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Maritime Workers Exposure to the Spread of Covid-19: Seaports to-and-fro Urban Center Interaction Health Safety Guide

Nwokedi Theophilus Chinonyerem[1], Ogwo Nwokeka[2], Eru John Udevieme[3], and Anyanwu Julius Okechukwu[4]

1. Department of Maritime Management Technology, Federal University of Technology, Owerri, Imo State, Nigeria

2. Department of Transport Management Technology, Federal University of Technology, Owerri, Imo State, Nigeria

3. Department of Maritime Transport and Logistics, Nigerian Maritime University, Okerenkoko, Warri, Delta State Nigeria

4. Department of Maritime Transport, Nigerian Maritime University, Okerenkoko, Delta State, Nigeria

Abstract: The study assessed the risk of exposure of shore-based and ship-based maritime workers to the spread of covid-19 pandemic by estimating the level of human-infective covid-19 pathogen-hosts to which the maritime workers are exposed per square kilometer of travel to-and-fro the ports; in the course of their routine travel interactions between the urban cum sub-urban built environments and the seaports as the domain, base and major host of most maritime operators. With the aim of providing knowledge to achieve the objective of flattening the curve of transmission of covid-19 between the maritime sector and other build environment types; the study identified the urban centers and the suburbs in the port cities comprising the Western, Eastern and Delta ports in Lagos, Warri and Onne/Port-Harcourt respectively as the covid-19 hotspots in each maritime region in Nigeria. It used the proximity model to analyze secondary data on confirmed covid-19 cases in each city to estimate the risk of exposure of maritime workers in each port zone to the spread of the covid-19 pandemic based on the proximity of the maritime port zones to the urban centers and the suburbs as covid-19 hotspots. It developed an exposure risk matrix for the Nigeria maritime industry as health safety guide for maritime workers in the course of their travel interaction from the port to-and-fro the city centers and sub-urban built environments.

Key words: Maritime-workers, exposure, covid-19, health, safety.

1. Introduction

The built environment(BE) representing the entire collection of both work and residential environments harnessed by humans including buildings, transport infrastructures and other artificially-built spaces have been identified as critical covid-19 domain and hosts; as a result, they constitute a major area of attention in the control of the spread of the covid-19 pandemic [1]. This is because direct-human-to human transmission has been identified in many studies as the fastest pathways for the transmission of the disease [2]. Its implies that strategic planning of the management of the built environment types in the face of spatial interactions among the different BE types, offers a good option of halting the spread of the covid-19 pandemic and flattening the transmission curve.

Leslie et al. (2020) [3] pointed out the necessity of having good knowledge of the potential transmission dynamics of COVID-19 within each BE ecosystem, given the disproportionate infective capacities, spatial dynamics, vulnerability levels in the individual BE ecosystems that potentially promote the spread and transmission of COVID-19. This knowledge is important in order to that human behavior in the course of interaction among and between built environments can be planned and be proactively influence to achieve a desired outcome of aiding the achievement of decline in the spread of covid-19 by flattening the curve of its transmission. Since human

Corresponding author: Nwokedi Theophilus Chinonyerem, M.Sc; research fields: maritime safety and environmental health. E-mail: nwokeditc@gmail.com.

populations in built environments are covid-19 pathogen hosts/carriers and potential transmission vector pathways; influencing model of behavior and interaction between individuals in infective communities and non-infective community will help to prevent the spread of the disease across spatial locations [1, 4, 5].

The seaports represent shore-based built environment in the maritime industry, domain of dockworkers and a host to ships of various types and maritime industry personnel of all kinds. The covid-19 pandemic has created issues related to the shipboard interface between seafarers and shore-based personnel during port calls. These issues are often related to the ship's crews and shore-based workers, such as agents, inspectors, pilots, stevedores, surveyors etc., following conflicting procedures to mitigate the risk of infection related to the virus. The statistics of confirmed cases of covid-19 made public by the Nigerian center for disease control [6] does not provide information on the exact residential and work locations of the infected individuals. As a result, maritime workers and like other groups are not aware of the exposure risks the face in their travel interactions to-and-from work and even at work. Exchange of vessel crew/seafarers in ports in the characteristic manner of work-shift strategy in practice in the global maritime industry has seriously faced friction following the covid-19 outbreak as a result. While some maritime jurisdictions place outgoing crew on compulsory fourteen (14) days quarantine before re-integration with their individual homes in the residential built environments; replacing crew follow similar process of been quarantined four 14 days prior to getting placed onboard. These challenges has seen maritime jurisdictions proffering differing procedures and standards are currently being set globally for shore-based workers by national Administrations, local authorities, professional organizations and employing companies compared with those being set by flag States and shipping companies to be followed on board ships by ship's crew [7, 8].

