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Marine Traffic Analysis

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Abstract

In this short paper we present our project on North American port network analysis. First is a review on literature about usage of AIS systems to analyze data accuracy and vessel safety. Next, data MarineCadastre.gov is standardized and discussed, following that there is an analysis based on minimum spanning tree (MST) analysis with inclusion of betweenness variation. The main discovery of this research is that after covid-19 ports network became more dense. The results might be used by cargo vessels and to rearrange AIS frequencies for safer navigation.

Introduction

In this paper we want to look at the structure of connections between ports in the North American region. This is possible via analysis of Automatic Identification System (AIS) data, particularly by connecting marine traffic to the ports. Doing that we will be able to see usual paths ships go through, connectivity between two particular ports or groups of ports. We take the data from the official US database, focusing on years 2019-2022. The main idea is to spot differences in the network structure, occurred in the period of covid-19, then compare it to previous year and year after.

Next part explains it in more detail, firstly there is a literature review, reflecting state of art in the AIS-based marine traffic analysis, then we elaborate on employed SNA methods and data sources for this project, and thirdly, the analysis of the networks built is discussed.

Literature review

AIS system and it's integrations

The opportunity to research marine traffic, its global trends and issues became possible because of the large amounts of data provided by AIS devices. Since 2002 bigger ships traveling to Europe were required to have such devices, and soon this tendency became worldwide.[1] Darren Wright and his colleagues, reviewing types of research done with the help of AIS, noted projects related to ensuring ship safety in critical areas, using ship data for accurate information on weather, and models tracking causes of oil spills.[2]

Networks are one of the more efficient ways to work with this type of data, because it allows compressing real world topological structures to much simpler and easier to process networks. For example, a research project by Chao, Wu and Tseng presents how fishing zone security can be facilitated by the usage of network structure in determining whether ship entered territory of the zone, if added as a first stage of currently used topology-based methods it allows to process data faster and in some cases get more accurate results.[3]

Another implication of AIS to improve safety and navigation wes proposed by researchers from Cambridge university. They found out that about 80% of accidents are connected with human error. The study that has been conducted on the AIS User Satisfaction Model has made a significant contribution in the field of maritime technology. The proposed framework can be used effectively to evaluate the satisfaction levels of navigators and the extent to which they use AIS. This model is highly likely to be used as a benchmark for measuring the attitudes and behaviors of navigators towards other similar maritime technologies. By using this model, the industry can gain valuable insights into the opinions

[1] "Directive 2002/59 EC."

[2] Wright et al., "Marine Observing Applications Using Ais."

[3] Chao, Wu, and Tseng, "AIS Meets IoT."

and preferences of navigators and make informed decisions regarding the implementation of new technologies. It is evident that the proposed framework holds great potential for improving the efficiency and safety of the maritime industry[4].

Networks are also used for large-scale descriptive analysis, like the research project on European port shipping flows supported by MarineTraffic - one of the biggest databases in the field.[5] There César Ducruet and his colleagues analyzed flows of cargo and liquid cargo shipping through the most popular European ports to determine the usual paths taken by ships, important connections between ports and highly interconnected groups of ports.[6]

Further studies address the problem of collision avoidance. the state: “AIS is an effective tool for accomplishing navigational safety goals, and by doing so, can provide critical pre-emptive maritime safety benefits, but also provides a data opportunity with which to understand and help mitigate the impacts of maritime traffic on the marine environment and wildlife. However, AIS was not designed with research or conservation planning in mind, leading to significant challenges in fully benefiting from use of the data for these purposes[7].”

Most studies during years question the reliability of AIS data and give various techniques to make it more precise. Biggest concern was related to satellite-based data. They analyzed performance and accuracy of this data collection method. Navigational safety is of utmost importance in the maritime industry. To ensure safe passage, ships need to be constantly monitored and their positions reported at regular intervals. Thanks to advancements in technology, a system has been developed that can meet the target user requirements with a ship position reporting interval of 3 hours[8]. This system utilizes a combination of satellite communication and automated reporting to provide accurate and timely information to ship operators and maritime authorities. By implementing this system, the risk of maritime accidents can be significantly reduced, ensuring the safety of crew members and cargo alike.

Today it can be said that data that is stored and received by marine vessels is becoming more accurate for end users[9]. Various error solving articles provided huge data for analysis and future predictions.

[4] Mokhtari, “Impact of Automatic Identification System (AIS) on Safety of Marine Navigation.”

[5] Spiliopoulos, “An AIS Data Analysis to Study the European Maritime Network Connectivity and Spatial Distribution.”

[6] Ducruet et al., “Maritime Network Analysis.”

