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Simulation for evaluating New Polar Routes and their Strategic Impact on Port Networks and Shipping Lines

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Abstract
Climate change is modifying both human priorities and perspectives and the resulting global warming is changing many aspects, including the North Pole and the Polar Cap, introducing future possibilities concerning shipping over the Eurasian Continent. Obviously, this could result in a major change for the entire world maritime trade impacting the routes connecting Asia and Europe and even Americas. It is claimed that the new possible routes could become convenient for commercial trade, influencing the World Economy, causing development in some regions and crisis in others. The question is if these routes will be commercial and when, as well as if so, what is going to be requirements to be able to use them as well as the impact of this phenomenon on the global scenario and specifically on the Mediterranean. From this point of view, this research developed models to evaluate these changes by adopting an innovative approach based on Strategic Engineering that combines Models, Data Analytics and AI in order to understand Complex Systems and quantify their performance in terms of ship requirements, feasibility, times, costs etc.

Keywords: Strategic Engineering, Climate Change, North Shipping Route, Modeling, Simulation

1. Introduction

The climate change is claimed to be active in melting of polar caps and there are evidence of these phenomena; so it is evident that this fact enables potentially New Polar Routes (NPR) providing an alternative to classical shipping flows moving from Far East to Europe through Suez Channel and Gibraltar, but to use these NPR, the ships require specific characteristics and engineering design as well as to sail over very challenging climate conditions and sea environment despite presence of the pack.

Indeed, there are many critical aspect to be addressed to be able to sail in that waters also in the hypothesis of ice pack melting such as small and micro ice pieces within water damaging the propellers and hulls, ice building over the ship creating instability, electromagnetic interferences with communications and satellite navigation problems, no daylights for months, impressive storms, no recovery ports in surroundings. In addition, the current geopolitical situation, even before the Ukraine crisis, highlighted the strong interest of Russia to control the polar areas, to impose fees (e.g. convoy escort) that suggest additional potential challenges. Therefore, this research has been carried out to estimate the evolution of these new possible routes and understand the nature of this shipping activity considering its feasibility with special attention to ship costs, reliability, sustainable cruise speed, safety issues, storm risks and impacts, maintenance due to ice presence in water. In facts, the sailing season duration is directly affected by many variables and, in particular, it is related to the ice pack presence and sea conditions on the Arctic Ocean and Barents Sea at North of Russia, between Bering Strait and Fram Strait. Our team analyzed the existing scientific literature and had also the opportunity to discuss with experts of Italian Navy Hydrographic Institute that conducts explorations in Arctic Ocean, even in Winter, commanding and operating the research NATO vessel; in this way there has been examined fundamental reports and data to extract the information needed to build a model in order to elaborate data from the real world (e.g. maritime trade, ships, ports, weather conditions, ice melting and distribution, piracy attacks to cargo ships and geopolitical situation) using Modeling, Simulation, Monte Carlo Techniques, Data Analytics and Machine Learning. The final model created includes stochastic variables and hypotheses and it simulates the current and alternative future scenarios over different aspects by considering the various factors that affect the NPR sustainability. The evaluation of these new routes and their impacts on world maritime trade is based on virtual model analysis reproducing the Strategic Engineering approach that is based on combining M&S, AI and Data Analytics to support Scenario Assessment and Decision Making (XXX). These models allow us to evaluate the time when climate change could make feasible to sail on NPR and the related progress of the phenomena on the routes; this research estimates also competitiveness and risks of the new routes; as well as the requirements for ships, the effective traveling times and costs. It is even fundamental to estimate risks over these routes with respect to traditional ones (e.g., South Route through Suez) and potential alternatives for Mediterranean Ports and Logistics Flows. In facts, one of the aims of this research is to evaluate best alternatives to minimize the overall logistics cost and their impact on different regions as well as the Sustainability of Mediterranean Ports and Economies in the future with respect to these changes (e.g., increasing South Europe to Africa trades due to economic evolution).

