International Research Project on Emergency Response to Infectious Disease Outbreak on Cruise ships

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Disclaimer

Authors

The report was researched and written by:

Dr Evangelia Chrysikou, Lecturer, Program Director MSc Healthcare Facilities, the Bartlett Real Estate Institute, University College London, United Kingdom

Eva Hernandez Garcia, Research Assistant, University College London, United Kingdom

Eleftheria Savvopoulou, Research Assistant, University College London, United Kingdom

Advisors

Dr Christos Hadjichristodoulou, EU HEALTHY GATEWAYS Joint Action Coordinator, Professor of Hygiene and Epidemiology, Department of Hygiene and Epidemiology, Medical Faculty, University of Thessaly, Greece

Dr Alexis Papathanassis, Faculty of Management & Information Systems, Professor for Cruise Management & e-Tourism, Chairman of the Cruise Research Society, Co-Director of the Institute for Maritime Tourism, Bremerhaven University of Applied Sciences, Germany

Professor Dimitrios Buhalis, Business School, Bournemouth University, United Kingdom
Dr Theodoros Konstantinidis, Laboratory of Hygiene and Environmental Protection, Director Hellenic Institute of Occupational Health and Safety, Medical School for Democritus University of Thrace, Greece

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4. Introduction

Emergence of newly recognized viruses spread with pandemic potential, including severe acute respiratory syndrome (SARS) and Middle Eastern respiratory syndrome (MERS), coronavirus (CoV) and influenza viruses have emerged. The global 2009 influenza A (H1N1) pandemic forced World Health Organization to declare Public Health Emergency of International Concern (PHEIC) facing the limited knowledge on effect, scope and control measures for viruses responsible for respiratory infectious outbreaks under several environmental conditions (Fineberg, 2014). Besides this first declaration, six instances have been in the last decade including the PHEIC of the ongoing coronavirus disease-2019 (COVID-19) pandemic (Mullen *et al.*, 2020).

The respiratory virus infection propagation has involved direct close contact, droplet and airborne, ocular and fomite-mediated routes (Weber and Stilianakis, 2008; Otter *et al.*, 2016; Thompson and Bennett, 2017; Kraay *et al.*, 2018; Abdelrahman, Li and Wang, 2020; C. Bin Sun *et al.*, 2020). Evidence has identified the airborne transmission of SARS-CoV-2 as highly virulent and dominant route for COVID-19 infection (R. Zhang *et al.*, 2020; Delikhoon *et al.*, 2021). Within contained spaces, studies suggest the SARS-CoV-2-bearing aerosols are accumulated, and with sufficiently long surviving time and long-distance for dispersion and dissemination both directly or via ventilation systems (Nissen *et al.*, 2020; Noorimotlagh *et al.*, 2021; Wiktorczyk-kapischke *et al.*, 2021). Several abiotic environmental parameters in limited indoor spaces such as thermal properties, humidity, solid surfaces/interfaces, air stability conditions, air quality, wind speed, ventilation methods, etc. affect the transmission, distribution, persistence, viability, survivability and infectivity of SARS-CoV-2 (Deng *et al.*, 2021; Kumar *et al.*, 2021; Rahimi *et al.*, 2021; Wiktorczyk-kapischke *et al.*, 2021). Their inter-relationship with biotic elements such as population density, behavioural characteristics, viral and host factors, in combination with hygiene practices, sanitation, medical care facilities, etc., impact on the dynamics of COVID-19 (Kumar *et al.*, 2021; Meyerowitz *et al.*, 2021).

Implementation of non-pharmacological interventions (NPIs) will continue to be essential in controlling COVID-19 spread as given the medium-term impact of protective efficacy and duration of vaccination and natural immunity against SARS-CoV-2 remains uncertain and so illustrating various scenarios in the COVID-19 trajectory next years (Saad-roy *et al.*, 2020). Even assuming the best-case vaccination scenario in terms of efficacy and coverage, the adherence to NPIs before safely resuming pre-pandemic activities ensures a decreased infection risk and hospitalisations (Patel *et al.*, 2021).

The collective response to the pandemic has also, in turn, created substantial economic effects across many sectors of our economy. The COVID-19 pandemic has heavily affected cruise operations both in the EU and globally. The restart of this important economic and employment activity needs to be gradual. Cruise operators need to ensure that cruises do not pose unacceptable health risks to passengers, staff and the general public, in particular when compared to other types of package holiday. The safe operation of any cruise ship normally requires the involvement of several parties, such as the cruise company, the ship's master and crew, the ports and terminals where the ship will berth/anchor, the Flag State and the Port States. The cooperation of these main parties concerned is essential to restart (or continue) safe operations and to respond to the challenges posed by the COVID-19 pandemic [Bottom up].

In the cruise ship context, because of indoor place-specific characteristics such as the long-term person-to-person contact, the complex passenger movement flows, smaller internal spaces, confined air-conditioned environment, deficient medical care facilities and defective infrastructure aboard can result an incubator for infectious diseases (Moriarty *et al.*, 2020). Cruise ships are semi-closed environments providing shared facilities for many people on board. Since the beginning of the COVID-19 epidemic, outbreaks have been reported on board cruise ships affecting both passengers and crew. Unprecedented challenges were faced by both the cruise ship industry, the public health authorities and all related sectors in dealing with cruise ship evacuations and management of outbreaks of COVID-19. Simulation analyses in the transmission dynamics of contact based infectious disease on a cruise ship scenario revealed that the virus transfer rate between surfaces determine the circularity of virus distribution, differing across the different functional areas (Zhang *et al.*, 2016). Travel-related control measures on time in cruise ships such as the entry and exit screening approaches, a combination of symptom-based and Polymerase Chain Reaction (PCR) testing for asymptomatic individuals, with subsequent observation during quarantine along with other travel measures can delay the infectious outbreak (Burns *et al.*, 2020). A recent comparative analysis addressing the outbreak containment response instituted on-board ships against COVID-19 and similar novel viral respiratory disease concludes six targets to be considered: active surveillance and disembarkation; do not quarantine on the ship; sanitation and hygiene measures; health education among crew and passengers; immunization if available; and health intelligence such as the knowledge in the infectious diseases prevailing at the next port (Gupta *et al.*, 2020).

Overall, the cruise tourism crisis induced by COVID-19 revealed a systematic failure to manage respiratory infectious outbreaks, having only basic plans focused on acute gastroenteritis threats. The cruise lines needs progress in three factors do not meet in the ongoing COVID-19 pandemic: organizational strategies (contingency plans and mechanisms of risk management), structures (dedicated logistics) and culture, organisational values (A Radic *et al.*, 2020). The global shipping industry is quickly adapting to the new reality of extraordinary precautions for the care and safety of both crew and passengers. This requires heightened levels of hygiene and cleanliness at terminals and on cruise ships. Rethinking passenger flows, cabin designs and onboard experiences through innovative technology and digital solutions can ensure a comfortable and safe journey [Bottom up].

COVID-19 created an unprecedented crisis on global tourism. For more than a year the entire tourism industry internationally was paralysed. The impact of the current COVID-19 pandemic is historic and of biblical proportions. 2020 saw 74% reduction on international of international tourism. As early as April 2020, 80% of flights worldwide were impacted

(International Air Transport Association 2020) and 75 million jobs in travel and tourism were at high risk according to the World Trade travel and tourism council (WTTC). According to IATA (2021), “Air passenger traffic measured by revenue passenger-kilometres plunged by 66% in 2020 which was the biggest shock that the aviation industry has experienced.” IATA confirms December figures reflects stagnating recovery in air travel.

In March 2021 still one in three destinations worldwide were completely closed to international tourism. According to the latest data from the World Tourism Organization (UNWTO), the emergence of new variants of the COVID-19 virus has prompted many governments to reverse efforts to ease restrictions on travel, with total closures to tourists most prevalent in Asia and the Pacific and Europe. Although there are consistent movements towards easing or lifting restrictions on travel, the persistent seriousness of the epidemiological situation has caused governments to adopt a more cautious approach. The UNWTO Travel Restrictions Report provides a comprehensive overview of the regulations in place in 217 destinations worldwide. As of the beginning of February, 32% of all destinations worldwide (69 in total) are completely closed for international tourism. Of these, around just over half (38 destinations) have been closed for at least 40 weeks. At the same time, 34% of worldwide destinations are now partially closed to international tourists. Of the 69 destinations where borders are completely closed to tourists, 30 are in Asia and the Pacific, 15 are in Europe, 11 are in Africa, 10 are in the Americas and three are in the Middle East.

Future developments illustrate uncertainty. The onset of mass vaccination is promising to the extent that there is widespread adoption and herd immunity worldwide. Evidence on the efficacy of the vaccines and their rollout across populations is encouraging for a future rebound of passenger revenues much speculation remains on the level of positive impact in the short to medium term. At the same time, the UNWTO research also indicates a trend towards adopting a more nuanced, evidence and risk-based approach to implementing travel restrictions. Growing numbers of destinations worldwide now require international tourists to present a negative PCR or antigen test upon arrival and also provide contact details for tracing purposes. Indeed, 32% of all worldwide destinations now have the presentation of such tests as their main requirement for international arrivals often combined with quarantine, while the same amount have made tests a secondary or tertiary measure.

The way forward is unclear, especially until 70-80% of the global population develops COVID-19 immunity, the virus becomes endemic and easily preventable with vaccines and treated by medicine. Top tourism markets remain cautious and different governments are issuing advice to their own citizens. Analysis of the top ten tourism source markets currently advising against non-essential travel abroad found they generated 44% of all international arrivals in 2018. UNWTO notes that advice issued by governments will play a crucial role in the restart and recovery of tourism in the weeks and months ahead. If the traveller remains sceptic about whether to be vaccinated, and whether to remain at home, away from the very popular branded dream sun, sea, and sand holiday package the problem will persist for unforeseeable future.

The global economic recession, high levels of unemployment, high taxation to pay for medical costs and investments as well as the furlough bills, and a high degree of failure in the global tourism is bringing a range of challenges in the post COVID era. High rates of cash burn continue (IATA 2021) and threaten airlines and other tourism business. The cash burn metric for airlines is the measure to watch as we seek to predict future trend in recovery. This is fundamental in estimating future survival or failure rates in the sector IATA (2021) suggests. Individual consumer buying power will determine and greatly impact recovery levels. Rebuilding tourism and transport infrastructure will take a minimum of 3-4 years. Encouragingly, the tourism industry and demand from tourists has demonstrated great resilience in the past as recovery from crisis have appeared to be quick with a return to the status quo after a relatively short period.

5. Purpose

This report explores multiple control measures and management strategies for mitigating novel viral respiratory disease outbreak on-board of a cruise ship and brings evidence-based recommendations for an emergency response against current COVID-19 outbreak and future infectious threats.

In order to provide an emergency response from short-term measures and long-term mechanisms rationally, the present guidance analyses why cruise ships promote an opportunistic environment for infectious outbreaks. Additionally, a strategy for reducing the risks for COVID-19 among cruise ship passengers and crew should cover the entire process, beginning at the time of booking and extending until passengers and crew have returned to their homes. National policies for accepting incoming tourists to cross borders and to board cruise ships at the turnaround ports should also be considered in cruise line plans.

This enables the understanding of what abiotic and biotic elements characteristic of cruise ships promote propelled SARS-CoV-2 transmission dynamics, and therefore which measures can have the highest value added to deal COVID-19 pandemic or newly infectious spreads.

6. Mass Outbreaks of Infection on Cruise Ships: Remarks & Challenges

6.1. Built-Environment Characteristics of Cruise Ships

6.1.1. Special Airtight Structures and Internal Microclimate (Intra-Building Transport)

A cruise ship is a closed-off, highly airtight environment that simulates the basic functioning of a city in terms of living conditions and interpersonal interactions (operational cabins, rooms for passenger accommodation, public spaces such as restaurants, theatres, swimming pools, shared sanitary facilities, etc.) but also an opportunistic scenario for community infectious outbreak (Moriarty *et al.*, 2020; Qin *et al.*, 2020). The social mass gatherings taking place in these closed indoor environments may cause superspreading events for propelled virus transmission dynamics and explosive outbreak with many secondary infections from an infected case (Althouse *et al.*, 2020).

Descriptive analysis informed the *Diamond Princess* outbreak was originated from a single introduction event, and initiated from decks for passengers and spread to zones for crew members, possibly through mass-gathering events in the recreational activities and facilities shared on-board (Sekizuka *et al.*, 2020; Tsuboi *et al.*, 2020). Public spaces promote flow of passengers and long stay mass gatherings in dining and entertainment rooms can amplify the infectious spread through contact transmission routes on cruise ships. In addition, some small cabins do not have neither window for ventilation nor natural lighting. Such cabins solely rely on air conditioning to maintain the air quality, which can lead to microclimate stagnation and increase infection risk by airborne (Rocklöv, Sjödin and Wilder-

Smith, 2020). Environmental sampling investigation on the *Diamond Princess* cruise ship showed high rates of SARS-CoV-2 RNA contamination on multiple surfaces inside symptomatic and asymptomatic case cabins after up to 17 days post-occupation, and low rates in common areas (Yamagishi, Ohnishi, *et al.*, 2020).

The unsuitable isolation and quarantine methods on cruise ships based on such semi-enclosed spaces, limited sanitation and restricted water and food supplies could accelerate the SARS-CoV-2 infections among passengers (L. Xu *et al.*, 2020). The potential factors such as air-exchange ratio, relative humidity, temperature, ventilation systems, etc. that could affect the crew and passenger's health outcomes in the *Diamond Princess* cruise ship are reviewed.

6.1.2. Ventilation-Thermal Conditions and Virus Viability and Stability (Aerosol Transmission)

Although some descriptive analysis suggest the close contacts (droplet and direct contact) as primarily responsible for COVID-19 spread on the cruise ship (Yamagishi, Kamiya, *et al.*, 2020), the airborne transmission of SARS-CoV-2 have not been ruled out. Environmental contamination represents a potential source of virus transmission (D. Wang *et al.*, 2020; Van Doremalen *et al.*, 2020). Particularly, data-driven analysis has suggested that the aerosol transmission via the central air conditioning system or drainage systems may have been involved in the transmissibility of COVID-19 on-board the *Diamond Princess* cruise ship (S. Zhang *et al.*, 2020). However, most of network-based transmission models have been focused on the high-density social contact patterns. Research considering the airborne transmission of infectious disease on cruise ships (beyond direct person-to-person contact) found that air change rate could mitigate the infection risk among passengers and crew members (Zheng *et al.*, 2016). Recently, it has been estimated that the contribution of airborne transmission of SARS-CoV-2 was 59% of disease transmission routes on the Diamond Princess cruise ship. Even establishing high ventilation rates and no re-circulating air, the inhalation of aerosols was the dominant pathway for COVID-19 spread among passengers (Azimi *et al.*, 2021).

Available growing scientific data recognises that the virus that causes COVID-19 can be spread through airborne transmission (Zuo, Uspal and Wei, 2020; Noorimotlagh *et al.*, 2021). This evidence led national and international institutions to recognise the airborne transmission and update their guidelines accordingly (Morawska and Milton, 2020). The United States Centers for Disease Control and Prevention (CDC) stated that airborne transmission of SARS-CoV-2 could occur within enclosed spaces that have inadequate ventilation (Centers for Disease Control and Prevention, 2020a). However, the World Health Organization (WHO)'s scientific brief (July, 2020) on modes of transmission describes the aerosolization in health care settings using aerosol generating procedures as a possible infection cause, but neglects including it as a general and plausible mode of transmission (World Health Organization, 2020c).

6.1.2.1. Spatial Distribution of SARS-Cov-2 and Aerosol Dispersion in Air

For oral fluid droplets above a diameter of 100 μm, the sedimentation outcome is insensitive to composition and environmental conditions (Walker *et al.*, 2021), and those droplets between 60 and 100 μm in aerodynamic size fall rapidly on the ground or surfaces by gravitation within 2 meters of distance (Fennelly, 2020).

In general, respiratory droplets emitted by coughing, sneezing or normal speaking in the size range between 5.0 and 10.0 μm have distances of transmission up to 2 meters in indoor environments from infected individuals in quarantine and isolation care (Santarpia *et al.*, 2020), although studies have found that clusters of droplets can spread longer distances up to 4.50 meters for coughing events (Loh *et al.*, 2020) and 8 meters for sneezing activities (Bourouiba, 2020).

The aerosols in exhaled particles generated by breath have a diameter smaller than 4 μm with the median mass represented between 0.7 and 1.0 μm (Bake *et al.*, 2019). Aerosol behaviour is determined by the particle size and ambient conditions (Zuo, Uspal and Wei, 2020). Therefore, these small particle aerosols remain airborne for undefined course if there is no ventilation systems for removal (Fennelly, 2020). Moreover, the exhaled droplets can transform into airborne particles by evaporation. The droplets exhaled by breathing, talking, coughing or sneezing smaller than 100 μm in aerodynamic size are suspended within the puff and go on forward. Those virus-laden droplets can evaporate within cloud and transform into inhalable droplet nuclei which can be transported (late-time dispersal) over large distances dependent on the air currents and turbulent dispersion (Balachandar *et al.*, 2020).

The number of pathogen-laden aerosols is conditional on the biophysical process generating infectious aerosol (Zuo, Uspal and Wei, 2020). Although an infected individual produces virus-laden aerosols in a broad size range, the virions are prone to prevail in those with aerodynamic size smaller than 5 μm (Fennelly, 2020). In a midsize, enclosed room with an infected individual of COVID-19 (constantly speaking and not wearing a mask), the evaporation effects prolong the sedimentation time of expelled droplets initially, increasing the airborne viral load of SARS-CoV-2. This leads to a virion inhalation frequency of at least 2.5 virions per minute by a passive bystander inside room. Even presuming a typical air-exchange rates within the room, this airborne viral load will only reduce the initial droplets of 20 μm insignificantly (Netz, 2020).

Interestingly, it has been estimated that each infected individual of SARS-CoV-2 could carry between 10^9 and 10^{11} virions during the peak infection (Sender *et al.*, 2020). These smaller aerosols are most likely to be deposited in the lower respiratory tract by the exposed individual (Fennelly, 2020; Stadnytskyi *et al.*, 2020), and it is known that inhaling 5 virions can cause infection in adults (Musher, 2003).

The aerosol dispersion in air depend on airflow, typically turbulent flows from ventilation in indoor built environments (Balachandar *et al.*, 2020; Zuo, Uspal and Wei, 2020). The movement of the expelled droplets inside room is mainly influenced by their size, angle, velocity, and environmental factors. For aerosols smaller than 40 μm in aerodynamic size, the gravity and inertia forces are insignificant compared to the effects of indoor airflow (Pendar and Páscoa, 2020). Moreover, the gas clouds emitted by sneezing, coughing and breathing with underlying specific humidity, temperature, momentum and chemical composition can influence on evaporation dynamics and its trajectory (Bourouiba, Dehandschoewercker and Bush, 2014; Berlanga, Olmedo and Ruiz de Adana, 2017; Bourouiba, 2020).

Therefore, the appropriate ventilation system could effectively control the trajectory of aerosols, minimize the virus transmission risk and so promote healthier spaces (Morawska *et al.*, 2020; Pendar and Páscoa, 2020). In addition, the performance of ventilation control system for removal of exhaled airborne SARS-CoV-2-laden aerosols from interpersonal breathing microenvironment (BM) is subject to the limited space air stability conditions (Deng and Gong, 2021; Deng *et al.*, 2021).

6.1.2.2. Viability and Stability of SARS-Cov-2 in Airborne

While in the free atmosphere the virus-laden particles can travel more than 8 m away from an infected person (Rezaali and Fouladi-Fard, 2021), these undergo natural denaturation or inactivation of infectious SARS-CoV-2 dependent on environmental conditions: sunlight, relative humidity and temperature (Mecenas *et al.*, 2020; Schuit *et al.*, 2020; Dabisch *et al.*, 2021; Herman, Biegel and Huang, 2021). In closed, stagnant air settings, the environmental parameters are crucial determinants in the diffusion, dispersion, deposition and residence time of SARS-CoV-2 in the indoor atmosphere (Azuma *et al.*, 2020; Jayaweera *et al.*, 2020; Mao *et al.*, 2020).

In contrast of large respiratory droplets, SARS-CoV-2 can remain viable in aerosols (< 5 μm) for the complete observation time of 3 hours with a half-life of 1.1 to 1.2 hours (Van Doremalen *et al.*, 2020), which is longer than the sedimentation times of droplets (Netz, 2020). Prerequisites of aerosol exposure, inhalation and infection for the disease could occur minutes or a few hours later near from an aerosol source (Bourouiba, 2020). The understanding of abiotic environmental parameters for cross-infection risk is key in the SARS-CoV-2 management, namely in the microenvironments. Moreover, the indoor environmental conditions should meet requirements for both SARS-CoV-2 inactivation and the hygrothermal comfort of the occupants. It has been found that the combination of optimal air temperature and relative humidity for virus inactivation are close to those that satisfy the regular human comfort, suggesting a specific enthalpy around 55 kJ/kg-dry air to achieve both objectives (Spena *et al.*, 2020).

Importantly, the ratio between initial size and the equilibrium diameter may impact on the lifetime of airborne saliva aerosols. This final aerosol diameter is reached after the evaporation effects, which correlates to 20% of the initial diameter, independent of environmental conditions for a relative humidity between 6% and 65%, and for a temperature between 20ºC and 29ºC (Lieber *et al.*, 2021). Overall, by increasing temperature in indoor spaces, the lifetime of airborne SARS-CoV-2-laden particles is prolonged as collision rate between aerosols and evaporated environment molecules (Shadloo-jahromi *et al.*, 2020).

Relative Humidity and Temperature. A substantial number of research has emerged to assess the effect of the thermal properties and relative humidity in the ambient on SARS-CoV-2 viability and COVID-19 spread (Rahimi *et al.*, 2021). A recent systematic study including 27 research papers assessing the stability and viability for SARS-CoV and MERS-CoV concluded that environmental conditions at temperatures ranged between 20ºC and 25ºC and relative humidity (RH) ranged from 40% to 50% could have an effect on virus viability in air (da Silva *et al.*, 2021). The relative humidity (RH) determines the evaporation effect of an airborne aerosols and thus, it is considered an extrinsic factor in the virus stability (Marr *et al.*, 2019). The expelled droplets will start the evaporation process in environments with RH lower than 100% (Netz, 2020). Indeed, it has been measured that at 50% RH (common value for room air), potentially virus-laden aerosols with initial size smaller than 50 μm are evaporated and remain airborne for a long-time, while those larger rapidly dropped on surfaces (Netz and Eaton, 2020). It is suggested that the suspended SARS-CoV-2 is more stable at low temperature and extreme relative humidity (Morris *et al.*, 2020).

