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Communication

COVID Pandemics and Inland Transportation in the Brazilian Amazon: A Note on the Risks of Infection in Typical Passenger Vessels

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Abstract: Located in the center of the largest river basin in the world, the State of Amazonas in Brazil has an extensive network of more than 20 thousand kilometers of navigable waterways, which is the main mode of transportation between localities, both for cargo and passengers. The region is practically disconnected from the rest of the country due to the lack of roads. Thus, the Amazon River network acted as an efficient means of transmission of the new coronavirus (COVID-19), rapidly transforming the region into an epicenter of the pandemic with one of the highest infection rates in Brazil. Despite the adoption of national and state measures to combat new infections, the situation continued to deteriorate for reasons still under investigation. Given this scenario, this work aims to identify possible infection risks in typical passenger vessels used in the Brazilian Amazon. Three case studies of different passenger vessels were considered, discussing possible scenarios that could allow the spread of COVID and proposing some recommendations for infection prevention. It is hoped that this communication will contribute to the dissemination of information related to the typical means of long-distance passenger transport in the Amazon, to the planning of infectious disease prevention strategies on board regional ships and to ensure a sustainable future for the Amazonian population. Furthermore, this research aims to contribute to the sustainable development goals of the United Nations 2030 Agenda on health and well-being.

Keywords: COVID; developing regions; inland transportation; infection risk; Amazon; health and well-being; sustainability

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1. Introduction

The Brazilian Amazon basin represents about 60% of the Brazilian river network [1] and covers almost nine states (Figure 1). Most of the municipalities and communities in the Brazilian Amazon are located along the rivers, where road and rail networks are virtually non-existent. As a result, there is little connectivity between the communities, the main northern cities and the rest of the country [2,3]. It is estimated that about 80% of the transport of people and goods in the region is carried out by water. Given this scenario, inland navigation is one of the most important modes of transport in the Amazon region, with relevance for the movement of people and, consequently, for the maintenance of jobs and services in the regional society [4].

Although the region has traditionally been considered remote and practically disconnected from the rest of the country in terms of transportation, the region has been severely affected by the pandemic of the new coronavirus (COVID-19), as presented in [6]. This is an issue of concern for the search for strategies to ensure a sustainable future of the

Amazonian population, as highlighted in the third UN Sustainable Development Goal related to the good health and well-being of all people, without distinction [7].

Figure 1. The Brazilian Amazon region, including the name of states (black letters) and their capitals (color circles) [5]. Figure used under a CC BY 4.0 license (https://creativecommons.org/licenses/by/4.0/).

Turkewitz and Andreoni [6] described the serious situation in the riverside municipalities of the Amazon/Solimões river around July 2020. It was noted that the adoption of protocols with restrictive measures regarding the transport of passengers by water was not enough to prevent the large number of deaths and infections due to the new coronavirus.

Perhaps the first infection scenarios were observed with people arriving in the region by air transport. Then, the Amazon's complex river network, essential for transporting cargo and passengers, contributed to the transmission of the new virus to riverine communities, quickly transforming the region into one of the epicenters of the pandemic, with one of the highest infection rates in the world. It is important to note that in the Amazon region alone, approximately nine million passengers a year use river transport for state, interstate, and national travel [8].

Following the classification of the new coronavirus (COVID-19) as a pandemic by the World Health Organization (WHO) and the worsening of the situation in the northern region of Brazil, national government agencies issued response measures. Some of these measures were specifically related to the transport of passengers by water, such as Resolution No. 7653 of 31 March 2020 [9] and No. 3 of 27 May 2020 [10]. These documents deal with general provisions on board vessels and in port facilities, such as a minimum distance of two meters between passengers, the use of PPE (Personal Protective Equipment), limitation of 50% of the passenger capacity of vessels, embarkation and disembarkation restrictions and mandatory guidance for passengers and crew provided by shipping companies, among others.

Despite these measures, the situation continued to worsen. In March, river passenger transport was banned in the Brazilian Amazon [11]. In July 2020, the six Brazilian cities with the highest rates of exposure to the virus were located along the banks of the Solimões/Amazonas River, with higher values than in Brazilian cities in other regions. For example, at that time, the probability of being infected in Tefé, a municipality of 60,000 inhabitants, was the same as in New York, one of the most populated metropolitan areas in the world [6]. In July 2021, during the "second wave" of the pandemic, Brazil still had the second highest number of COVID-19 deaths in the world, and the state of Amazonas had the highest mortality rate in the country [12].