2. State of the art

Today, more than 100’000 ships a year (www.statista.com) pass through the Strait of Malacca, while nearly 13’000 ships (www.statista.com) cross the Panama Channel. The Suez Channel, crossed by almost 20’000 vessels a year, can be considered the primary commercial route between Asia and Europe, as 90% of the total amount of goods traded between the two continents passes through this channel. The Northern Sea Route (NSR) could become more and more important in the future, represent an alternative sea corridor primarily for the movement of goods from the states of the Far East to Africa, America, and Europe, and divert a significant amount of freight traffic from the aforementioned passages. There are evident economic benefits from using the Northern Sea Route: the distance between Shanghai and Rotterdam is 14’900 km through NSR, while the distance between the same ports through Suez Channel is 19’200 km. Therefore, compared to the existing routes the travel time is 40% shorter (15 days less) according to the International Northern Sea Route Program (INSROP), and the saving in fuel – and incidentally carbon emissions - is around 20%. The Northern Sea Route used to be open for navigation for around 3 months per year but, as consequence of Climate Change, in the past few years it has been viable for up to 6 months (from 15th of June to 30th of November). Freight vessels could run this route at an average speed of 10 knots, except for the first days of the season. Global warming has supported a steady increase in cargo turnover along the route during the last years: the Northern Sea Route turnover increased from 130 thousand tons in 1930 to 34850 thousand tons by 2021. If the period considered is from 2014 to 2021 the total increase is equivalent to nine times compared to 2014. Navigating the NSR, however, still presents some challenges like the presence of small particles of ice in the water and in the air can cause damages on the infrastructure of the ship, and above all on powertrains; the presence of electromagnetic fields causing problems in communication, unpredictable storms etc. specific regulatory challenges. Ships need to be compliant to a list of requirements for the design, equipment, and supplies of vessels from the Collection of Resolution of the Counc1il of Ministers of the USSR (16 September 1971) and the Regulations for Navigation on the Seaways of the Northern Sea Route (14 September 1990). Therefore, it’s easy to understand that not every vessel and ship can sail the route, in fact they need to be built to the standards of an “ice class” vessel. This designation refers to a notation assigned by a ship classification society or a national authority to denote the additional level of strengthening and other arrangements that enable a ship to navigate through iced sea. In this paper we consider and analyze ice classes that follow the Russian Maritime Register of Shipping (RMRS) standards. The RMRS ice class rules have been revised and the class notations changed several times over the years. As of 2017, the ice classes are divided between non-Arctic, Arctic and Icebreaker classes. The ice class notation is followed by a number which denotes the level of ice strengthening: Ice1 to Ice3 for non-Artic ships, Arc4 to Arc9 for Artic ships, and Icebreaker6 to Icebreaker9 for icebreakers.

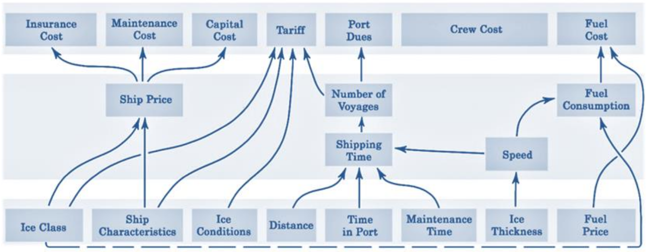

Fig.1 Main Cost model to Compare NSR and SCR (Suez Canal Route)

Ships of the highest ice class are designed to operate in difficult ice conditions mainly without icebreaker assistance, while ships of lower ice classes are assumed to have to rely on icebreaker assistance. In addition, icebreaker classes have additional requirements for minimum shaft power and icebreaking capability. It is important to outline that necessity to operate icebreaker will be a veto for commercial routes not only due to its costs, but even because the time to go through ice breaking result unpredictable, often including risk to be blocked for months also by the most effective icebreakers. In addition, many researchers believe that sea ice will continue to act as the single greatest obstacle to navigation in the Arctic at least up o the end of current century and that the proposed scenario are still far away in the future, however these models are an effective tool to be used along time to check, based on new updates, the situation and decisions to be done in time to react to shipping and port global evolution.

3. Materials and Methods

In order to compare NSR and SCR (Suez Channel Route) there was developed a basic model, including the variables that affect the shipment cost; considering these variables and their dependence on specific cost sources we propose the cost structure proposed in figure 1. In order to increase the reliability and precision of the model, the most sensitive variables were identified analyzing the data of the past years in terms of statical analysis related to mean and standard deviation. This analysis allowed to develop the basis to create the stochastic elements of the model. It’s clear since the beginning that looking at several past forecasts on climate change made by experts in the field, it resulted clear that to sail in the NSR is necessary to use special kinds of vessel and so the authors finalized a preliminary analysis on which are the most appropriate vessels to be used in these routes.

3.1. Stochastic Simulation to compare Scenaris

A large quantity of data was collected and processed for this work. The data used for this work were found in platforms of the major shipping companies and major research centers such as NASA, NOAA, and generally in the literature. The data were normalized by period of the year, route and part of it, it is known that the same route present different characteristics.