Other studies pointed that in indoor settings with RH below than 40%, the SARS-CoV-2 transmission risk are higher than those indoors with RH above than 90%, being an optimum value range between 40% and 60% RH for human comfort and health outcome (Ahlawat, Wiedensohler and Mishra, 2020). However, it has been found that both temperature and simulated sunlight are higher determinant environmental factors on the persistence of SARS-CoV-2-laden aerosols than the humidity factor. In indoor environments (absence of sunlight), the decay time for a 90% aerosolized SARS-CoV-2 was measured from 35 minutes at 30ºC (70% RH), 58 minutes at 40ºC (20 RH) to above than 2 hours for other environmental conditions (Dabisch *et al.*, 2021). Also, other study showed that SARS-CoV-2-laden particles remain stable for hours at 22ºC (Sharma *et al.*, 2021).

Air-Change Rate. Importantly, the intensive temperature gradient (temperature stratification in limited spaces) can propitiate a confinement effect of airborne aerosols in a layer near BM. For ventilation rate (VR) at 3.0 air-change per hour (ACH), the exhaled SARS-CoV-2-laden aerosols are (a) confined in the upper BM for neutral condition, (b) accumulated in a layer at release height of infected individual (in the interpersonal BM) and penetrated towards horizontally both passive and infected individual for stable conditions (the highest infection risk), and (c) deviated from the mainstream rapidly after being exhaled and diluted by ambient air for unstable conditions (Deng *et al.*, 2021). If the VR is increased at 7.4 ACH, it has been suggested that the airborne in the BM is fully mixed by ventilation airflow accelerating the transmission of airborne exhaled aerosols. Under neutral and unstable conditions, the aerosol cloud in BM is dispersed horizontally and vertically to the entire limited space. While under stable conditions, the airborne aerosols remain suspended with a slight expansion and distribution out of the BM (Deng *et al.*, 2021).

By increasing ACH may prolong the rate of the virus-laden aerosol transmission through HVAC systems in connected rooms. It has been demonstrated that higher ACH increases the peak concentration of virus-laden aerosol in the connected rooms from the source room, specifically from 11 to 30 minutes for 1.8 to 12 ACH, respectively (Pease *et al.*, 2021). Similarly, forced-air ventilation systems may increase virus transmission risk. Although the filtration of re-circulating air can reduce spread risk, but it may not counteract the increased transmission risk by high horizontal air-change rates (Farthing and Lanzas, 2021).

Air Quality. It has been evidenced the association between air pollution and risk of severe COVID-19 outcomes (Conticini, Frediani and Caro, 2020; D. Liang *et al.*, 2020). In addition, the contaminants such as particulate matter (PM), nitrogen dioxide (NO_2), and carbon monoxide (CO_2) at high concentrations may sustain the survival of SARS-CoV-2 in the air under certain favorable environmental conditions (Frontera *et al.*, 2020). The air pollutant particles may act as fertile carrier for SARS-CoV-2 (Martelletti and Martelletti, 2020; Tung *et al.*, 2021).

The virus-laden aerosol could operate as sink of pre-existing ultrafine particles of 0.01μm in aerodynamic size (Belosi *et al.*, 2021). The association of $PM_{2.5}$ and NO_2 with the COVID-19 incidence and mortality has been confirmed (Copat *et al.*, 2020), as the SARS-CoV-2-laden small particles can reach upper airways (particles > 3 µm in aerodynamic size) and penetrate into deep airway (particles < 1 µm) with high probability (Madas *et al.*, 2020). Notably, the PM can upregulate the angiotensin-converting enzyme 2 (ACE2) expression in the lungs, and SARS-CoV-2 has high affinity for its receptor, thus may facilitate the viral adhesion and exacerbate the inflammation (Tung *et al.*, 2021). Also, it has been suggested a relationship between SARS-CoV-2-laden $PM_{2.5}$ and design -layout and dimension- of the studied indoor microenvironment (Nor *et al.*, 2021).

Although further investigation is required for understanding the potential effect between the complex interactions of SARS-CoV-2 with air pollution and underlying mechanisms, by enhancing the indoor air quality may decrease the risk of SARS-CoV-2 via ACE2 expression.

6.1.2.3. Internal Circulation System and Ventilation Mechanisms

Poor ventilation in confined indoor spaces is associated with increased transmission of respiratory infections (Knibbs *et al.*, 2011). There has been a number of COVID-19 transmission events associated with closed spaces (Lu *et al.*, 2020; Rothe *et al.*, 2020; World Health Organisation, 2020). COVID-19 is thought to be primarily transmitted via large respiratory droplets, however, an increasing number of outbreak reports implicate the role of aerosols in COVID-19 outbreaks. Aerosols consist of small droplets and droplet nuclei which remain in the air for longer than large droplets (Ong *et al.* 2020). Studies indicate that SARS-CoV-2 particles can remain infectious on various materials, as well as in aerosols in indoor environments, with the duration of infectivity varying based on humidity and temperature (Dietz *et al.*, 2020).

Several outbreak investigation reports have shown that COVID-19 transmission can be particularly effective in crowded, confined indoor spaces such as workplaces and during indoor events, such as restaurants, gatherings and parties, shopping centres, dance classes, cruise ships and vehicles (Leclerc *et al*., 2020).

In addition, studies have addressed the role of ventilation in COVID-19 outbreaks. Three outbreaks involved an index case that was reported to be pre-symptomatic, and ventilation in an enclosed space, aided by air conditioning. [Top Down]. In a restaurant outbreak in Guangzhou, China, there were 10 cases across three families (Li *et al.*, 2020).

Evidence has concluded that Heating, Ventilation and Air Conditioning (HVAC) control systems can facilitate the airborne transmission of SARS-CoV-1 and MERS-CoV in healthcare and community settings (Chirico *et al.*, 2020). Now, It is well-established that HVAC systems have an important complementary role in the mitigation of the airborne transmission of SARS-CoV-2 (European Centre for Disease Prevention and Controls, 2020).

The analysis considering the airborne transmission of infectious outbreak on cruise ships by including several single engineering control measures in the modelling showed: (a) increasing the ventilation rate (VR) of HVAC in crew cabins and restaurants could mitigate the infection risk; and (b) installing High-Efficiency Particulate Air (HEPA) filters or Ultraviolet Germicidal Irradiation (UVGI) devices in the HVAC systems could reduce the attack rate by 84.9% and 87.8%, respectively (Zheng *et al.*, 2016).

In a cruise ship, the internal ventilation method used is mostly regulated by central air-conditioning. Although filters installed in the air-conditioning throughout passenger cabins, the central air-conditioning was ineffective for SARS-CoV-2 removal, indicating that the internal circulation system does not facilitate a supportive environment for quarantine requirements on-board a cruise ship (Liu and Chang, 2020).

The presence of SARS-CoV-2 has been detected in samples of air-conditioning filter (Liu *et al.*, 2020; Mouchtouri *et al.*, 2020). This emphasized the importance of implementing engineering and environmental methods to manage the airborne SARS-CoV-2-laden aerosols and mitigate virus transmission risk in indoor built environments, especially limited spaces. However, if HVAC operational practices are not used appropriately, the systems can contribute to COVID-19 spreading (Correia *et al.*, 2020). Samples of SARS-CoV-2 RNA were detected in the ventilation exhaust filters of central vent ducts at distances over 50 meters from infected patient rooms with vent openings and ACH between 1.7 and 3.0 (Nissen *et al.*, 2020), significantly below the recommendation of 12 ACH for airborne infection isolation rooms (Qian and Zheng, 2018).

Several building ventilation systems, mixing ventilation (uniform distribution of suspended aerosols in the air), natural and mechanical displacement ventilation (contaminants tend to upward to the top of the space by temperature gradient for removal), wind-driven ventilation (outdoor openings of the space) have been examined in terms of fluid mechanics and infectious spread in indoors (Bhagat *et al.*, 2020).

Moreover, experimental studies addressing the dispersion of exhaled aerosols in BM in limited spaces with ventilation system (displacement ventilation system and energy radiant air-conditioning system) and several indoor air stability conditions have found the following:

- Under stable conditions (vertical temperature gradient increases with height), a confinement effect of the exhaled aerosols is produced in BM. Even the supplied air with a relatively high velocity and brought turbulent mixing, the concentrated layer of aerosols is higher than neutral and unstable conditions (Deng and Gong, 2021; Deng *et al.*, 2021).
- In contrast to stable conditions, the aerosol concentration in BM decrease with the combination of displacement ventilation system and unstable conditions (vertical temperature gradient decreases with height) as these are dissipated widely beyond BM (Deng and Gong, 2021).
- High airflow rates can reduce the aerosol concentration in BM under stable condition and displacement ventilation. However, increasing airflow rates in unstable condition, little difference of aerosol levels in BM was yielded compared to lower rates (Deng and Gong, 2021).

Table 1 shows a summary of studies on COVID-19 outbreaks in indoor environments, airborne transmission of SARS-CoV-2-laden aerosols and the role of HVAC systems.

Table 1: The Impact on HVAC Systems on Airborne Transmission of SARS-Cov-2-Laden Aerosols in Several Indoor Settings.

Author and year	Country	Study design	Indoor setting	Role of HVAC system
(Borro *et al.*, 2021)	Italy	Computational fluid dynamic model	Waiting and hospital rooms	Infected droplets in indoor environment are reduced by removal via HVAC system (with doubled airflow rate) or deposition on the surfaces. The use of Local Exhaust Ventilation (LEV) system can completely decrease airborne

				transmission within rooms.
(Pease *et al.*, 2021)	USA	Experimental well-mixed model	Connected rooms. Central HVAC system with minimum efficiency reporting value (MERV) rated filter to the individual rooms	HVAC-related virus transmission. For typical rates of recirculation, higher filtration levels can reduce the viral aerosols and the risk of infection among connected rooms. High air change rate may increase the rate of virus-laden aerosol spread via HVAC systems.
(Kennedy, Lee and Epstein, 2021)	USA	Experimental, modeling	Multi-room facilities	By applying HEPA filtering system on recirculated ventilation air and higher airflow, the infection risk can decrease by 70%.
(Deng *et al.*, 2021)	China	Experimental, modeling	Ventilated room	ventilation system on removing airborne virus-laden aerosols is dependent on the limited space air stability conditions.
(Deng and Gong, 2021)	China	Experimental, modeling	Room with displacement ventilation system	The performance of displacement systems in decrease airborne virus-laden aerosol is affected by the indoor air stability.
(Azimi *et al.*, 2021)	Japan	Modeling. Markov chain model	Cruise Ship. *Diamond Princess*	Airborne transmission by virus-laden aerosols was the dominant mode of transmission. Ventilation rate assumptions of 9-12 ACH and no air-recirculation.
(Lai *et al.*, 2021)	Taiwan	Modeling. Susceptible-Exposed-Infected-Recovery (SEIR) model	Cruise Ship. *Diamond Princess*	Within-deck transmission due to virus-laden aerosols was the dominant transmission route, recognizing the role of air-condition related transmission.

(Liu, Li and Zhu, 2020)	China	Modeling strategy by using parameter perturbation and ensemble simulation	Cruise Ship. *Diamond Princess*	The air exchanges are crucial for controlling airborne virus transmission in the closed settings.
(S. Zhang *et al.*, 2020)	Japan	Observational	Cruise Ship. *Diamond Princess*	Quarantine measures inside ship. Aerosol transmission via the central air conditioning system or drainage systems (intra-cabin transport).
(Mizumoto *et al.*, 2020)	Japan	Modeling	Cruise Ship. *Diamond Princess*	Transmissibility of intra-cabin, but mainly due to close contact transmission. Only diagnosed cases analysis in the modeling. No spatiotemporal distribution of case; no role of HVAC systems.
(Emery *et al.*, 2020)	UK	Modeling	Cruise Ship. *Diamond Princess*	Symptomatic, and asymptomatic cases in the modeling, but no role of HVAC systems.
(Mouchtouri *et al.*, 2020)	Greece	Sampling strategy	International ferryboat; hospital wards; nursing home	Virus was detected on the air exhaust duct surface and filter of wall mounted split air conditioner.
(Nissen *et al.*, 2020)	Sweden	Sampling strategy of central ventilation HEPA filters	Hospital rooms	Virus can be transported long-distances via central HVAC system, increasing airborne transmission risk. Virus found in ventilation exhaust filters located at least 50 meters from infected patient room.
(Anghel *et al.*, 2020)	Romania	Modeling, Computational Fluid Dynamics approach	Intensive care unit room	Dispersion of airborne virus-laden aerosols in indoor by equipped HVAC system.
(Qian *et al.*, 2020)	China	Observational	Workplace, healthcare and community	Poor or insufficient mechanical or natural ventilation.

			settings: home, restaurant, entertainment and shopping venues, hospitals, hotel rooms	
(Lelieveld *et al.*, 2020)	Germany	Modeling	Community settings: office, classroom, choir, reception	By applying high-volume HEPA ventilation, the individual infection risk decreases by a factor of ten.
(Buonanno, Stabile and Morawska, 2020)	Italy	Modeling	Community settings: pharmacy, supermarket, restaurant, post office, bank	The mechanical ventilation systems can reduce the concentration of infected aerosols in indoors.
(Lu *et al.*, 2020)	China	Observational	Restaurant	Droplet transmission was prompted by air-conditioned ventilation system.
(Li *et al.*, 2020)	China	Observational, experimental modeling	Restaurant	Virus transmission due to poor or insufficient mechanical ventilation.
(Liu *et al.*, 2020)	China	Sampling strategy	Hospital areas	room ventilation can reduce the concentration levels of airborne virus-laden aerosols. Droplet transmission is facilitated by air-conditioned ventilation and direction of the airflow is a determinant.
***(Farthing and Lanzas, 2021)**	USA	Modeling; spatially-explicit agent-based model	Community settings	Filtering re-circulating air can reduce virus transmission risk, but this may not counteract the high transmission risk by increasing horizontal air-change rates.
***(P. Xu *et al.*, 2020)**	Japan	Observational	Cruise Ship. *Diamond Princess*	Central air conditioning system does not influence on transmission.

Infection control measures with proven evidence for reducing the risk of SARS-CoV-2 transmission should be emphasized, in accordance with national and local regulations. For example, heating, ventilation, and air-conditioning systems should be maintained in accordance with the manufacturer's current instructions, particularly in relation to the cleaning and changing of filters. There is no benefit or need for additional maintenance cycles in connection with COVID-19. Direct air flow should be diverted away from groups of individuals to avoid pathogen dispersion from infected subjects and transmission. Also, the minimum number of air exchanges per hour according to regulations should be ensured at all times. Increasing the number of air exchanges per hour will reduce the risk of transmission in closed spaces, something that can be achieved by natural or mechanical ventilation, depending on the setting. [Top Down]

Despite the emerging knowledge on the role of environmental factors in close settings, spatial dynamics, effects of ventilation systems on stability and viability of SARS-CoV-2 transmission, further research addressing these aspects is required (Azuma *et al.*, 2020; M. Guo *et al.*, 2021). A broad range of factors could impact on the airborne SARS-CoV-2 detection such as environmental conditions, sampling methods, airflow rate, performance of HVAC systems and application of disinfectants, but ventilation and air filtration should be incorporated as preventive measures (Aghalari *et al.*, 2021).

6.1.2.4. Airborne Infection Controls

Disinfection by Fogging with Hydrogen Peroxide

By spreading the hydrogen peroxide vapour (HPV) together with an air stream around the room, it can be used as a decontamination strategy for microorganisms in closed settings (Pottage *et al.*, 2020). This disinfectant produces reactive oxygen species (ROS) which deteriorate cell components such as DNA, lipids and proteins. Moreover, the inanimate fomites in contact with the disinfectant gaseous are decontaminated. The fumigation of HPV showed to be effective in decontaminating surfaces and furniture of rooms as well as air-conditioning systems ducts (Taneja *et al.*, 2011). The hydrogen peroxide method for disinfection of HVAC system applied to the rotating dehumidification wheels eradicated microbiological contamination (Totaro *et al.*, 2019). However, this airborne infection control should be performed in vacated and pre-cleaned rooms. The disinfectant vapours can irritate the eyes and skin and mucous membrane if inhaled, and the system does not allow a continuous strategy to decontaminate (Oon *et al.*, 2020).

The continuous system using dilute hydrogen peroxide (DHP) have not demonstrated statistically significant effect on the reduction of microbiological contamination of surfaces, but the study design was not blinded (Oon *et al.*, 2020). Overall, research shows that the use of both vapour or dry mist airborne hydrogen peroxide can be an effective infection control method for decontaminant and propose for the systematic application (Falagas *et al.*, 2011; Totaro *et al.*, 2020). Recently, dry fogging a mixture of peroxyacetic acid and hydrogen peroxide (PAA-HP) highly effective against a wide spectrum of microorganisms has been recognized as a suitable airborne disinfection method for efficiently SARS-CoV-2 inactivation (Schinköthe *et al.*, 2021). In fact, The Environmental Protection Agency (USA) has listed several PAA-based disinfectants to be used against SARS-CoV-2 (Environmental Protection Agency, 2020).

Ozone Generators

It has been demonstrated that the gaseous ozone is effective to inactivate bacteria, fungus, parasites, and viruses. The performance of the ozone as a sanitation system has resulted in a reduction above 90% of microbiological contamination (Moccia *et al.*, 2020; Zucker *et al.*, 2021). Therefore, the use of ozone gas as a disinfectant method for SARS-CoV-2 inactivation in indoor areas is emerging. Several studies have evaluated the efficacy of gaseous ozone for SARS-CoV-2 inactivation. It has been demonstrated that in small rooms an exposure of conservative doses between 5 and 10 ppm for a period ranged between 10 and 50 minutes may disinfect efficiently the virus. Moreover, the maximum effectivity of this method is dependent on the humidity which reaches above 90% RH (Blanco *et al.*, 2021).

By using lower concentrations of ozone between 1.0 ppm and 6.0 ppm (as higher concentrations may damage some surfaces and equipment) at 25ºC and RH of 60-80% may inactivate the virus in 55-60 minutes (Yano *et al.*, 2020). Other study found that by applying low doses ranged between 0.23 ppm and 1.13 ppm of ozone and exposure times of up to 70 minutes is highly efficient for virus inactivation at high levels of RH (Dubuis *et al.*, 2020). Similarly, an exposure to a concentration of 4.0 ppm ozone for 30 minutes resulted above 90% of virus reduction (Criscuolo *et al.*, 2021). A recent preliminary study evaluating low ozone concentrations at 0.5 ppm, 1.0 ppm and 2 ppm found a significant reduction of virus contaminant by fumigating during 40 minutes, suggesting the gaseous ozone as a sanitizing method for high-risk indoor rooms (Percivalle *et al.*, 2021).

Importantly, as the risk of lung toxicity to humans of high concentrations of ozone, very low ozone doses around 0.075 mg/m3 (0.038 ppm) in the presence of people could be feasibly for partially mitigation of SARS-CoV-2 spread (Yao *et al.*, 2020; Blanco *et al.*, 2021). Ozone concentration below 0.1 ppm could treat the air inside vacated rooms without requirement of respiratory protective equipment. By using ozone destructors for treating the recycled air in HVAC plenum may contribute to continuous air treatment method in occupied rooms while inactivates the airborne SARS-CoV-2-laden aerosols. Moreover, as applying lower ozone concentrations do not require a high-capacity generator, the system involves more cost- and energy-saving (Dubuis *et al.*, 2020).

Filters

The filters are classified according to their efficiency-class certified by standardised tests (European Committee for Standardization, 2009). For air filtration, although efficient particulate air (EPA), high-efficiency particle air (HEPA), and ultra-low penetration air (ULPA) filters have been widely used for applications of ventilation and air-conditioning in several industries, HEPA filters are commonly recommended to control dust and bioaerosol spread (Farnsworth *et al.*, 2006; Ehsan S. Mousavi *et al.*, 2020). HEPA filtering systems can remove nearly all particles, and are highly efficient in exhaled aerosols of 1 µm in aerodynamic size (Ehsan S. Mousavi *et al.*, 2020). By applying high-volume HEPA ventilation, the individual infection risk may decrease by a factor of ten in indoors, similar to stay in an active room ventilation wearing facemasks (by all subjects)(Lelieveld *et al.*, 2020). Similarly, the installation of HEPA filtering system on recirculated ventilation air besides increasing airflow rate results a reduction of infection risk by 70% (Kennedy, Lee and Epstein, 2021).

Therefore, it has been suggested that HEPA filters may be remarkably efficient in capturing SARS-CoV-2-laden particles and reducing virus exposure and thus, as well as the substitution the pre-existing filters in rooms with HEPA filters as a short-term response (Augenbraun *et al.*, 2020; Correia *et al.*, 2020)(Centers for Disease Control and Prevention, 2020b). Also, the incorporation of portable HEPA filter systems within rooms have shown a highly efficient performance in reducing viral load (Ehsan S Mousavi *et al.*, 2020).

The efficiency of HEPA filters depends on the aerodynamic size of virus-laden particles. HEPA filters do not have properties to actively inactivate microorganisms, but these can capture and hold them in the matrix of the filter (Bolashikov and Melikov, 2009; Goyal *et al.*, 2011). The majority of exhaled aerosols generated by breathing have a median mass between 0.7 and 1.0 µm (Bake et al., 2019), but the SARS-CoV-2 virions has been reported to be between 0.06 and 0.14 µm (Tang, Comish and Kang, 2020). Therefore, airborne SARS-CoV-2-laden aerosol can spread through the HEPA filters outside HVAC system within other indoor spaces (Nissen *et al.*, 2020)(Rezaei *et al.*, 2020). A recent study evaluating whether HEPA filter is capable of filtering particles the size of SARS-CoV-2 virus found a filtration efficiency of 99.9% for all microspheres the size tested (0.02 µm, 0.042 µm, 0.109 µm and 0.989 µm), however future investigation needs to be performed by testing viral loads (Brustowicz and Yuki, 2020).

In addition, it has been shown that those microorganisms deposited in the filters installed in the HVAC systems can be distributed into air ducts and rooms at higher levels of flow velocity such as 30 m/s, and this reemission rate depends on the size particulate and structure. (Miaskiewicz-Peska and Lebkowska, 2012). In addition, HEPA filters do not have ways for self-cleaning or self-disinfecting, and the filter replacement process can result virus transmission risk (Miaskiewicz-Peska and Lebkowska, 2012).