Scudellari [13], together with health experts, presented a review with models and projections of the pandemic in future years. In all scenarios, the experts agreed that new seasonal pandemic outbreaks would occur even after the vaccination of most of the world's population. The main reason would be the high mutation rate of the virus. In this scenario, new preventive measures are urgently needed, as there are new discoveries about the characteristics of the virus and its mutations.

Due to the recent catastrophic public health situation in the Amazon region and worldwide as a result of the COVID-19 pandemic, a future scenario with periodic resurgence of airborne virus infections is possible [13]. Given the high risk of infection through waterway transport, it is urgent to identify potential risks in order to develop new infection prevention measures on vessels and passenger terminals. This is relevant in the Amazon region and other similar regions of the world, where water transport is necessary for daily activities and where regulation of ship operations is scarce, particularly in remote regions.

This brief communication aims to discuss the potential risks of infection in typical vessels used for the transport of passengers and cargo in the Brazilian Amazon, considering those commonly used in the State of Amazonas. First, relevant proposals for maritime regulations to prevent COVID-19 infection are presented. Then, the main potential areas of infection are discussed for three common vessels in the region, named as: *Gaiola/recreio*, *Expresso* and *Regional ferryboat*. It is hoped that the present research will serve as a basis for the development of new protocols for the prevention of COVID-19 infection based on recommended maritime practices and regulations, as well as new knowledge on the process of virus spread.

This work is organized as follows: Section 2 summarizes key maritime recommendations for COVID-19 infection prevention. Section 3 introduces and describes the three regional passenger ships and Section 4 discusses potential risks of COVID-19 infection in these vessels. Finally, Section 5 summarizes the conclusions of the present work.

2. COVID-19 Prevention Recommendations for Maritime Transport

Following the classification of the new coronavirus (COVID-19) as a pandemic by the World Health Organization (WHO) and the worsening health situation in the northern region of Brazil, Brazilian government agencies adopted response measures. Some of them were targeted to waterborne passenger transport, such as Resolution No. 7653 of 31 March 2020 [9] and No. 3 of 27 May 2020 [10]. These resolutions deal with measures on board vessels and in port facilities.

International resolutions and guidelines can be cited in this regard, such as the *Guide for Public Transportation Pandemic Planning and Response*, issued by the Transportation Research Board (TRB) [14], the Circular Letter No. 4204 and addenda, issued by the International Maritime Organization (IMO) [15], Guidelines on the exercise of the free movement of workers during COVID-19 outbreak, issued by the European Commission [16], and others.

As regards the practical measures established on the basis of these regulations in relation to vessels and passenger terminals, the following should be highlighted:

- Use of face masks in circulation environments (surgical type, PFF2 or N95).
- Provision of alcohol gel at circulation points on ships and passenger terminals.
- Use of alcohol gel or hand hygiene with soap and water whenever possible.
- Frequent cleaning of environments and surfaces.
- Prohibit symptomatic passengers from boarding.
- Social distancing (1.5 to 2.0 m) in circulation areas.
- Limit maximum capacity in common areas with seats.
- Communicate prevention measures through signs, banners, monitors and other media.
- Use membranes to separate environments, seats and hammocks.
- Adopt new air filters for air conditioning, such UV and ozone filters.
- Adopt indoor air quality detectors for CO_2 level (ppm, NDIR-Non-dispersive Infrared sensors).
- Adopt forced ventilation systems in enclosed environments.

– Contactless ticketing for boarding and other vessel activities.

3. Description of Regional Passenger Vessels

3.1. Traditional Passenger Boat (Gaiola)

One of the most common and traditional vessels in the Amazon region, for the transport of passengers and general cargo, are the *gaiolas* ("cages") or "*recreios*". The typical general layout of this type of vessel is multi-deck, with cargo stowage areas on the lower and main decks and passenger areas on the upper decks [17]. The average values for the main dimensions are ~28 m in length and ~7 m in width. The average age of vessels is ~13 years and average capacity ~150 passengers [18]. Their routes connect municipalities and local communities (longitudinal transport). Examples of this traditional type of vessel are shown in Figure 2a,b.

According to regional tradition, the origin of the term "*gaiola*" comes from the arrangement of hammock zones, where passengers swing back and forth, like a bird in a cage [17]. An example of a hammock zone is shown in Figure 2c.

