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IMPACT OF GLOBAL SHIPPING ROUTES ON THE SPREAD OF INFECTIOUS DISEASES

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Abstract
The prevention and management of the risk associated with the importation of the coronavirus illness (COVID-19(C19)) has swiftly emerged as a significant concern. Besides air freight, maritime vessels significantly contribute to the dissemination of C19 through regular visits to nations with infected populations. This study presents a methodology for the dynamic evaluation of vessel infectious risk via a data-driven method. It autonomously recognizes the ports and nations these vessels visit by utilizing their Automatic Identification Services (AIS) information and a spatio-temporal density-based spatial grouping of uses with noise (ST_DBSCAN) technique. The research generates daily and 15-day cumulative ship exposure indexes derived from various country-specific metrics, including population density, total confirmed infections, and the rate of growth in confirmed diseases. The indexes are categorized into higher, medium, and lower-risk stages, designated as red, yellow, and green, respectively, by the health Quick Reaction (QR) code derived from the standard exposure index of Wuhan in April 2020. This technique was utilized on a container vessel operating on an Eurasian path. The findings indicated that the suggested approach monitors ships' infectious risk and offers a decision assistance system to mitigate and manage the importation of C19 infections from shipping abroad.
Keywords – Shipping Routes, Infectious Diseases, Ships, Marine

1. INTRODUCTION

The novel coronavirus illness (COVID-19(C19)) was initially documented in December 2019 in Wuhan, China [1]. C19 is a coronavirus characterized by elevated person-to-person transmission and infectiousness, perhaps surpassing those of the previously reported severe acute respiratory syndrome (SARS) and Middle East Respiratory Syndrome (MERS) [11][3]. Recent data from multiple studies indicate that the mean fundamental reproduction number (Ro) of C19 suggests that infected individuals create a mean of 3.28 additional infections in the absence of assistance [2][12]. Regrettably, the lack of particular antiviral medications and vaccinations for this novel infection necessitates reliance on evaluates that avoid transmission from person to person, including maintaining appropriate distance from others, family isolation, and even imposing citywide lockdowns to limit population movement, which have thus far become the primary, if not sole, option for numerous countries [4]. These precautions remain inadequate to halt the swift proliferation of this coronavirus worldwide. Numerous countries have experienced a speedy rise in confirmed infections, and C19 has commenced its global dissemination [20].

Mitigating the risk of importing C19 cases while facilitating the revival of the regional economy has emerged as the primary objective for numerous nations [5]. The resumption of employment and production will lead to large-scale commuting, substantially elevating the danger of pandemic dissemination [19]. To successfully avert a repeat of the global epidemic and facilitate a seamless return to work and manufacturing, the Alibaba Corporation has implemented a tracing healthcare Quick Reaction (QR) code system to assess varying levels of infection risk according to individuals' routines and travels [6]. Individuals can acquire a medical code by submitting their phone number, name, and identification [21].

Although most imported C19 cases primarily arrive through land borders or airports, contingent upon border control regulations, maritime transportation significantly contributes to the international dissemination of C19. Worldwide shipping has significantly facilitated global commerce and supply chains during the pandemic [7]. Vessels frequently navigate various nations and areas, and C19 can be transmitted from one jurisdiction to another by the onboard employees. This positions ships as a potential vector for virus transmission, albeit likely at a lower scale and size than aircraft [13].

Recent technological advancements related to Automatic Identification Systems (AIS), particularly the development of microsatellite clusters, now enable the global monitoring of ship movements with great spatio-temporal precision [8]. AIS is a maritime identifying system relaying real-time vessel itinerary data through radio transmitters. AIS is mandated on all vessels of 250 gross tons or greater and involved with international journeys, every cargo vessel of 600 gross tons or more, and all tourist vessels regardless of size. Specific nations mandate AIS implementation on supplementary vessels [9]. AIS is mandated for EU fishing boats exceeding 18 meters in length. AIS is being utilized voluntarily by many vessels, especially smaller fisheries and recreational crafts, thus offering a distinctive chance to monitor the locations of a diverse array of vessels globally. Notwithstanding certain system constraints (e.g., small vessels without AIS and transmission interruptions), historically and real-time AIS information have demonstrated exceptional use in elucidating shipping-related consequences and informing conservation strategies across many spatial and temporal dimensions. AIS is currently utilized to evaluate the probable transmission of C19 and to delineate the decreases in maritime activity at localized levels [14].