To address some of these issues, several studies have suggested the following:

- The application of a longitudinal air to air heat exchanger (LAIAHE) to the waste heat recovery of the chiller condenser, by producing exhaust air with temperatures ranged between 50ºC and 80ºC and HR ranged between 40% and 50% has been suggested as a system for SARS-CoV-2 elimination (Rezaei *et al.*, 2020).
- Solid oxygen-purifying (SOP) filters meet the potential characteristics for self-disinfecting, filtering and inactivating up to 98.9% aerosol-laden viruses. These low-cost filters can be included in the HVAC systems to prevent airborne transmission (Versoza *et al.*, 2020).
- Gas-phase singlet oxygen ($^1O_2$) generation from panel of light-emitting diode (LED) lights-irradiated and Rose Bengal (RB)-impregnated filter material has demonstrated effectivity for bacteria and virus inactivation as well as air pollutant removal in indoor settings if are incorporated into air purifier device or air conditioning units (Sunday and Sakugawa, 2020).
- Ultraviolet (UV)-C germicidal lamps/irradiation (UVGI) in the 207-280 nm range could reduce SARS-CoV-2 transmission in closed spaces and be implemented both integrating into HVAC system or supplementing it in a fast, scalable, and affordable way (García De Abajo *et al.*, 2020). Upper-room UVGI can supplement natural and mechanical air-conditioning systems if it used the vertical air movement as ventilation method. Bare lamps producing 254-nm UV radiation can be installed above a suspended ceiling with eggcrate ceiling panels to minimise airflow resistance and disinfect airborne particles in occupied spaces (Linnes *et al.*, 2014). Recently, it has been demonstrated that far-UV-C wavelengths ranged between 207 and 222 nm have similar efficiency inactivating

microorganisms, while providing more safety in protecting human health (Buonanno *et al.*, 2016, 2017; Narita *et al.*, 2018). The upper-room UVGI based on LED sources has shown to be efficient for microbial contaminant disinfection in the air within indoors (Nunayon, H. Zhang and Lai, 2020; Yildirim, Kiliç and Muammer Karakaş, 2021).

For SARS-CoV-2 inactivation, the performance of upper-room UV-C technology has been potentially demonstrated and its application suggested in poorly ventilated spaces, especially in buildings where achieving higher VR might not be possible or ways of ventilation or air-conditioning does not exist (Beggs and Avital, 2020). Moreover, the rotating UV-C-LED device could improve the efficacy by 22-50% in spaces where the airborne aerosols are unevenly distributed and poorly-mixed ventilation conditions exist (Nunayon, H. H. Zhang and Lai, 2020). Most importantly, the UV-C irradiation of the HEPA filter surface has shown to be more effective in reducing microbial load than irradiating the air stream for RH lower than 60% (D'Orazio and D'Alessandro, 2020). Regarding the implementation of far-UV-C light in ventilated rooms, it has been shown that by applying this approach the disinfection rates can be increased further between 50 and 85% compared to a room using ventilation method without UV-C device as supplementary (Buchan, Yang and Atkinson, 2020).

6.1.3. Surface Interactions and Virus Viability

6.1.3.1. Fomite Transmission

The detection of SARS-CoV-2 viral RNA on fomites has been reported on *Diamond Princess* cruise ship, even 17 days after the evacuation of passengers (Moriarty *et al.*, 2020).

It has been evidenced that both physical contact with fomites and airborne aerosol sedimentation on fomites (untouched surfaces) can lead to infectious transmission hours and days after SARS-CoV-2 deposition (Fedorenko *et al.*, 2020; Van Doremalen *et al.*, 2020; Orenes-Piñero *et al.*, 2021). The risk of the fomite route depends on the time in contact with infectious viruses (Mao *et al.*, 2020).

SARS-CoV-2-laden droplets post-evaporation shrink to a residue form on surfaces and show long-term stability and durability, and so virus survivability according to the materiality characteristics and environmental conditions increases (Guo *et al.*, 2021). High temperatures and low RH (< 40%) can inhibit the residues, which led to lower survival rates of virus on surfaces and COVID-19 spread through surface contamination (He *et al.*, 2021). In surfaces at 22ºC do not stimulate the degradation of SARS-CoV-2-laden particles and can increase the survivability of virus. However, the SARS-CoV-2 dried out on those surfaces at 34ºC is degraded rapidly (Sharma *et al.*, 2021). Indeed, closed spaces at temperature of 24Cº, the half-life of SARS-CoV-2 on surfaces ranged between 6.3 and 18.6 hours according to RH ranged from 60% and 20%, respectively. While in the room at 35ºC the virus half-life took values ranged from 1.0 to 8.9 hours. It has been found that the times for 90% infectivity loss are by 52 and 21 hours at 24ºC and 35ºC temperatures (Biryukov *et al.*, 2020).

Although the droplet hydration state and environment RH are key aspects in the virus viability, recently it has been highlighted that the virions in human saliva show viability 14 hours after sedimentation on surfaces. This reveals that the association with the components of saliva (the mass of salts, proteins, and surfactants) is also involved in the virus survival (Fedorenko *et al.*, 2020). In fact, the effect of survivability of SARS-CoV-2 in the culture medium with saliva albumin (protein) on aluminium and glass surfaces prolonged its half-life from 2.5 hours and 17 hours respectively to more 96 hours, compared to the virus without serum albumin (Pastorino *et al.*, 2020).

6.1.3.2. Surface Materiality

An important aspect is the decay rate constants of the virus on several fomites, which differ greatly according to the surface characteristics such as surface porosity (L. Guo *et al.*, 2021). Recently, it has been shown that non-porous surfaces present at air temperature of 54.5ºC can promote the 90% infectivity loss in approximately 36 minutes for SARS-CoV-2 (Biryukov *et al.*, 2021). Other similar study analysing the survival rates of SARS-CoV-2 on several common surface types (such as glass, stainless steel, paper, polymer banknotes, vinyl and cotton cloth) demonstrated that at indoor temperature and humidity at 20ºC and 50% RH, the virus remain stable for 28 days on non-porous surfaces, while if temperature is increased at 30ºC and 40ºC, the virus viability decreases for 7 days and 48 hours, respectively (Riddell *et al.*, 2020).

Table 2 summarises the survivability of SARS-CoV-2 on several surfaces collected from various studies. However, the differences of viral stability among these studies may be explained not only the environmental conditions in the experiments, but also the titre of virus used in each investigation and methodology carried out. Although this further insights on SARS-CoV-2 stability on surfaces, it is crucial to strengthen the testing method standardization among investigations to ensure data comparability (Bedrosian *et al.*, 2020).

Table 2: Persistence and Viability of SARS-Cov-2 on Most Commonly Used Surface Material Types

Author and year	Environmental Conditions	Viral stability
	Plastic	
(Van Doremalen *et al.*, 2020)	Temperature 21-23 ºC; RH, 40%	72 hours
(Pastorino *et al.*, 2020)	Temperature 19-21ºC; RH, 45-55%	>96 hours
(Kasloff *et al.*, 2020)	Temperature 20ºC: RH, 35-40%	>7 days
(Riddell *et al.*, 2020)	Temperature 20ºC; RH, 50%	28 days
(Riddell *et al.*, 2020)	Temperature 30ºC; RH, 50%	7 days
	Stainless steel	
(Van Doremalen *et al.*, 2020)	Temperature 21-23 ºC; RH, 40%	48 hours
(Szpiro *et al.*, 2020)	Temperature 25ºC; RH, 65%	72 hours
(Szpiro *et al.*, 2020)	Temperature 7ºC; RH, 65%	>96 hours
(Kasloff *et al.*, 2020)	Temperature 20ºC: RH, 35-40%	>14 days
(Riddell *et al.*, 2020)	Temperature 20ºC; RH, 50%	28 days
(Riddell *et al.*, 2020)	Temperature 30ºC; RH, 50%	7 days
(Riddell *et al.*, 2020)	Temperature 40ºC; RH, 50%	<48 hours
	Cooper	
(Van Doremalen *et al.*, 2020)	Temperature 21-23 ºC; RH, 40%	4 hours
	Aluminium	
(Pastorino *et al.*, 2020)	Temperature 19-21ºC; RH, 45-55%	>96 hours

Glass		
(Pastorino *et al.*, 2020)	Temperature 19-21ºC; RH, 45-55%	>96 hours
(Riddell *et al.*, 2020)	Temperature 20ºC; RH, 50%	28 days
(Riddell *et al.*, 2020)	Temperature 30ºC; RH, 50%	7 days
Paper		
(Riddell *et al.*, 2020)	Temperature 20ºC; RH, 50%	28 days
(Riddell *et al.*, 2020)	Temperature 30ºC; RH, 50%	21 days
Cardboard		
(Van Doremalen *et al.*, 2020)	Temperature 21-23 ºC; RH, 40%	24 hours
Facemasks		
(Chin *et al.*, 2020)	Temperature 22ºC; RH, 65%	96 hours (surgical masks)
(Kasloff *et al.*, 2020)	Temperature 20ºC: RH, 35-40%	>21 days (N-95 masks)
Cloth (cotton)		
(Harbourt *et al.*, 2020)	Temperature 22ºC, RH, 40-50%	4 hours
(Kasloff *et al.*, 2020)	Temperature 20ºC: RH, 35-40%	4 hours
(Chin *et al.*, 2020)	Temperature 22ºC; RH, 65%	24 hours
(Harbourt *et al.*, 2020)	Temperature 4ºC, RH, 40-50%	96 hours
(Riddell *et al.*, 2020)	Temperature 20ºC; RH, 50%	7 days
(Riddell *et al.*, 2020)	Temperature 30ºC; RH, 50%	3 days
Skin		
(Harbourt *et al.*, 2020)	Temperature 37ºC, RH, 40-50%	8 hours
(Harbourt *et al.*, 2020)	Temperature 22ºC, RH, 40-50%	96 hours
(Harbourt *et al.*, 2020)	Temperature 4ºC, RH, 40-50%	14 days

6.1.3.3. Disinfection and Cleaning Action

Environmental cleaning procedures are effective for SARS-CoV-2 removal from surfaces and limit the transmission risk through fomite pathway (Hirotsu *et al.*, 2020). Another aspect is the type and manner of disinfection products against SARS-CoV-2. Inside case cabins vacated by infected passengers in isolation on board of the *Diamond Princess* ship and that were disinfected by hypochlorite spraying, SARS-CoV-2 RNA was detected. This suggests that the use of wiping for environmental surfaces may be safer removing the virus in outbreak conditions (Yamagishi, Ohnishi, *et al.*, 2020). The effectiveness of surface disinfection has been dependently linked to the prevalence rates and contact frequency, suggesting that both hand and surface disinfection are of great importance in community settings (Pitol and Julian, 2021). Therefore, to deal with the infectious spread, the implementation of disinfection routine in the appropriate frequency and intensity, especially the public spaces and environments with poor ventilation is needed (Hirotsu *et al.*, 2020). In fact, through quantitative analysis, when the disinfection frequency on a cruise ship was increased to once per hour, the highest risk had only 600 virus. It has been demonstrated that a disinfection frequency of once every 4 hours is the inflection point to effectively decrease the risk of infection among passengers (Zhang *et al.*, 2016).

The cleaning intervention effectiveness applying UV-C-light, ethanol, hydrogen peroxide, and hypochlorite on most common surfaces has shown a reduction by 99.9% of SARS-CoV-2 (Bedrosian *et al.*, 2020). Recently, it has been highlighted that the different compounds among some biocidal agents used for the virus inactivation does not seem to be an important factor due to SARS-CoV-2 has shown to be extremely susceptible to these common disinfectants (Barrios Andrés *et al.*, 2021).

UV-C-Light

- Short-term deep ultraviolet light-emitting diode (DUV-LED) irradiations (280 nm wavelength and 20 second contact time) on hard surfaces demonstrated a rapid inactivation of SARS-CoV-2 (Inagaki *et al.*, 2020).
- UV-C light irradiation (254 nm wavelength) inactivated rapidly SARS-CoV-2 applied on both dried and wet virus in a contact time of 9 seconds and 4 seconds respectively (Storm *et al.*, 2020).
- Intermittent irradiation of UV-C light (222 nm wavelength) for disinfecting surfaces contaminated SARS-CoV-2 showed a virus inactivation in a fluence-dependent manner (Kitagawa *et al.*, 2021).
- Far-UV-C light (207-222 nm wavelengths) efficiently can inactivate SARS-CoV-2 by 90%, 99% and 99.9% with irradiation of 8, 16 and 25 minutes respectively (Buonanno *et al.*, 2020).

Hydrogen Peroxide (DHP)

- Dry hydrogen peroxide (DHP) fumigation, no-touch disinfection method, has shown to reduce the residual virus microorganisms on surfaces safely for occupied spaces, reaching all areas within a room without interrupting activity inside (Ramirez *et al.*, 2020).

Hypochlorite

- Electrostatic sprayer device which contains 0.25% sodium hypochlorite disinfectant (noncorrosive to common materials) can reduce microorganisms on surfaces and provide rapid decontamination even in large areas (Cadnum *et al.*, 2020).
- Disinfection with 0.1% sodium hypochlorite (exposure of 1 minute) has also shown significantly reduce coronavirus infectivity (Kampf *et al.*, 2020).

Ethanol

- Similarly, ethanol at concentrations between 62% and 71% has demonstrated to reduce coronavirus infectivity within 1 minute of exposure on several surfaces like metal, plastic and glass (Kampf *et al.*, 2020).

Gaseous Ozone

- Gaseous ozone treatment. After 40 minutes fumigation with gaseous ozone at different concentrations (0.5 ppm, 1 ppm and 2 ppm) on various surfaces such as aluminum, FFP2 mask, surgical gown, glass, plastic and stainless steel, the SARS-CoV-2 was significantly reduced on all assessed surfaces, suggesting a suitable disinfectant method in those materials not susceptible to corrosion (Percivalle *et al.*, 2021).

6.2. Prevention and Control Measures

6.2.1. Hand Hygiene Practices and Hand Sanitisers

Cruise operators should ensure that hand sanitizer/hand washing stations or wipes are conveniently placed around the ship for guests' and crew members' usage, especially in high-traffic areas. Additionally, crew members should be thoroughly trained on all aspects of infection control with emphasis on proper hand hygiene techniques. In addition to providing hand sanitizer and hand washing stations on board, operators should encourage hand washing or use of hand sanitizer before and after guests participate in recreational activities. [Bottom up]

Additionally, it has been demonstrated that passengers on-board far away from the restrooms have a higher infection rate than passengers near the restrooms with an increasing probability and efficiency of hand washing. If the control measure of hand washing is kept over 70% of probability, the infection spread can be significantly reduced on board ships (Zhang *et al.*, 2016).

A human being can self-touch up to 50 times per hour in the face, and 68 times per hour in the facial T-zone (eyes, nose, mouth, chin), which may lead to a bidirectional infectious transmission of contact-fomite pathways. So, handwashing frequently is a fundamental instrument to reduce COVID-19 transmission from these involuntary actions (Rahman, Mumin and Fakhruddin, 2020). It has been highlighted that hygiene promotion programmes which include a combination of infrastructural improvement -durable infrastructure associated with handwashing such as water supply systems, sanitation and handwashing facilities- and hygiene promotion result to be highly determinant on the handwashing behaviour (White *et al.*, 2020).

Regarding the effectiveness of different hand hygiene products in reducing virus spread, a systematic review addressing the cleaning hands with ash compared to soap, mud, soil and other materials found uncertain results (Paludan-Müller *et al.*, 2020). In addition, there is no evidence that chlorhexidine gluconate-based antimicrobial soaps have more efficiency than other products such as non-antimicrobial soap, triclosan and alcohol-based products in reducing infection transmission (Baraldi, Gnatta and Padoveze, 2019).

Particularly, alcohol-based sanitisers -mainly products composed by 62-95% n-propyl, isopropyl, ethanol or a combination- have become standard products for handwashing against SARS-CoV-2 during the COVID-19 pandemic, besides the use of water and soap (Jing *et al.*, 2020). However, the repeated exposure to alcohol-based disinfectants restricted to 60% n-propanol can have irritant effects on skin (Tasar, Wiegand and Elsner, 2021). As the hand rubs with certain products may cause acute and chronic dermatitis, qualified sanitisers based on ethanol as the main component has been prioritised for hand decontamination (Yan *et al.*, 2020). In fact, sanitisers based on ethanol at 42.6% concentration inactivated effectively the virus while producing less skin irritation (Jing *et al.*, 2020). Recently, it has been evidenced that those alcohol-free hand sanitisers with formulation including quaternary ammonium compound disinfectants are as effective as alcohol-based products for inactivating SARS-CoV-2 within 15 seconds of contact (Ogilvie *et al.*, 2021).

6.2.2. Face Masks Wearing

To prevent the spread of SARS-CoV-2, cruise operators should require passengers and crew to wear cloth face coverings/face masks in accordance with local/national public health guidelines. The type of face covering (non-medical or medical) should be selected based on the level of risk and the availability of masks. Medical face masks must be prioritized for use as Personal Protective Equipment (PPE) by healthcare workers. [Bottom up]

In cases of passengers with intellectual disabilities who are traveling alone, they may need assistance to navigate. While this wayfinding assistance does not usually require physical contact, it does involve proximity between employee and passenger and therefore hygiene measures including use of face masks, is recommended. [Bottom up]

Additionally, it is advised that passengers should use face masks in transport hubs, particularly when it is a challenge to maintain appropriate physical consistently distancing measures (at least 1.5 metres) In addition to the use of face masks, travellers should observe proper and frequent hand hygiene. [Bottom up]

The use of surgical masks by crew members serving in restaurants, bars, lounges, or small public places could be enforced during an infectious outbreak (Zheng *et al.*, 2016). It is also advisable that precautions should be taken by all shore-based personnel who temporarily board ships during port calls, e.g. inspectors, maritime pilots, ship agents, medical personnel, port workers, shipyard workers etc. to minimize exposure risks. Requirements for protective measures when shore-based personnel board a ship, including which PPE should be used and when, can vary between both countries with different national legal frameworks and shipping companies. The same applies to venues and instances where proper distancing is not possible, including show lounges, casino, gyms, lifts, ship tenders, shoreside terminals and tour dispatch areas. [Top Down, Bottom up]

The use of transparent masks especially by frontline staff are recommended so as to alleviate the communication barrier with passengers who are deaf: for passengers who are deaf or hard of hearing, the availability of detailed information pre-trip via websites, apps, emails etc. will minimize the need for communication at the vessel or port. This is especially important during COVID-19 when the use of non-transparent masks creates a communication barrier for those who rely on lip reading, and physical distancing also limits the ability to hear. Having visors or transparent masks available for frontline staff can help alleviate the problem. [Bottom up]

A saliva droplet dispersion analysis confirmed that face mask-wearing as a protective measure in a closed space can reduce the transition area about one-third of distance above compared to the droplet initial trajectory by a naked face (Pendar and Páscoa, 2020). It has been shown that wearing loose-fitting masks in a room (<100 m^2) with a highly infectious individual does not prevent the SARS-CoV-2 infection. Respirators with high quality, such as FFP2 and FFP3, must be considered in indoor spaces (Lelieveld *et al.*, 2020). Importantly, airborne simulation experiments have shown that medical facemasks (surgical masks and even N95 masks) are not able to block full transmission of SARS-CoV-2 aerosols (Ueki *et al.*, 2020). It has been demonstrated that surgical masks can significantly reduce the aerosol particle emission rates during coughing and talking by 74% and 90%, respectively, compared to not masks-wearing (Asadi *et al.*, 2020). Interestingly, face mask-wearing increases the humidity of inhaled air, hydrating the respiratory tract which has been recently suggested to be a link with lower severity of COVID-19 outcomes (Courtney and Bax, 2020).

Many investigations have remarkably highlighted that the effectiveness of medical face mask-wearing by the general population is dependent on the compliance and adherence to other preventive approaches, namely intensive hand hygiene practices. Moreover, there is no direct evidence sustaining the use of cloth face masks to effectively control SARS-CoV-2 transmission (Chaabna *et al.*, 2021; Daoud *et al.*, 2021), but the adoption of public cloth mask-wearing as a form of source control has been recommended (Howard *et al.*, 2021). Currently, evidence for comparisons about several face mask-wearing in health care and community settings and SARS-CoV-2 infection risk remains uncertain (Jefferson *et al.*, 2020; Chou *et al.*, 2021; Nanda *et al.*, 2021).

6.2.3. On-Board Isolation, Quarantine and Community Containment

Non-pharmaceutical public health interventions to control infectious disease outbreaks can involve: interrupting transmission to non-infected, isolation; mitigating potential transmission from suspected people, quarantine; and reducing personal interactions of unidentified infected community member with non-infected, community containment (Wilder-Smith and Freedman, 2020). The intervention of community containment includes among others social distancing, community-use of facemasks, cancellation of mass-gathering events, and risk areas closures to cordon sanitaire (Wilder-Smith and Freedman, 2020). The implementation of these measures could prevent community transmission on-board cruise ships (Brewster, Sundermann and Boles, 2020). However, these present several challenges and remarks.

Several operational difficulties have been found in the quarantine process on the *Diamond Princess* cruise ship. Although securing traffic lines were demarcated, exceptions may occur as the use of some specific areas or infrastructures on-board may not be available for infected and non-infected passengers separately. The coordination of accepting facilities and transport was challenging: hospital allocation for the infected individuals' isolation and their complex transportation to designated medical institutions; risk of patient deterioration during displacement and transport; expand transportation of family members. Moreover, people isolated inside cabins needed daily supplies (medical, water, food, etc.) with personal considerations like allergy, cultural or religion issues (Yamahata and Shibata, 2020).

Ship-based cabin quarantine has shown to eliminate the interactivity of passengers and likely reduced many new cases, but it is not effective at halting SARS-CoV-2 transmission inside cabins (Nishiura, 2020). Evidence has showed intra-cabin secondary transmission of SARS-CoV-2 among cabinmates during the cabin quarantine period on *Diamond Princess* cruise ship outbreak (Plucinski *et al.*, 2020; Yamagishi, Ohnishi, *et al.*, 2020). Virus transmission toward the end of the quarantine period appears to have occurred mostly within passenger and crew members' cabins (Jimi and Hashimoto, 2020). In fact, modelling the spread of COVID-19 on-board outbreak on the *Diamond Princess* cruise ship revealed that although public health measures reduced infected persons compared to a scenario without implementation, an early evacuation of all passengers and crew members at the onset time of first confirmed case would have prevented many more infected cases (Rocklöv, Sjödin and Wilder-Smith, 2020). The number of infections with COVID-19 could have been reduced by at least 60% if early comprehensive testing and early isolation had been implemented for all passengers and crew members on-board (J. Zhang *et al.*, 2020). This modelling study supports the advice issued by the European Union 'Healthy Gateways" joint action on the 3rd of February for COVID-19 prevention and control (Healthy Gateways, 2020).