The multideck arrangement with a displacement monohull design dates back to the mid-19th century, when the first steam-powered vessels were introduced to the region, sailing from the ports of Belém, Pará, Brazil, passing through the port of Manaus, Amazonas, Brazil (Figure 2d), and arriving at the port of Nauta, Peru [19].

Figure 2. (**a**) Side of a *gaiola* vessel. (**b**) A complete view of a *gaiola* vessel in the port of Manaus. Credits: Daniel Bitencourtt. (**c**) Typical hammock area arrangement in a *gaiola* vessel. (**d**) Porto de Manaus, nowadays. Figure credits: (**a**–**c**) Daniel Bitencourtt, 2021; (**d**) [20].

The upper decks, typically reserved for passengers, have some cabins in the bow region and large open areas reserved for hammocks, with a minimum area of one passenger per m^2 [21], usually between the center of the ship and the aft region. If a vessel has a galley and a dining room (70% of the fleet) [18], they are typically located in the aft area of the main deck.

As technology evolved, steam engines were replaced by more efficient diesel engines. Hull and superstructure design also evolved, although larger boats were still being built in wood. When welding processes became available, the same traditional shipbuilding

methods, such as a transversely reinforced structure and displacement hull forms, that were used in the construction of new vessels were retained but using combined materials [17]. Today, both materials are used in the construction of new vessels, but wood is slowly being replaced by other materials. In 2009, 95% of the Amazon fleet was built with wood [22]. In 2013, this percentage dropped to 61.6%, followed by 15.7% steel, 13.6% aluminum, and 9.1% fiberglass and other composite vessels [18]. This decline is due to several factors, including increasingly stringent regulations issued by state and municipal environmental agencies regarding the legalization of wood used in shipbuilding [23].

3.2. Fast Passenger Ship (Expresso)

"Expressos" are another longitudinal transport option in the region, pre-planning steel or aluminum boats. With high length/beam ratio (a narrower beam for the same length as a traditional boat), small superstructures and powerful engines, expressos make faster trips on routes similar to *gaiolas*, reducing trips times from days to a few hours [18]. The cost is a more expensive ticket, and there are fewer seats. Examples of expressos operating in the state of Amazonas are shown in Figure 3a.

Figure 3. (**a**) Examples of *expresso* vessels on the port of Manaus. (**b**) Typical interior arrangement of the *Expresso*. Credits: Daniel Bitencourtt (2022).

The typical layout of an expresso is that of a semi-displacement monohull with a single deck, where the passenger seating is located, similar to the layout of a bus, as shown in Figure 3b. Toilets are usually located in the aft section. As their voyages normally do not exceed 12 h, they do not require a galley or refectory room [21].

3.3. Regional Ferryboat

Amazon ferries are barge-type hulled, flat-bottomed vessels. This type of hull is easier to build due to its simpler shapes and lines, which results in larger deck areas [17]. The mean length and beam of this type of vessel are larger than those of traditional vessels, but they operate with shallow drafts. The larger size of ferries translates into a greater capacity for passengers and general cargo. These vessels operate longitudinal (between cities and municipalities) and transverse (river crossings) routes.

Smaller ferries, used mainly for transverse transport, may have a single deck (with physical separation between cargo stowage areas and areas reserved for passengers [21]), but the most common arrangement is a multi-deck design. Some examples are shown in Figure 4a–c.

