CO2 Emissions Reducing Framework for Near Shore Ship Traffic

M. Furkan Oruc

1. Introduction

As the global trade volume is increasing, so as the maritime traffic. The growth of volume in maritime traffic is primarily creating results in congested and narrow waterways around the world. Due to increasing volume, environmental impact of ships in these areas are being more and more costly. Some of these impacts can be mentioned as greenhouse gas emissions. International shipping owns 2.89% of global anthropogenic CO2 emissions. It's a threat for city life in residential areas which are near ports and waterways, such as Port of Antwerp, Singapore Strait, Kattegat in the Baltic Sea, and the Strait of Istanbul (SOI) (Altan and Otay, 2018; Goerlandt et al., 2017; Qu et al., 2011). Thus it is essential to reduce CO2 emissions and environmental impact in these regions and implement preventive measures.

2. Purpose

In this study, a quantitative analysis to measure greenhouse gas emissions in the Strait of Istanbul and Singapore Strait will be conducted. Patterns and scale of environmental impact in different ship classes and groups will be mapped. Statistical analysis on amount and diversification of gas emissions will be presented. Environmental impact will be modeled via additional data sources and Automatic Identification System (AIS) Data. Predictive modelling will be conducted to reduce emissions' impact to the surrounding residential areas via benefits of speed and route optimization for transit and local ships.

In the remainder of this proposal, a detailed literature review is presented. Then, data and methodology is outlined. Next, challenges and limitations are presented. Lastly, references are provided.

3. Literature Review

Researchers approached from various aspects to model environmental impact of shipping activities near ports and waterways. While the main purpose of the research is to model environmental impact of shipping to residential areas, this subject is closely related to many interdisciplinary areas. This requires an in-depth analysis of subjects ranging from ship traffic, pollution by ships, vulnerability of cities to air pollution and geographic conditions covering narrow and congested waterways.

(Lin and Lin, 2006) represent regulation aspect of international maritime environmental impact based issues. Based on International Maritime Organization's protocol which was going to be active starting from 2005, actions to reduce air pollution have been framed. The paper also suggests possible precautions that can be taken to improve environmental efficiency in the scope of this initiative. Some of the practical implementations cover from attachment of advanced air pollution detector devices to ships, to inclusion of legislative authorities to support implementation of rules. Also, decision to set up a database to track gas emissions is also presented in the scope of the paper and subject regulation changes.

(Lucialli et al., 2007)'s case study focuses on the Harbor Ravenna in Italy, and explains the impact of harbor traffic to surrounding region's air quality. The paper analyzes impact of ship traffic to air quality via pre-determined pollutant metrics, specifically NOx and PM. To determine the amount of pollution in the region, several methodologies are combined and compared. A site experiment is conducted to capture air pollutants via a monitoring device and measure them. Also, a simulation model is developed to present the amount of pollutants and these to models are combined to achieve final results. Also, these results are broken down to pieces of ship by ship pollution based on ships' operating situations and fuel consumptions. This study is shaped to predict the amount of pollution via simulations, rather than modelling an action framework to reduce it, so it differs from this study in this sense.

(Trozzi and Vaccaro, 2000)'s work present an overall picture on types of pollutants emitted from ships. Further, Trozzi and Vaccaro also analyze other port activity based emissions, other than ships. Also, the study provides a context on other pollutions, such as soil pollution and water pollution, an overall analysis on environmental impact of port activities.

(Trozzi et al., 1995) 's case study also focuses on air quality impact of maritime traffic in harbors. In this study, parameters affecting pollution such as gross tonnage and fuel consumption are also included to model air quality impact by ships. Also, the study introduces ship maneuver type based insights on air pollution production, which are sourced by fuel consumption rate, specifically. The methodology is applied in harbors, Venice and Piombino in Italy. An important outcome from the study is presented as the importance of types of maneuvers inside harbors in determination of air pollution. While, impact by quantity of the ships inside harbors is determined to be less relevant. Modelled pollutants are described as NOx, SOx and CO_2.

(Pirotta et al., 2019)'s examines global shipping traffic's impact on marine life. The study approaches the problem from a perspective based on terrestrial road traffic's impact to life surrounding those. Pirotta et al. model ocean road networks of ships to formulate these ocean networks' impact on the marine life in subject regions. The study is relevant in the sense of modelling a terrestrial based impact testing approach to suit marine environment. Air pollution modelling of vehicles are conducted by various researchers, and the perspective by Pirotta is relevant to adopt right approach from terrestrial to maritime.

