want to maintain the original schedule and speed up to the next port

and ask port arrangement with first priority for berthing on arrival; On the contrary, almost all the companies have the same option intending to speed up to mending the lost schedule and regain customer trust and shipping market reputation, it would exacerbate the port congestion.

The normal routing services just give you the pre routing as required, no designated person monitoring the voyage all the way, sometime the berthing prospect changed but not responded by routing service timely, which caused unnecessary consumption. The best economic speed is setting a constant RPM (Revolutions per Minute). However, due to catch up the original port call plan, ship masters have to speed up with maximum engine output, then slow down for the remaining few days, the oil consumptions from varieties of RPM are much bigger than running with constant RPM, the fuel consumption of a ship is proportional to the cube of the main engine revolution speed, the power output required for propulsion is a function of the speed to the power of three. For this reason, there has emerged a growing interest in the relationship between speed and emission reductions. With increasing fuel costs and more public focus on maritime transport emissions, reducing fuel cost and emissions has become a necessity for shipping lines (Haakon Lindstad, Bjørn E. Asbjørnslett, Egil Jullumstrø. 2013). The additional oil consumption cost and greenhouse gas emission would increase the operational cost for shipping companies, as the Carbon Emission Trading Scheme is slowly being discussed and implemented, which is a market-based approach used to reduce greenhouse gas emissions by providing economic incentives for firms, corporations, and other entities. In this scheme, emissions are freely traded just like any other commercial commodity and are assigned a price determined by supply versus demand (Min Wu, Kevin X. Li, Yi Xiao, Kum Fai Yuen. 2017).

2.4.3 Data retrieval prior to departure and subsequent onboard predictions are occasionally indispensable because ample data retrieval through communications satellites during the voyage may not be feasible (Kenta Kurosawa, et al. 2020), not all ships have been equipped with good internet. In the past, narrowband satellite communication was used at the ship end, with low transmission rate and very high cost. It could only be used for a limited period of time, which did not have the conditions for real time online application. Satellite channel itself has high latency, jitter and packet loss rate, plus the ship satellite communications services generally share bandwidth is used, the other ship end informationization application takes up bandwidth resources (Ji Cheng, et al. 2020), caused the data transformation is not stable and lost critical facts, making the weather information updates could not be achieved successfully or stuck during the process data updating.

Now, the most common way of weather routing is to send the data packages to the ship side application, then the ship crew download these data packages when connecting satellite communication and updates the voyage of weather routing information. Sometimes, due to the signal problem, such as the shore gantries cover the satellite antenna, the quality of the device is not up to the standard, and the device cannot run properly which could not connect to the data terminal (He D. C. 2021), the weather routing information on the ship side terminal can not be updated properly and possible lost some vital information for the total voyage management. Due to frequently change voyage information, too many data packages updated caused ship crew confused and lost some important updates, resulting incorrect weather routing information implemented by ship side.

2.4.4 Ship crew, company and weather routing service company are not well

cooperated, as the accuracy of weather forecast downgrade sometimes, also include some reasons describe above, ship master will lost confidence for the weather routing service, does not fully comply with weather routing service proposed, the staffs in different departments in shipping company no communication with each other, only care about the responsible part who in charge of and cannot achieve the optimized route and efficiency as weather routing service planned.

Quantifying the significance of uncertainty in the weather routing process allows the credibility of the predictions to be quantified, managing the expectations of the operators with regards to the accuracy of the supplied route (Thomas Dickson, Helen Farr, David Sear, James I R Blake. 2019). Most of the original weather routing would be changed due to weather data forecast limitations, the accuracy of port operation information, error in numerical calculation in the solution of the optimization algorithm, sometimes due to satellite signal poor could not be logged in by ship side terminal and communication failed, making real time weather routing difficult (Qiao qianfang. 2013). The captain lost patient for the “unreliable” weather routing and chose the route he trusted, whatever, captain is the person to make the final judgment to navigate with which route. Many captains completely follow their own ideas, do not communicate and contact with weather routing services effectively. This situation causes charterers and other charterers to pay extra attention to the fuel consumption and speed of the ship. The charterers will make huge claims against the ship owner and the master for speed and fuel consumption based on the final weather routing service report provided by the weather routing service company at the end of the voyage, diluting the ship owner's profit and wasting a lot of the ship owner's time to argue and arbitrate,

which seriously affects the economic and social benefits of the ship and the ship owners (Liu, G. 2012).

2.4.5 Due to the maritime regulations continue updating and the limited conditions on board, keeping track of all regulations, identifying correlations and ensuring that operations are adjusted accordingly are a time-consuming, laborious and error-prone tasks. Even the most experienced crew members can misunderstand baselines or forget to consider some local rules such as day light saving time and marine protected areas along the route. These common mistakes can lead to illegal discharges or accidental incursions into restricted areas, which can lead to huge fines and disastrous environmental impacts. Sometimes, ship crew forget to update ship's time to consistent with local time, caused different ETA report and incorrect entering seasonal load line area, what's more, the ship would be detained and serious investigations due to deficiencies about poor regulations compliance and ship safety management, caused economic lost and company reputation damaged.