Aside ensuring safety at the interface between the shore-based and ship-based maritime workers at the port, to holistically guarantee safety of all categories of maritime workers; the routine interaction between the visiting seafarers, shore-based personnel and other categories of maritime workers and the urban cum sub-urban built environments and settlements represent covid-19 infective pathways in the maritime transport system that also needs to be controlled, and managed to flatten the transmission curve and spread of the disease. To achieve this, there is need to limit the exposure to covid-19 risks faced by the ship, the shipping crew and shore-based maritime workers in each identified covid-19 infective travel/interaction pathway. Thus, knowledge of the quantum of disease carriers in each pathway gives an idea of the intensity and concentration of the covid-19 pathogen host in each identified pathway and is necessary for the workers to guide against infection in the course of their interaction. In Nigeria, confirmed cases of covid-19 have not been reported in the maritime industry as at the time of this writing this article. But all the maritime port zones comprising of the Western ports, the Delta ports and the Eastern Ports have had confirmed covid-19 cases in the urban and sub-urban settlements from which most maritime workers access the seaports (maritime zones) for work. By implication, we can view the urban and sub-urban built environments in the port cities/zones as the covid-19 hotspots in each maritime zone such that the exposure of maritime workers in each zone to the spread of the pandemic can be measured based on their interaction with and proximity to the urban cum sub-urban settlements which are covid-19 host domain [9-11]. Maritime worker interaction with and proximity to covid-19 infective domain and pathogen hosts poses danger and risks of exposure and vulnerability to infection such that human behavior in the maritime environment must be planned to limit such interaction and proximity induced exposure in order to ensure that the curve of spread and transmission of the disease in flattened for safe maritime operations [12, 13].

This is the reason why most maritime authorities request each ship to furnish the port authorities with details of previous and last ports calls prior to arrival within their ports. Ships that traded in proximity to covid-19 hotspots are quarantined in line with general covid-19 standard regulations as they seek access ports. Given that the health of the seafarers and shore-based maritime workers is vital for the continuous operations of the port logistics sector; it is not adequate to seek knowledge of the level of exposure to covid-19 transmission between shore-based personnel and ship-board personnel as vessel access the port interfaces. A more holistic approach will involve understanding also the level of exposure to the spread and vulnerability to covid-19 infection in the course of maritime workers interaction with the urban cum sub-urban populations in the seaport regions. This will provide a good guide to maritime workers to proactively guide against covid-19 infection and flatten the curve of transmission.

As a result, flattening the curve of transmission of the pandemic in the seaport environment cannot be done in total isolation of the adjoining built environments and cities as covid-19 infective interaction pathways.

To achieving a maritime industry free from covid-19 and promoting the health and safety of the shipping crew and shore-based personnel, influencing behavioral change in line with the theory of planned behavior and social distancing rules will require the implementation of proximity-based exposure risk measures to address the spread and transmission of COVID-19 among all personnel involved in port-to-ship-interaction pathways, ship-to-ship-interaction pathways, external-port-to-port-interaction pathways, internal-port-based interaction pathways, internal-ship-based-interaction pathways, on one hand; and between the built environment of the maritime industry consisting of seaports cum ships and the work and residential built environments in the city centers and sub-urban areas on the other hand. Concentrating combative efforts only on the maritime industry will only ensure that a healthy port today is infected with the virus on a later date after interaction with an infective pathway beyond the seaport environment [14-18].

In Nigeria, maritime workers in the Western, Delta and Eastern ports of Lagos, Warri, and Onne-Port-Harcourt faces the risk of exposure to the spread of covid-19 infection in their daily and routine travel interactions to work to-and-from the urban cum sub-urban settlements in the port cities already identified as covid-19 infective-host domains. The seeming lack and inadequately of information on the risk of exposure to covid-19 spread of the infection facing the shore and ship based maritime workers associated with their proximity and interaction with the urban cum sub-urban settlements necessitated this study. They study therefore aims to estimate the maritime workers exposure to the spread of the pandemic in the course of their travel interactions with and proximity with to the urban centers in the various ports of Lagos, Warri and Port-Harcourt. This knowledge will form a useful health and safety guide for the maritime workers in their interaction with the urban and sub-urban centers from the base seaports. The maritime locations covered are shown in Fig. 1.

See Fig. 2 below for the identified total interaction pathways between ports and the urban cum sub-urban built environments in Nigeria.

The purpose of this work therefore is to develop a covid-19 exposure risk matrix based on proximity models for dockworkers, seafarers and other maritime workers interacting with and/or accessing the seaports from the urban cum sub-urban settlements in Nigeria. The overall aim being to flatten the curve of spread and transmission of covid-19 and bring about an end to the pandemic, by eliciting a behavioral change that promote social distancing rules in high exposure risk maritime regions, in ship and shore based maritime workers in Nigeria.