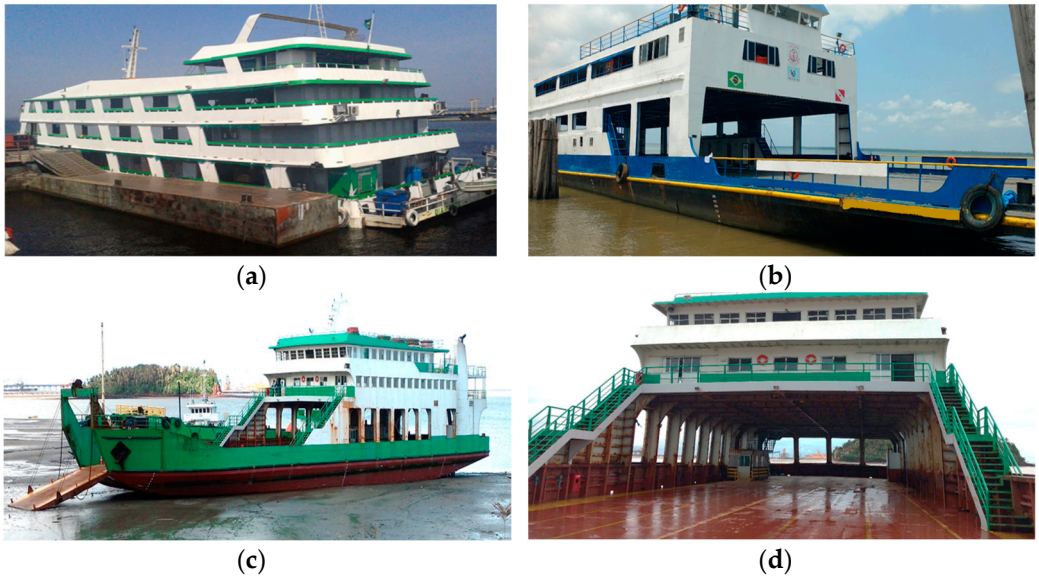

Figure 4. (**a**–**c**) Typical ferryboats that operate in the Amazon region. (**d**) Typical main deck of a ferryboat. Credits: (**a**) [20]; (**b**–**d**) Harlysson Maia (2022).

In this common arrangement, the main deck is used to accommodate cars (e.g., Figure 4a), trucks, and other general and/or heavy cargo (Figure 4d), with an access ramp at the bow (most common). The upper decks are reserved for passengers in air-conditioned (or not) seating areas. In larger ferries for longer routes, there may be some additional cabins (and galleys for trips longer than 12 h [21]).

4. Identification of Infection Risks in the Amazonian Scenario

4.1. Traditional Passenger Boat (Gaiola)

The passenger areas (hammocks and seats) and circulation areas of the *gaiolas*, the type of vessel preferred by some users due to the lower cost of tickets compared to other vessels, are mainly spacious and ventilated areas with large windows, as shown in Figure 5a.

Since the most important factor for infection prevention is the renewal of ambient air, forced ventilation is not usually applied in these open areas. Otherwise, as these hammock areas tend to be crowded (Figure 5b), physical barriers, such as the use of masks and separation membranes, would be more appropriate.

The other common passenger areas on a *gaiola* vessel are the cabins (e.g., Figure 5c), which are limited air-conditioned areas for one or two people, with a private bathroom,

a mini fridge (commonly) and a bunk bed. Specific measures for cabins would be the adoption of UV air filters or ozone in the air-conditioning system.

Figure 5. (**a**) Area reserved for hammocks in an upper deck of a *gaiola* boat (wood). (**b**) Area reserved for hammocks in an upper deck of a *gaiola* vessel (steel). (**c**) Common arrangement of a cabin in a *gaiola* boat. (**d**) Sign in the passenger terminal before the boarding area. It reads "*Do not litter the river/Do not enter without a mask*". Credits: (**a**,**b**,**d**) Daniel Bitencourtt (2022); (**c**) Adapted from [24].

All the other measures would be taken in common and private areas of the vessel (including cabins and hammock areas), such as the use of face masks, prohibiting symptomatic passengers from boarding, frequent use of alcohol gel and cleaning of surfaces, social distancing, issuance of non-contact tickets, use of air quality detectors and communication of prevention measures, such as the sign shown in Figure 5d.

4.2. Fast Passenger Ship (Expresso)

Expressos are faster options for the same routes as *gaiolas*. As travel time is reduced, the potential exposure time to a virus is also reduced. Otherwise, the interior layout is confined, similar to that of a bus or airplane, with a main deck with rows of seats on the sides and an aisle in the center/centerline of the vessel, as seen in Figure 6.

Most expressos have sliding windows and air conditioning. Considering this scenario, preventive measures would be the adoption of UV or ozone filters in the air-conditioning, separation membranes, air quality detectors, mandatory use of face masks, frequent use of alcohol gel and cleaning of surfaces.

4.3. Regional Ferryboat

Passenger spaces on ferries are similar to those on *gaiolas*, but in larger areas. Crossing ferries usually have seating areas with sliding windows, with or without air-conditioning, as shown in Figure 7. Appropriate measures would include mandatory use of face masks, use of UV or ozone filters in the air-conditioning, forced ventilation (if operating with

windows closed), separation membranes, seating signage to enforce social distancing, air quality detectors, frequent use of alcohol gels and surface cleaning.