CHAPTER 3 WEATHER ROUTING REFINED MANAGEMENT SECTOR

Weather routing for refined management of the passage is a general purpose integrated service for shipping. According to the technical parameters of a particular ship and the loading condition of the voyage, the sea keeping indexes of the ship in different wind and wave flow fields, such as large angle swing, synchronous rolling, deck wetness, propeller racing, etc., are evaluated. By continuously collecting the speed, slip, fuel consumption and other sailing performance of a specific ship in different loading states, different wind and wave flow fields, integrating and revising with marine meteorological data to build a model of speed loss and fuel consumption characteristics of a specific ship.

Then, based on the above characteristic model, combined with high-precision marine meteorological model forecast or integrated forecast, through computer simulation and optimization calculation, the voyage docking plan and route design scheme meeting the requirements of different missions are obtained. Specifically, it includes the economical route with the lowest voyage cost, the most profitable route, the fastest route to the destination, the punctual route to meet the shipping demand, and the comfortable route to meet the passenger and cargo demand.

The refined management system integrates the numerical forecasts of all elements of marine meteorology issued by international authorities, including wind, waves, currents, pressure, temperature, visibility, precipitation, humidity, water temperature, cloud cover and global tropical cyclones, tides in major ports, etc.; provides real time AIS ship positions, historical track records, voyage marine meteorological data of global ships; and integrates electronic nautical charts, restricted discharge zones and Particularly Sensitive Sea Area (PPSA), Load line zones, Search and rescue areas, ports and anchorages, and other harbor and navigation data.

3.1 Technical parameters of a particular ship and the loading condition

The parameters of a particular ship and loading condition are the basic data and vital factors for the refined management weather routing. The different loading conditions in several voyages for the same ship are also presenting different technical parameters. As ship energy efficiency management is drawing more and more attention by no matter maritime organization or shipping company, trim optimized is also considered in weather routing refined management of passage. Because of the non-linear relationship between ship speed and fuel consumption, a ship that goes slower will burn much less fuel and produce much fewer emissions than the same ship going faster. Hence speed reduction is a tool that could reduce both fuel costs and emissions at the same time, and may potentially constitute a win-win proposition (M. Wen, D. Pacino, C.A. Kontovas, H.N. Psaraftis. 2017).

3.1.1 Under the same weather condition, different ship will show different performance; the same ship, it will also different performance under different loading condition. The parameters of a particular ship and loading condition are the basic data and vital factors for the weather routing of refined management. It includes not only initial stability GM, draft, freeboard and deck cargo as most weather routing requested (Qiao qianfang. 2013), but also cargo details, stability summary of the ship, age of the ship, hull strength, reliability of main and auxiliary engines, water tightness, navigation instruments, etc. the refined management will simulate ship status and expected encountered weather conditions on the refined management platform to verify if the planned weather route suitable for the coming voyage.

3.1.2 The ship sailed under the constant power of the main engine with the interference of current、wind and waves in the process of the ship's sailing. As

the cargo different, the route would be changed. For example, bulk carriers laden with some grains must choose low humidity route to help grains good ventilation and avoid mass of cargo damaged. As the ship loading condition different, the draft and trim will be different, the resistance on the ship will be vary also. These characteristics for a particular ship and selected route are influenced by weather conditions in the navigation area. Therefore, the problem of optimal weather routing has an essential practical significance (Margarita V. Sotnikova, Evgeny I. Veremey. 2018).Trim optimization can be regarded as one of the easiest and cheapest methods among many fuel saving measures recommended by IMO as it does not require any hull shape modification or engine upgrade (IMO, 2016a).

Investigations from various parties have found that by sailing under optimal trim conditions, vessels can save by 2–5% on fuel costs, with a corresponding reduction in greenhouse gas emissions (ABS, 2014; IMO, 2016b). Many different companies such as classification societies, ship operators and vessel monitoring system providers offer trim optimization solutions (Emil Shivachev, Mahdi Khorasanchi, Sandy Day, Osman Turan. 2020). How to achieve the best draft difference for fore and aft draft when ship fully loaded, how to minimize the frictions from water and wind when ship with ballast conditions, how to adjust ballast water to reduce wind area when container ships fully loaded with light cargo or empty containers, it must be calculated by computers with numbers of technical parameters. Such parameters will be considered during the refined weather routing planning.

3.2 High-precision marine meteorological model forecast or integrated forecast

The forecasters feel qualitative forecast errors when apply numerical forecast

products, in the field of domestic or foreign numerical models in terms of timing, movement, strength, etc., which brings some difficulties to weather forecasting. This poses certain difficulties for weather forecasting. Conducting numerical forecast product inspection and error analysis is the best way to use numerical forecast products and improve weather forecast accuracy (Yang Chang Xian, Zheng Yan, Lin Jian Xing, Li Fan. 2008).

Weather forecast data model is an essential model in the process of ship weather routing optimization. The reliability and availability of weather forecast data model determine the feasibility of the ship route optimization result (Wei Du, et al. 2022). There are a lot of meteorological forecasting models at present, the most popular models are GFS and ECWMF (EC) mode. GFS means Global Forecast System. ECMWF stands for European Centre for Medium-Range Weather Forecasts and is the name of the organization and model.

3.2.1 GFS is a global model run by the US government under the leadership of the National Oceanic and Atmospheric Administration (NOAA) and its affiliated agencies. GFS global models generate forecast outputs for the entire globe, typically extending one to two weeks into the future. Because these models cover a wider area and have a longer time span, they typically operate at lower resolution, both spatially (fewer predicted points per given region) and temporally (fewer points in time to get a prediction) (Jack Sillin. 2019). EC models have higher resolution, but only cover parts of the globe and provide forecasts of only a few days. The advantage of these models is that their higher resolution allows them to see features, particularly thunderstorms, which are missed by global models.