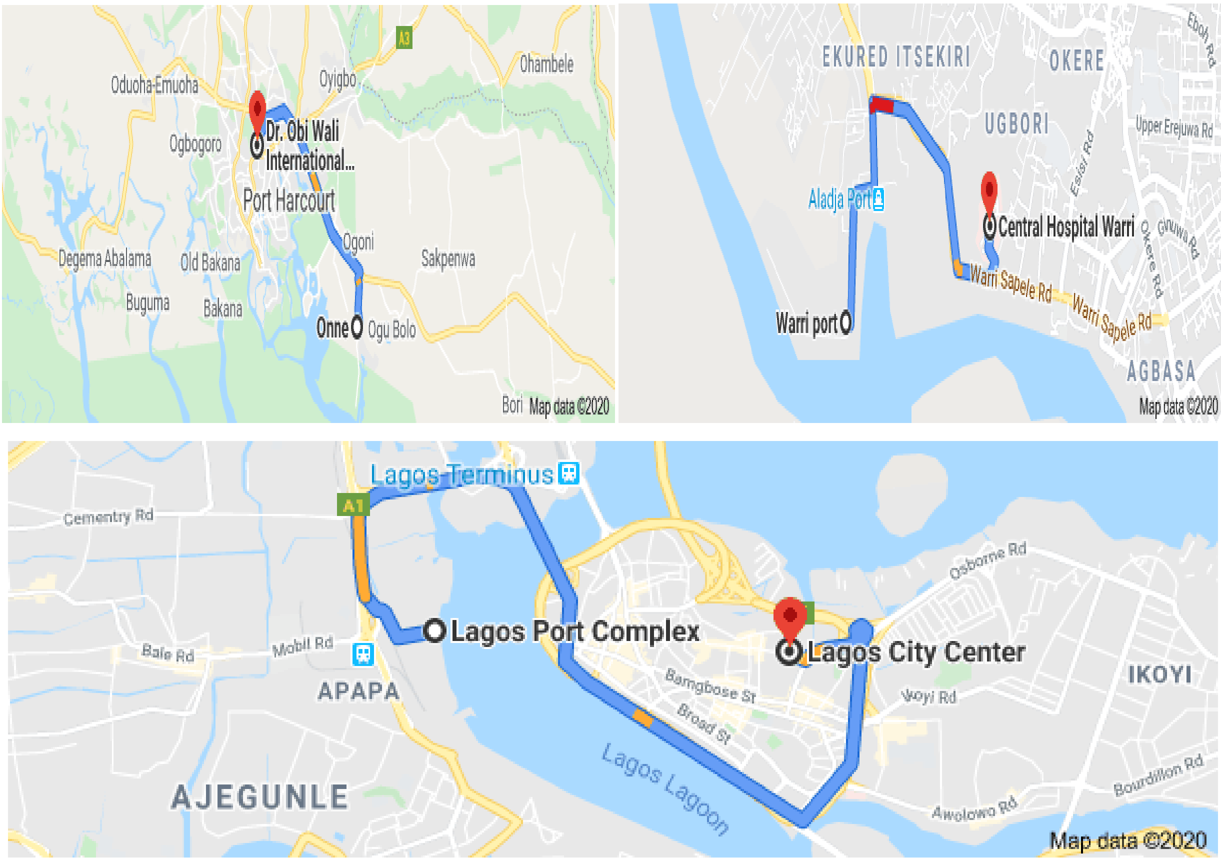


Fig. 1 Locations of Port zones covered in the study and identified pathways to city centers.
Source: Modified by author(s) from City digital maps by Google.

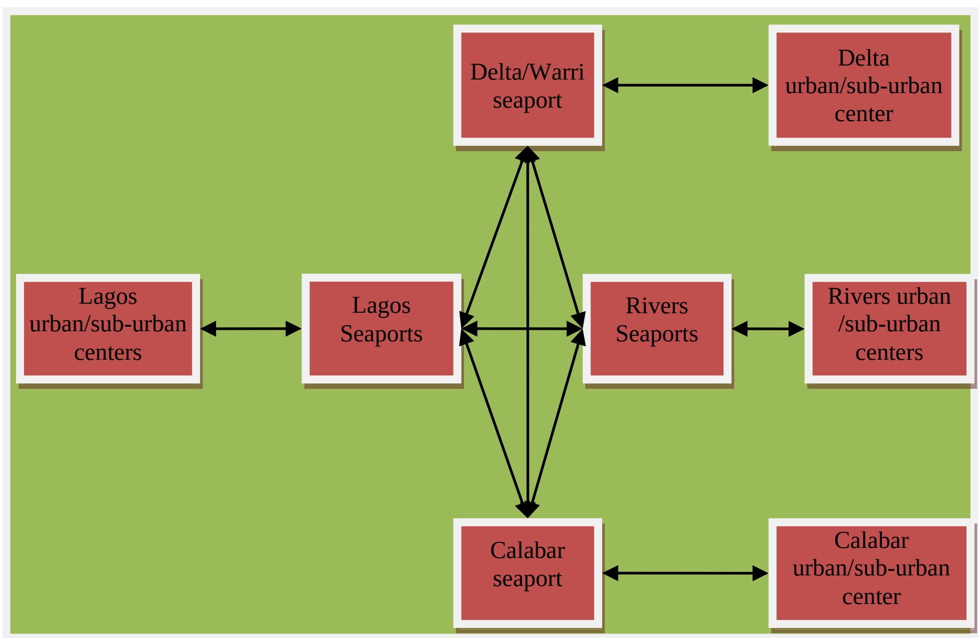


Fig. 2 Interaction Pathways of shore and ship based workers between ports and urban/sub-urban environments and port-port-interactions depicting potential covid-19 infective channels and pathogen hosts.