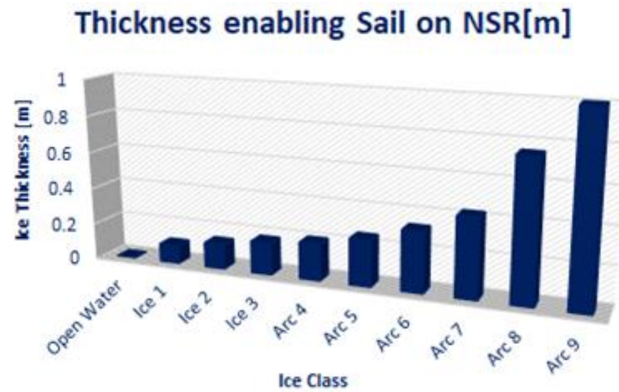

Fig. 2 Cost computation by models on Ice 1, Ice 3 & Arc 6 Class Vessels

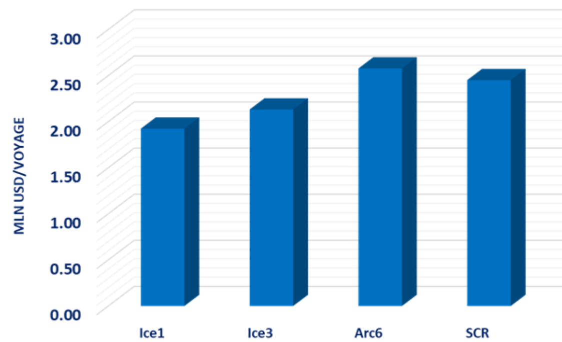

Fig. 3 Total Cost per Voyage on a specific Year for different Ice Classes

The sampling is an approximate representation of the total amount of data, as it is quite variable, due to the different sources and considering that the collected data have been estimated in different years, over different periods of the year, seasons, climatic conditions etc. These considerations obviously affect the proposed research and should be considered, therefore the approach could be updated with more reliable and consistent data sets in case they turn available. Indeed, in case this experimentation will have to be updated in the future with more data, a less approximate and consequently more accurate result would certainly be available. Most of the data used are quantitative only for climate estimates, sometimes qualitative data were also used. The data previously collected was used as input in MATLAB to create the code for the calculation of the Probability Density Function (PDF) and for the extraction of values based on a distribution by means of Monte Carlo simulation, which takes the PDF as input. Using the MATLAB code, random values were generated based on the introduced distributions, which were used to provide the details into the FAFNIR Fast Time SIMULATOR for each different parts of the routes over different regions. Indeed the fast time simulator is a stochastic discrete event simulator that include a GUI in 2D and 3D format, implemented bt using Ansys' System Tool Kit, where routes were drawn with an accuracy of 100km.

These routes were divided into parts, this because some parts of the routes covering different regions and areas and characterized by different sailing speed, weather conditions and different travel times and delay probabilities (e.g.: entry and exit from ports, Suez channel and the part of the NSR where ice could be found).

The data collected through NASA and NOAA Databases, normalized by the season, over the different route parts have been processed to analyze three main scenarios to be studied:

- SCRR Shanghai-Rotterdam via Suez: 19’200 km
- SCRG Shanghai-Genoa via Suez: 15’800 km
- NSR Shanghai-Rotterdam in Artic Sea: 14’900 km

SCRR is an example of most popular routes nowadays, while SCRG represent an example of an actual route serving south Europe, pretty convenient from sea transportation point of view, but affected by higher costs due to the ground transportation and logistics that overcompensate currently the saving on sailing times and costs. NSR is a good reference for potential future NPR running from East to West over the pole.

The FAFNIR Simulator was designed and implemented to carry out several runs over different year months and routes and to compare costs, time and performance over the hypotheses on the climate change effect over the future years.

The models allowed to carry out Monte Carlo simulation and considering the variable shipping times all over the different parts of the routes that are affected by possible delays like the departure and the arrival from and to the different ports, the Suez Channel and the part of the Polar Routes where you can face different issues and critical conditions affecting the times and costs of navigation.

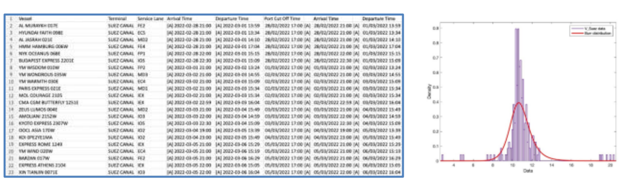

Fig. 4 Data and Models used for the Probability Den sity Function,PDF

The FAFNIR simulator provides also a graphic dynamic representation that it is quite useful to present these three different routes and their very different time ranges.