3.2.2 The ECMWF ensemble (mean) forecast is more stable than the deterministic forecast for the medium term situation, and more accurate for the weather

system phase forecast, but the intensity forecast is weak, and its standard deviation field can qualitatively evaluate the accuracy of the situation field forecast (Li Qing, Wang Liqun, Ma Weimin & Jiang Min. 2014). ECMWF uses High Resolution Forecasts (HRES), Ensemble Forecasts (ENS) and EC Ocean Wave Model (ECWAM) to describe future global atmospheric and oceanic data respectively. ECMWF offers multiple ways to download weather forecasts. The weather forecast data file with horizontal resolution of 0.25◦ × 0.25◦ and in NetCDF format are used in weather routing optimization, and it is updated every 3 h (Wei Du, et al. 2022). From 25 January 2022, a wide range of ECMWF's forecast data across the globe is openly available. This moves towards 'open data' comes after a large range of forecast charts were earlier made available to anybody interested in them. The data that are becoming available are based on a range of high resolution forecasts (HRES – 9 km horizontal resolution) and ensemble forecasts (ENS – 18 km horizontal resolution) (ECMWF. 2020). See table 1

Ensemble means and standard deviations			
Steps for times 00z &12z: 0 to 144 by 3, 150 to 360 by 6.			
Short Name	Long Name	ID	Level
gh	Geo potential height	156	300, 500, 1000
t	Temperature	130	250, 500, 850
ws	Wind speed	10	250, 850
msl	Mean sea level pressure	151	Single

Table 1 – Ensemble means and standard deviations

Weather routing for the refined management of passage is using the high-precision marine meteorological model forecast or ensemble forecast data, to increase the accuracy of weather forecast. The system will choose data to compare those information from different models and give the best high precision for weather routing service. Meanwhile, the user also can select the mode between EC and GFS as needed. Through the different forecast mode and data, it would increase the accuracy of mid to long term weather forecast, to help weather routing operators achieve refined management of the passage.

3.3 Designated Marine Satellite Data Transformation System

This system is a comprehensive application system which integrates weather routing information and electronic charts and display system (ECDIS).

3.3.1 With the development of Internet technology and satellite communication technology, accessing the Internet at anytime and anywhere has become an important part of people's daily work and life, infiltrating into all aspects. Broadband maritime satellite communication system is an important achievement of modern network technology and maritime satellite communication technology development (Gao Y. 2020). With the help of broadband maritime satellite communication system, the ship's navigation information can be transmitted in time, such as navigation data, weather forecast and other information, so as to take timely measures to avoid risks. At the same time, the crew can exchange wechat and short messages with their families through the wireless network on board the ship, making maritime satellite communication more modern and humanized.

International Maritime Satellite Organization (Inmarsat) has launched Inmarsat-6 satellites on 22 Dec 2021, which are the most technologically

advanced and largest communications satellites (Inmarsat. 2022). Inmarsat 6 can transfer much bigger capacity data on the same bandwidth, the new generation broadband service delivers information on a second by second basis, which can keep shipping routes always on connectivity to receive data exchange in real time and attain global cover.

3.3.2 Weather routing for the refined management of passage is using a sole internet terminal connection with the best satellite communication Inmarsat Global Xpress (GX). The GX system is the world's first and only globally available high-speed broadband network, owned and managed by a single operator. GX operates in Ka-band and can be seamlessly integrated with L-band networks to provide strong and reliable connections (Xue jing-jing, Zhang Xue-ling & Wu Xiao-song. 2021).

The weather routing for the refined management terminal on board will connect with GX all the time, keeping the data exchanged in real time. The satellite communication for refined management is through a special band and separates with ship other satellite communications, such as emails and Internet of things (IoT). The sole connecting with shore data exchange can keep the system stable and update information in real time. This can avoid the information update failure due to broadband network congestion if used the same broadband network with the other ship normal operation communications. The system update logs can be checked if any error occurred preventing the system updating from weather routing service. For safety reason, it is also can be updated by email data packages through Universal Serial Bus (USB), download the files from email computers and update the weather routing terminal system as normal weather routing operated now.

The weather routing which decided by Master will be displayed on the special

weather routing terminal same as normal ship ECDIS operation. Once the weather routing service for the refined management of voyage started, the weather routing service company, the ship and the ship owner or charterer who requested the weather routing service can share the same viewing about ship routes, weather information and voyage information on the weather routing terminal and mobile application. The master of the ship can check routes and meteorological information in the cabin by mobile tablet or phone which connected weather routing system; the persons from the shore who in charge of the ship, no matter from owners or from charters can check the ship through mobile phones application at any time and any place, so that it would not be missed if any change or alert raised from the refined management.

3.4 System function and realization principle

Based on the above advantages of refined management, the system function is obviously achieved.

3.4.1 Under the refined management, the ship crew would not be disturbed by annoying update information. The sole internet connection can download the data automatically and update route information autonomously. The Master just need to verify if the running route is the one he or she chose, and compare the parameters which supplied by weather routing service if correct; meanwhile the master can give feedback to the weather routing service company that if the forecast weather data are obviously difference with service company predicted. It is the double check of weather routing accuracy.