2. Literature Review

Studies by Leslie, Patrick, David, Mark, Jonathan and Kevin (2020) [3], Andrei, Kenji, Sung-mok, Natalie, Ryosuke, and Hiroshi, (2020) [2] agree that limiting exposure to pathogen host within the built environments will help in curtailing the spread and transmission of the covid-19 pandemic and can be achieved by limiting proximity to infective-hosts. Hess, Bachler, Momin and Sexton (2019) [16] and Brody, Highfielf and Alston (2004) [19] emphasized the importance of exposure assessment in environmental health hazards and disease studies for purposes of developing distancing regulations and metrics for maintaining appropriate levels of distances from infective pathogen hosts to avoid exposure and vulnerability to infection among populations. According to Hess, Bachler, Momin and Sexton (2019) [16], adverse health effects have been made limited by distance-based exposure surrogates. Distance-based exposure metrics thus reflect in variations in vulnerability following the associated distance and duration induced disproportionate exposure.

The international Maritime Organization [20] following the outbreak of the cononavirus disease and the disruptions of maritime operations associated with the disease outbreak issued guidelines aimed at ensuring that the seafarers and other maritime workers are adequately protected from getting the infection. Part of the regulations issued in IMO (2020) [20] is the need to ensure that those working in ports with access to ships are provided with appropriate personal protection equipment (PPE) and other means of preventing the spread of the virus prior to contact with seafarers, while also requesting the corporation of port authorities and shore-based personnel to comply with protocols put in instituted by visiting ships to address the spread of covid-19. Most port authorities as well require the prior declaration of health of shipping crew and all passengers onboard by the Master before ship arrival and access to port facilities [7]. While port authorities emphasized the need to quarantine high risk ships for 14 days before granting access to port facilities after the confirmation of the covid-19 status of the ships, port authorities view is that proximity to and visits to seaports in a covid-19 hotspot or regions increases the risk of exposure, vulnerability and or infection. Both the international maritime Organization [20], Government of the Peoples Republic of Bangladesh [7] and the International Chamber of Shipping [8] recommend working remotely as a way of limiting exposure to spread of covid-19 and proximity to hotspots. The organizations also support a risk management approach to the fight against the spread of the pandemic in the maritime industry in cases where working remotely is not possible.

In the views of IMO (2020) [20], the risk management approach should aim to keep all ship-based and shore-based personnel as safe as possible, with all parties encouraged to work to and see how best to manage risks related to COVID-19. The emphasis on the establishment and implementation of risk control measures to ensure that exposure risks and impacts are pushed to tolerable regions was made a compulsory duty that both shore-based and onboard stakeholders must carry out to promote health and safety in the maritime industry. As an aid to the actualization of this need to curtail the spread and impact of the disease in the industry, the Occupational safety and Health Academy [21] and the International Chamber of Shipping [8] developed a hierarchy of controls as guide for managing and depressing covid-19 risks that prioritizes elimination as first control strategy and option to be established by ship and shore based stakeholders in the maritime industry. See Fig. 3 below for the hierarchy of controls and guide for depressing risk of covid-19 infection and impact in the maritime sector.

ICS (2020) notes that work practices that eliminate the risks of covid-19 transmission onboard ship involves remote work practices such as remote ship inspection that eliminates attendance on board, if the work cannot be postponed and must be carried out immediately. Where attendance and/or interfacing with the ship and/or shore based personnel cannot be eliminated through remote work practices, risk reduction measures as the second priority in the hierarchy of controls can then be adopted to reduce the risk of transmission and infection. Covid-19 transmission risk reduction practices centers on the reduction of the number of persons, for example, ship inspectors and surveyors attending to the work. Work shift strategies can equally be used as a risk reduction measure to reduce drastically the number of persons working onboard and on shore based facilities in the seaports as risk reduction measure in situations where the work cannot be done remotely. It is clear from the foregoing that both elimination and risk reduction control types aim at limiting exposure to covid-19 transmission, spread and infection by eliminating proximity to suspected and/or potential infective-pathways and pathogen-hosts.

Fig. 3 Hierarchy of controls for establishing measures for reducing risk of covid-19 spread.

Once it is obvious that attendance onboard is necessary and the associated risk has been reduced by limiting the number of workers as far as possible, administrative control measures for various stakeholders, e.g., shore-based shipping companies, port authorities, stevedores, onboard administrative controls, etc are timely communicated to all with details on how to control the remaining risks using administrative control measures which must be mutually agreed upon and implemented by all parties [8]. In addition to administrative control measures, the use of Personal Protective Equipment (PPE) in line with the guidelines of the World Health Organization [22], such as the use of face masks; are implemented to further reduce vulnerability to covid-19.