(Weng et al., 2020) focuses on the reverse aspect of the issue, environment's impact on ship collision frequency. Researchers suggest that maritime traffic flow amount, density of maritime traffic, traffic lane width and adverse weather conditions are determinant of ship collision frequency. The study helps to understand how reverse impact towards ships is modelled.

(Makkonen and Repka, 2016)'s work presents how environmental regulations drive innovation in the industry, which shows how capital can be leveraged in the industry and how it plays in the practice. (Birpınar et al., 2008) 's work examines ship traffic's environmental impact in the Strait of Istanbul. The study is primarily relevant to this research since it provides statistics on ship traffic in the Strait of Istanbul. It shows how number of tankers passing through the strait are increasing, ranging from 4,000 to 10,000 per year between 1996 to 2006. It also provides historical accidents' records and show the environmental impact by oil spills in the region. Although these accidents are creating the primary pollution impact in fauna, flora and water, the resulting long waiting periods of other ships passing through is another indirect result of air pollution with accidents. The study also predicts the increase of tanker traffic, in correlation with economic growth of countries in the Black Sea region, which is the sea connected to the Strait of Istanbul. Also, study shows how a potential accident may impact the surrounding geographical region, covering Aegean Sea to Black Sea. Considering the high scale impact of ship-ship accidents, a threat to historical and natural heritage of Istanbul is also expressed to be under threats of these incidents. This can be identified as a quite relatable issue since air pollution is harmful to buildings and Istanbul is a city with more than 5,000 years of heritage with numerous historical sites.

(Liu et al., 2021) presents a machine learning based model in the ship anchorage pressure to improve sustainability. It is a relevant research in the scope of implementing machine learning in maritime domain to improve marine health.

Utilized literature resources create a framework for understanding the environmental impact of maritime traffic on different locations and occasions, and suggestions to model these impacts. Also, studies conduct recommendations to better manage these environmental impacts for protecting the environment and life surrounding these situations. On the other hand, few researchers present actionable insights to take steps on the way to improve health and reduce pollution via preventive measures. In the scope of this study, emphasis will be on development of a model which will result with decreased environmental pollution, specifically air pollution and usefulness of the model will be demonstrated. This point is identified as a research gap, along with integrating ship data to understand details which make a ship more pollutant than other. While some researchers identified maneuver, gross tonnage and ships' fuel consumption behaviour to be important determinants, no quantitative model of these features have been presented. Another important contribution of this research is aimed to have a quantitative suggestions for ships, which can be explainable and applicable. An example can be mentioned as advising a change in limit speed in subject waterways, if that result is believed to have potential positive impact for a less pollutant region. The study also aims to bring recommendations in line with subject IMO regulations.

4. Data and Methodology

1. Data

Automatic Identification System (AIS) (Tu et al., 2018) is a system to track marine activities. Based on international regulations, all ships subject to basic conditions are supposed to carry an AIS transmitter and this data can be collected by terrestrial and satellite stations. AIS data are transmitted in short time intervals, ranging from every 3 seconds to 60 seconds. In total, AIS data are made of 27 types of messages. Due to comprehensiveness of the AIS data, only relevant information will be retrieved. These relevant parts will be made of AIS type 1,2,3,5 messages, since these message types include information about ship type, ship MMSI (Maritime Mobile Service Identity) number, IMO (International Maritime Organization) number, LOA (Length Overall), Beam, Draught, SOG (Speed Over Ground), COG (Course Over Ground), HDG (Heading), Latitude and Longitude. In this study, data collected from a long period of time (e.g. >1 year) will be used. The unit of analysis will be a certain point in the time domain for each vessel, since each vessel transmits a data point which includes various information regarding state of that vessel in that exact time. Location of each vessel will be important for the analysis, so coordinates will be collected from the database, as well as speed of vessels and other relevant information. Also, regional pollution datasets will be collected to compare and correlate outcomes. Dataset will be stored in an SQL database to ensure reliability and efficiency. Dataset will be highly complex to deal with, considering vast amount of missing positions and incorrect submissions. Preprocessing will be conducted to have an accurate representation of the real world. Filtering will be implemented to include only the relevant vessels in the scope of the study. Python and R will be benefited together with SQL to manage preprocessing. Data will be provided by private corporations for research purposes.