Restriction of persons who may have been exposed to a contagious disease may be successful in the early detection of cases when contacts have been traced within a short time frame. The early isolation of suspected passengers and crew members may be critical in controlling the infection transmission. Moreover, the availability reserve staff as relief strategy may allow the continued operation of organisational functions in the ship in the event of an infectious outbreak (Tokuda *et al.*, 2020). Moreover, these types of interventions needs psychological support, food, water and medical supplies (Wilder-Smith and Freedman, 2020). Both passengers and crew members on isolated cruise ships are subject to severe distress and stress, including anxiety, panic, insomnia, fatigue, depression, anger and suicidal intention (Takahashi *et al.*, 2020). Therefore, physical and mental care during the quarantine process should be provided (L. Xu *et al.*, 2020; Nakazawa, Ino and Akabayashi, 2020). A disaster psychiatric assistance team (DPAT) should be introduced. As an important lesson learned from the *Diamond Princess* case, the separation and isolation of family passengers should be avoided. If quarantine, interactive communication tools within the rooms for multi-language and various ages should be incorporated (Takahashi *et al.*, 2020).

Isolating a cruise ship and the ship-based cabin quarantine, keeping people on board is only morally justified if there are no other options such as refused disembarkation. To reduce infection transmission, it has been suggested to transfer all infected passengers and crew members to medical care off-ship to ensure appropriate isolation during the quarantine time (Batista *et al.*, 2020). In case of no other alternatives, isolation of passenger or crew members in their own cabin should be conducted under proper guidelines which address the prevention of intercabin transmission (Yamagishi and Doi, 2020).

6.2.4. Healthcare Provision System on Cruise Ships

6.2.4.1. Medical Treatment

An evaluation and response plan to provide the appropriate medical treatment in case of infected tourists, especially those cruise passengers who are frequently middle-aged or elderly with underlying medical conditions with specific needs and treatment, need to be in place. Systems for preventive care of travel medicine should perform a pretravel risk assessment, analyse passengers' itineraries and select medical supplies and vaccines as well as prepare the pre-traveller and traveller with resources, provide counselling and education on prevention, transmission and self-treatment and self-monitoring to keep infectious diseases on-board at bay (Spira, 2003; Hill *et al.*, 2006).

Points of entry (PoE). The core capacity of PoE should be established under the requirement of the International Health Regulations (IHR) (2005). These should have the essential capacity to identify the event, initiate standard preliminary responses in the port and evaluate the event risk both at port and on-board the cruise ship (ensure a safe environment for travellers) to take timely adequate measures. Moreover, PoEs should provide appropriate medical service and personnel for the care of infected travellers and for their evacuation (S. Zhou *et al.*, 2020).

Although liners are equipped with medical facilities and personnel, there are limitations to the medical care. Recruitment of multiple teams of relevant specialists may ensure an appropriate crisis management, inter-organisational coordination as well as communication outbreaks (Tokuda *et al.*, 2020). Cruise line companies should establish a contingency plan to manage various psychological effects of the COVID-19 outbreak on their crew members who are stuck at sea. The cruise ships must be equipped with suitable healthcare facilities on-board as well as qualified professionals and specialist team for infectious outbreak (Yazir *et al.*, 2020). These on-board specialists could assist crew employees experiencing mental disorders in these crisis events (Aleksandar Radic *et al.*, 2020).

6.2.4.2. Artificial Intelligence Technologies for Infectious Outbreaks

The government authorities should build up maritime medicine techniques and healthcare for potential infected passengers such as using the big data science and mobile sensor for monitoring health status and contact tracing or conducting preboarding screening for any potential risk people (Yazir *et al.*, 2020).

The importance of Artificial Intelligence (AI) in the early detection of COVID-19 is rapidly evolving (Allam, Dey and Jones, 2020). Indeed, the progress in AI has also become a useful tool to identify disease outbreaks earlier compared to traditional approaches, thus sustaining more timely programme planning (Lake *et al.*, 2019). Several types of AI methods are being used for health interventions and COVID-19 management, including but not limited to: (a) diagnosis, (b) patient morbidity risk assessment, (c) disease outbreak prediction and public health surveillance, and (d) clinical decision-making and health policy and planning (Chen and See, 2020; Schwalbe and Wahl, 2020). The applicability of big data technology in the prevention and control of COVID-19 has also become an important role in personal tracking, medical treatment, and patient-level resource allocation by using location and travel data, medical electronic health records (EHR), media data, etc. The data collection and access can be improved by collecting apps-based electronic questionnaires, which involves more accuracy data (Wu *et al.*, 2020). Therefore, it has been suggested that by integrating IA techniques/tools into local healthcare systems could provide personalised patient management planning in an infectious outbreak scenario (van der Schaar *et al.*, 2021). For instance, cloud-based AI technology has been also designed for supporting proactively the clinical care psychiatric issue management and monitoring regular mental health of on-board SARS-CoV-2 infected individuals in isolated and quarantined conditions (Mittal *et al.*, 2020). The continue communication though chat sessions via smartphone applications is prepared to make appointment by contacting the local authority's emergency centre according to the progression (Mittal *et al.*, 2020).

In the future, the use of AI methods will enable effectively to manage massive infectious outbreaks and surveillance as well as monitoring oriented to COVID-19 and other potential infectious disease (Wong, Zhou and Zhang, 2019; Chen and See, 2020).

The use of a wearable device that communicates with thousands of sensors on the vessel and a mobile app, enabling guests to house their passport, travel and payment information, plan activities, order food, do wayfinding etc. is also proposed. [Top Down]

6.2.4.3. Remote Health Monitoring System

In the COVID-19 outbreak on the *Costa Atlantica* cruise ship the early detection of infection by monitoring crew members' health status remotely without disembarkation of asymptomatic or mild patients was applied, which minimized the activity of support onboard while preventing their infection. This allows the self-monitoring of health conditions via smart phone, collect information by task force headquarters, share clinical data for assessment by clinical staff and manage the evacuation by outboard support base to transfer the several patients to hospital (Sando *et al.*, 2020).

It has been suggested that the data about patients from electronic health records may be combined with data from cellular operators, airlines, traffic applications though cooperation between public and private sectors. Individual and healthcare infrastructure-level interface could alert both patients to undergo testing, health monitoring via mobile applications and medical personnel to assess the evolving risks of patients. The telehealth applications could provide care and follow-up for isolating individuals (van der Schaar *et al.*, 2021) as some infected patients could need to have continued and careful health status monitoring; their respiratory condition may present complications rapidly from the onset of detection (Sano *et al.*, 2020).

Recently, a variety of remote patient monitoring programmes to manage both their physical and mental status during COVID-19 pandemic have emerged. These have demonstrated to have a daily high patient engagement and to be effectively to escalate to a telemedicine appointment with a clinician for assessment if the patient worsens (Annis *et al.*, 2020; Mittal *et al.*, 2020; Morgan *et al.*, 2020; Schinköthe *et al.*, 2020; Tabacof *et al.*, 2020; Aalam *et al.*, 2021). If an infectious outbreak occurs, infected or suspected individual's physiological vital data needs to be routinely monitored during early isolation and quarantine. In this context, remote smart healthcare support system via mobile applications has been proposed for monitoring patients' health status and receiving doctors' indications while staying in closed spaces. This system has both sensors and a hyperspace analogue to context incorporated in the closed room and monitoring application to automatically capture individual's physiological health parameters in a daily basis -through direct measurements such as a sphygmomanometer for blood pressure, a thermometer for body temperature and a glucometer for sugar level- and control setting scenario -temperature, cooling system, and other basic appliances inside room- towards patient conditions' improvement (Taiwo and Ezugwu, 2020).

A telehealth solution accessible via laptop or mobile device that equips cruise lines to offer virtual cabin visits to assess suspected illnesses among crew and guests, is also suggested. In addition to secure voice and chat communications, the system could offer video connection between the on-board medical center and any guest or crew member. [Bottom up]

6.2.5. Management Tactics and Cooperation

Multilateral coordination, cooperation and collaboration mechanisms between states, intergovernmental organizations, private sectors and industry and establishment of roles and responsibilities across the different stakeholders are needed to successfully deal infectious diseases on cruise ships (S. Zhou *et al.*, 2020; Choquet and Sam-Lefebvre, 2021).

All travel-related preventive and control measures require the cooperation of the ship and port epidemic prevention department. Although cruise ships and berthing ports are relatively fixed, each port may have different emergency response capabilities. In addition, the existence of foreign factors may lead to a conflict between personal jurisdiction of the country of nationality of passengers and crew and the territorial jurisdiction of the port country when handling public health emergencies (Liu and Chang, 2020).

The criteria acceptance for addressing the decision of allowing vessels with suspected infected patients to dock needs some considerations. Mainly, (a) nation's geopolitical considerations such as proximity to infected areas and secure routes for transporting symptomatic or asymptomatic infected passengers to health care facilities, and (b) nation's availability of medical resources and capacity to provide adequate health care (Nakazawa, Ino and Akabayashi, 2020).

Recently, members of the Expert Taskforce for the COVID-19 Cruise Ship Outbreak, after appropriate analysis, recommended enforcing the following key points: (a) public health authorities should adjust the emergency response to asymptomatic infection phases; (b) the scientific community should further address the non-contact transmission pathways and the role of different phases of infection (asymptomatic, pre- and post-symptomatic) on the transmission; and (c) international maritime community should maintain collaborative communication with national governments to inform the feasibility of mass quarantine process on cruise ships (Expert Taskforce for the COVID-19 Cruise Ship Outbreak, 2020). Some key challenging issues in the maritime setting in the COVID-19 era include but not limited to: management of a infected case on board and close contacts; the social, physical distancing establishment and other preventive measures such as the use of PPE on board; access to pre-employment medical assessment and testing; management of mental health issues on board; interaction with shore based staff in port and medical care services overseas; crew changes at ports; possibilities for shore leave; and contract extension (Stannard, 2020).

6.3. Early Detection of SARS-Cov-2

Early detection, prevention, and control of COVID-19 on ships appeared to play an important role both on protect the passengers' and crew members' health and to avoid SARS-CoV-2 transmission by disembarking individuals who are suspected of being infected (Centers for Disease Control and Prevention, 2020c; World Health Organization, 2020b). Isolation-based intervention is largely ineffective for infectious outbreaks with a high proportion of asymptomatic or pre-symptomatic individuals (Wilder-Smith and Freedman, 2020). Research has found that nearly 46% of infected people belong to pre-symptomatic transmission (Ferretti *et al.*, 2020). Moreover, it has been reported that the delay between the onset of clinical symptomatic cases and their isolation has the largest role in controlling a COVID-19 outbreak (Hellewell *et al.*, 2020). Therefore, the mitigation of the impact of mass gathering (population density occupying confined setting and limited space) on infectious disease expansion and particularly COVID-19 transmission, rather than containment approaches, becomes a priority during infectious outbreaks (Ebrahim and Memish, 2020; Mizumoto *et al.*, 2020). The adoption of a variety of surveillance and screening strategies could effectively reduce the risk of an infectious outbreak onboard.

6.3.1. Surveillance Methods

6.3.1.1. Symptom-Based Surveillance

High rates of SARS-CoV-2 positivity in cabinmates of individuals with asymptomatic infections suggest that triage by symptom status in shared quarters is insufficient to halt transmission (Plucinski *et al.*, 2020). Many studies have evaluated the symptom-based surveillance to provide an early indicator of new COVID-19 cases, however, these are regularly limited to fever, cough, shortness of breath or sore throat screening, leading to miss even symptomatic cases at the onset of disease (Chow *et al.*, 2020; Gostic *et al.*, 2020). The asymptomatic cases may account for approximately between 40% and 45% of COVID-19 infections (Oran and Topol, 2020).

As of the non-specific nature of the symptoms and co-infections with other viruses, the symptom-based strategies such as symptom surveys have limited applicability to reduce COVID-19 spread. Recently, the feasibility of symptom-based screening was measured, and it was shown that this strategy is not effective in identifying the likelihood of cases having SARS-CoV-2 and so it is not sufficient for controlling COVID-19 (Bartha *et al.*, 2020; Callahan *et al.*, 2020; Gandhi, Yokoe and Havlir, 2020).

Overall, COVID-19 surveillance based on symptom is challenging if there is a high proportion of asymptomatic and pre-symptomatic individuals, and moreover the symptomatic cases present delays to symptom onset (Smith *et al.*, 2020). Therefore, it is imperative to include other multi-component surveillance tactics alternative to symptom-based programmes for managing COVID-19 spread and to understand the burden across different population community.

6.3.1.2. Wastewater-Based COVID-19 Surveillance

Remarkably, the early detection of virus through wastewater surveillance can effectively supplement clinical surveillance (Ahmed et al., 2021). It has been observed that infected patients had SARS-CoV-2 positive results by faecal specimen despite being negative by pharyngeal swabs (C. Chen *et al.*, 2020; L. Chen *et al.*, 2020). In fact, wastewater-based monitoring can surveil the presence or absence of pre-symptomatic and asymptomatic SARS-CoV-2 infections in large populated areas up to three weeks before the first clinical case detected (Ahmed *et al.*, 2021). The skimmed milk flocculation method for wastewater-based environmental surveillance of SARS-CoV-2 is particularly recommended because of its detection consistency, feasibility of conducting uninterrupted surveillance and simplicity since does not require extensive laboratory resources while being useful in resource limited settings (Philo *et al.*, 2021). This means that this surveillance method may be a feasible and manageable tool to carry it out on community settings like cruise ships.

Passengers are provided with on-board sanitation facilities during the cruise ship course. SARS-CoV-2 RNA has been detected in wastewater samples from cruise ship-based sanitation systems (Ahmed *et al.*, 2020). The frequency of SARS-CoV-2 RNA detection is higher in cruise ship influent wastewater compared with the cruise ship effluent sample, which indicates that the removal of virus can occur though the wastewater treatment processes (Wurtzer *et al.*, 2020). Therefore, wastewater-based COVID-19 surveillance in the vessels' sanitation systems could be a cost-effective system for screening of a large proportion of the passenger population to inform and prioritize clinical testing and contact tracing among disembarking passengers. Moreover, the combination of early screening methods, including wastewater and clinical surveillance could amplify the sensitivity of SARS-CoV-2 detection upon entry the cruise ship (Ahmed *et al.*, 2020). Thus, such alternatives like on-board wastewater testing programmes for SARS-CoV-2 may serve as an early indicator for a COVID-19 outbreak on cruise ships (Brewster, Sundermann and Boles, 2020).

The COVID-19 Wastewater-Based Epidemiology (WBE) Collaborative in a global effort to coordinate methodologies in wastewater monitoring has been established (Bivins *et al.*, 2020), and studies continue to reach global standardized analytical protocol in wastewater evaluation for detection of SARS-CoV-2 and future disease outbreaks (Hamouda *et al.*, 2021).

6.3.1.3. Automatic Identification Systems-Based

The organisational planning for management of infectious outbreak event should be anticipated and crew should be trained on simulation activities. A command-and-control structure well-established (the scope of responsibilities, relevant participating organisations/institutions, daily communication of inside situation, and conducted activities, etc.) would be critical in the adequate outbreak response (Tokuda *et al.*, 2020).

The Automatic Identification Systems-based data in real-time may support the operational responses to risk management of infectious outbreaks on cruise ships. Origin-destination matrices can become a complementary source to inform possible transmission routes, for instance, disembarking passengers in cities with high risk areas which expect arrival in next ports, and so estimate severe risk of COVID-19 imported from international shipping (Hoffmann Pham and Luengo-Oroz, 2020; Z. Wang *et al.*, 2020).

As a result, a risk assessment system of COVID-19 infection has been proposed in order to estimate dynamically the individual's risk probability of infection in real-time based on collecting the individual's detection data and whereabouts information via the Global Positioning System of the terminal. This risk assessment technique includes handheld terminals which measure and record the individual's physical data such as body temperature and position information, and it is assessed by the individual's current epidemic risk in the cloud processing centre. Moreover, further development in this method can introduce the region's risk locations of COVID-19 or other infectious outbreaks. Interestingly, this system has been suggested not only to guide potentially which areas or locations are safer, but also to assist the case tracing (Wei, Li and Nie, 2020).

6.3.1.4. Digital Contact Tracing

It has been concluded that successful approaches to control SARS-CoV-2 transmission include wide testing and non-manual contact tracing together with physical distancing strategies (Juneau *et al.*, 2020; Idrees, Nowostawski and Jameel, 2021). Therefore, technology-based approaches for case finding and digital contact tracing should be included as a long-term emergency response (Sun and Viboud, 2020). Given the high transmissibility of SARS-CoV-2 and asymptomatic and presymptomatic transmission, phone app-based digital contact tracing is proposed as a feasible technology for a most effective COVID-19 control in combination with other preventive measures. This enables building a memory of proximity contacts and allows instant notification of contacts of positive cases (Ferretti *et al.*, 2020). Indeed, optimising testing and adding high mobile app-based contact tracing coverage could reduce delays in the case tracing process and identify potential cases before symptom onset occurs (Kretzschmar *et al.*, 2020).

Recently, a systematic review addressing an overview of smartphone health applications currently available for COVID-19 found a total of 63 apps, and most of them had high ratings in their comprehensive assessment based on Mobile Application Rating Scale (MARS), especially for overall quality and functionality. Although there is a large number of apps in the market, few scientific studies are addressing this subject. Moreover, application download among population widely differ across regions and pose a determinant for successfully tracking and managing the infectious outbreaks (Davalbhakta *et al.*, 2020). Interestingly, another systematic review identified several barriers for the public engagement with contact tracing services during the infectious disease outbreak, including privacy concerns (personal information used by institutions); mistrust and/or apprehension, especially of technology among older people; gaps in information provision and support; fear of stigmatization; and mode-specific challenges, for example psychological barriers to engaging with technology. In contrast, many people were strongly influenced by collective responsibility to help deal the infectious outbreak, being a facilitator for public engagement to contact tracing systems (Megnin-Viggars *et al.*, 2020). Ultimately, to address the privacy and confidentiality concerns, it has been proposed the blockchain technology for handling personal data transactions securely, offering an optimal approach for the corresponding application in the digital contact tracing process and apps (Idrees, Nowostawski and Jameel, 2021). Therefore, a clear communication and supportive services about digital contact tracing applications will be translated into community benefit controlling COVID-19 spread (Megnin-Viggars *et al.*, 2020).

Overall, the feasibility of halting COVID-19 outbreaks through case isolation and contact tracing also depends on the precise characteristics of transmission and public engagement. These two combined measures might not contain COVID-19 unless contract tracing reaches high levels (Davalbhakta *et al.*, 2020; Hellewell *et al.*, 2020).

6.3.2. Clinical Screening Approaches

6.3.2.1. Widespread Clinical Testing

For a SARS-CoV-2 outbreak, on-board quarantine can spread significantly the disease if asymptomatic cases are not detected (Batista *et al.*, 2020). Initially, statistical modelling relied on diagnosed cases only and estimated the proportion of asymptomatic infections on-board the *Diamond Princess* cruise ship to be nearly 17.9% (Mizumoto *et al.*, 2020). However, a recent study including symptom-agnostic testing in the simulation, found that a 74% of infections derived from asymptomatic cases, which may contribute substantially to SARS-CoV-2 transmission. (Emery *et al.*, 2020). A study evaluating behavioural, clinical and biological interventions for prevention and control of SARS-CoV-2 outbreak on a cruise ship the size of the *Diamond Princess* found that the implementation of early mass screening strategies and immediate case isolation upon diagnosis would have reduced the projected incidence by 38% (Jenness *et al.*, 2020). Therefore, an early diagnostic testing could disrupt community transmission of COVID-19 and prompt quarantine of passengers (Brewster, Sundermann and Boles, 2020).

However, when dealing with insufficient medical resources, the challenges of appropriate test for widespread screening can lead to emergency medical resource allocation issues (Araz *et al.*, 2020). It means an appropriate timing and testing to undertake inspections for all passengers and crew members. It should be priority to adhere to systematic cross-sectional and widespread testing approaches to detect both presymptomatic and asymptomatic cases, all passengers and crew members to be tested, rather than adopt categorization strategies for testing that prioritize those symptomatic infections (Brewster, Sundermann and Boles, 2020; Plucinski *et al.*, 2020; Yamagishi, Kamiya, *et al.*, 2020).

6.3.2.2. Diagnostic Testing: Serological Antibody and Inflammatory Tests

Given the large number of investigations have shown that infected individuals had an initial false negative rate of Reverse Transcription Polymerase Chain Reaction (RT-PCR) assays for SARS-CoV-2, particularly before the onset of symptoms or individuals who are asymptomatic, it is strongly recommended the repeated testing in suspected patients of COVID-19 infection (Arevalo-Rodriguez *et al.*, 2020; Kucirka *et al.*, 2020). Passengers and crew members might get false negative results at their first examination (Qin *et al.*, 2020). Interestingly, positive serum immunoassay Immunoglobulin G (IgG) and IgM confirmed both asymptomatic and symptomatic SARS-CoV-2 infection among passengers who had been on board the *Diamond Princess* cruise ship (Hung *et al.*, 2020). Both IgG and nasopharyngeal swab RT-qPCR were the most sensitive. And a combination of nasopharyngeal swab quantitative RT-PCR and serology should be implemented to screen for contact tracing in a community outbreaks, which ensure early diagnosis, prompt isolation and treatment (Hung *et al.*, 2020). A comprehensive systematic review and meta-analysis addressing the serological antibody testing (IgG, IgM, IgA) as diagnostic tool of COVID-19 supported their supplemental role in the detection, but early in the onset of disease could have capacity limited (Chen *et al.*, 2021).

Moreover, assessment of severity is crucial to manage a large number of passengers during a potential infectious mass outbreak on board. High serum lactate dehydrogenase (LDH), aspartate aminotransferase (AST) and C-reactive protein (CRP) levels and low serum albumin level and lymphocyte count have been found to be predictors of severe COVID-19 outcomes like pneumonia (Kato *et al.*, 2020). Hospital management for such infected passengers or crew members may be desirable.