Nallon (2020) [23] agrees that ports in line with the World Health Organization [22] guidelines for quarantining suspected covid-19 pathogen hosts commenced the quarantining of vessels for up to 14 days before allowing ships access to interface with shore-based facilities and personnel in the destination port. The decision to quarantine is influenced by the ship's last port visit and whether it was in a highly infected country. This was following a confirmed case of COVID-19 on a container ship. Thus understanding the level risks of exposure to covid-19 faced by ships and maritime workers based on proximity to covid-19 hotspots will help operators to proactively reduce their exposure and vulnerability risk levels.

Obviously, by prioritizing risk elimination and reduction strategies achieved through remote work practices that eliminates physical presence in the work environment and reduction of the number of workers with physical presence in the work environment for jobs that cannot be done remotely respectively; the hierarchy of controls for curtailing the spread and impacts of the disease developed for the maritime industry as shown above prioritizes limiting exposure to the disease by limiting proximity to the infective-hosts, pathogen sources and infective-pathways.

While much of the available literatures implicitly notes the roles of proximity to the exposure and vulnerability of personnel and ships to the covid-19 infection, they did not consider spatial interaction pathways between maritime workers and other built environment types, such as urban cum sub-urban residential and work settlements, as possible potential infective-pathways and covid-19 pathogen-hosts, that could infect and/or re-infect the maritime environment with the disease. Most literatures on combating the spread of the pandemic in the maritime sector have centered only on internal communication pathways within the maritime industry alone, as earlier identified. There is seeming lack of empirical evidences on the level of exposure and vulnerability of the seaports and maritime workers, to the spread of the disease based on their interaction with and proximity to the pathogen host in urban and sub-urban settlements, in order to elicit safe behavior in line with the social distancing rules, and to promote maritime and port workers health and safety in their interaction with other built environments close to but beyond the ports. The approach of providing covid-19 preventive guidelines for the maritime industry that isolates the built environments close to but beyond it, fails to identify those built environments as part of maritime workers spatial interaction pathways, infective-routes and pathogen-hosts that could infect a health port and/or maritime domain in the course of interaction [24, 25]. These are the gaps which the current study sets to bridge in the drive to curtail the spread and transmission of covid-19 across spatial locations and industries from the perspectives of Nigerian maritime transport and port logistics sector.

3. Materials and Methods

3.1 Sources of Data

Data used for the research were obtained from secondary sources. Data on the confirmed cases of covid-19 in the various port Cities of Lagos, Onne-Port-Harcourt and Warri in the respective Western, Eastern and Delta maritime zones were sourced from the Nigerian center for Disease control [26]. The distance between each port and the urban/city center was obtained from the urban planning Department of the Ministries of Land, Housing and Urban Development in Lagos for Lagos Port, Port-Harcourt for Onne port, Rivers State, and Asaba in Delta state for, Warri Port. This City center was chosen as the datum for measuring the distances to the port because for purposes of urban planning, the city center represents the centriod of all geospatial distances to the city suburbs. Like most disease and epidemic exposure models, we assumed that the infected population in each domain with confirmed cases of the disease remained carriers cannot be cured in the short-run [27]. Though most of the confirmed cases are usually isolated from the asymptomatic population, the study assumes that there is at least one individual among the asymptomatic population that has been infected in each domain with a confirmed case before the isolation. Asymptomatic does not guarantee the total absence of infected pathogen-host but an indication that symptoms have not yet developed. This assumption is validated by the continuous daily increase in trend of confirmed covid-19 cases even with the isolation of confirmed cases in almost all the study areas identified [26]. Given the fact that the NCDC does not provide information on the exact residential and work location, Local Government Area and/or Community/suburb of the confirmed covid-19 pathogen carriers, the study assumed all suburbs of the city to have equal concentrations of the disease while the City centers; having the greatest population of human interaction, host the highest concentration of the confirmed cases such that as the city center is approached from the suburbs, the risk of exposure increases. This assumption validly help us to overcome the challenge posed by unavailability of information on the exact locations within the urban areas that host the greatest of covid-19 pathogen carriers and enables the overcoming of the fear posed by the lack of that information among the population. Using the statistics on confirmed cases of covid-19 in each port city and the distance of each port (maritime zones) to the urban center as covid-19 hotspots; we used the proximity model to estimated the risk of exposure to the spread of covid-19 facing maritime workers in Nigeria in terms of the concentration of human-infective covid-19 pathogen carriers per square kilometer traveled from the ports to-and-fro urban cum sub-urban centers.

3.2 Data Analysis Method

The gravity model provides evidence of the relationship between proximity or distance-based metrics and the magnitude cum intensity of exposure to the flow of hazards, trade, etc between the infective domains and the interacting locations/regions. Thus maritime workers exposure to the spread of the covid-19 pandemic based on the physical interactions between seafarers/dockworkers and the work and residential built environments (WRBEs) within city centers and beyond in the various ports in Nigeria can be measured using the proximity model as a variant of the gravity model [16, 28]. Exposure to the spread of covid-19 as a measure of the concentration of human-infective pathogen-host that a healthy population risks interfacing with in the course of interaction in an environment is indicative of the intensity of the pathogen host per distance of interaction.