[7] Robards et al., “Conservation Science and Policy Applications of the Marine Vessel Automatic Identification System (AIS)—a Review.”

[8] Cervera and Ginesi, “On the Performance Analysis of a Satellite-Based AIS System.”cer

[9] Yang et al., “How Big Data Enriches Maritime Research – a Critical Review of Automatic Identification System (AIS) Data Applications.”

Methodology

Data collection

In terms of sources for the data we were limited to free ones, to use records from the U.S. Coast Guard's national network of AIS receivers available at MarineCadastre.gov. "With over 300 data layers from numerous sources, MarineCadastre.gov is one of the premier sources for authoritative ocean data and tools. A cooperative effort between the Bureau of Ocean Energy Management (BOEM) and the National Oceanic and Atmospheric Administration (NOAA), MarineCadastre.gov works closely with national, regional, and state partners to develop and provide direct access to the best-available data and tools to meet the growing needs of the blue economy[10]." This project allows us to analyze longitudinal data from 2000 -2022 years and compare obtained results. We decided to focus on the last four years, to spot the recent changes. In this way we are able to see pre-covid communication, period of covid-19, post-covid restoration of network and situation during 2022 geopolitical conflict.

Data is stored in an achieved form, with one archive for each year. Using R we automatically downloaded all of them, filtered for the anchored status and type of ship, including only big ships - tankers and cargo ships. Afterwards port location for each ship was calculated using latitude and longitude, all the data united in 1 dataset and individual trips between two ports modeled. In the end we had two datasets - full one, storing all the information about ships and communications and source-target dataset including only names of ports.

Methods

For our data analysis and network modeling we used R. Firstly we built basic networks on blank background and the USA map to notice changes visually, then we analyzed basic properties of a network, generally there was not much variation in all parameters except betweenness, so we decided to map it closer. For that purpose we used Minimum Spanning Tree (MST) algorithm, to make the network denser, and combined it with clustering algorithm, to see how the network structure and detectable clusters change over time. Since we are doing descriptive data analysis no predictive model was constructed, we base this paper solely on analysis of MST graphs with clusters.