Several meta-analyses have shown that high neutrophil-to-lymphocyte ratio (NLR) levels and low prealbumin and albumin concentrations are associated with severe outcomes of COVID-19. The accessibility, cost-effectiveness, scalable manufacturing process and suitability for self-testing of these clinical predictive factors make a useful tool for predicting severity symptoms and disease in COVID-19 patients (Paliogiannis *et al.*, 2021; Simadibrata *et al.*, 2021; Zinellu and Mangoni, 2021). Therefore, it has been recommended the use of NLR or albumin concentrations to perform early risk stratification of patients in resource-limited healthcare settings and selection of appropriate care pathways in this vulnerable groups and their management (Paliogiannis *et al.*, 2021; Simadibrata *et al.*, 2021; Zinellu and Mangoni, 2021). This may enable evidence-based decisions on-board for transfer and evacuation of potential patients at risk of COVID-19 severity.

6.4. Biotic Factors

6.4.1. Older Age and Comorbidities

Biotic factors like age, sex, gender, blood type, population density, behavioural characteristics, etc. on the transmission, persistence, and infectivity of this newly recognized SARS-CoV-2 virus has been investigated (Kumar *et al.*, 2021). Given the COVID-19 outbreaks on aboard cruise ships, the US Department of State—Bureau of Consular Affairs (9 March 2020) recommended to the U.S. citizens with underlying health medical conditions not to travel by cruise ship as an emergency response (United States Department of State—Bureau of Consular Affairs, 2020).

As long as the pandemic continues, special considerations may be applied to passengers and crew belonging to high-risk groups, including people over 65, people with multi-morbidities or people of any age with underlying medical conditions, such as chronic diseases including cardiovascular diseases, diabetes, respiratory diseases and immunocompromised individuals. It is advised high risk groups to visit a doctor for pre-travel medical consultation to assess if they are fit to travel. Specifically, for crew members in vulnerable groups, they could work in positions where there is little or no interaction with other individuals and advanced respiratory protection may be used [Bottom up].

According to the Cruise Lines International Association (CLIA), cruise passengers tend to be older people, with the 60–69-year-old group accounting for the majority of passenger age groups (Cruise Lines International Association, 2018). The older age appears to increase susceptibility to symptomatic SARS-CoV-2 infection and/or risk factor for severe COVID-19 disease outcome progression according the retrospective analysis of mass infection on the *Diamond Princess* cruise ship (Tabata *et al.*, 2020). People aged more than 60 years old who are more likely to have underlying chronic medical comorbidities and multimorbidities are at increased risk of severity of COVID-19 outcomes (Yang *et al.*, 2020). A significant challenge during the quarantine time in the COVID-19 outbreak on-board the *Diamond Princess* cruise was that the clinical information regarding the health conditions for all the passengers and crew members was not available (Yamagishi and Doi, 2020).

Currently, the age and comorbidity as risk factors for severe COVID-19 outcomes have been widely evidenced from the onset of the pandemic. Vulnerable people of older age, and/or with underlying cardiovascular diseases (CVDs), hypertension, diabetes, congestive heart failure, chronic kidney diseases, respiratory diseases such as chronic obstructive pulmonary disease (COPD), and cancer comorbidity -including cancer survivors- have higher risk of mortality from COVID-19 infection (Carreira *et al.*, 2020; Levin *et al.*, 2020; Mesas *et al.*, 2020; Parohan *et al.*, 2020; Singh *et al.*, 2020; Ssentongo *et al.*, 2020; Zheng *et al.*, 2020; Id *et al.*, 2021; Tian *et al.*, 2021).

Although cardiovascular comorbidities are highly prevalent in older people, it has been suggested that hypertension and diabetes -risk factors for CVD- have been associated with fatal outcomes in COVID-19 (Matsushita *et al.*, 2020; Bae *et al.*, 2021). Moreover, younger patients with COVID-19 aged below than 50 years who had a lower prevalence of cardiovascular comorbidities had a higher relative risk of developing severe outcomes compared to older patients aged more than 60 years (Bae *et al.*, 2021). The obesity is another important clinical risk factor for severe COVID-19 cases and is associated with in-hospital deaths from SARS-CoV-2. A high excess adiposity has been associated with an increased risk of severe illness, especially in people aged 60 and older (Mesas *et al.*, 2020; Seidu *et al.*, 2021).

Individuals with these comorbidities or immunosuppression should be regularly monitored (Li *et al.*, 2021), and infection prevention strategies should be tailored around this high-risk population towards COVID-19 prognostic improvements (Singh *et al.*, 2020; Ssentongo *et al.*, 2020).

6.4.2. Movement Behavioural Patterns and Mobility Restrictions

The restrictive measures during COVID-19 pandemic have massively entailed a long-term effect on individual mobility patterns, adding on individual perceived risk for all transport modes. Therefore, people's cognitive assessment towards travel and mobility restrictions should be taken into consideration (Barbieri *et al.*, 2021). In addition, it has been highlighted that the role of regulations and information provided about the spread of COVID-19 are determinants of community response on human mobility (Mendolia, Stavrunova and Yerokhin, 2021).

The number of secondary SARS-CoV-2 infections among passengers on board *Diamond Princess* cruise ship was reduced after imposing the movement restriction policy (Nishiura, 2020). Community movement pattern behaviours are strongly correlated with reduced number of cases of COVID-19, which sustain the effectiveness of social distancing measures in controlling transmission during an infectious outbreak (Badr *et al.*, 2020; Sulyok and Walker, 2020). Thus, changes of behaviour in the mobility network have direct effects on virus spread dynamic (Schlosser *et al.*, 2021). Remarkably, optimal combinations of restriction measures on human mobility (such as general mobility restrictions, lockdown of high-risk regions/areas, intra-community mobility restriction, or mobility restriction for infected/suspected cases) and magnitude have shown to be an effective strategy to control infectious disease spread. The effect of combining mobility restrictions for individuals with symptoms at high-risk areas was substantial to reduce COVID-19 spread. Restrictions for those individuals and inter-region/area mobility at 20% and 80% respectively, resulted in the outbreak peak to be delayed by 2 and 4 weeks and the peak of number of cases in both mobility measures to be reduced by 50% compared to none intervention scenario (Y. Zhou *et al.*, 2020).

While the mobility restrictions measures can reduce the human-to-human contact and act as a control mode of infectious spread, other pathways of virus transmission (environmental and asymptomatic transmissions) should be kept under consideration. Monitoring real-time human mobility flow has been suggested to be a useful emerging source to understand movement patterns in order to support the decision-making of area restrictions. The use of mobile device location data has proved to be a suitable tool for monitoring and quantifying flows both spatially and temporally, as well as allowing the evaluation of the effectiveness of mobility restrictions implemented (Pan *et al.*, 2020; Couture *et al.*, 2021). Moreover, movement patterns data can also provide valuable information for managing those densely populated and large traffic areas, like increasing the frequency of disinfecting routine in surface highly touched surfaces by passengers (Zhang *et al.*, 2016).

6.4.3. Population Density

Under conditions of strict lockdown policies, the population density seems not to affect infectious spreading (Gerli *et al.*, 2020; Z. Sun *et al.*, 2020), since lockdown period significantly reduced temporal spatial infection and dynamics (Laroze, Neumayer and Plümper, 2021). However, the increase of contact rates in greater density areas have been associated with greater rates of SARS-COV-2 transmission (Rashed *et al.*, 2020; Sy, White and Nichols, 2020). Moreover, the prolonged infectious spread duration and decay stages have been highly correlated with higher population densities (Diao *et al.*, 2021).

Therefore, population density has shown to be a factor predicting the cumulative cases of infection along with the variability of vulnerable population subgroups and space characteristics influencing on the outbreak impact (Wong and Li, 2020). The implementation of physical distancing measures has become the highest asset on limiting the COVID-19 community spread, particularly in areas where individuals are living close to each other (Gao *et al.*, 2020; Rubin *et al.*, 2020; Tammes, 2020; Yin *et al.*, 2021). But, the implementation of the recommended social distancing (2-metre distance) in those scenarios and areas with higher population densities can be challenging (Rocklöv and Sjödin, 2020; Tammes, 2020). However, it has been recently demonstrated that connectivity and spatial aspects could be a significant factor rather than population density in the spread of infectious outbreaks, and thus posing the community design and planning to have an important role on the transmissivity (Hamidi, Ewing and Sabouri, 2020; Rubin *et al.*, 2020).

7. Recommendations for Short and Long-Term Responses

7.1. Guidance for Coordination and Management Plan

7.1.1. COVID-19 Port Management Plan

It is highly recommended that ports and terminals have their own COVID-19 Port Management Plan, detailing the key processes and key personnel dealing with the implementation of COVID-19 mitigation measures. The way in which such a plan is implemented will differ widely in each Member State, as in some States, all tasks might be concentrated in one authority while for others they can be distributed amongst different authorities. Member States are recommended to create multi-disciplinary teams who will cover all elements of this port plan so as to be able to facilitate the coordination and communication with the cruise companies intending to visit their ports. It is recommended that each Port State, establishes and publishes contact points which can be used by cruise companies for direct communication with regard to the re-starting of operations in that State. Ideally, there should be a single contact point per Port State who could internally coordinate all the national procedures. Where this is not possible, the contacts should be provided with a brief description of the responsibilities that each contact has [Bottom up].

So that all perspectives are covered, it is also recommended that this Port Plan is agreed and shared among the different authorities involved (for example Port State, health officials, terminal operator) [Bottom up].

The COVID-19 port management plan it is recommended to include at least the following piece of information [Bottom up]:

- Duties and authorities: Duties involved in the implementation of the plan as well as duties and responsibilities of each of them.
- Minimum conditions to receive cruise ships, such as the implementation of this Guidance on board the ship, the number of passengers allowed on board or any other relevant consideration.
- Passenger terminal arrangements for both embarkation and disembarkation: This part should include all the embarkation arrangements both for crew and passengers. Different aspects should be covered for both, such as (advance) information and communication, physical distancing, PPE, cleaning and disinfections, health screening, security screening, etc.
- Persons/entities authorised to visit the ship and protection measures: e.g., pilots, Port State Control (PSC) inspectors, health inspectors and suppliers should be defined as well as the protection measures for them to go on board the ship.
- Contingency plan in case of COVID-19 outbreak: The Plan should also include measures to be taken in case an outbreak of COVID-19 takes place on board a ship. Points which are suggested to be addressed are the following: testing arrangements, procedures for

disembarking possible or confirmed cases of COVID-19, protection of local communities, procedures for repatriation, contact tracing.

- Port authorisation: It is likely that each port would have to implement different measures based on its local circumstances. This part of the plan should establish the procedures to approve such local plans where appropriate.
- Authorisation to receive a cruise ship: The procedure to authorise the visit of a cruise ship should be described, for example the documentation required, the preliminary verification of the COVID-19 Company and Ship Management Plan and the type of authorisation granted.
- Other considerations: The COVID-19 Port Plan should also include the health and sanitary measures to be applied when stores are being supplied to cruise ships and when they make use of any port service. In addition, the treatment of COVID-19 related waste from visiting ships should also be considered [Bottom up].

7.1.2. COVID-19 Cruise Ship Management Plan

An outbreak management plan for the prevention and control of COVID-19 transmission on board the ship should be prepared by the operating cruise line. It is suggested that the plan should be submitted to the competent authority of at least one of the ports of call (preferably the home port or another port which can provide sufficient facilities), in order to be reviewed and ensure interoperability with the port public health emergency contingency plan. The contingency plan, for both the cruise ship and the port, should also include transport plans and hygiene protocols, as well as the role and responsibilities of the crew and the procedures that should be followed in case they display signs and symptoms of COVID-19 [Bottom up].

Cruise operators should identify where appropriate that the implementation of their COVID-19 Management Plans is verified by a qualified and independent third party to demonstrate implementation of policy [Bottom up].

For the implementation and execution of the written plan, one named individual / coordinator or an outbreak management committee should be appointed. It is suggested to have a dedicated Public Health Officer or medical person who will coordinate the execution of the company's infection prevention and control program. The contingency plan should include the following as applicable: preventive measures, measures for management of a possible case of COVID-19, information on supplies and equipment, pre-board and on-board measures, cleaning and disinfection guidelines, food safety rules as well as spatial considerations of the different areas of the cruise ship [Bottom up].

7.1.3. Coordination between Cruise Ships and Ports in Relation to COVID-19 Matters

One of the key elements to restart operations of cruise ships is to ensure a safe ship/port interface, where roles and tasks are well defined and understood by both parties as well as the associated responsibilities. For that reason, a number of issues have to be settled in relation to the exchange of information between the Port State authorities and the cruise ship before arrival, such as: plans to disembark persons with COVID-19 compatible symptoms, embarkation/disembarkation of crew and passengers regardless of whether COVID-19 cases are declared or suspected on board, quarantine arrangements for contacts, repatriation and establishment of protocols for those visiting the ship, such as port workers, pilots, surveyors, auditors, suppliers, etc. It is recommended that both parties share their COVID-19 plans well in advance of the ship call, to ensure its interoperability and take, where necessary, addition measures to ensure compatibility. In addition, Port States should ensure that any special requirements or pre-arrival information required from ships, due to measures introduced in response to COVID-19, are effectively shared and communicated as quickly as possible to cruise ships and all relevant stakeholders [Bottom up].

7.1.4. Exclusion Policy

Cruise lines should develop an exclusion policy with regard to COVID-19 and inform potential travellers about this policy through their travel agents, cruise line operators and other businesses operating in the tourism sector. All relevant information as well as any pre-requisites and country specific rules should be available on the cruise line websites and electronic reservation systems. Ideally, it should be obligatory to read the information in order to complete the reservation. These materials should be available in the national language, English and, where needed, other languages based on the most common language profiles of the passengers. Moreover, relevant information could be shared directly with passengers via email, text message, mail, website, or other means of communication [Bottom up].

Harmonisation of this policy in the cruise industry, or consistent wording would facilitate acceptance and understanding by the public. As a result, symptomatic passengers, any person experiencing symptoms compatible with COVID-19, or if identified, anyone who has been in contact during the last 14 days with a confirmed case of COVID-19, or anyone who is tested positive for SARS-CoV-2 by RT-PCR would not be accepted on board cruise ships [Bottom up].

7.1.5. Copying with Stress during COVID-19

The circumstances associated with the ongoing COVID-19 outbreak may pose unique challenges to seafarers and their families. Seafarers may become bored, frustrated or lonely, and their families may also be experiencing difficulties. Everyone reacts differently to events, and changes in thoughts, feelings and behaviour vary between people and over time.

As the current COVID-19 situation adds stress to individuals and may impact their mental health, shipping companies should take a mental health emergency as seriously as a physical health emergency. Seafarers may think they are having a mental health crisis and no longer feel able to cope or control their situation. Great emotional distress or anxiety, unable to cope with daily life or work, are some of the effects current epidemiological situation may have on their mental health. [Top Down]

Several measures to enhance mental health and wellbeing are proposed. It is suggested that people when on board, should try and maintain a healthy lifestyle - including proper diet, sleep, avoid smoking and alcohol, exercise when possible and pursue social contacts with other crew members, family and friends. Reduce time spent watching, reading or listening to media coverage to limit worry and agitation. Instead, draw on past skills which helped them manage previous difficult situations to help handle your emotions at this time. Try to manage panic and anxiety, by trying to go outside daily, open windows if possible to let fresh air in and arrange space to sit with a nice external view and get some natural sunlight. [Top Down]

Additionally, cruise operators during this COVID-19 period, should keep into account concerns of their crew mental health. The continuous changes driving new operational realities has highlighted the need for Operators to provide tools and information that will assist crew to utilize new personal fatigue risk mitigations, such as changing financial status of households, uncertainty over employment stability, concerns over health of themselves or family members. Operators need to assist crew by raising awareness around this increased risk of personal fatigue factors. Training on fatigue risk management for crew is also necessary. [Bottom up]

7.2. Considerations for Cruise Terminal

7.2.1. Design Considerations

For the protection of cruise terminal staff and ship crew, the use of protective glass or plastic panels and appropriate PPE should be considered at locations where physical distancing cannot be maintained [Bottom up].

The division of terminals into designated zones (for example arrival, screening, post-screening etc.) and the creation of separated user flows through which travellers must pass before being cleared for boarding and embarkation may be considered [Bottom up].

The use of floor markers to ensure social distancing, arrows to indicate directional flow, appropriate signage, audio announcements for travellers and optimizing layouts so as to restrict number of indoor cruise terminal users should be considered [Bottom up].

In case of permanent, non-moving seats either indoors or outdoors, there should be a special marking on where a passenger is and is not allowed to sit in order to maintain physical distance. When possible, the use of outdoor spaces is encouraged. Furniture that encourages crowding, such as couches and tables (which ate movable) could be removed [Bottom up].

Stations with alcohol-based hand solutions should be available at all entrances of the terminal and other areas such as toilets, counters, terminal zones and at embarkation etc. [Bottom up].

An appropriate isolation room should be designated for isolating possible cases of COVID-19. The isolation room should be equipped with appropriate supplies such as medical face mask, tissues, and appropriate waste disposal bins. It is important that the room’s door is kept closed at all times and entrance is restricted only to personnel trained for responding to possible cases of COVID-19. It is recommended that isolation cabins are positioned far away from the general population of the ship. [Bottom up].

7.2.2. Digital Methods

It is encouraged to use as many digital methods for processes at the terminal as possible (such as on-line purchasing, issuing of boarding passes, automatic passport and ID scanners), in order to help in reducing the time that passengers spend in the terminal and also to avoid congestion [Bottom up].

7.2.3. Management of Possible Cases and Their Contacts

Once a possible case is detected a contingency plan/outbreak management plan should be activated. The possible case should be asked to wear a medical face mask as soon as they are identified [Bottom up].

7.2.4. Considerations Regarding Preventive and Control Measures

Issues regarding cleaning and disinfection of luggage and surfaces touched by terminal staff and users, sanitation, thermal and ventilation conditions inside cruise terminal, health monitoring of terminal staff as well as management of possible cases are widely developed in recommendation section 9.5.

7.3. Prerequisites Before Starting Journey, Prior to Cruise Ship

7.3.1. Monitor of the Epidemiological Situation

It is essential that cruise lines monitor the epidemiological situation worldwide, at the cruise ship destinations, as well as at the places of origin of incoming passengers and crew. That was it will be easier for them to assess the risk and adapt policies for screening and evaluating cruise ship passengers as well as crew members from countries with high numbers of COVID-19 cases, and furthermore to avoid destinations in countries with a high incidence of COVID-19. For that reason, it is necessary that cruise lines have access to real-time information on the situation regarding borders, travel restrictions, travel advice, public health measures and safety measures at the destination ports [Bottom up].

7.3.2. Simulation Activities & Timing of Inspections

It is recommended that cruise ships perform a simulated voyage or a series of simulated voyages before restart journeys, demonstrating the cruise ship operator’s ability to mitigate the risks of COVID-19 on board its cruise ship [Bottom up].

Additionally, construction and renovation inspections for consultation during construction or renovation of cruise ships is recommended. For example, the CDC and Vessel Sanitation program (VSP) collaborated with the cruise ship industry to proactively protect the health of travellers and prevent illness transmissions to US ports. VSP conducts inspections while the ships are in the shipyard, to analyse a ship’s design to eliminate environmental health risks and to incorporate modifications that create healthy environments [Bottom up].

7.3.3. Pre-Travel Risk Assessment

According to the IHR (2005), designated ports must have the capacities to provide appropriate public health emergency response, by establishing and maintaining a public health emergency contingency plan [Bottom up]. Cruise companies need to assess all identified risks in relation to the COVID-19 pandemic, its ships, crews, passengers, and the communities visited, and establish appropriate safeguards to reduce the risk to the utmost. This assessment should be properly documented. In establishing safeguards, available codes, guidelines, and standards regarding COVID-19 should be taken into consideration. This includes relevant Flag State, International Maritime Organization (IMO), World Health Organization (WHO) and other EU COVID-19 related documents.

It is recommended that each cruise company nominates coordinator(s) for this Plan and contact person(s) responsible for dealing with COVID-19 matters both on board and ashore. These persons should be responsible for the implementation of the Plan and act as a contact point for the relevant authorities. Also, the company should ensure that adequate resources are available to implement all aspects of the Plan (e.g. sufficient medical staff and facilities). The cruise company should also assess the maximum number of passengers that can be carried on board so as be able to implement all the required measures effectively [Bottom up].

Before starting journeys, arrangements for medical treatment and ambulance services should be in place. Cruise ship operators should ensure with ports of call that, if needed, arrangements can be made for passengers and crew members to receive medical treatment ashore. This should be clearly described in both written contingency plans of cruise ships and at least of one of the ports of call (preferably the home port, with the possibility of also using other ports during the voyage) [Bottom up].

Arrangements between the cruise line and the local authorizes for quarantine of close contacts, in case of exposed passengers or crew members should be in place. It is important that facilities are agreed pre-specified as well as the cost recovery for the health measures implementation. Residents of the country of disembarkation could be quarantined at home, according to local rules and procedures [Bottom up].

Arrangements between the cruise line and the local isolation authorities of the home port (or at least one of the ports of call) for procedures and facilities for isolation of asymptomatic/ pre-symptomatic travellers (passengers or crew members with positive test results for SARS-CoV-2) should also be considered. Again, facilities should be pre-specified [Bottom up].

All involved parties (ship agents, post and state control authorities) must ensure that written and clearly defined procedures are agreed upon and implemented for immediate reporting of any possible case of infection, to the health authority at the next port of call [Bottom up].

Before starting journeys, arrangements should be made to ensure that cruise ships have adequate laboratory testing capacity for SARS-CoV-2 on board or through arrangements with shore side laboratories to be used when a passenger or crew member is suspected of being infected [Bottom up].

Arrangements for repatriation should also me in place. Cruise ship operators should ensure with ports along the route that in case this is needed, repatriations and crew changes can be arranged. It is suggested that cruise lines have in place repatriation plans for passengers and crew members, considering different scenarios for partial or complete ship evacuation in the event of a COVID-19 outbreak. Cruise ships' home ports (or at least one of the ports of call) should have airports operating international flights allowing repatriation of passengers and crew as necessary [Bottom up].

7.3.4. Safety Education Training

- Each cruise ship operator should design a regular and on-going training plan for their employees focused on: instructions regarding the recognition of the signs and symptoms compatible with COVID-19, physical distancing measures, managing crowds, use of PPE, as well as protocols for cleaning and disinfection [Bottom up].