Another data source will be public resources on characteristics of ships which identify environmental impact. This data will be collected from multiple online resources.

a. Data Cleaning Procedure

One of the main challenges of the project can be mentioned as the overall data quality. Since poor data quality can be a limitation for further steps of the analysis and results, considering the complex nature of the dataset. To overcome this problem, different data cleaning procedures will be conducted. Since AIS data is bounded by regulations and rules, these limitations will be used to filter irrelevant and problematic data points.

MMSI, in other words, identity number is a 9 digit number representing each vessel. MMSI of each vessel will be checked and filtered based on suitability and correctness. Next, physical dimensions of each vessel will be validated and erroneous data will be removed, such as 0 as length of the ship. Following, duplicate data points will be eliminated. Also, ships from different ship types will be eliminated based on their identity number, representing their specific class. For example, ports also transmit AIS data and ports data transmission will be removed from the dataset. Further, quantitative variables such as speed and heading have their natural limitations. Heading, for instance, is not supposed to exceed 0-359 boundaries. Data cleaning on quantitative variables will be conducted on this basis. Also, time data will be also another important component of the analysis. Time data will be formatted and shaped based on requirements of modelling.

5. Methodology

Main phases of the project can be summarized as, retrieval of the data and joining multiple datasets. This will be followed with an exploratory procedure, as well as extensive data cleaning procedure. Then, statistical analyses will be conducted to describe data, for better explaining the current state. Then, data will be analyzed and quantitative outcomes will be presented. This will be followed with simulation presentations, as well as visualizations to show changing situations. Finally, suggestions for future will be presented as the result of the research.

Initially, catalogue based general information for each type of ship will be retrieved. This information set will rely on categorization of ships from different aspects, such as length, fuel consumption type, fuel consumption rate, ship type, maximum ship speed, ship gross tonnage. These categorizations will be filled with environmental impact of each ship category based on their specifications. This way, a map of environmental impact from each ship type will be created. In the next step, using the large AIS database, category based environmental impact information of ships will be merged using specific categories. To conduct this, MMSI number of each ship will be benefited. MMSI numbers present are identification of ships, so they provide each distinct information of ships. Following this merger, resulting dataset will be filtered and rearranged to cover only specific time frames and geographical regions.

Secondly, for each ship, journey in the Strait of Istanbul and Kattegat Sea will be summarized. To present this summaries, certain aggregation based SQL queries will be run. These aggregations will provide information such as length of the journey by a ship, duration of the ship's passage from the waterway. These aggregation based intelligence will be combined with other categorical pollution related information. In the next step, waterways will be divided into cells which represent different area blocks. This combination will be based on multiplication of air pollution potential of a ship and duration and distance spent in each waterway cell. Within these area blocks, aggregation computation will be summarized and each geographical cell will be represented with journey of each ship passing through.

Using categorical pollution information from each ship, each geographical cell will be presented with daily, monthly and yearly total pollution. For each cell, an impact area in the terrestrial region will be determined, using Geographical Information Systems. This will be made via a simple distance based classification of regions. As a result, terrestrial regions will be divided based on their belongings to each waterway cell. Of course, many terrestrial regions will be subject to more than 1 cell. Terrestrial regions' air pollution will be summed based on distance and amount of impact generated from each waterway cell.

As the result, terrestrial air pollution will be visualized based on amount of impact from each waterway cell. To present preventive measures, a simulation methodology will be conducted. A replicate of the same database will be generated. In this replicate, ship's data will be changed based on certain percentages and pollution impact in terrestrial regions will be recorded. Examples are changing maximum speed, duration of journey, type of fuel consumption, degree of maneuvering.

Based on traffic forecasts for following years, predictive analysis will be conducted. Also, using the AIS route information of ships, different routing scenarios will be tested. These routing scenarios will be created based on coordinate information of ships. This way, increase in air pollution based on degree of density in maritime traffic will be presented in the terrestrial areas. Resulting products will be visualizations, quantitative results and simulation scenario based quantitative suggestions for maritime authorities.

6. Challenges/Limitations

The main challenge can be the size and complexity of the maritime data, as well as data quality problems in the AIS data. Another challenge can be limitation of ship based data to understand each ships' characteristics' environmental cost. This can also come up as missing values for specific characteristics of ships.

7. References

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