This results quite evident, watching at some simulations. Indeed, even in the months when it is possible to sail the Polar Routes, the difference between best and the worst results, in terms of time and cost comparison. Therefore, considering the SCRR and the NSR it is evident that in case the climate change forecasts will come true, we will have to deal with new polar routes that result much shorter in terms of timing, and potentially, also quite sustainable, because of the reduced fuel consumption.

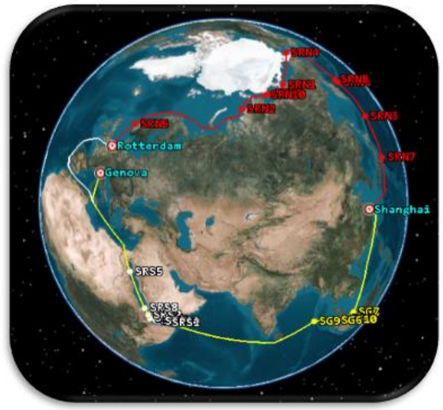

Fig. 5 FAFNIR Simulation and 3D fast time route dynamics

These simulators allow to change easily the hypotheses and modify the normalization of input data set to guarantee the possibility to repeat the experimentation over different conditions and data, especially in the case that in future, there will be more reliable data to study this problem.

3.2. Climate Analysis and Forecasts Interpretations

A Climate analysis was made, starting with long research in the literature and looking at the reports of major research institutes; alle the variable regarding sea condition and weather condition were listed and makings some correlation tests, the most affecting variables (such as ice thickness, ice extension, sea level and sea temperature, etc.) were selected and the structure of the climate forecasting models were made; several past data about the selected variables were collected and all these data were used to create a trend and an approximation of which will be the value in the next years of all the variables (this research takes into account all the years in the current century). After all the approximations were found.

3.3. Verification, Validation and Accreditation (VV&A)

Throughout the development of the study, the VV&A processes were applied; for the verification process, in order to continuously determine that the models implementations and their associated data accurately represent the predefined conceptual description and specifications, step by step, several similar models were consulted and compared; for the validation process, in order to determine the degree to which the models and their associated data were providing an accurate representation of the real world from the perspective of the intended uses of the models, real data from the real world were compared with the results, computed on past years data, of this research; For the accreditation process multiple confrontation with experts were conducted in shipping industry, hydrography and simulation field.

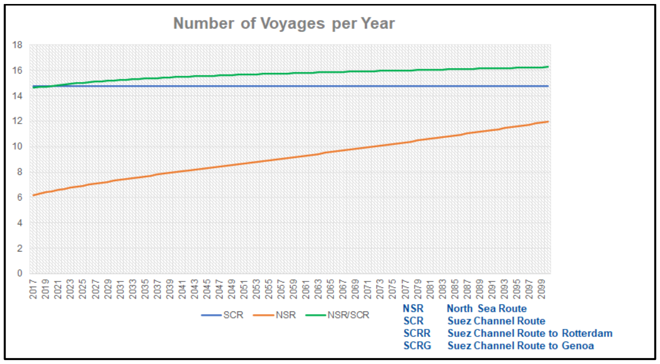

Fig. 8 Number of voyages (y axis) per year (x axis) using NSR, SCR and both combined.

In facts, the models, simulation predictions and final results were compared with the ones of major research organizations in the field, such as, National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA).

3.4. Model Output and Graphic Representation

The output of these models and simulations have proposed within an intuitive visual framework by the graphics of the simulator to enable possible stakeholders in this field to understand the impact of different hypotheses as well as to figure out the involved impacts and the evolution of these phenomena. The models and algorithms used in this system are implemented both by evolved language as well as tools (i.e. AGI Systems Tool Kit). Machine Learning has been used to combine different estimates related to Climate Change hypothesis respect Simulation Results in order to evaluate validity ranges of the different results and the Sustainability of the future maritime trades and regional developments.

The analysis of this study is focused on Eurasian Traffics, Far East to Europe, therefore the model could investigate all world routes. In facts, these models are structured to allow continue further improvements and developments while more and more new data arrives from the real world and research Institutes.