- All individuals intending to work on board (for example ship officers, crew members, suppliers, external contractors etc.) who interact with passengers or crew on board or ashore should complete training about COVID-19. Regular table-top exercises or drills should be conducted to make sure all parties are well trained on procedures related to prevention, surveillance and response to COVID-19, response time, department cooperation, procedures and equipment [Bottom up].
- The safety education training should be strengthened to effectively respond to any clinical situations and emergency (Yazir *et al.*, 2020).
- It is also important that medical staff should be trained in sample collection and the field laboratory testing performance on board the cruise ship would need to be verified, with their routine use quality assured in accordance with national regulations and international professional standards for medical laboratory services [Bottom up].

7.3.5. Prevention through Design. Engineering Control Measures and Ventilation

Prevention through Design (Ptd). The configuration of cruise ship-based indoor environments able to deal with and mitigate infectious hazards can be applied during design phase, construction and vessel retrofitting such as the installing of engineering controls (Brewster, Sundermann and Boles, 2020). It is encouraged to rethink the design and layout of vessels, by implement more dining settings with fewer seats rather than a large restaurant area; redesign other shared spaces which can accommodate fewer passengers with more personal space to avoid mass-gathering; create larger cabins rather than limited accommodations, etc. (Brewster, Sundermann and Boles, 2020).

Engineering Controls. The implementation of these technologies (such as ventilation methods) throughout cruise ships can have an important role in mitigating virus transmission risk (Brewster, Sundermann and Boles, 2020). The retrofitting stage of existing ships for the optimized ventilation by installing high efficiency particulate air filters and limiting air recirculating and dilution with outdoor air is recommended (Brewster, Sundermann and Boles, 2020).

7.4. Pre-Board Measures (Embarkation)

Cruise lines, travel companies and agencies should provide relevant pre-travel information about mitigating the risk of COVID-19 infection to their passengers and crew as a part of their travel information. During the ticketing process passengers should be informed about eligibility requirements. It is suggested that information should include among others the following: symptoms compatible with COVID-19, including sudden onset of at least one of the following: newly developed cough, fever, shortness of breath, sudden loss of taste/smell; advice on the risk of travelling for all individuals with chronic diseases; hygiene measures; the need to immediately report to cruise ship crew if they develop COVID-19 compatible symptoms during travel; the need to self-isolate and seek immediate medical care if they develop symptoms [Bottom up].

Pre-boarding screening aims at identifying symptomatic individuals by assessing the presence of symptoms and/or the exposure to COVID-19 cases of arriving travelers. Cruise lines could consider performing laboratory molecular testing for SARS-CoV-2 to all incoming passengers, ideally before boarding to start a cruise [Bottom up].

Additionally, it is suggested that travelers declare their travel and contact information before embarking and complete a health questionnaire 48 hours prior to their cruise departure. Companies and travel agencies should inform travellers that they may be refused boarding if they have symptoms which are compatible with COVID-19, have had positive RT-PCR test results for SARS-CoV-2 or have been exposed to a COVID-19 confirmed case [Bottom up].

So as to avoid congestions, guests should receive assigned staggered time of arrival. Luggage should be disinfected before it is brought aboard.

7.5. On-Board Measures for Guests and Crew Members

7.5.1. Prevention and Control Measures

7.5.1.1. Cleaning & Circular Disinfection

- It is recommended that in shared public areas/facilities, such as for example dining and entertainment areas, increased frequency of cleaning is applied as surfaces are frequently touched by crew and passengers, such as handrails, elevator buttons. Items such as magazines, brochures, should be removed and information provided in alternative contactless ways. [Bottom up]
- Regarding public toilets, it is recommended that they are cleaned and disinfected regularly to promote a clean and healthy environment. Where urinals are sited close together every other one should be taken out of use. Where feasible, doors should be left open to reduce touching of handles etc. Passengers and seafarers should be encouraged to use their own bathroom. [Top Down]
- Evidence supports the recommendation to disinfect surfaces in a frequent base even untouched surfaces (Orenes-Piñero *et al.*, 2021). On cruise ships, regular disinfection of seats near the main aisle, door handles of the restrooms, handrails of stairs and on the sightseeing deck can effectively reduce the total number of infected passengers. By increasing the disinfection frequency of surfaces to once every 4 hours can reduce efficiently infection transmission on cruise ships (Zhang *et al.*, 2016).
- UV-C light irradiation has been proposed to be an effective, affordable no-contact method for disinfection of surfaces contaminated with SARS-CoV-2 both dried and wet format (Inagaki *et al.*, 2020; Storm *et al.*, 2020; Kitagawa *et al.*, 2021). The implementation of irradiation of UV-C light at 207-222 nm wavelengths for short-period (between 16-25 minutes) on surfaces has been recommended to be a safer tool compared to another UV-C wavelength irradiation (Buonanno *et al.*, 2016, 2017, 2020; Narita *et al.*, 2018).
- By using gaseous ozone as a sanitizing method for those high-risk indoor spaces, on surfaces not susceptible to corrosion, could reduce significantly SARS-CoV-2 infectivity via fomite route (Percivalle *et al.*, 2021).
- A series of effective no-touch disinfection methods for using safely in occupied settings such as dry hydrogen peroxide have been recommended for reducing SARS-CoV-2 infectivity through fomite transmission (Ramirez *et al.*, 2020).
- Disinfection of luggage and especially the hand contact parts may be considered before loading luggage on board. Baggage handlers should perform frequent hand hygiene. [Bottom up]
- Staff should keep in mind that cleaning and disinfection should take place with an increased frequency for surfaces that are frequently touched by terminal staff and users. Cleaning of and disinfection of the terminal is important to be conducted before and after each embarkation [Bottom up].

- Extensive sanitation of transfer coached and terminals as well as all staterooms and public spaces multiple times a day [Bottom up].
- Regarding laundry, in case of a suspected COVID-19 patient, patient’s clothes, towels and bed linen should be washed separately. If possible, the person collecting clothes and linen should wear heavy-duty gloves before handling them and never carry soiled linen near his body. Machine wash at 60–90ºC with laundry detergent is also suggested. Alternatively, soak linen in hot water and soap in a large drum, using a stick to stir, avoid splashing. If hot water is not available, soak linen in 0.05% chlorine for approximately 30 minutes, rinse with clean water and let linen dry in sunlight. Do not forget to wash hands at the end of the process. [Bottom up]

7.5.1.2. Sanitation & Hand Hygiene

- It is imperative that enhanced sanitation protocols are employed to protect against the risk of SARS CoV-2. Cruise operators should educate guests in advance of travel about the sanitation measures that are being used preboard, on board, and at private, cruise line-owned and operated destinations [Bottom up].
- For hygiene promotion, durable infrastructure including water supply systems, sanitation and hand washing facilities is encouraged as this can act as a reminder and have a positive impact on the individual’s handwashing behaviour (White *et al.*, 2020).
- Hand sanitisers based on ethanol at low concentrations has been recommended for both hand decontamination of SARS-CoV-2 and protection of skin and mucous membrane injury (Jing *et al.*, 2020; Yan *et al.*, 2020).
- Quaternary ammonium compound disinfectants have been recently recommended for hand washing as these rapidly and completely inactivate SARS-CoV-2 (Ogilvie *et al.*, 2021).
- Stations with alcohol-based hand rub solutions should be available at key areas such as all entrances to the ship and in other areas such as crew/work areas, check-in areas, entertainment venues, casinos, bars and restaurants and all the spaces where persons are expected to be present [Bottom up].
- Users of the terminal should be encouraged of good hygiene techniques, either by hand washing using soap and water or when this is feasible, by hand rub solutions. The use of gloves does not replace hand hygiene [Bottom up].
- More specifically, in areas such as the casino, cleaning and disinfection should follow routine procedures, but with an increased frequency in the slot area and electronic gaming machines, which is suggested to be cleaned and disinfected after each use. Additionally, passengers may be provided with disinfectant wipes or solutions to wipe frequently touched hand contact surfaces. It is recommended that food service is suspended in the casino area [Bottom up].
- At pools, it is recommended that the seats, tables, call buttons for the waiters and menus, are made, or covered with, materials that are suitable for cleaning and disinfection. Also, it is recommended that the facility provides washable coverings that can cover the entire surface of the seat and that the seats are disinfected after each use. Additionally, bathers may be separated by a schedule or if possible, by different facilities for swimming and service for different groups [Bottom up].
- At all shared facilities (e.g. hairdressers, beauty salons, spas etc.) and public spaces (e.g. areas near public toilets, should offer hand rub alcohol-based solution for the passengers [Bottom up].
- Regarding lifts, it is advised that passengers should avoid the use of elevators when possible. To allow social distancing, the maximum capacity of elevators should be revised

and reduced. The use of face masks in lifts is recommended. Hand rub alcohol-based station should be placed at elevator entrances and crew should advise passengers to use upon entering and exiting the area. The elevators should be regularly cleaned, and attention should be paid to frequently touched surfaces such as buttons, knobs etc. To help ensure physical distancing, other precautions such as floor markings, placement of cones etc. may be implemented [Bottom up].

7.5.1.3. Facemasks

- Medical face mask-wearing should be a practice adopted among individuals for controlling SARS-CoV-2 transmission in combination with other preventive measures such as frequent handwashing, especially in setting where physical distancing may not be possible (Chaabna *et al.*, 2021).
- The usage of widespread face masks in public is highly recommended as form of source control and adjunctive method for the COVID-19 outbreak (Asadi *et al.*, 2020; M. Liang *et al.*, 2020; Howard *et al.*, 2021).
- Although preclinical findings suggest that face masks-wearing may reduce COVID-19 spread, the available evidence is limited (Nanda *et al.*, 2021).
- There is not enough evidence for recommending the use of cloth masks in preventing SARS-CoV-2 transmission (Chaabna *et al.*, 2021; Daoud *et al.*, 2021).
- Similarly, there are unclear differences between the usage of medical/surgical face masks and N95/P2 respirators in reducing the virus transmission (Jefferson *et al.*, 2020).
- Passengers and other users of the cruise terminal, who are not ill or showing symptoms compatible with COVID-19, should be advised to wear a face mask, taking into consideration their national epidemiological aspects and the international spread of the disease. Additionally, respiratory etiquette should be encouraged in terminals: the nose and mouth should be covered with disposable paper tissue when sneezing or coughing and then the tissue should be disposed immediately in a no touch bin. [Bottom up]

7.5.1.4. Physical distancing

- Physical distancing of at least 1.5 metres (or otherwise as per national/local health authority requirements of the home port or the port of call) should be maintained during boarding at transport stations or at the reception's areas. Cruise ship crew could oversee the process and compliance with physical distancing measures. Special floor markings could be considered at possible traveller points, such as: reception, ticket offices, bars, restaurants, shops, entertainment areas and shared toilets to ensure physical distance is maintained. In cases where appropriate physical distancing cannot be guaranteed, the use of protective transparent panels should be considered. Such areas could be the reception areas, the bars or the restaurants. Additionally, in areas where there are permanent non-moving seats either indoors or outdoors, there should be special markings on where a passenger is and is not allowed to sit, in order to maintain physical distance [Bottom up].
- The maximum number of passengers and crew on board should be re-evaluated. Cruise ship operators should reduce the number of passengers and crew on board to ensure that measures related to physical distancing can be maintained, as well as temporary isolation and quarantine of passengers and crew can take place individually in cabins, if needed. Especially for the initial phase of restarting cruises, cruise ship operators are advised to ensure they are able to individually and temporarily isolate or quarantine in a single cabin possible COVID-19 cases: 5% of passengers and 5% of crew staff on board if they cannot disembark within 24 hours from detection of the first possible COVID-19 case or 1%

passengers and 1% crew for ships that are able to disembark these cases within 24 hours. (these numbers will need to be revised according to the epidemiological status) [Bottom up].

- Overcrowding should also be prevented in entertainment venues so to maintain appropriate physical distancing. The frequency of entertainment events may be increased to reduce numbers. Cruise companies may consider the option to divide passengers, crew, even children (in child activities) into cohorts, so that each group could be given scheduled times for food service, embarking and disembarking and participating in some on board activities. If it is not possible to maintain separate groups on board, these should be maintained for shore-based activities, by limiting Interaction between different cohorts as much as possible [Bottom up].
- The WHO has prescribed maintaining a 1-metre social distancing, based on the assumption that SARS-CoV-2 transmission is mainly in large, isolated droplets (World Health Organization, 2020a). Even the 2-metre physical distancing rule is not consistent with the underlying science of indoor air and airborne transmission, rather it is based on based on outdated science looking experiences of past viruses (Jones *et al.*, 2020).
- Under certain environmental conditions and settings, it has been suggested that distance should be increased to around 4 meters to improve safety (Pendar and Páscoa, 2020). Therefore, 2-metre social distancing should be adapted and used in combination with other preventive measures to reduce transmission, especially maximizing the ventilation in indoor spaces and regular face coverings where appropriate (Jones *et al.*, 2020).

7.5.1.5. Built Environment Considerations

- Airborne infection isolation rooms in combination with other infection control measures against airborne transmission are indicated for SARS-CoV-2 (Fennelly, 2020).
- It has been suggested that a HEPA air purifier in a temporary plastic anteroom could prevent the migration of aerosols into adjacent corridor by 98%, in combination with a single portable air purifier located at the bed within the isolation space (Ehsan S Mousavi *et al.*, 2020).
- The use of cooper alloy surfaces in public settings has been recommended as they can reduce infection transmission via contact of surfaces (Guo et al., 2021).
- In potential infectious outbreaks, the implementation of demarcation of zoning areas (contaminated and non-contaminated) should be carried out early. The administrative workspaces should be positioned mainly in green areas or established outside of potentially exposed zones (Tokuda *et al.*, 2020).
- Also, proper signage (such as posters, videos etc.) that promote the importance of control and preventive measure such as hand hygiene and explain how to perform effective hand hygiene should be available in different areas of the ship [Bottom up].
- In the scenario where there are few confirmed cases, specific quarantine zones may be designated on the cruise ship, or at broad places as temporary shelter hospital such as wharves and gyms which can accommodate more people. However, in case of a gathering outbreak, quarantine on a cruise ship does not effectively control the infectious outbreak (L. Xu *et al.*, 2020).
- The following spatial consideration should be into consideration:

Reception Area: In order to maintain appropriate physical distancing, the cruise ship should configure the reception desk. The use of deck markings at distances of at least 1.5 metres so as succeed proper social distance is suggested. Furniture should be properly arranged so as to manage the queue, reduce waiting times and avoid overcrowding, especially during check-in and check-out.

It is recommended to use electronic alternatives for check-in and check-out. The possibility of using an outdoor based check-in may also be considered. It is recommended that passenger expenses are paid electronically where possible (cash should be accepted only in exceptional cases) and that bills, invoices and receipts are sent electronically, as well [Bottom up].

Casinos: Casino layouts should be reviewed so that physical distancing of least 1.5 metres (or otherwise as per national/local health authority requirements) is respected and the maximum capacity of passengers allowed to enter the casino area should be determined to avoid overcrowding. At gaming tables, the number of players per table should also be estimated and defined to help ensure physical distancing measures. Slot and electronic gaming machines and gaming tables should be positioned in a way so as to maintain the physical distancing measures between passengers. The above could be achieved by relocating the machines or tables, removing chairs, by disabling some slot and electronic gaming machines and by adding protective screens when possible. Floor markings could also be used especially in the entrance to the casino area to ensure physical distancing measures. If necessary, seats may be removed or taken out of use from slot and electronic gaming machines. Appropriate signage should also be displayed at the entrance of the casino area informing passengers of the maximum capacity limits, advising them to apply regularly alcohol-based hand rub solutions, not to touch their face and to respect physical distancing measures [Bottom up].

Shared Facilities (e.g. hairdressers, beauty salons etc.): Where possible, the installation of transparent dividers to act as sneeze guards at the spa’s and the hairdressers’ reception is recommended [Bottom up].

Nursery and Play Areas for Children: It is preferable to operate the outdoor children’s play areas only. In case where this is not possible, the number of children using the indoor areas should be reduced to such levels so that staff could maintain physical distancing. The number of children in the outdoor children’s play areas/playgrounds may also be limited. The possibility of cohorting groups of children for the duration of the voyage should also be considered [Bottom up].

Gyms: Workout machines should be positioned in a way to ensure physical distancing of at least 2 metres. Hand washing or disinfection kits using alcohol-based hand rubs should be positioned in key areas when entering and leaving the gym. It is also important to keep record of any persons using the gym [Bottom up].

Recreation Water Facilities: The operation of indoor swimming pools is not recommended. However, the operation of indoor swimming venues that can be converted as outdoor after removing walls/roofs that allow with natural ventilation, could be allowed. It is important to rearrange seats (sunbeds, chairs, poufs, lounge chairs) etc. so as to ensure social distancing and allow to travelers to use the facilities. Additionally, the showers for the outdoor recreational water facilities should be separated, so as to ensure both bather's privacy and also to facilitate the efficient showering of the bathers before they enter the pool. Additionally, the entrances of showers should be equipped with hand rub alcohol-based solutions for sanitary issues [Bottom up].

Retail Stores: Physical distancing and electronic payments should be followed in commercial stores on cruise ships. Clothes and other items should not be tried on unless they can be disinfected afterwards [Bottom up].

Cabins: All cabins should be thoroughly cleaned and adequately ventilated (naturally if possible with open windows and doors) between check out and check in. It is advised that any item that cannot be cleaned and disinfected between cabin occupancies should be removed from the cabin (e.g. items such as menus, brochures, coffee or tea packaging, mini bar products etc.). Additionally, it is recommended to remove coffee machines, kettles, and all mini bar products from the cabin, unless these products are offered from a dispenser or can be disinfected between occupancies. It is preferable that the above devices or mini bar products be made available upon request, so that their disinfection is ensured. The mini bar can be used as a refrigerator by passengers and should be disinfected after each check out [Bottom up].

Guests should be provided individual PPE kits in their cabins.

A disposable cover should be placed on the TV and the air-conditioning remote controls to facilitate proper disinfection. All types of surfaces and materials which may be touched, including textile surfaces (e.g. cushions, rugs, furniture, wallpaper) should be cleaned between occupancies. During occupancy of a cabin by the same passenger/passengers, clothing and towels should be changed upon a passenger's request or routinely [Bottom up].

7.5.1.6. Thermal and Ventilation Conditions

Regarding the HVAC system, it is recommended that the cruise ship company consults with the manufacturers of the HVAC systems on board regarding proper maintenance and applying COVID-19 related revisions if needed. This may include: the frequency of cleaning of HVAC system parts, changing or replacing filters where appropriate to minimise the potential risk of contributing to the spread of small droplets SARS-CoV-2, increase the number of air exchanges per hour so as to reduce the risk of transmission in closed spaces. Additionally, direct air flow should best be diverted away from passengers or staff to avoid potential pathogen dispersion from asymptomatic persons [Bottom up].

A comparison was conducted addressing the proposed strategy to control SARS-CoV-2 transmission in the buildings related to HVAC system by several guidelines from different societies, including the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE), the Federation of European Heating, Ventilation, and Air Conditioning Associations (REHVA), the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE), Architectural Society of China, and the Chinese Institute of Refrigeration. The study found several conflicting aspects, but commonly agreed countermeasures among guidelines (M. Guo *et al.*, 2021):

- The running time of HVAC systems should be increased, and HVAC-related device opening in the 2 hours pre- and post-occupancy.
- A continuous maintenance of the filters should be applied. Portable room air cleaners are suggested.
- The air-recirculating should be avoided, if possible.
- Negative pressure in toilets should be maintained, and the water seals should be regularly inspected.

- SHASE has recommended temperatures ranged from 17ºC to 28ºC and RH ranged between 40% and 70% as temperature and humidity setpoint of the air-conditioning system.

The scientific recommendations regarding measures that should be taken to mitigate airborne transmission risk include (Morawska and Milton, 2020; Morawska *et al.*, 2020):

- Provide appropriate and effective ventilation systems, supply clean outdoor air, avoid or minimize any air-recirculating within the ventilation control system.
- Supplement the ventilation control system with airborne infection controls such as local exhaust, high efficiency air filtration, and germicidal ultraviolet lights.
- Adequate replacement of the mechanical filtration systems and maintenance and disinfection of filters, other devices and equipment for airborne infection control.
- Use of cleaning technologies such as UVGI in-rooms and in the stream (Joppolo and Romano, 2017).
- Use of air purifiers units with HEPA filtration in rooms to reduce local airborne viral concentration (Joppolo and Romano, 2017; Ehsan S Mousavi *et al.*, 2020).

In addition, it has been recommended for limited spaces:

- Neutral and unstable conditions are preferable for removal of airborne SARS-CoV-2-laden aerosols in BM. Total volume ventilation methods are suitable for neutral and unstable conditions and local ventilation methods are appropriate for stable conditions. High ventilation airflow rates can counteract the confinement effect of airborne related to stable conditions, but increasing VR may not always decrease the risk of cross-infection of SARS-CoV-2-laden aerosols (Deng *et al.*, 2021).
- In a displacement ventilated room, by creating unstable condition (vertical temperature gradient decreases with height) -i.e. floor heating in winter seasons, or ceiling cooling in summer- with a low airflow rate for reducing aerosol concentration in the BM and minimizing the risk for the occupants. In addition, this ventilation design can save energy consumption while maintain its effectiveness (Deng and Gong, 2021).
- In forced-air ventilation systems, maximize rates of three-dimensional aerosol removal (Farthing and Lanzas, 2021).
- Displacement ventilation systems are appropriate to control the local SARS-CoV-2 transmission risk in contrast of mixing ventilation systems (Bhagat *et al.*, 2020; Farthing and Lanzas, 2021).

Regarding cruise ship terminals:

- Indoor areas should be adequately ventilated. Natural ventilation is preferable where possible. In case of mechanical ventilation, the number of air exchanges per hour should be maximised together with the fresh air supply as much as possible. However, draughts should be avoided since these could create a risk of spreading any aerosolized droplets further [Bottom up].

7.5.2. Methods for Early Detection of Virus at the Community Level

7.5.2.1. Surveillance Systems

- Early detection of SARS-CoV-2 through wastewater-based surveillance may be useful for COVID-19 management and warning on cruise ships, and it has been suggested as supplementary to other surveillance systems. This environmental surveillance can effectively monitor the infectious disease at a community level on-board a cruise ship and detect cases before the first symptomatic one, and so support decision-making in mass gathering-based clinical screening approaches (Ahmed *et al.*, 2020, 2021; Brewster, Sundermann and Boles, 2020; Philo *et al.*, 2021).