This research presents a way to assess the dynamic risk of C19 outbreaks via international shipping using a data-driven methodology. The technique initially identifies stop events by analyzing ports encountered and the nearest nations using AIS information and the ST-DBSCAN method, a density-based method for detecting clusters in extensive geographic databases with disturbances, and it effectively incorporates time and space measurements. The C19 exposure indices of the vessels over the preceding 15 days are calculated and simulated using the daily infection information of the relevant nations, incorporating factors such as population, accumulated reported instances, and the rate of rise. The indices are categorized into three risk levels according to the tri-color code: red, yellow, and green [15].

2. RELATED WORKS

The paper intersects with three main streams of research: Research about C19 in Operations Management (OM) and Supply Chain Management (SCM); examination of container shipping marketplaces, especially during the global epidemic; and investigations of rivalry and partnerships among container shipping firms [16].

Numerous recent investigations in OM and SCM have explored the diverse effects of C19. The latest edition examines six overarching themes: public policies and governmental actions, healthcare operations and ability, epidemic propagation, relief efforts, business relationships, and vaccine manufacturing. A particular subset of papers within this extensive body of research strongly corresponds with the inquiry [17].

These publications adeptly use epidemiological frameworks in their operational evaluations. They systematically construct and thoroughly evaluate a model that analyzes the effect of health services on decreasing total fatalities and mitigating virus transmission. Their methodology accounts for a limitation on hospital bed availability. By augmenting the traditional approach, they explore the complex dynamics of people's access to constrained medical services [18].

They analyze three hospital admittance methods implemented by different countries: hierarchical, mixed, and the novel Fangcang method. It significantly surpasses both options, especially under conditions of limited medical competence. The study presents an entire structure for handling a pandemic, utilizing artificial intelligence predictions to evaluate the risk of serious illness.

Their methodology employs a modified model, enabling the simulation of various isolation and departure strategies predicated on risk categories. By analyzing C19 data from Europe, they illustrate that their regulations might substantially alleviate isolation requirements for millions, while maintaining manageable Intensive Care Unit (ICU) capacities. They explore the obstacles and ramifications of executing such strategies. The study investigates pandemic patterns by integrating queueing theories and systems. Their emphasis is on essential measures concerning peak load, which is directly associated with the need for healthcare services [10].

Utilizing these indicators across 15 states, they forecast infection surges under different policy situations. They offer significant suggestions for reducing transmission risk and efficiently controlling peak load [10]. The study conducts a compelling analysis, weighing the intricate trade-off between revenue generation and mortality reduction during a pandemic. Utilizing a probabilistic multi-objective dynamical scheme, they ascertain the best magnitude and timing of actions. By comparing both passive and active confinement strategies, they demonstrate a Pareto-efficient set of policies that balance saving lives and maintaining economic vigor. Numerous studies have concentrated on logistical challenges during the pandemic, including resource allocation and vaccination logistics. A significant body of work examines the relationships between the epidemic and different modes of transportation [16].

Although numerous studies have examined the container transporting market throughout the global epidemic, most are empirical and rarely explore the consequences of dynamic rivalry tactics utilized by shipping lines, or the influence of government actions and regulations, including vaccination initiatives and port congestion alleviation [9]. This research addresses this gap by profoundly understanding the maritime industry's development during the global epidemic. The research regarding rivalry and alliances between container transport companies is extensive. The research concentrates on utilizing game designs, predominantly featuring non-cooperative game types. A limited number of studies employ collaborative gaming models [18].

Notwithstanding their application of gaming theory, this research primarily depends on static modeling. In these frameworks, the competitive tactics remain invariant throughout time. This static methodology fails to account for the dynamic adaptations implemented in reaction to fluctuating market circumstances during a global epidemic. Conversely, the study presents a differential gameplay theory [19]. This paradigm facilitates dynamic optimization, wherein the tactics are regulated by equations that change and can be modified in reaction to real-time fluctuations in the afflicted community. The model contributes significantly to existing research on shipping competitiveness, especially on the effects of a global outbreak [20].

3. SPREAD OF INFECTIOUS DISEASES

Fig. 1 delineates the primary methodology and statistics employed in this investigation. The C19 ship risk evaluation methodology is a data-driven technique comprising four essential variables and six sequential phases.