4. Results and Discussion

The cost computation over proposed models was focused on specific kinds of ship and, in particular, respect the Ice 1, Ice 3 and Arc 6 classes. Ice 1 ships are expected to travel with light ice condition, Ice 3 on 7 ft ice thickness at 3 knots; while Arc 6 correspond to a real Icebreaker. In any case, as anticipated, it is not possible, nor convenient to use icebreakers for commercial transport, but it is useful to consider these ship to support the comparative analysis and evaluate the cost computation. Comparing the results between these kinds of vessels and a ship traveling on regular no-ice conditions through the Suez Channel it provides a reference to conduct cost and time analysis. Indeed on the conducted analysis, in the best-case scenario, there is a slight cost saving in the case of Ice 1 for fuel consumption per day. However there is a huge volatility for these phenomena, but if there is Ice Pack present in the North Sea it will not be possible to travel the route on a convenient speed and because of that the cost-saving would be hard to get making it very difficult to adopt it as commercial route; obviously this is strongly dependent on how much the climate change will affect the area, the number of months where it will be possible to sail, the quantity of ice in water, the storm impact, etc. Indeed, the models allow to calculate the challenge of not being able to travel for the whole year long and to estimate how many months are available for the NPR. According to data published by Nasa, the graphics of climate evolution show that it might take almost a century for the North Shipping route to be navigable the whole year. For the moment it is possible to go through it only for up to 5 months. There is the possibility to alternate the North and South Routes during the year, but in this case the investment on different kinds of ships could not result profitable in cost-terms. From other point of view in case the climate change happens soon and the possibility to use North Polar Routes, this could be disruptive over current shipping and could cause a huge crisis for the Mediterranean Area that would lose competitiveness to North Europe. Indeed, nowadays, Suez routes directed into North Europe Port absorb around 75% of whole European Traffic, even if the South Europe Port guarantee a saving of 5 sailing days (overcompensated by additional ground logistics costs); therefore in case the Polar Routes turn more convenient the traffic to North Europe will further increase over 75%. For instance, at the moment Genoa Port (major Italian Port and among major impot Port in South Europe) is quite small respect Rotterdam (major Port in Europe, located in North Europe) being around 1/6 in terms of traffic. Currently the ships prefer going North because of infrastructure costs are lower and the Rotterdam is large with low fees and good connection through barges, trains, trucks: new polar Routes could further shrink the traffic directed to South Europe and reduce competitiveness of industrial activities over there due to logistics connections.

At the same time we should outline a way out of this problem where FAIFNIR could be useful to support; indeed the New Polar Route impacts might be compensated in South Europe Countries due to the North Africa growth and demographics that could increase future traffic.

There is high instability in this region, but we are talking about phenomena that would happen in the next half of the century. Cultivating and promoting the industrial and social development of North Africa, part of the traffic that actually arrives from Asia could be provided bv south Mediterranean, reducing the distances of travel and the environmental impact by 83%. All this change should happen counting on technology and smart organization to use at the best way possible the spatial margins that we have.

The port reality would change, there would be the need to increase capacity of cranes from 25-30 to 35-50 containers per hour; to increase the number of cranes, for example in the port of Genoa Pra to pass from 9 to 15 cranes. Improving the waiting time of containers on the platform would make the process much faster, for instance to pass from 15/20 days of wait to a couple of days. This could be possible only through smart organization, improving railway transport and road transport making them as much coordinated as possible and Strategic Engineering could support this change

5. Conclusions

It is very difficult to predict the evolution of future traffic over a long period because of the presence of many stochastic variables and a high degree of interconnection of the different layers (e.g. climate change, economics, geopolitics). For example, hunger, plague and wars could worsen the situation in Africa for the next ten years causing a huge crisis for the world, especially in Europe, with a long-term impact. There is no way to predict the future with certainty, it is possible only to adapt and readjust the estimations and plans according to updates, evolving the knowledge and transforming ideas and hypotheses into concrete data. It is certain that the North Shipping Route will have a huge impact on port realities and infrastructure, and not just that, but also on railway transport, road transport and industrial tissue. In a particular way it will have a negative impact on the Mediterranean traffic causing a decrease and loss of competitiveness to North European Ports. Anyway, the increase of demographics in North Africa could bring, instead, positive results if the area will improve socially and industrially, causing an increase of traffic and connections. All these changes should happen counting on the development of technology and infrastructure and should be guided by adopting smart decision Making. From this point of view the use of Strategic Engineering approach based on models such as FAFNIR is crucial to proceed by smart changes able to allow the use of space margins in the best way possible, acting in time and anticipating challenges to transform them into opportunities.

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