3.4.2 Under the refined management, the ship operation staffs would be harmonized on this Unitemeteo platform with sharing information. First, the efficiency of information and communication between staffs will be improved, the

phenomenon of information island and information asymmetry would be eliminated, and the interest game between the company's management and all departments and member units can be effectively solved. All staffs can share the information from the platform. Second, internal information and communication methods can be improved, and the applicable information transmission system can be adjusted reasonably in time with the change of the shipping business environment. The crew department can arrange crew change according to the latest berthing prospects; the repair department can order shore service to be on board repairing once ship arrived in the port.

3.4.3 Weather routing for refined management of passage not only can provide weather routing service as traditional company, but also can manage some operations of shipping company. The precise boundary of the environmental protection area, load line area and some other important navigation information near and along the route can be clearly displayed on the ECDIS compatible digital interface of the electronic chart (Figure 3); it also can reduce the risk of ship delay and construction damage caused by bad weather; The same operation modules can be viewed and accessed by all relevant personnel on shore and ship, providing coordination between ship and shore and reducing uncertainty. The refined management uses visual & audio notification systems to make it easy understood what should do and what should not do at a given location and in a particular area, which waypoint should speed up and which waypoint should send notice of ETA and notice of readiness (NOR) to relevant department; Dedicated teams continuously monitor and update the database of regional and national regulations; weather viewing, assessment of other risks and operational information are displayed at the same time to facilitate the coordinated consideration of all parameters.

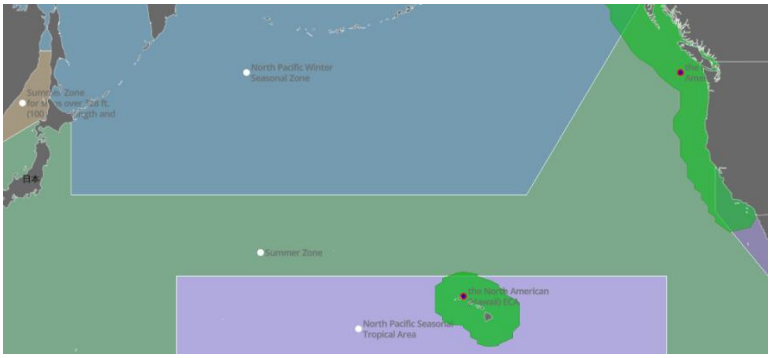


Figure 3 – Refined management platform interface

Also, as the refined management improved weather routing reliability, the Master will be more confidence on this, any change by master personal opinion will be shown on the weather routing terminal and seen by relevant parties, then the alternative route evaluation will be calculated soon for ship and shipping company, the feasibility report will be made for ship and other relevant parties to help the master and company to decide the possibility of alternative route, which plays an significant role on reducing the unnecessary operational cost and additional fuel consumption.

CHAPTER 4 THE CASE OF REFINNED MANAGEMENT OF PASSAGE

4.1 Refined management for the optimized route

One serviced vessel was preparing voyage plan from Port of Point Lisas via the Cape of Good Hope to Vietnam, and the captain intended to sail close to the shore in Brazil and rhumb line across the South Atlantic.

After checking the planned route and hydrographic conditions, it was found that the ship would encounter strong current 3 knots or more from dead ahead direction. If the ship sailed close to the shore, the strong adverse currents would seriously affect the speed performance on the one hand and increase the risk of safe navigation on the other hand, due to a lot of small fishing boats working close to the shore and very difficult to be found by radar or other ways of looking out (Figure 4).

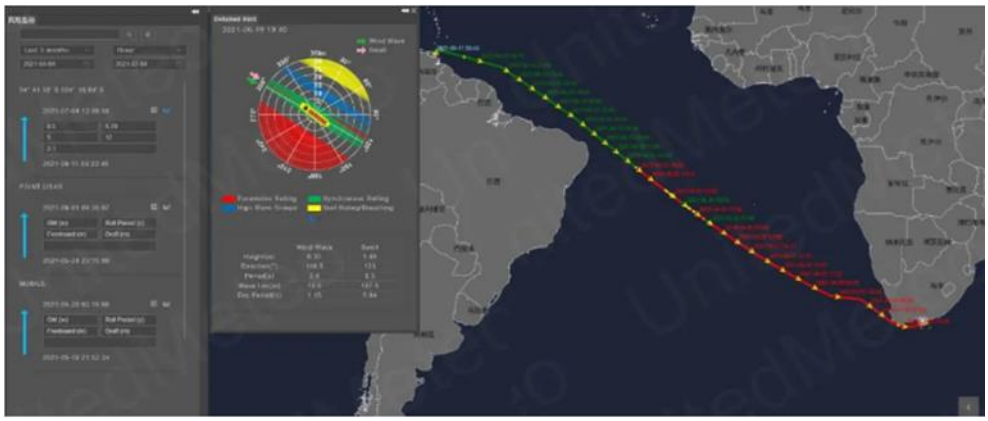


Figure 4 – RISK ASSESSMENT

Through the refined management platform, after analyzing the original route plan from captain, it is very obvious to see that the Guyana and South Equatorial Current would seriously affect the speed performance of the vessel (Figure 5), and the distance would be shorter if sailed by Great Circle mode compared to rhumb line mode across the South Atlantic.