Starting with the basic gravity model for trade, Jose et al. (2012) [29] and Schlaich et al. (2020) [30] posit that:

$$F_{ij} = G * \frac{MiMj}{D_{ij}^2} \quad (1)$$

Where:

F_{ij} = spatial interaction induced magnitude of trade flow from origin location (i) to destination (j)

G = constant term, M_i = GDP represent economic size of origin location (i)

M_j = *GDP* representing economic size of destination location (j).

D_{ij} = distance between the two airport locations.

Evidently, distance/proximity is seen from the above equation to influence magnitude of flow and spread of trade and other environmental factors. Thus, the more proximate two spatial locations are, the greater the magnitude of flow between them, and vice versa.

According to Baier and Bergstrand (2009) [31], for econometric applications, it is traditional to specify that:

$$F_{ij} = G * \frac{Mi^{\beta 1} Mj^{\beta 2}}{\left(D_{ij}^{\beta 3}\right)\mu_{ij}} \quad (2)$$

Where: μ_{ij} = *error term.*

Where β_0 = constant term, β_1, β_2, β_3 = coefficient of terms.

Traditional General linear Model (GLM) estimation involves taking natural log of both sides as shown:

$$In(F_{ij}) = \beta_0 + \beta_1 In(M_i) + \beta_2 In(M_j) - \beta_3 In(D_{ij}) + \mu_{ij} \quad (3)$$

Over the years, studies such as those of Xinhuai, Huidong, Dejian and Zhibin (2011) [27] and Hess, Bachler, Momin and Sexton (2019) [16], among others have developed variants of the gravity model such as the proximity model for modeling exposure to the spread of diseases, infections and environmental health hazards from infective host domains to healthy domains.

In particular, Hess, Bachler, Momin and Sexton (2019) [16] developed a proximity model which determines the inverse relation between magnitude/concentration of hazards and/or infectious diseases in an environment and square of the distance between the host sources of the pathogen and the healthy population of interest as a measure of the proposed population's exposure to infection/hazards based on its proximity to the domain of the infective host. Thus proximity-based exposure to the spread of disease or health hazard from infective region i to healthy region j is calculated as:

$$EXPOSURE_j = \sum_{i=1}^{n} \frac{Ki}{D_{ij}^2} \quad (4)$$

Where: K_i = concentration and/or quantity the pathogen/hazard (infective host) in the originating infective domain (i).

D_{ij} = distance/proximity of the infective host domain and the healthy population facing the risk of exposure.

$EXPOSURE_j$ = the exposure of the healthy population to the spread of the disease.

n = number of infective host domains, interaction pathways or spatial locations constituting infective hosts of the disease.

For econometric modeling we write that:

$$In(EXPOSURE_{ij}) = \beta_0 + \beta_1 In(Q_i) - \beta_2 In(D_{ij}) + \mu_{ij} \quad (5)$$

In order to determine the exposure of the seaports (maritime workers) to the spread of the covid-19 pandemic in the maritime sector, we first have to identify the maritime industry interaction pathways which represent potential infection pathways (n). The summation of the exposure levels in all identified infective pathways; represent the overall level of exposure of maritime workers to the spread of the pandemic. We modified Eq. (5) to capture the exposure to the spread of covid-19 pandemic and other environmental health hazards faced by a single healthy population domain (j) in a scenario that more than one spatial location or pathway constitute the infective community (multiple infective pathways); i.e.: i > 1; the exposure to the transmission and spread of the disease is the summation of the exposures from each contributing infective pathway. For example, where a seaport faces exposure to spread of covid-19 via ship-to-port interaction pathway (STP_{ij}), external-port-to-port interaction pathway ($EPTP_{ij}$), urban/sub-urban-to-seaport interaction pathway (UTP_{ij}), and internal-shore-based-port-interaction-pathway ($ISPP_{ij}$); which gives 4 infective domains/regions as a result of physical interaction with the four different infective pathways having varied concentration of the infective pathogen; then I = 4; 4 > 1. The set formed by the infective pathways is as shown in the Fig. 4 below:

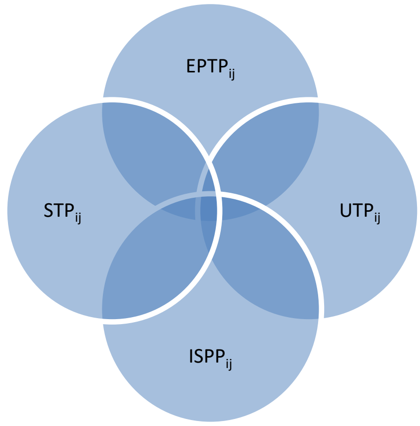


Fig. 3 Using set theory and notation to aggregate the exposure of a port system to the spread of covid-19 pandemic from multiple infective interaction pathways.