- Automatic identification systems for the risk assessment of infection has been suggested to become a useful, complementary tool to guide in real-time potential transmission routes and risk areas/locations in regions for benefit of disembarking passenger, as well as to assist the case tracing method (Hoffmann Pham and Luengo-Oroz, 2020; Wei, Li and Nie, 2020; Z. Wang *et al.*, 2020).
- Digital contact tracing services based on mobile applications is commonly recommended to control outbreaks of COVID-19 (Ferretti *et al.*, 2020; Kretzschmar *et al.*, 2020; Sun and Viboud, 2020). By promoting the use of app-based contact tracing, and encourage a high level of coverage into a community, infectious disease transmission could be reduced (Davalbhakta *et al.*, 2020; Hellewell *et al.*, 2020; Kretzschmar *et al.*, 2020). For the public engagement, clear communication and supportive services about digital contact tracing applications should be translated into community, especially among older people (Megnin-Viggars *et al.*, 2020).

7.5.2.2. Screening Methods

- As per WHO technical guidance (2020) during past public health events, entry or exit screening measures are generally conducted as a two-step process: primary screening and secondary screening. Primary screening includes an initial assessment by personnel, who may not necessarily have public health or medical training. Activities include: visual observation of travellers for signs of the infectious disease, body temperature measurement, completion of a questionnaire by travellers asking for presence of symptoms and/or exposure to the infectious agent. Those who have signs or symptoms or have been potentially exposed to the infectious agent, are referred to secondary screening, which should be carried out by personnel with public health or medical training. Secondary screening includes an in-depth interview, a focused medical and laboratory examination and second temperature measurement. [Top Down]
- Early widespread testing for all passengers and crew members on-board ship has been suggested to disrupt community infectious transmission rather than applied categorization strategies for testing only symptomatic cases (Brewster, Sundermann and Boles, 2020; Plucinski *et al.*, 2020; Yamagishi, Kamiya, *et al.*, 2020).
- The use of a combination of nasopharyngeal swab quantitative RT-PCR along with serological antibody testing (IgG, IgM, IgA) has been recommended in being implemented to screening in the community infectious outbreaks (Hung *et al.*, 2020; Chen *et al.*, 2021).
- For assessment of severity of COVID-19 among confirmed cases, the use of inflammatory testing including measurement of LDH, AST, CRP levels, and especially of NRL and albumin concentrations has been recommended as a cost-effective clinical tool for predicting severe symptoms (Kato et al., 2020; Paliogiannis et al., 2021; Simadibrata et al., 2021; Zinellu and Mangoni, 2021). The implementation of this type of testing could evaluate potential patients at risk of severe outcomes and so, support decisions-making on-board for evacuation issues and transfer to healthcare facilities.
- It is recommended that terminal staff follow the same screening protocols as travellers for entry to the terminal. They should practice frequent hand hygiene and wear appropriate PPE according to their work duties. It is also suggested to conduct on a regular basis laboratory testing for COVID-19 of terminal workers [Bottom up].

7.5.3. Management of a Possible Case

7.5.3.1. Mobility Restrictions and Movement Patterns

- As changes in mobility patterns have a direct impact on dynamic process of virus spread (Schlosser *et al.*, 2021), it is necessary to provide information about the implemented optimal combination of restriction mobility measures (i.e. restrictions for infected or suspected individuals along with mobility restrictions for high-risk areas for all) so as to sustain the control of transmission during an infectious outbreak (Badr *et al.*, 2020; Sulyok and Walker, 2020; Y. Zhou *et al.*, 2020; Mendolia, Stavrunova and Yerokhin, 2021).
- Monitoring of real-time human mobility flow using personal smartphone device location data could be employed as a source to understand movement patterns spatially and to support decision-making of which areas should be restricted and assess the effectiveness of its implementation (Pan *et al.*, 2020; Couture *et al.*, 2021).
- It is recommended that crew should advice passengers to immediately stop using shared facilities if they start feel unwell and report to staff [Top down].

7.5.3.2. On-Board Isolation & Quarantine Methods

- Cruise line should have set an isolation/quarantine plan in case of possible COVID-19 cases. Cruise ships should also have a communication strategy so as to inform contacts of a confirmed COVID-19 case among passengers or crew. Definition of roles, duties and tasks of the crew in case of an outbreak is necessary. Collaboration with national competent authorities for contact tracing, quarantine of contacts and isolation of cases is also recommended [Bottom up].
- Following a preliminary medical examination, if the ship's designated officer determines there is a possible case of COVID-19 on board, the patient should be isolated in an isolation cabin, room or quarters and infection control measures should be applied until these cases are disembarked and transferred to a hospital ashore. Isolation plan including the identification of designated spaces for isolation of possible, probable or confirmed passengers or crew with COVID-19 until disembarkation and transfer to a health care facility, including communicating to the crew their entitlement to paid sick leave in case of infection or quarantine, should be in place [Top Down, Bottom up].
- The early isolation of suspected passengers and crew members is critical in controlling the infection transmission. Available reserve staff as relief strategy can allow the continued operation of organisational functions in the ship in the event of an infectious outbreak (Tokuda *et al.*, 2020).
- Cruise lines should designate a cluster of cabins and an adjacent corridor to be used specifically for isolation of cases on board, with a separate ventilation system (arranged in a way that there is no ventilation connection between the rooms and/or the corridor). Children should be quarantined in the cabin with one of their parents and similar consideration should be given to support those with special needs [Bottom up].
- The isolation of passengers or crew members in their own cabin should be conducted under proper guidelines which address the prevention of intercabin secondary transmission (Yamagishi and Doi, 2020). The designated cabins should be located near the ship’s medical facility for ease of accessibility by crew and if possible, have windows to promote appropriate air exchange [Bottom up].
- Contact with patients in isolation should be restricted to only those necessary, and crew in contact with the isolated patient (e.g. medical personnel) should wear appropriate PPE. Managing communications between departments (for example, medical, housekeeping,

laundry, room service, etc.) about persons in isolation or quarantine should also be in place [Bottom up].

- Both passengers and crew members should receive timely quality physical and mental care during a quarantine process (L. Xu *et al.*, 2020; Nakazawa, Ino and Akabayashi, 2020).
- An interactive risk communication tool for multi-language and various ages should be incorporated to appropriately manage quarantine period (Takahashi *et al.*, 2020).
- Procedures for disembarking infected persons (medical evacuations), for safe-handling bodies of deceased persons with suspected or confirmed COVID-19 and, in worst case scenario, for putting the ship in quarantine and termination of the voyage, should be pre-defined in case needed. [Top Down]

7.5.3.3. Health Status Monitoring

- Overall, people aged over 60, and suffering from comorbidities (cardiometabolic diseases, chronic kidney diseases, respiretory diseases, and cancer survivorship) face a greater risk of developing worse prognosis of the COVID-19. Clinical testing of these vulnerable people should be carried out to assess the progression of COVID-19 (Carreira *et al.*, 2020; Mesas *et al.*, 2020; Parohan *et al.*, 2020; Ssentongo *et al.*, 2020; Zheng *et al.*, 2020; Id *et al.*, 2021; Tian *et al.*, 2021).
- Among the infected or suspected patients, it is crucial to pay special attention to older patients with cardiovascular comorbidities as well as young patients with underlying risk factors for cardiovascular comorbidities such as hypertension and diabetes as they have higher risk of developing fatal outcomes due to COVID-19 (Bae *et al.*, 2021).
- Obese and overweight people should be considered as high-risk group as they can present severe COVID-19 outcomes, particularly in older age groups (Seidu *et al.*, 2021).
- Individuals with comorbidities, malignancy or immunosuppression are at high risk for developing severe COVID-19 and should be frequently monitored (Li *et al.*, 2021). Tailored measures, risk stratification planned and policies targeted for these clinical groups should be taken into account in order to improve infectious disease prognosis (Carreira *et al.*, 2020; Levin *et al.*, 2020; Singh *et al.*, 2020; Ssentongo *et al.*, 2020).
- Routine on board health monitoring for all crew can help with early detection of symptomatic COVID-19 cases. Daily contactless temperature measurement is proposed for staff and immediately reporting to supervisors in case of any mild or severe symptoms compatible with COVID-19. Daily contactless temperature measures are also suggested for passengers as well. In case of a possible COVID-19 case on board, the frequency of contactless temperature measurement may be increased [Bottom up].
- Remote patient health monitoring also provides an effective and safe approach for managing and delivering care to confirmed and suspected individuals while minimizing COVID-19 exposure worsens (Annis *et al.*, 2020; Morgan *et al.*, 2020; Schinköthe *et al.*, 2020; Tabacof *et al.*, 2020; Aalam *et al.*, 2021).
- Implementation of remote smart healthcare support system -with a hyperspace analogue to context and several sensors incorporated into closed rooms and monitoring application- has been proposed for capturing the physiological parameters and controlling indoor conditions, and thus accurately monitoring individual's health status (Taiwo and Ezugwu, 2020).
- Available IA technology (via smartphone applications) has been recommended for the monitoring of mental health and for delivering psychological care of confirmed and suspected COVID-19 patient during isolation-quarantine period on-board by specialist team (Mittal *et al.*, 2020) (Taiwo and Ezugwu, 2020).

7.5.3.4. Medical Assistance (Supplies and Equipment)

The necessity of a team of highly trained medical staff as part of the crew, including doctors and nurses on board who have experience in caring for a broad range of medical conditions, is proposed. Whenever possible, on board outpatient and inpatient facilities with critical care capabilities modified for infection control practices, including dedicated air handling systems with 100% fresh air supply and HEPA exhaust filtration is also suggested. Also, the attendance of a certified public health officer trained in the cruise's outbreak prevention protocol as well as local health sanitation programs, who will work closely with the medical team and would oversee outbreak mitigation and cleaning protocols, is proposed.

Adequate medical supplies and equipment should be available on board to respond to the case of an outbreak. Additionally, adequate supplies of disinfectants, hand hygiene supplies, supplies of PPE (including gloves, long-sleeved impermeable gowns, goggles or face shields, medical face masks and filtering face-piece (FFP) respirators) should be carried on board as well as made available at embarkation stations.

An adequate supply of RT-PCR diagnostic panel test kits and equipment for collecting specimens to be tested at ashore facilities or on board should be also available. Contaminated items as well as medical waste need to be properly sealed and disposed of according to health and safety guidelines.

In cases of assisting passengers, protocols should be developed for passengers with wheelchairs and sanitizing any equipment provided, e.g., transport wheelchairs, electric buggies, ambu-lifts, boarding chairs, hoists, transfer slings, etc. after each use. Procedures for the adequate use of gloves, wipes, hand sanitizer, face covering and masks when coming into close contact with passengers and their mobility equipment should be introduced [Bottom up].

7.6. Re-Embarkation Following an Excursion/Protection of Communities Visited by the Ship

Persons going ashore and re-embarking: It is recommended that the Cruise Management Plan gives special consideration to the strategy to be implemented for persons (both passengers and crew) going ashore and intending to re-embark. The cruise company should be in contact with the local public health authorities in the relevant ports to obtain up-to-date information on the level of transmission risk, what local measures are in place and to communicate this to all persons disembarking [Bottom up].

7.6.1. Protection of Communities Visited by the Ship

It is important that apart from crew and travelers, residents of the visited ports should be protected during those interactions. To this end, information should be provided to the disembarking passengers about the local measures required at the visiting ports. Cruise operators should communicate with the Port State to ensure that the appropriate measures are implemented to avoid overcrowding and maintain appropriate physical distancing while passengers or crew disembark and re-board the ship. Cruise operators should also ensure that any excursion provider, tour operator or external service provider offer at least the same level of protection as on board the ship, related to physical distancing measures, the use of PPE, and cleaning and disinfection protocols.

Any external provider who interacts with passengers such as tour guides should follow relevant cruise line protocols. If any means of transport are used to move passengers, physical distancing measures and protocols for their frequent cleaning and disinfection should be implemented. If tendering services are offered by local companies, local health regulations need to be applied. In those cases, it should be checked whether these measures are equivalent of those taken on board the cruise ship. Cleaning and disinfection of any means of transport used, including tenders should be conducted between each use. Crew and passengers should be informed before the ship's arrival in each port of call about the measures mentioned above [Bottom up].

7.7. Disembarkation. Mechanisms of Batch Transfer and Evacuation Methods

The disembarkation and evacuation of passengers and crew members are recommended immediately once a COVID-19 outbreak on-board is confirmed (L. Xu *et al.*, 2020).

As soon as a possible case is detected on board and for the duration of the journey until arrival at the final destination, a risk assessment of the event should be conducted (in cooperation of the port health authority and the ship officers) in order to decide if new passengers should not be allowed to board at intermediate destinations. [Top Down]

An assessment regarding the medical evacuation coverage for COVID-19 infected individuals onboard revealed that only half of the ship-management and shipping companies involved in the study trusted the sufficiency of its own policy to deal with any COVID-19 outbreak (Hebbar and Mukesh, 2020). The ship is required to have a specialised intensive team and conduct patient screening for prolonged interhospital transfer, as well as asses the risk of patient transport and confirm the feasibility and safety of medical evacuation (Nguyen *et al.*, 2020).

In cases of crew or passengers who need emergency medical attention that cannot be provided on board, cruise lines should coordinate with the shoreside healthcare facility. Infected persons should wear a face mask during the disembarkation process and throughout transportation to the shoreside healthcare facility. All escorting personnel should wear appropriate PPE per local/national guidance. Cruise ship operator must ensure a separate pathway where the disembarking people will exit with their personal belongings such as luggage. The pathway used for disembarkation, any potentially contaminated surfaces (e.g., handrails) along the pathway, and any equipment used (e.g., wheelchairs) should be cleaned and disinfected immediately after disembarkation. [Top Down]

There have been some challenges in the process of medical transport and evacuation of on-board patients. The admission for family members with positive results for SARS-CoV-2 in the same healthcare facility could depend on the capacity of available isolation beds. While some members with positive results disembark, the others tested negative stay on-board because of infection control and quarantine law. The separation of family members and lack of communication can create stress among passengers but also attending doctors (Anan *et al.*, 2020). The transport of both patients and their family members regardless of infection should be translated to the same healthcare setting, by using general hospital beds as well as modifying legal practices (Anan *et al.*, 2020).

7.8. Repatriation

7.8.1. Repatriation of Persons

It is recognised that as border restrictions apply to EU/EEA MS, arrangements for repatriation of crew members will not be possible immediately after the ship will have arrived, but will take place gradually. It Is advised that crew members stay on board until this is possible. It is the ship's captain responsibility to inform, at all times, the port authorities about the persons who are on board and their health condition.

The primary responsibility for arranging the return of passengers and crew members' rests with the cruise ship operator. If a need to repatriate passengers arises, the Flag and Port States should support the cruise ship operator (the level of support should be specified in agreed arrangements) in making the necessary arrangements for repatriation in line with the Guidelines on protection of health, repatriation and travel arrangements for seafarers, passengers and other persons on board ships.

For ships flagged in an EU Member State, the flag State should allow passengers and crew to disembark in one of its ports and support the cruise ship in adopting necessary arrangements for repatriation and access to medical care.

Repatriation should be undertaken as quickly as possible while ensuring good medical infrastructure and transport connections for those persons being repatriated. In case of COVID-19 cases on board, the State of the port of call should give consideration to disembarking where surrounding hospitals/healthcare facilities have sufficient capacity to provide adequate medical care. In cases of non-infected or asymptomatic travellers/ crew members, they should be taken to quarantine facilities, if this is necessary for follow-up medical checks, or otherwise be directly repatriated. [Top Down]

Additionally, ship operators or captains should cooperate with port competent authorities to arrange for the provision of water and food supplies, medicines, medical equipment and any other vital supplies or equipment required for ship operation. [Top Down]

Special attention should be paid to persons with special needs and accessible welfare services should be provided. [Bottom up, Top Down]

7.8.2. Changes of Crew

In order to keep maritime services operational, Member States should permit crew changes to take place in their ports. Even where crew changes are permitted, it has become challenging for seafarers to travel to the country where they are meant to board the vessels, as transport connections are now very limited. Consideration should be given to dedicated travel arrangements to facilitate seafarers travelling from and to maritime ports. It is advised that ports should be geographically dispersed and should be connected to operational airports and rail stations. Member States should envisage the possibility of dedicated or regular flight and rail operations to ensure the transport connections for crew changes and repatriations of seafarers. [Top Down]

It is recommended that Port States and their relevant national authorities should do everything possible to facilitate ship crew changes and the repatriation of seafarers, notwithstanding any restrictions that may continue to apply in response to the COVID-19 pandemic. Access to medical care onshore for crew members in need should also be granted under any circumstances [Bottom up].

7.8.2.1. Ensure Safe Ship Crew Changes and Travel till Joining a Ship

Period (a): Time Spent at Place of Ordinary Residence: Ship companies need to ensure, as far as practicable, that seafarers are healthy and they monitor their health during time spend at their residence when they travel to join ships and to control the risk of crew becoming infected with COVID-19 or infecting other persons, immediately before leaving their place of ordinary residence to begin travel to join a ship. Shipping companies based on any applicable national requirements or in liaison with its representatives or agents in the country, will apply the duration of the period for which records should be kept for the time spent at the place of ordinary residence immediately before departure. They also need to comply with standard infection protection and control precautions related to social distancing, self-isolation and hygiene in accordance with WHO as well as national or local guidance. In Government level, the following should be taken into account: Permit and facilitate airports and airlines operating under their jurisdiction to conduct flights for the purposes of travel to perform ship crew changes, consider prioritizing testing for COVID-19 for seafarers travelling to join ships. [Top Down]

Period (b): Travel from Airport to Departure: It is important to facilitate safe crew travel to the airport of departure and to control the risk of seafarers becoming infected with coronavirus (COVID-19), or infecting other persons, while travelling to the airport of departure. [Top Down]

Period (c), (d), (e): Travel by Airplane: Inform them appropriately for the time spent in airports before travelling, during flight and at the airport of arrival. [Top Down]

Period (f): Transfer to Any Hotel, Temporary Accommodation or Similar: Ship companies need to manage the safe crew travel to the place of any required hotel stay, temporary accommodation or similar, and to control the risk of seafarers becoming infected with COVID-19 while travelling to any such places. Unless seafarers are required by local authorities to quarantine prior to travelling to the port to join their ship, ship companies should consider the feasibility of arranging for crew to travel directly from the airport of arrival to the seaport. However, for practical reasons, a stay at a hotel or temporary accommodation, may be necessary before transfer to the seaport. Shipping companies should arrange to provide appropriate means of travel to the hotel, temporary accommodation, etc. that minimizes contact with other persons after leaving the airport, avoid contact with persons to appear unwell or show any COVID-19 symptoms and wear PPE as instructed for the duration of the travel It is also advised that they carry and handle their own luggage to the extent possible. [Top Down]

Period (g): Time Spent at Hotel or Temporary Accommodation: Manage the safety of seafarers while staying at any hotel etc. and control the risk of seafarers becoming infected with coronavirus (COVID-19) while staying at any such places. It is important that sea crew comply with any relevant local or national instructions and procedures (these might include instructions regarding isolation or quarantine, hygiene and PPE requirements etc.). [Top Down]

Period (h): Travel to Port: It is important to facilitate safe crew travel to the seaport from and to control the risk of seafarers becoming infected with coronavirus (COVID-19), while travelling to the port. It is advised that shipping companies will arrange to provide appropriate means of travel to the seaport, such as a private transfer, so as to minimize contact with other persons. Shipping companies should avoid, as far as possible, travel by means of public transport. [Top Down]

Time Spent at Place of Ordinary Residence Immediately after Repatriation: It is essential to ensure that seafarers comply with applicable national/local requirements or guidance related to the control of coronavirus (COVID-19) after completion of their repatriation to their ordinary place of residence. [Top Down]

7.9. Report & Analysis of Cases

7.9.1. Cases Identified On-Board (On-Board Outbreak)

Reporting should include possible, probable or confirmed COVID-19 cases, failures/shortcomings in implementing the Plan and any other hazardous situation in relation to COVID-19 risks. All accidents and hazardous situations in COVID-19 related matters should be reported to the company, investigated and analysed with the objective of improving the efficiency of the Plan ensuring the implementation of any corrective action, which should be no later than the start of the next cruise by the ship and across the company's cruise ship fleet. [Bottom Up]

Disembarking persons with possible, probable or confirmed COVID-19 infection: In accordance with the International Health Regulations (2005), it is recommended that the officer in charge of the ship immediately informs the competent authority at the next port of call about any possible COVID-19 infections on board. Port States which receive calls by cruise ships should have the capacity in the port of call itself or a nearby port to provide an appropriate public health emergency response, which response plan should include information on contact tracing and management, and the quarantine of contact persons. Port States should develop procedures for disembarking infected passengers or crew who are to be transferred to hospital facilities. During the disembarkation of persons with possible, probable or confirmed infections, every effort should be made to minimise their exposure to other persons and to avoid environmental contamination. Any available medical record, Passenger or Crew Locator Forms or any other relevant information should be provided to the relevant health care personnel onshore. [Bottom Up]

7.9.2. Cases Identified Post On-Board Outbreak (Passengers and Crew Members Follow-Up)

It is also important to rapidly identify and trace the contacts of anyone who, after the end of their time on the cruise ship is diagnosed with COVID-19 and is determined to have been infectious while on the ship (with the infectious period starting from 2 days before symptom onset). Contact tracing should be initiated by the local health authorities where the case is diagnosed, and the cruise ship company would be contacted to help facilitate identifying and contacting passengers and crew who were exposed to the case.

Measures to facilitate such tracing could be simple, for example asking passengers to provide contact details for follow-up if required. Collection of contact information should ideally be done electronically to facilitate and speed up the process of contacting persons at risk and for merging this information with the contact tracing database. It should be noted that the identification of a single confirmed case that was infectious on the cruise (from two days before symptom onset) results in all passengers and crew who were on board at the time being considered high-risk contacts. All passengers should therefore be contacted and informed about management including quarantine for 14 days since last exposure and be advised to contact the public health authorities where they are staying for further advice [Bottom up].

8. Summary

This international and interdisciplinary research report examines multiple strategies and control measures for preventing and limiting gathering transmission of infection and overcoming infectious disease outbreaks on cruise ships. It has been commissioned by The International Academy Forum (IAFOR) to assess the COVID-19 burden on cruise ships and ensure an emergency response to potential outbreaks of infectious diseases on cruise ships aligned with what evidence shows and lessons learned. The research project focused primarily on identifying comprehensively the multidimensional remarks and challenges for mass outbreaks of infection and then, on providing recommendations in short- and long-term responses for minimising the infection risk and managing an outbreak situation, across all stages of the journey on cruise ships.