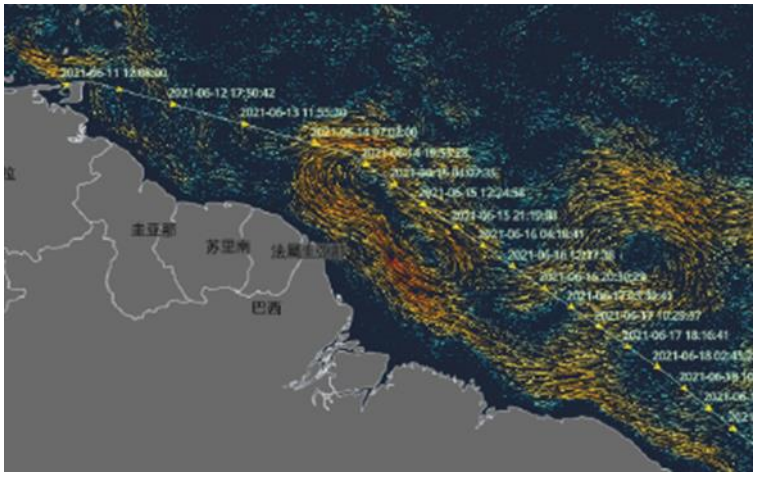


Figure 5 – Route evaluation by integrated calculation

Then the captain followed the suggestion and changed route as refined management optimized, which reduced the impact of the Guyana and South Equatorial currents, and help the ship to maintain good speed performance. After the ship sailed, according to the dynamic data collected from refined management platform and noon report from ship side, the oil consumption has been improved tremendously (Figure 6). Finally, the ship arrived destination port with low consumption and the total operation cost reduced a lot, the charterer expressed great gratitude for the refined management.

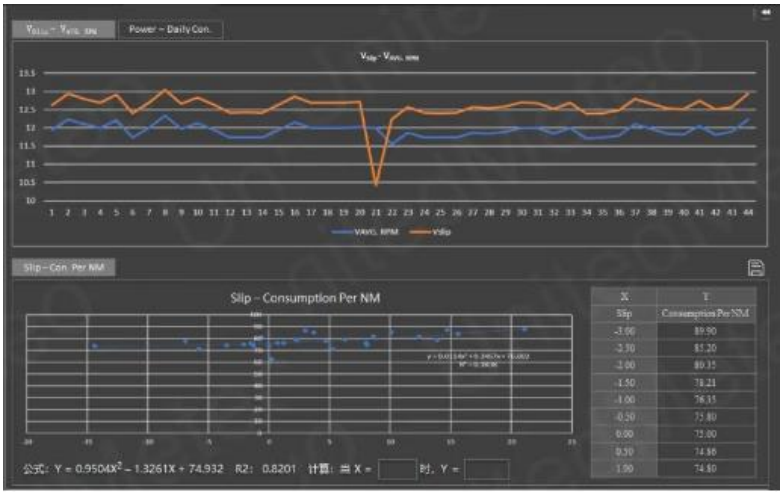


Figure 6- Oil consumption analysis

4.2 Refined management for successfully avoiding double typhoon

In early September 2020, Typhoon No. 9 (MAYSAK) and Typhoon No. 10 (HAISHEN) were generated off the coast of China in quick succession. Maysak was generated east of Luzon Island in the Philippines and first circled in place before moving towards the southeastern part of the East China Sea. Maysak was upgraded to a super typhoon by the Central Weather Bureau on September 1, and its maximum wind strength was still Beaufort force 14 at landfall on September 3. The typhoon Haishen was generated south of Japan and continued to move northwards, gradually gaining strength. It was upgraded to a super typhoon by the Central Weather Bureau on 4 September, and its maximum wind strength was still Beaufort force 13 at landfall on 7 September.

One service vessel was on a voyage "Qingdao, China - Malacca Strait - West Coast of Africa" when it would encounter the double typhoons "Maysak" and "Haishen" shortly after leaving port. The refined management of weather routing service team collected the ship voyage information and technical parameters, calculated the different weather routing with different typhoon path and intensity, compared some other famous national typhoon forecast information, simulated ship’s safe route for maximum reducing the impact of bad weather and financial loss, then advised ship master to sail as plan along the designed route and adjusted speed as per waypoint requested.

The refined management platform analyzed different weather forecast prediction mode, accurately forecasted the path and intensity of the typhoon, which helped the vessel to avoid the double typhoons effectively. The refined management of weather routing service team fully considered the impact of the double typhoons on the safe navigation of the vessels, and repeatedly balanced the options of adjusting the route,

adjusted speed for accelerating and slowing down, guiding the vessel to stay away from the Beaufort force 10 wind circle of Maysak, and sailing away from Maysak before the arrival of Haishen (Figure 7). The ship arrived next port as planned and saved huge economic loss.