The sum of exposure risk to the spread of the pandemic is viewed as the union of the exposure risks posed by each infective pathway.

i.e.: $\text{Total port expsosure to the spread of covid} - 19 \text{ from multiple infective pathways} = COVEXPOSURE_{Tj}$

$$COVEXPOSURE_{Tj} = EPTP_{ij} \cup STP_{ij} \cup ISPP_{ij} \cup UTP_{ij} \quad (6)$$

Eq. (6) can be expressed as the algebraic summation of the level of exposure to the spread of the disease faced by port workers in each infective pathway in the terms of equation above. Thus the risk of exposure to the spread of the disease faced by ports in the 4 multiple infective pathways is summed algebraically as the aggregate of individual exposures faced in all infective interaction pathways is:

$$COVEXPOSURE_{Tj} = \sum_{i=1}^{n} \frac{K_{i-3}}{D_{ij}^2} + \frac{K_{i-2}}{D_{ij}^2} + \frac{K_{i-1}}{D_{ij}^2} - \frac{K_{i-0}}{D_{ij}^2} \quad (7)$$

Since the objective of the study is to determine the exposure of local seaports to the risk of spread of covid-19 based on the ports' proximity to the infective urban city centers, only a single infective pathway, i.e., the urban/sub-urban-to-seaport (UTP) interaction pathway was considered. We used Eq. (4) to determine the exposures faced by maritime workers to the spread of the pandemic in the identified infective pathways.

Similarly, Eq. (7) was used to aggregate the total risk of exposure to the spread of the covid-19 pandemic following the physical interaction of seafarers and maritime workers in multiple ports differing concentration of confirmed covid-19 cases. For example, seafarers call in Lagos seaports and Port-Harcourt seaports and subsequent interaction with the urban and sub-urban built environments in each port regions is expressed as the aggregate of exposures faced in each port region. This is estimated using Eq. (7) as:

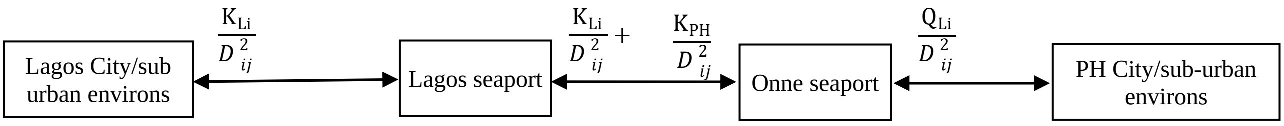
$$COVEXPOSURE_{j(L \cup PH)} = \sum_{i=1}^{n} \frac{K_{PHi}}{D_{ij}^2} + \frac{K_{Li}}{D_{ij}^2} \quad (8)$$

Where:

$$COVEXPOSURE_{j(PH \cup L)}$$

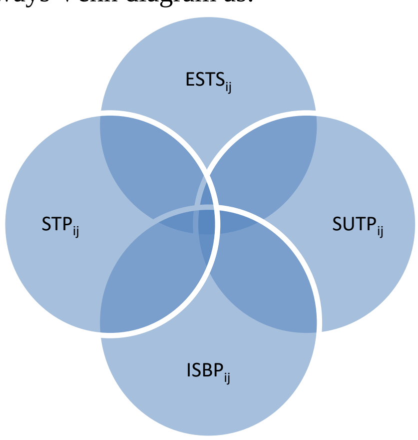
$$= \text{of exposure to covid}$$
$$- \text{19 faced in sptail interaction in each of Port}$$
$$- \text{Harcourt and Lagos port regions.}$$

The infective pathways are broken-down further as follows:



As aforementioned, Eq. (4) was used to estimate port and maritime workers exposure to the spread of covid-19 in infective pathways between the local seaports and urban and sub-urban built environments in the identified maritime regions while Eqs. (7) and (8) were used to measure to dockworkers exposure to the spread of covid-19 pandemic from multiple port regions in Nigeria.

Note that each vessel based on routine geospatial interaction also faces exposure to multiple infective pathways which include: external-ship-to-ship interaction pathway ($ESTS_{ij}$), ship-to-port interaction pathway (STP_{ij}), internal-ship-based-interaction pathway ($ISBP_{ij}$) and ship-to-urban/sub-urban interaction pathway ($SUSP_{ij}$). Similarly, we represent the pathways Venn diagram as:



Similarly the total risk of exposure faced by each ship is the union of the exposre faced in all the infective interaction pathways given as:

$$COVEXPOSURE_{Tj} = ESTS_{ij} \cup STP_{ij} \cup ISBP_{ij} \cup SUSP_{ij} \quad (9)$$

4. Results and Discussion

The result indicates that while maritime workers in the western ports of Lagos are faces covid-19 exposure risks of 49.22 human covid-19 pathogen host (infective host) per square kilometer of human-to-human interaction from the seaport to and fro the Lagos City center; shore and ship based workers in the Delta port of Warri and those in the eastern port of Onne, Port-Harcourt, experience covid-19 exposure levels of 139.12 and 1.66 infective population per square kilometer traveled from the ports to and fro the City centers**.** Consequently, we infer that the shore and ship based workers (maritime workers) in the Delta port of Warri faces the highest risk of exposure to the spread of the covid-19 pandemic. This is followed by the maritime workers in Western port of Apapa, Lagos whose risk of exposure to the pandemic is moderately high and lastly by the maritime workers in the Eastern port of Onne, Port-Harcourt, who faces lower risk of exposure to the spread of pandemic.