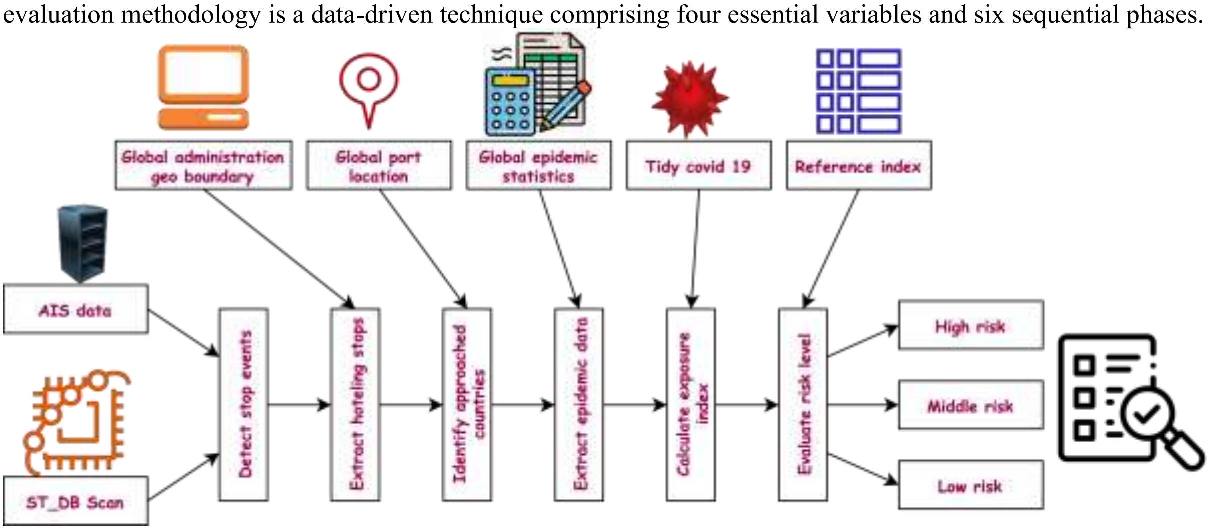

Fig. 1. Framework of the infection risk of ships

The initial phase involves identifying ship "stop" occurrences using the ST-DBSCAN method, which incorporates ship AIS data as parameters to extract "stops" in both spatial and temporal dimensions. The identified stops are categorized as hoteling pauses and other stops according to the lengths from their sites to land borders. Similarly, hoteling stays are then correlated with their nearby ports and nations according to their proximity to such ports. This enables us to estimate and ascertain the arrival and departure times and the trip itineraries of the seaports and nations associated with a particular vessel.

The databases are utilized to retrieve C19 pandemic data analysis for the countries of interest throughout a ship's visit, employing the tidy-C19 R package aims to offer transparent accessibility to diverse authoritative, freely accessible C19 information sources at the national level daily. This enables us to calculate daily C19 contact indices and the cumulative exposure indices for 15 days. A contamination index indicates how much a ship is exposed to contaminated nations (which will be elaborated upon in subsequent sections). The final phase is to utilize Wuhan's exposure score in April 2020, after the city concluded its lockdown, as an example index. This referencing index categorizes the 15-day total exposure indices into three risk levels. The risk stages, jointly with the ship's attributes, have been put into quick response codes colored red, yellow, or greenish to signify high, medium, and minimal risk, respectively.

4. ANALYSIS OF SHIPPING TRAFFIC PATTERNS

Vessel densities are information products that illustrate the spatial distribution of vessels and marine activity in designated locations; they are extensively utilized to comprehend shipping operational trends. Multiple methods exist for calculating vessel densities from AIS information. This study uses a method for estimating density maps by aggregating the lengths of all tracklets that contact each cell of a predetermined grid within the area of interest. The cell's area reduces the resultant quantity in square miles of water. This choice is based on the fact that the generated maps depict the number of explored miles; hence, the unit of measurement is nautical miles. It can be interpreted as the two-dimensional integral of the density across a specified area by excluding any distortions from the projection. Density maps offer a supplementary viewpoint on the evaluation: whilst the latter delivers a composite quantitative assessment of alterations in shipping activity, the former precisely illustrates the spatial distribution of these modifications.

The analysis concentrated on a month, specifically from the thirteenth of March 2019 to April 2020, to maintain brevity. Rather than merely displaying the density across two times that are comparable to emphasize variations from one year to the next, the research calculate the variations and assign colors to every grid cell based on an ordered colormap: if the contents of a cell in 2020 is markedly greater than that in 2019, it is rendered bright yellow; inversely, if a cell's appreciate in 2020 is significantly lower than in 2019, it is depicted in dark purple; values that exhibit minor changes in 2020 relative to 2019 are represented in gradients from blue to greenery. Thus, locations characterized by an abundance of purple-colored cells indicate regions wherein vessel travel significantly decreased in 2020 compared to the prior year; regions dominated by brilliant yellow signify areas with a rise in traffic 2020 relative to 2019.