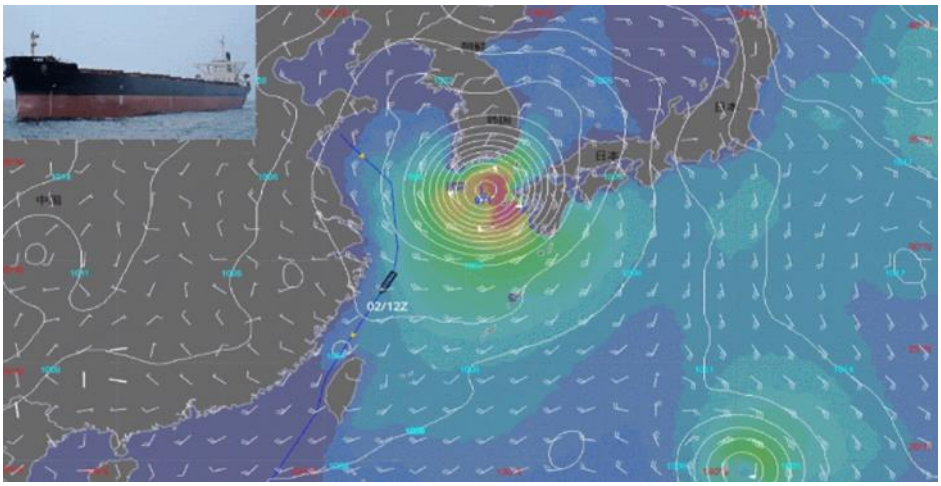


Figure 7 – Avoiding double typhoon

CHAPTER 5 CONCLUSION

Maritime transportation is one of the most important modes of transportation in global trade nowadays. Sea transportation plays a huge role in promoting the development of world economy and international trade. As shipping is turning page towards a greener, more sustainable future, it is crucial to leverage key insights from past routes in order to identify approaches that minimize both the financial cost of operations and their greenhouse gas footprint (Christos Gkerekos, Iraklis Lazakis. 2020). The application of weather routing refined management can not only reduce the cost of navigation, but also improve the safety of ships in ocean going navigation.

Under the concept of smart navigation, the weather routing service product is actually the unit and core of its value generation. On the basis of cross-border integration, the core of product design is to take the product deeper into the customer's business processes, rather than simply providing weather data, and to have different solutions for who and how the data is used in each application scenario. Through product design, weather routing services should cover all service chains, realize the whole process, such as forecasting and warning - intelligent dispatching and control, and establish decision models for all factors, including meteorological factors and operation cost. The design of weather routing refined management begins with a clear definition of what the product is and what its core elements include. There is data, there is an object, there is an application scenario, and there is a "sense-feedback-act" logic chain. Data is not a product per se, but the data is the bottom layer of the product, and the refined management product is based on the data, which is given new connotations and values through a specific presentation and application logic.

Weather routing for the refined management of passage is a data product for shipping

company. The refined management can effectively guarantee the safety of ships in the ocean, reduce ship carbon emissions, improve economic benefits, optimize traffic efficiency and improve the competitiveness of shipping industry by giving full play to the advantages of new navigation technology and improving the intelligent level of ship route alignment. Based on weather data and ship operation parameters, the optimized route is designed by intelligent algorithm, which can achieve the maximum benefit profit and low greenhouse gas emission.

REFERENCE

ABS. (2014). Ship Energy Efficiency Measures Advisory.

Andrew Rawson, Mario Brito, Zoheir Sabeur, Long Tran-Thanh. A machine learning approach for monitoring ship safety in extreme weather events, Safety Science, Volume 141, 2021, 105336, ISSN 0925-7535, https://doi.org/10.1016/j.ssci.2021.105336.

Berit D. Brouer, Jakob Dirksen, David Pisinger, Christian E.M. Plum, Bo Vaaben, The Vessel Schedule Recovery Problem (VSRP) – A MIP model for handling disruptions in liner shipping, European Journal of Operational Research, Volume 224, Issue 2, 2013, Pages 362-374, ISSN 0377-2217, https://doi.org/10.1016/j.ejor.2012.08.016.

Chen, H. (2002). Weather routing: a new approach. Ocean System Technical papers, (https://ww1.jeppesen.com/documents/marine/commercial/Safety_at_sea.pdf)

China Meteorological Administration (CMA), China's ocean-going Weather routing Service Consortium was formally established, 2020.

Chong Pan. Zhanshuo Zhang. Weikang Sun. Jun Shi. Hongbo Wang. (2021). Development of ship weather routing system with higher accuracy using SPSS and an improved genetic algorithm. Journal of Marine Science and Technology, 26(4), 1324-1339. https://doi.org/10.1007/s00773-021-00800-6.

Christos Gkerekos, Iraklis Lazakis. A novel, data-driven heuristic framework for vessel weather routing, Ocean Engineering, Volume 197, 2020, 106887, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2019.106887.

DNVGL. (2015). Energy management study 2015 (Høvik, Norway). www.dnvgl.com.

Doelle M, Chircop A. Decarbonizing international shipping: An appraisal of the IMO's Initial Strategy. RECIEL. 2019; 28:268–277. https ://doi.org/10.1111/reel.12302

DTN. (2018). Why DTN. https://www.dtn.com/weather/shipping/

ECMWF. (2022). ECMWF makes wide range of data openly available. https://www.ecmwf.com/en/about/media-centre/news/2022/ecmwf-makes-wide-range-data-openly-available.

Emil Shivachev, Mahdi Khorasanchi, Sandy Day, Osman Turan, Impact of trim on added resistance of KRISO container ship (KCS) in head waves: An experimental and numerical study, Ocean Engineering, Volume 211, 2020, 107594, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2020.107594.

Gao Y. (2020). Basic characteristics and application of broadband maritime satellite communication system. Digital Communication World (07), 190-191.

Guang-wen Ma. Transportation Dictionary: Shanghai Jiao Tong University Press, 2005.01.