Figure 6. Interior expresso arrangement with some passengers. Adapted from [25].

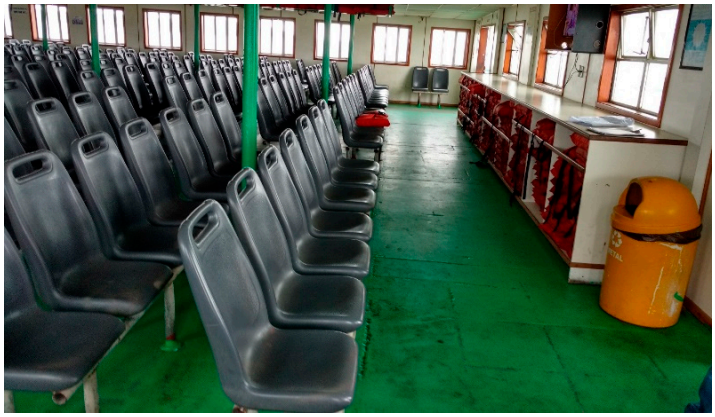

Figure 7. Passenger area with seats in a ferryboat. Credits: Harlysson Maia (2021).

Larger ferries (for longer trips) may have seating and hammock areas, as in the arrangement shown in Figure 7. The recommended measures for hammock areas on ferries would be the same for hammock areas in *gaiola* vessels. All the other measures are recommended for general circulation areas on ferries.

Despite the preventive measures recommended by national and international regulations, it is important to encourage research and the development of engineering studies to identify potential infection risks on ships. A relevant issue is related to the proper distribution of passengers in different types of vessels. At the time of the COVID-19 pandemic, regional regulations encouraged the maintenance of a minimum distance of 1.5 m between people and the mandatory use of face masks [26]. However, specific regulations for different types of vessels, based on scientific research, are still lacking. Therefore, it is important to investigate this topic in order to plan possible response strategies.

In recent years, research has been conducted on the potential for COVID-19 virus transmission on cruise ships [27–30], considering the case of the Diamond Princess cruise ship, which was anchored in the port of Yokohama, Japan, since 3 February 2020, at the beginning of the pandemic. In addition, [31] has investigated the control of COVID-19 infection on board, while Jerome [32] proposed practical procedures to monitor potential infection on board ships.

On the other hand, recent engineering studies have investigated adequate layout of passengers and cargo areas of passenger vessels using numerical methods [33,34], as well as the duration and health impact of COVID-19 outbreaks in cargo vessels using mathematical approaches [35]. Huang et al. [33,34] used computational fluid dynamics

methods to evaluate the dispersion of airborne fluids, such as those derived from coughing, and proposed guidance on the recommended passenger distribution to avoid interaction with the fluid. The most recent application of this approach has been presented by [36], who investigated the distribution of COVID-19 viruses on a fishing vessel, considering various wind and wave conditions. These types of studies could be extended to determine suitable configurations of different types of vessels employed for a wide range of activities in the Amazon, such as smaller, high-speed vessels [37] and floating structures [38]. These marine devices can be used in the Amazon rivers for fishing, scholar transport, research, health care and ambulance services, among other activities involving the transport of groups of people.

5. Conclusions

In this study, the problem of the COVID-19 pandemic in river transportation in the Amazon region was presented in a synthetic way. Three common types of passenger transport vessels in the State of Amazonas were described: *gaiola/recreio*, *expresso* and *regional ferryboat*. These vessels are used in daily activities on the Amazon waterways. The *gaiola* and *ferryboat* vessels operate on a displacement basis, which allows for the transportation of a large number of people, while *Expresso* vessels are semi-displacement vessels that move faster and are used in longitudinal transportation. Like bus transport, these vessels may not have a safe distance between seats, and sometimes there is a lack of regulation on the Amazonian waterways, resulting in unsafe situations. It is concluded that there are different needs to achieve the suggestions of international agencies to prevent infection by airborne viruses. One way to address these obstacles could be to improve the training of crews and users regarding the implementation of preventive procedures. In addition, there is a need for increased enforcement during the trips and at port facilities to ensure that vessels follow prevention guidelines. It is hoped that this communication will disseminate information regarding typical long-distance river transport modes in the Amazon region, which may be helpful for planning and implementing strategies to minimize infectious disease risks in the future. This, in turn, can contribute to the achievement of the third UN Sustainability Developing Goal, which seeks the health and well-being of all people.

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