Table1 Dockworkers exposure to spread of covid-19 on interaction on pathways between seaports and host port regions/stats in Nigeria.

Interaction Pathway(s)	Lagos seaport ⟷ Lagos City center and suburbs	Rivers/Onne Seaport ⟷ Port-Harcourt City center and suburbs	Delta/Warri seaport ⟷ Warri City Center and suburbs
Exposure to spread of covid-19 (human-infective pathogen-host/Km^2)	49.22	1.66	139.12

Source: Authors calculation

The implication of this to the dockworkers, seafarers and shipping company and port authority staff in there daily and/or routine journeys to and from work leading to the associated interactions with the human populations in the port cities, interactions with humans within the identified port to urban and sub-urban travel pathways must be minimized to be less than the exposure values. For example, since travel from Lagos port to the City center causes each Lagos dockworker and other maritime workers to face risk of exposure to 49.2 human covid-19 infective hosts; the dockworker can only limit his vulnerability to infection by adapting behavioral changes that enables him/her to drastically reduce human-to-human contact on this pathway to be far less than 49.2; among other measures. Also increases in the kilometers of travels to the city center from ports by the workers and human-to-human interactions in each identified pathways increases the workers exposure and vulnerability to covid-19 infection. By implication, maritime workers should in line with the social distancing regulations of the World Health Organization [22] limit their kilometers of travels that exposes workers to increased human-to-human interaction on their individual port-to-urban center travel pathways. These will help limit human exposure to the spread of the disease to flatten the transmission curve of the covid-19 pandemic along port-to-and-fro-urban and sub-urban pathways.

The results of the study also hold very important policy information for port planners and other groups of transport infrastructure planners. As shown by the result of the study, the Delta Port of Warri is the most proximate to the City center with a distance of 3.1kilometer from the Warri City center. Thus, it has the highest level of risk of exposure of maritime workers to the spread of the pandemic. This supports the findings of YU-Li and Batterman S. (2000) [5] and Leslie et al. (2020) [3] that the more proximate a human settlement and/or transport infrastructure is to a source of health hazard, the greater the exposure of the population in the settlement to the risk of harm, damage, infection, death and/or injury associated with the health hazard. Thus planners of transport infrastructures (seaports, airports, etc) should always endeavor to domicile it kilometers away from urban and sub-urban work and residential populations. See figure below showing the maritime workers covid-19 exposure risk matrix as a health safety guide for port-to-and-fro-urban and sub-urban interaction in the various maritime regions in Nigeria. The national maritime labour exposure to the spread of the covid-19 pandemic is determined as by (6) and (7) is 190.06 human-infective pathogen-host per square kilometer. See Fig. 5 below.

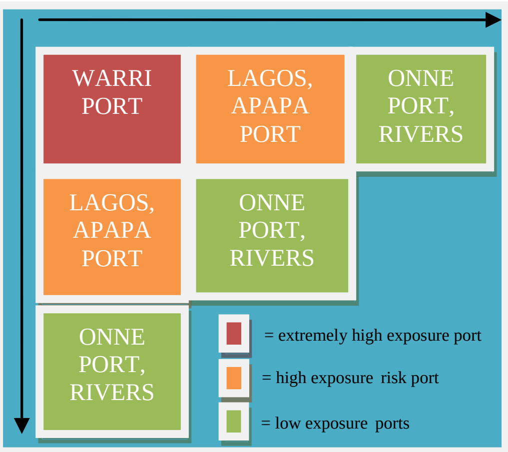


Fig. 5 Risk Matrix indicating the disproportionate exposure of maritime workers to spread of covid-19 in local seaports.

Decreasing order of exposure spread of covid-19 in various ports.

5. Conclusion

From the foregoing, it is obvious that the maritime workers in the various identified maritime port regions are faced with disproportionate levels of exposure to the spread of covid-19 pandemic based on the proximity of the ports as base for maritime operators to the urban centers. The dockworkers in Delta port of Warri face highest covid-19 exposure levels of 139.12 human-infective pathogen-hosts per square-kilometer between the seaport and urban and sub-urban settlements. This is followed by maritime workers in Western ports of Lagos with exposure risks of 49.2 human-infective pathogen-hosts per square kilometer between the port and urban centers; and lastly, Eastern port of Onne, Rivers State, with 1.66 human-infective pathogen-host per square kilometer.

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