Haakon Lindstad, Bjørn E. Asbjørnslett, Egil Jullumstrø, Assessment of profit, cost and emissions by varying speed as a function of sea conditions and freight market, Transportation Research Part D: Transport and Environment, Volume 19, 2013, Pages 5-12, ISSN 1361-9209, https://doi.org/10.1016/j.trd.2012.11.001.

Hanssen, G. L. (1960). Optimum ship routing. Journal of Navigation, 13(3), 253-272.

He, D. C. (2021). Exploring common interference in satellite communication and countermeasures. Yangtze River Information and Communication (08), 116-118. Hydrographic Office, Washington.

Helong Wang, Wengang Mao, Leif Eriksson. A Three-Dimensional Dijkstra's algorithm for

multi-objective ship voyage optimization, Ocean Engineering, Volume 186, 2019, 106131, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2019.106131.

IMO. (2009). Report of the Marine Environment Protection Committee on its Fifty-ninth Session. MEPC 59/24.

IMO. (2016). MEPC. 282(70) 2016 Guidelines for the development of a ship energy efficiency management plan (SEEMP).

IMO. (2016a). Guidelines for the development OF a SHIP energy efficiency management plan (SEEMP). MEPC 282 (70). https://doi.org/10.5151/cidi2017-060, 9, 10.

IMO. (2016b). EE Appraisal Tool for IMO Project Report 45.

IMO. (2018).Initial IMO strategy on reduction of GHG emissions from ships. Annex11. Resolution MEPC.304 (72).Adopted 13th April.

IMO. (2021a). MEPC. 334(76) 2021 Guidelines on survey and certification of the attained energy efficiency existing ship index (EEXI).

IMO. 2021b. Marine Environment. https://www.imo.org/en/OurWork/Environment/Pages/Default.aspx

Inmarsat. (2022). Watch I-6 F1 launch from JAXA Tanegashima Space Center on 22 December 2021 at 15:32 GMT. https://www.inmarsat.com/en/about/technology/satellites/i-6-f1.html

Jack Sillin. (2019). Model Mania: What Are the ECMWF and GFS Models, and Why Are They Different? https://blog.weather.us/model-mania-what-are-the-ecmwf-and-gfs-models-and-why-are-they-different/#respond

James J. Corbett, Haifeng Wang, James J. Winebrake, The effectiveness and costs of speed reductions on emissions from international shipping, Transportation Research Part D: Transport and Environment, Volume 14, Issue 8, 2009, Pages 593-598, ISSN 1361-9209, https://doi.org/10.1016/j.trd.2009.08.005.

James, R.W., 1957. Application of wave forecast to marine navigation. US Navy Hydrographic Office, Washington.

Ji Cheng, Wang Chenyong, Hua Shaojie & Xu Wei. (2020). A Ship Satellite Communication service System based on VSAT. Journal of Shanghai Ship and Shipping Research Institute (03), 6-11+17.

Kenta Kurosawa, Yusuke Uchiyama, Taichi Kosako. (2020). Development of a numerical marine weather routing system for coastal and marginal seas using regional oceanic and atmospheric simulations, Ocean Engineering, Volume 195, 2020,106706, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2019.106706.

Leng Jiaohang. (2010). Severe weather sea conditions and safety of ship navigation. (Eds.) Proceedings of Meteorological Marine Environment and Safety of Ship Navigation (pp. 147-150).

Li Jian, Deng Chuang, Zheng Weicai & Wei Chen. (2018).Research on Weather Routing Based on the Mobile Internet. Meteorological and Environmental Research (04), 55-60. doi:10.19547/j.issn2152-3940.2018.04.014.

Li Qing, Wang Liqun, Ma Weimin & Jiang Min. (2014). Comparative analysis of extra tropical cyclone prediction performance using ECMWF and GFS models. Marine Forecasting (01), 22-28.

Li zhihua, Gao Chao & Wu Jinchao. (2000). Shipping climate routes and meteorological routes. Marine Navigation Committee of the Chinese Society of Navigation.(eds.)

Proceedings of The Marine Navigation Committee of the Chinese Society of Navigation on Weather, Ocean and Maritime Safety (pp.130-132).

Liu, G. (2012). Modern ship captains and meteorological navigation. China Water Transport (second half) (08), 5-6.

Lokukaluge P. Perera & C. Guedes Soares. 2016. Weather routing and safe ship handling in the future of shipping. Ocean Engineering, doi:10.1016/j.oceaneng.2016.09.007.Meteorol. 11, 429–443.

M. Wen, D. Pacino, C.A. Kontovas, H.N. Psaraftis. A multiple ship routing and speed optimization problem under time, cost and environmental objectives, Transportation Research Part D: Transport and Environment, Volume 52, Part A, 2017, Pages 303-321, ISSN 1361-9209, https://doi.org/10.1016/j.trd.2017.03.009.

Margarita V. Sotnikova, Evgeny I. Veremey. Algorithms for Motion Optimization on a Given Trajectory Taking into Account Weather Forecast and Constraints, IFAC-Papers on Line, Volume 51, Issue 32, 2018, Pages 389-394, ISSN 2405-8963, https://doi.org/10.1016/j.ifacol.2018.11.415.

Min Wu, Kevin X. Li, Yi Xiao, Kum Fai Yuen. Carbon Emission Trading Scheme in the shipping sector: Drivers, challenges, and impacts, Marine Policy, Volume 138, 2022, 104989, ISSN 0308-597X, https://doi.org/10.1016/j.marpol.2022.104989.