The research generated density maps in three regions: globally, in the area known as the Mediterranean Ocean, and in the vicinity of the Suez Canal (SC). It illustrates a noticeable decline of activity along significant shipping routes, including the passage from the Strait of Malacca, Malaysia to the Mediterranean Ocean via the Canal of Suez, the path between the United States and the Strait of Gibraltar, and areas surrounding the West African coast and the peninsula of Spain, among others. Examining the number of dry and wet bulk ships indicates an overall rise in navigation in certain areas, such as the Canal of Suez and the East-West route toward the Cape of Good Hope. At the same time, a decline is observed in other places, particularly along various Atlantic routes linking the European Union to South and North America. Overall, all segments of commercial shipping exhibit heightened activity in the East and South China Seas, indicating China's endeavor to restore normalcy more rapidly than other nations. The high volume of passenger ship traffic further substantiates that this category was the most adversely impacted by the epidemic, as seen by a significant decline in shipping operations worldwide. The minor increases in activity, such as between the Cape of Good Hope and West Africa, or off the coastline of South Australia, are attributed to the homecoming activities of the cruise ship personnel and passengers.

3.1 SC

The SC facilitates rapid links between Europeans and the Near and Far East. It plays a pivotal role in trading and warrants a more concentrated investigation. A recent market study by the Baltic and International Maritime Council (BIMCO) indicates that travel through the SC has remained robust. A substantial rise in the traverses of fuel tanks and dry bulk carriers mitigated the reductions in container ship traverses, as reported by BIMCO. The density maps align entirely with BIMCO's findings and offer additional corroboration for this evaluation. This mainly results from the heightened number of vessels circumventing the SC, opting for a path around the Cape of Good Hope, driven by reduced fuel prices and diminished demand in European marketplaces.

3.2 Mediterranean Ocean

The examination of traffic density variations between 2020 and 2019 in the Aegean Ocean, illustrated in Fig., indicates a scenario akin to that previously addressed in the vicinity of the SC. Examining AIS data for container ships reveals a mixed scenario, characterized by a significant decline on the west coast, given that lockdowns in Italy, France, and Spain were implemented earlier than in northern nations, such as Europe. The examination of the numbers of both moist and dry bulk cargo vessels indicates an overall rise in transportation in most locations, except Italy, where a significant decline is noted.

5. CONCLUSION

Mitigating and managing the escalating threat of C19 smuggled from abroad has become a primary worry for numerous nations as they implement strategies to safeguard their populations and rejuvenate the economy. This study presents a data-driven and artificial intelligence methodology to automatically and dynamically assess the international C19 risk associated with shipping. It acknowledges the significance of brought-in risk and its potential for global applicability. It offers decision support systems to avoid C19 illnesses from ocean-going vessels for all nations involved. The efficacy of the proposed methodology was demonstrated and implemented on a real container vessel, which effectively generated a daily record of total exposure indices and risk assessments for the experimental vessel.

The demonstrative actual ship application indicates that the suggested approach applies to epidemic risk monitoring across most vessels. Provided that ship AIS information is accessible, the model concepts might be employed to assess the contamination risk of a boat on every day of the week. This document primarily targets international sailing vessels, although it applies equally to domestic commerce and waterway ships.

The suggested approach can ascertain a vessel's exposure indices and risk levels near any nation, assisting various countries in preventing the importation of illnesses. The epidemic has significantly disrupted the cargo schedules of numerous ships. It is customary for vessels to bypass ports, potentially resulting in a discrepancy between the actual navigation path and the timetable. The utilization of AIS data facilitates precise monitoring of ship paths and offers significant insights into ship behavior.

Numerous avenues remain to enhance the technique at both the informational and analytical levels. The whole travel record of a seaman and the actual exposure circumstances during their visit to a place substantially affect the risk of illness. Infection information and associated risks are further delineated at the local and port levels; however, such information is not always accessible. The danger of ship disease is indeed correlated with the preventive measures implemented by the respective ports and nations. Due to its qualitative evaluation challenges, this component has not yet been incorporated into the modeling technique. Although the existing methodology is utilized for maritime paths and assessing ship infection dangers, the basic concepts are applied in terrestrial and aerial trajectory circumstances with few modifications.

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