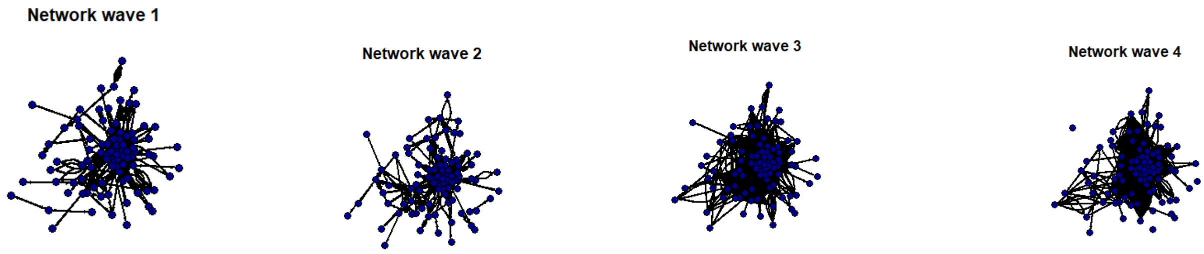
Results

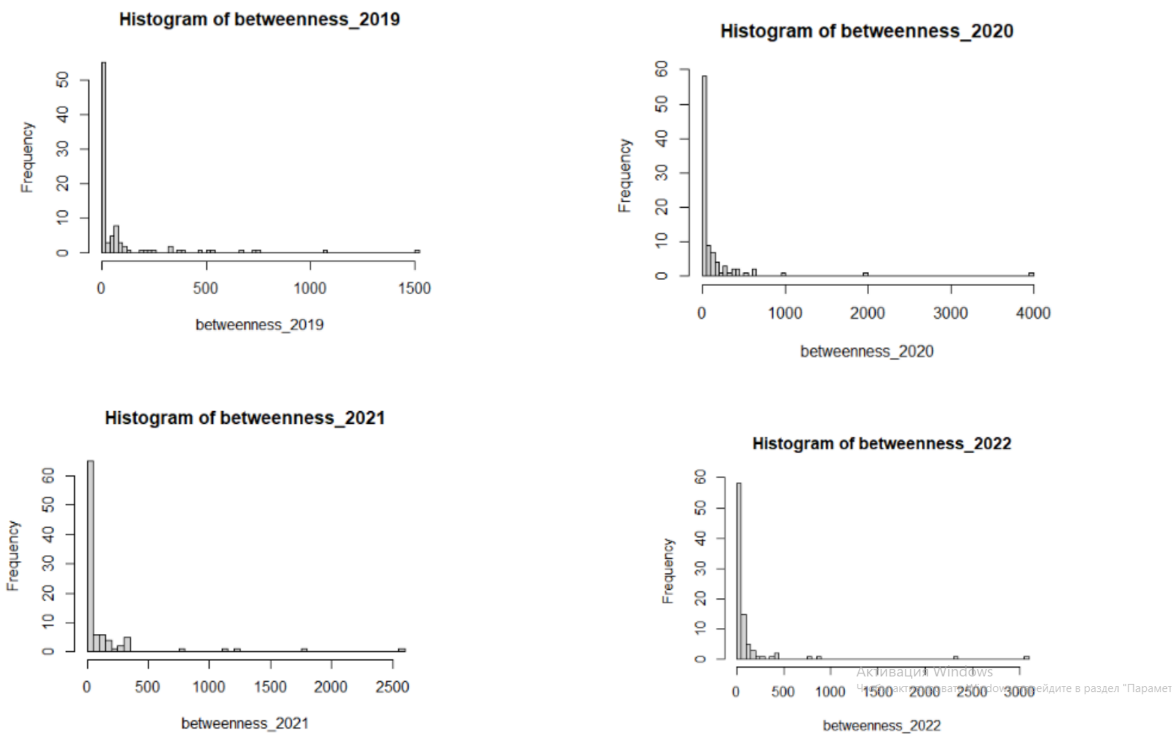
Looking at the basic networks (see below) we can notice that network density decreases from 2019 to 2020, which might be explained by the covid restrictions. Then in the years 2021 and 2022 density grows. Structure of the net remains pretty much the same with more linkages appearing over time. If we look at another network global parameter - transitivity, it also experiences the same dynamics: it is equal to 0,35 in 2019, then it drops to 0,31 in 2020,

[10] "MarineCadastre.Gov | Vessel Traffic Data."

rising back to 0,34 and 0,36 in two following years. From those graphs we can notice this small change in 2020, but it does not seem significant enough for further investigation.

Below you can also see the betweenness histograms, showing distribution of nodes with different betweenness. Here it is noticeable that the number of nodes with higher betweenness grows throughout the years, reflecting the notions from the visual graph analysis.

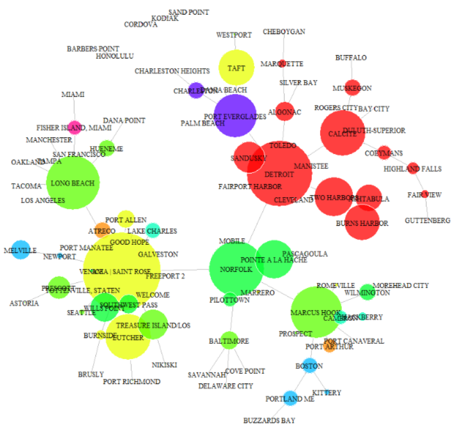


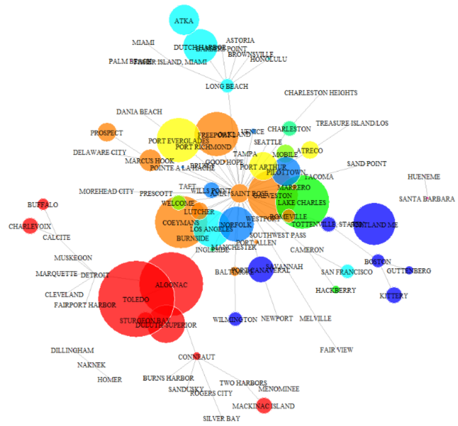


That is why it seems reasonable to use betweenness in further analysis, to be able to see changes in betweenness of particular nodes in all 4 periods.

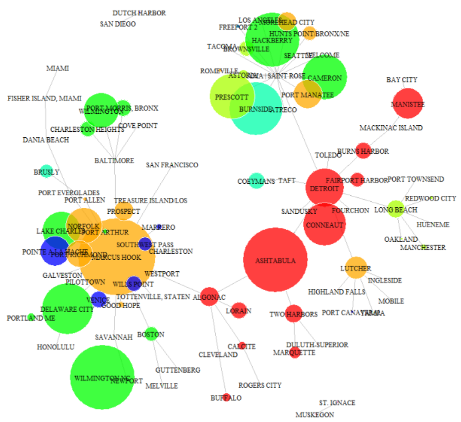
Now let’s use MST algorithm, to select only the most important part of the graph and then plot it, adding node size equal to betweenness (actually its square root for better proportions) and create clusters with cluster_optimal function from igraph.The plots below show the result of this modeling:

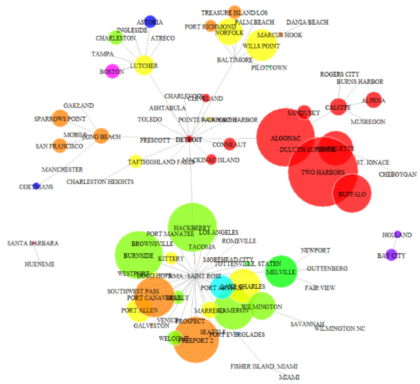
2019-2020



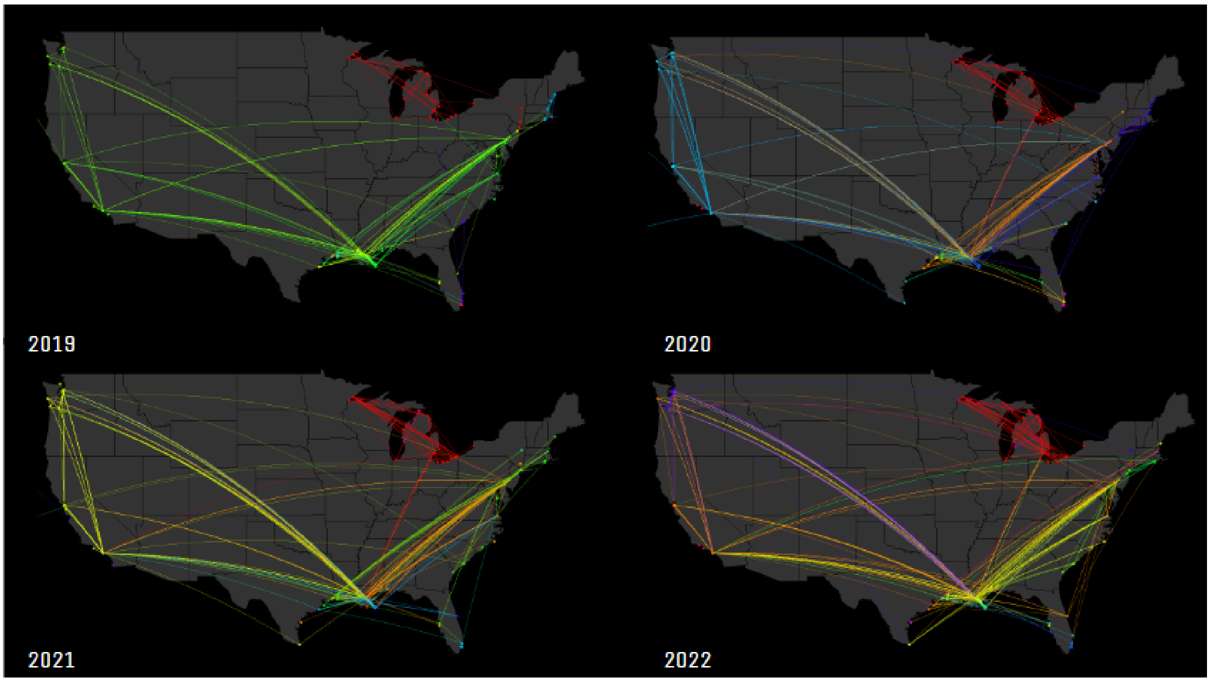


2021-2022





It can be noticed that in the 2019 plot there are about 5 main nodes with clusters around them and some minor clusters. In 2020 the same nodes that had the most importance suddenly lost it, but nodes surrounding them became more important, also the number of linkages dropped a little. And in the years 2021-2022 the continuation of the same dynamics can be seen - betweenness of previously not important ports grows, but at this time with the growing number of links. This shows the changing structure of the net in the post-covid period. If we look at the changes on the map (see below) we can see how different clusters start communicating more in the span of 2021-2022, with only the red cluster remaining stable (probably because it was already well-connected before the pandemic.



Discussion

The main finding of this paper is that after covid-19 ports network became more dense. If initially there were two main ports with high betweenness degrees, forming clusters around themselves, now there are some new ports with growing significance. If we try to interpret it from the economic point of view, we can suppose that after the supply shock of covid-19, when some international shipments were canceled and provision of produce of certain industries was complicated (like microschemes), the US became more self-sustainable in turn having more intra-state communication. Although it would be useful to know the ratio of foreign trips to intra-country trips to be sure about that.

Those results might be useful for businesses using ships for cargo delivery, allowing them to get relevant information about the structure of the industry. As well as port's management to adjust frequency of information shared through AIS devices or develop a more precise net of sensors.

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