Qiao qianfang. 2013. Analysis and evaluation of Ship Meteorological Navigation. Editorial Department of Zheng He Studies (EDS.) Zheng He Studies 2013 (3) (pp.49-51).

Roberto Vettor & C. Guedes Soares. 2016. Development of a ship weather routing system. Ocean Engineering (), doi:10.1016/j.oceaneng.2016.06.035.

Rui Feng, Chen Shen, Liangxiong Huang, Xuan Tang, Does trade in services improve carbon efficiency? —Analysis based on international panel data, Technological Forecasting and

Social Change, Volume 174, 2022, 121298, ISSN 0040-1625, https://doi.org/10.1016/j.techfore.2021.121298.Session. MEPC 59/24.

Silvia Pennino, Salvatore Gaglione, Anna Innac, Vincenzo Piscopo and Antonio Scamardella. 2020. Development of a New Ship Adaptive Weather Routing Model Based on Sea keeping Analysis and Optimization. Journal of Marine Science and Engineering, 8(4). https://doi.org/10.3390/jmse8040270

Simonsen, Martin & Larsson, Erik & Mao, Wengang & Ringsberg, Jonas. (2015). State-of-the-Art within Ship Weather Routing. 10.1115/OMAE2015-41939.

StormGeo, 2020. Voyage Planning and Route Optimization. https://www.stormgeo.com/solutions/ shipping/on-board-services/. Accessed 12 March 2020

Taskar, B., & Andersen, P. (2020). Benefit of speed reduction for ships in different weather conditions. Transportation Research Part D: Transport and Environment, 85. https://doi.org/10.1016/j.trd.2020.102337

Thomas Dickson, Helen Farr, David Sear, James I R Blake, Uncertainty in marine weather routing, Applied Ocean Research, Volume 88, 2019, Pages 138-146, ISSN 0141-1187, https://doi.org/10.1016/j.apor.2019.04.008.

Varelas, T., Archontaki, S., Dimotikalis, J., Turan, O., Lazakis, I., Varelas, O., 2013. Optimizing Ship Routing to Maximize Fleet Revenue at Danaos. Interfaces 43 (No.1), 1–11.

Wang Hui, Bai Chunjiang. Meteorological Navigation of Ships [M]. Dalian: Dalian Maritime University Press, 2018.

Wang, H., 2018. Voyage Optimization Algorithms for Ship Safety and Energy-Efficiency. Licentiate Thesis. Chalmers University of Technology, Gothenburg, Sweden.

Weatherize the Future. 2018. Meteo Group, Europe's largest weather company, has been strategically acquired. https://mp.weixin.qq.com/s?__biz=MzI2ODYwOTQzNw==&mid=2247484083&idx=1&sn=1c42158ceab83be19861b279a1f3e0ed&chksm=eaedb041dd9a39578dbb0e9a3cb53ca1c83fbab6c25850fe2c7c44967b6994404dd6cfae9d83&scene=21#wechat_redirect

Wei Du, Yanjun Li, Guolei Zhang, Chunhui Wang, Baitong Zhu, Jipan Qiao, Ship weather routing optimization based on improved fractional order particle swarm optimization, Ocean Engineering, Volume 248, 2022, 110680, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2022.110680.

WNI. 2021. Corporate outline. https://global.weathernews.com/corporate-outline/

Xue jing-jing, Zhang Xue-ling & Wu Xiao-song. (2021). Development of a new maritime satellite communication system. Radio of China (05), 86-89.

Xue-feng Yang. (2018). E - autonomous meteorological navigation environment of shipping routes design method (a master's degree thesis, Dalian Maritime University). https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201801&filename=1018044038.nh

Yang Chang Xian, Zheng Yan, Lin Jian Xing, Li Fan. 2008. Inspection and evaluation of numerical forecast products. Meteorological Research and Applications (02), 32-37.

Yu He Shu, Liu You Qi. 1993. Global Marine meteorological navigation service technology. Meteorological Science and Technology (02), 6-9.doi:10.19517/J.1671-6345.1993.02.002.

Yu He Shu, Xu Xiao Feng, Liu You Qi. 1995. Technical principles and benefits of modern

meteorological navigation. Meteorological Monthly (04).

Zhang Jian lei. 2020. China's ocean-going Meteorological Navigation Service Consortium was formally established. China Meteorological News /2020 / Dec.14 / edition 001

Zhang Xiaochuan, Cui Jianhui & Rong Lei. (2014). Design and selection of optimal meteorological Route. Tianjin Hanghai (01), 4-5.

Zhang zenghai, Liu Tao, Cao Yuenan, Yang Zhenglong & Guo Yiying. 2020. Business overview and development status of Marine meteorological navigation. Journal of Marine meteorological (03), 11-16. doi:10.19513/j.cnki.issn2096-3599.2020.03.002.

Zhang, G., Wang, H., Zhao, W., Guan, Z., & Li, P. (2021). Application of Improved Multi-Objective Ant Colony Optimization Algorithm in Ship Weather Routing. Journal of Ocean University of China, 20(1), 45-55. https://doi.org/10.1007/s11802-021-4436-6

Zhang Yongning. Marine Meteorology and Oceanography [M]. Dalian Maritime University Press, 2008.

Zoppoli, R., 1972. Minimum-time routing as an N-stage decision process. J. Appl. Meteorol. 11, 429–443.