The advice came of tackling the topic from perspectives of cruise ship and tourism industry, global public health, built environment field, occupational and environmental health. We have identified six key themes throughout the literature review and the iterative process of interviews/discussions with the multi-disciplinary expert panel (see section 12. Appendix B: Methodology), which shapes the following:

Layout Reconfiguration and Prevention through Design of Cruise Ships

The built environment characteristics of cruise ships, closed-off, highly airtight environment, and its mass-gathering activities and mobility flows among passenger’s community propitiate superspreading events for virus transmission and outbreaks of infections. The configuration of cruise ship-based indoor spaces through its design phase or retrofit stage is considered of great importance as it can anticipate, prevent, and mitigate the infectious risks. Re-thinking the layouts of shared spaces towards more intimate areas to reduce mass-gathering events as well as redesigning broader cabins which empower new services and facilitate a range of personal experience inside by its users rather than just limited to passengers' accommodation, needs to be considered. These considerations can potentially impact the changes of movement behavioural patterns both spatially and temporally among all community on-board, concentration of risk areas/zones, interactions density in human-to-human contact, frequency of physical contact with fomites and so prevalence of touched/contaminated surfaces, spatial distribution of airborne aerosol, etc., factors predicting the cumulative infection cases and magnitude of an infectious outbreak on cruise ships.

Spatial-Environmental Interactions and Building Services Systems

Owing to the scientific evidence supporting the spread of infectious disease via airborne transmission, certain national and international institutions have updated their guidelines to recognise this transmission route, particularly in enclosed, non-ventilated spaces. It has been identified that diffusion, dispersion, deposition, and persistence time of aerosol particles in the airborne in indoors depend on a mixing of interactions of spatial and environmental properties. First, a combination of airflow (turbulent flows), relative humidity, temperature, momentum, and chemical composition which influence on the evaporation effects of airborne aerosols and virus stability and can impact on the transmission dynamics. Second, an appropriate choice of heating, ventilation and air conditioning methods and the filtering/inactivation systems of virus, and its maintenance is crucial not only as a complementary control measure to manage airborne aerosols and infection risk, but also to facilitate a supportive environment (for temporary isolation requirements) in shared spaces and cabins. Indoor rooms should meet both requirements to effectively mitigate the infectious spread and hygrothermal comfort of the passengers. Third, the performance of ventilation control systems is in turn subject to the limited space air stability conditions. Therefore, the implementation of these engineering control measures should be considered along with the spatial reconfiguration and environmental conditions to effectively mitigate the infection transmission risk.

Interplay between Fomites and Infectious Risk

Both physical contact with fomites and airborne aerosol sedimentation on surfaces can contribute to the infectious transmission hours and days after virus deposition. While the studies carried out at the onset of COVID-19 pandemic demonstrated that the SARS-CoV-2 virus can survive and remain infective on fomites for 3 days, now it has been shown that virus-laden droplets can have a long-term stability and durability on surfaces more than three weeks. Survival rates of SARS-CoV-2 can differ greatly according to the surface characteristics such as porosity and its thermal properties as well as the temperature and humidity in the indoor atmosphere. We identified the persistence and viability of the virus across several surface types related with the environmental conditions. These newly insights can conveniently sustain the materiality retrofitting of the furniture that building the spaces and guide the disinfection routine implementation in the appropriate frequency and intensity. There is a wide range of disinfectant products and methods that have demonstrated to be effective in inactivating the virus.

Defining Vulnerable People On-Board

Early analysis identified several risk factors for severe infectious disease outcomes, especially older age and a broad-spectrum of pre-existing medical conditions such as cardiometabolic, respiratory, chronic kidney diseases, cancer survivorship, etc. and clinical risk factors including but not limited to hypertension, diabetes, obesity, and immunosuppression. Many passengers on a cruise ship are counted within elderly group, who tend in turn to suffer from these chronic medical comorbidities and multimorbidities. However, younger population aged below 50 years with underlying lower prevalence of certain comorbidities has shown to have a higher relative risk of developing severity of infectious outcomes compared to elderly people. In addition, several conditions like cancer survivorship have evidenced recently to be an increased risk of fatal infectious outcomes. Therefore, this necessarily involves re-evaluating the definition of high-risk groups as vulnerability may spread to medical conditions and ages not considered in the past. This also means a significant challenging in the management of these vulnerable passengers on-board and in the strategies for their regularly health monitoring.

Surveillance and Screening Methods and Passenger Engagement

By implementing a series of prevention and control measures on-board -such as physical distancing, distribution of hand sanitisers in all areas, face mask wearing in shared areas, preparedness of isolation rooms, healthcare provision system- the probability of an infection spread can be significantly mitigated on-board ships. Moreover, strategies for the early detection of virus presence have shown to be a key aspect to effectively halt transmission, particularly in a scenario with a high proportion of pre-symptomatic and asymptomatic transmission. The adherence to uninterrupted surveillance methods based on wastewater from sanitation facilities, automatic identification systems and/or digital tracing could respectively: a) monitor the presence/absence of infection before the onset of clinical symptoms; b) assess in-real-time the risk level of COVID-19 across different areas, region's locations and ports; and c) identify potential cases earlier than clinical manifestation. However, optimal communication to passengers throughout certain methods that needs the public engagement to work effectively is essential for its feasibility of halting infectious outbreaks. In addition, clinical screening approaches for all passengers and crew members (not applying triage by symptom) and immediate case isolation could reduce the projected incidence during an infectious outbreak. Overall, these widespread surveillance and screening measures are considered as cost-effective tools for the early detection in large passenger population.

Isolation, Health Monitoring and Mental Health Services

Although quarantine can reduce many new cases, early evacuation of all passengers and crew members at the onset time of the first confirmed case have shown to prevent many more infected cases. Therefore, the early isolation of suspected passengers could be critical in controlling the infectious spread. As learned lessons, cruise ship isolation and cabin-based infected or suspected individuals' quarantine has revealed the need of daily supplies with personal considerations, and more importantly, psychological support as these are subject to severe distress and stress. Moreover, the passenger's evacuation and transportation to the designated healthcare facility at later stages need to assess the risk of patient deterioration and to expand transportation of family members. Therefore, in case of no other alternative, passenger isolation should follow proper guidelines which tackle the intercabin secondary transmission, the health status monitoring and both physical and mental health care by using remote smart healthcare support systems. This articulation requires the multilateral coordination, cooperation and collaboration mechanisms of national and international public and private actors.

9. Appendix

9.1. Appendix A: Methodology & Process Diagrams

The Bartlett Real Estate Institute UCL is preparing a report based on our research into the preparedness and response for the case of infection disease outbreaks in cruise vessels, focusing on both passengers and crew. For this report, a planned strategy for multistage mixed methods has been employed for developing the material which is presented in the final report. First, a series of consultations with the four experts of the UCL research team was conducted. Second, a review of the literature was performed using both systematic and narrative approaches. Research team then summarised the main issues and draft this report.

Approach A: Consultation Sessions

The research team planned and conducted a small workshop and expert consultations session with four key experts. These were selected from different disciplines: two from public health and epidemiology -with expertise on cruise and occupational health and safety- and two from tourism, with expertise on cruise and tourism management including air travel, accessibility and old age. Through these interviews/discussions, they identify key issues related to the subject, the protocols, regulations and measures in place that already exist so as to prevent an outbreak on a cruise vessel, any insurance guidelines in place or relevant policies. They were highlighted on what needs to be in place before getting on board, while you are on board and after, focusing both on passengers and crew. The four experts who were advising at all stages:

- **Prof Christos Hadjichristodoulou**, EU HEALTHY GATEWAYS Joint Action Coordinator, Professor of Hygiene and Epidemiology, Department of Hygiene and Epidemiology, Medical Faculty, University of Thessaly, Greece

Focus for the report: Prof Hadjichristodoulou's Lab participates in the Joint Action Preparedness and action at points of entry (ports, airports, and ground crossings) with acronym HEALTHY GATEWAYS and leads the Work Package on Maritime transport.

- **Prof Alexis Papathanassis**, Chancelor - Faculty of Management & Information Systems, Professor for Cruise Management & e-Tourism, Chairman of the Cruise Research Society, Co-Director of the Institute for Maritime Tourism, Bremerhaven University of Applied Sciences, Germany

Focus for the report: Cruise management and maritime tourism. An academic from the cruise industry (he will introduce us to the cruise industry perspective, existing regulations, who the dealt with the case of COVID-19. Will also guide us on the major regulatory bodies, especially in relation to preparedness and health & safety and the physical environment for cruise).

- **Prof Theodoros Konstantinidis**, Laboratory of Hygiene and Environmental Protection, Director Hellenic Institute of Occupational Health and Safety, Medical School for Democritus University of Thrace, Greece

Focus for the report: Occupational health and safety medicine (what is already in place for prevention and monitoring).

- **Prof Dimitrios Buhalis**, Business School, Bournemouth University, United Kingdom

Focus for the report: Expert on tourism sector in relation to air travel and COVID in hospitality industry. Lessons learned: how IATA and other relevant stakeholders dealt with COVID-19 pandemic.

The four experts coming from different disciplines provided a unique multi-disciplinary perspective to the research question. Dr Evangelia Chrysikou conducted a first circle of consultations with the four experts in December 2020 and they provided keywords and material to start working on the literature review for the next stage. Additionally, on 27 January, February and March 2021, Dr Chrysikou organized consultation sessions with Prof Hadjichristododoulou and Prof Satoh discussing what actually happened on the case of *Diamong Princess* cruise ship and lessons learned. The main focus of the discussion was on responsibility and legislation for pandemic response and the EU regulations relevant to crew and passenger health, issued as a result of the outbreak. The role of the built environment of the cruise ship and whether the spatial characteristics of vessels could play a role in the preparedness of a ship in case of such an emergency as a pandemic was also discussed, a point our research team explored in next steps.

Approach B: Literature Review

Consultation sessions provided the research team with the keywords/key themes on where there was need to focus so as to better address the research question.

The Arksey and O'Malley, 2005 and Levac, Colquhoun and O'Brien, 2010 frameworks as well as World Health Organization, 2017 Practical Guide (Tricco *et al.*, 2017) on rapid review approaches for health policy-making and systems were used partially by the review team members to guide the design and process of the present evidence synthesis. The report progressed adhering to the following five-stage methodological framework: (1) multiple systematic and narrative searches for identifying the relevant material; (2) selection of the best available evidence; (3) data extraction; and (4) evidence synthesis and reporting the results.

Stage 1. Multiple Searches to Identify Relevant Evidence

To identify a broad range of literature (published, unpublished, and in progress), a wide range of methods including searches in electronic databases, reference lists and grey literature aimed to capture a whole picture of existing evidence. As such, our approach included:

a) Systematic Searches from Electronic Databases

The identification of empirical evidence relevant to this report was achieved by searching electronic databases of the published literature, which included Medline and Scopus. A preliminary search in Medline by using the medical subject headings (MeSH) term "COVID-19" and the "cruise ships"- related free-text words, conducted on 21 of January 2021, identified 191 potential citations. The scanning of the resulting items facilitated the reviewers to become increasingly familiar with the subject matter, and particularly with relevant terminologies, topics and evidence sources. The database searches were conducted on 24 January 2021 and were updated to the last date before completing the review report to ensure the stated goal of providing the best scientific evidence available to inform the final report.

In an initial search, we combined the terms referring to COVID-19 or infectious outbreak and terms associated to cruise ships. The table 1 shows an overview of the search strategy designed for Medline. The scientific databases were supplemented with searches in the web-based academic search engine Google Scholar to retrieve relevant material and some grey literature components in institutional repositories and presentations not formally published in peer-reviewed journals. As an iterative approach was employed throughout the literature review process, the initial search strategy required further refinement for conducting restricted systematic searches to focus on specific parameters and key themes.

The following combination of keywords and descriptors were implemented to construct the search strategy: "COVID-19", "coronavirus disease 2019", "SARS-CoV-2", "2019-nCoV", "SARS coronavirus", "disease outbreak", "infectious disease" and "cruise ships", "ocean liners".

Table 1. Overview of implemented MEDLINE search strategy[1].

	COVID-related
#1	COVID-19.mh. or COVID19 virus.tiab. or COVID-19 virus. tiab. or COVID19. tiab. or coronavirus disease 2019. tiab. or SARS-CoV-2. tiab. or SARS coronavirus 2. tiab. or severe acute respiratory syndrome coronavirus 2. tiab. or 2019-nCoV. tiab. or 2019 novel coronavirus. tiab. or 2019 novel coronavirus infection. tiab. or coronavirus disease-19. tiab. or 2019-nCoV disease. tiab. or 2019 novel coronavirus disease. tiab. or 2019-nCoV infection. tiab.
#2	Disease outbreaks.m.h. or pandemics.mh. or epidemics.mh. or infectious disease outbreak.tiab or pandemic.tiab. or epidemic.tiab. or spread.tiab. or transmission.tiab. or infection.tiab. or infectious.tiab. or contagious.tiab.
#3	SARS virus.mh. or SARS coronavirus.tiab. or SARS-associated coronavirus.tiab. or SARS-CoV.tiab. or SARS-related coronavirus.tiab. or severe acute respiratory syndrome.mh. or severe acute respiratory syndrome virus.tiab. or severe acute respiratory syndrome-related coronavirus.tiab.
#4	#1 or #2 or #3
	Cruise ships-related
#5	Ships.mh. or ship.tiab. or cruise.tiab. or cruise ship.tiab. or cruise ships.tiab. or ocean liner.tiab. or ocean liners.tiab.
#6	#4 and #5

[1] This table of search terms and queries provides an overview of the search strategy for this report.

b) Citation Searches or "Snowballing" Technique

The reference list of retrieved papers in the formal initially driven search strategy was checked to identify relevant evidence missed. The process of citation snowballing is an accurate iterative-based method (tracking backwards and forwards for studies) in achieving the additional material not retrieved in the conventional systematic search, contributing to best practice (Horsley et al., 2011; Levay et al., 2016).

c) Narrative Literature Searches and Grey Literature

The narrative literature searches retrieved potentially eligible material, guidelines from government, protocols, health agencies, cruise companies, academy and industry and grey literature (policy literature, government and non-government reports, documents from organisations and authorities). The key terms and free-text words were introduced into customised web search engines, university and governmental open databases, targeted websites, etc. We used inside brackets the phrase “Top Down” for the recommendations coming from government guidance, or either “Bottom Up” for the advice from industry, academia or regulatory bodies. Narrative searches were carried out in December 2020 and were conducted throughout all review stages to complete the report.

Stage 2. Selecting the Best Available Evidence

Based on the preliminary exploratory search, we established the pre-specified eligibility criteria of scientific papers for systematic searches. Studies reporting both qualitative and quantitative data in relation to COVID-19 or other infectious outbreaks (learned lessons, preventive measures, control, and management) in cruise ships were considered for inclusion. No restrictions were applied either on the type of study design or publication time frame. However, time frame limitations were applied in the restricted searches to retrieve the most recent publications from COVID-19 research.

In addition, the eligibility for narrative searches was based on ad hoc selection, and research experience. The inclusion criteria of original publications and government, health agency and industry guidelines may be partially adopted of quality assessment and data analysis process conducted in each retrieved item.

Stage 3. Data Extraction

The initial systematic search strategy identified 2,203 records (24 January 2021). We managed the records into reference management software and the duplicates were automatically removed, resulting in 1,855 references. The review team conducted the screening process of title and abstracts according to the eligibility criteria by using a management/analysis tool of semi-automation process and 364 papers were identified to screen in title and abstract as well as the results from restricted systematic searches and citation searching (217 records identified). These relevant publications were screened in full-text for data extraction and subsequent synthesis. For the final inclusion of items in this report, 312 empirical research and 34 guidelines (from governments, health agency, industry and academy) were identified and managed. The reviewers classified the data into an initial categorization and emerging themes, which guided the next evidence summary.

The figure 1 shows the decision process of study selection reported according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flow diagram.

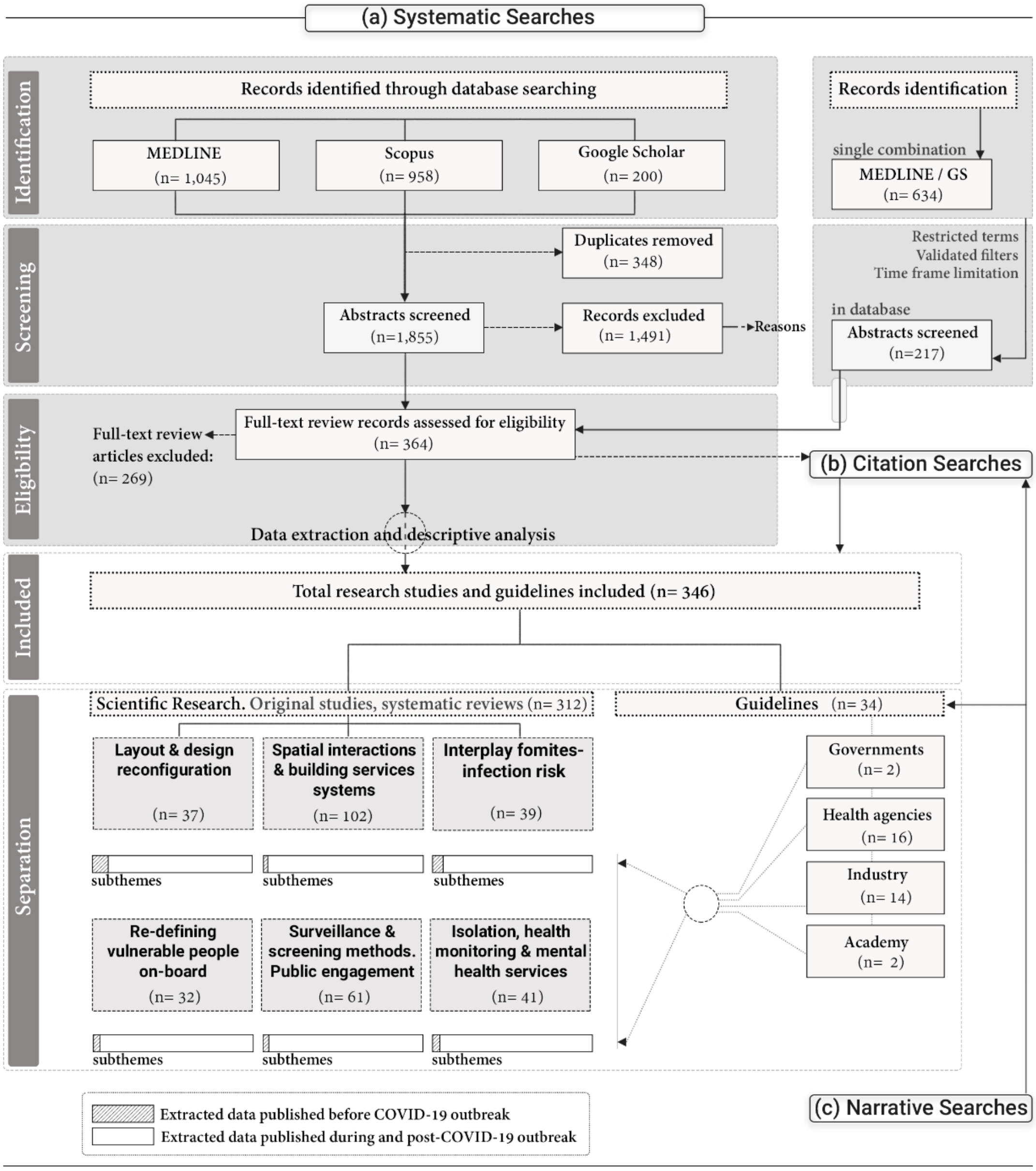

Figure 1: Flow diagram representing an overview of search strategy and methodology for conducting the report.

Stage 4. Synthesize Data & Reporting Results

At this stage the research team synthesized data collected from two previous approaches of the consultation with experts and the literature review. The preliminary themes retrieved from systematic and narrative searches were refined and verified in major themes and subthemes by research team and expert panel throughout the consultation sessions. Then, we conducted the narrative knowledge synthesis, a descriptive summary of studies reporting the results of included material and discussions.

Deliverable of this stage is the research team’s final report which includes data on the preparedness and response for the case of infection disease outbreaks in cruise vessels. This research project could act as the start to establish a voluntary code of practice and see how this could be adopted.

9.2. Appendix B: Glossary of Terms, Abbreviations and Acronyms

ACE2	Angiotensin-Converting Enzyme 2
ACH	Air-Change Hour
ASHRAE	American Society of Heating Refrigerating and Air-Conditioning Engineers
AST	Aspartate Aminotransferase
BM	Breathing Microenvironment
CDC	Centers for Disease Control and Prevention
CLIA	Cruise Lines International Association
CO_2	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
CoV	Coronavirus
COVID-19	Coronavirus Disease-2019
CRP	C-Reactive Protein
CVD	Cardiovascular Disease
DHP	Dry Hydrogen Peroxide
DPH	Dilute Hydrogen Peroxide
DUV-LED	Deep Ultraviolet Light-Emitting Diode
EHR	Electronic Health Records
EPA	Efficient Particulate Air
FFP	Filtering Face-Piece
H1N1	Influenza A - Hemagglutinin Type 1 and Neuraminidase Type 1
HEPA	High-Efficiency Particulate Air
HPV	Hydrogen Peroxide Vapour
HVAC	Heating, Ventilation and Air Conditioning
IATA	International Air Transport Association
Ig	Immunoglobulin
IHR	International Health Regulations
IMO	International Maritime Organization
LAIAHE	longitudinal air to air heat exchanger
LED	Light-Emitting Diode
LEV	Local Exhaust Ventilation
LHD	Lactate Dehydrogenase
MARS	Mobile Application Rating Scale
MERS	Middle Eastern Respiratory Syndrome
MERV	Minimum Efficiency Reporting Value
NLR	Neutrophil-to-Lymphocyte Ratio
NO_2	Nitrogen Dioxide
NPI	Non-Pharmacological Intervention
PAA-HP	Peroxyacetic Acid and Hydrogen Peroxide
PHEIC	Public Health Emergency of International Concern
PM	Particulate Matter
PoE	Points of entry
PPE	Personal Protective Equipment
PSC	Port State Control
PtD	Prevention through Design
RB	Rose Bengal
REHVA	Federation of European Heating, Ventilation, and Air Conditioning Associations

RH	Relative Humidity
ROS	Reactive Oxygen Species
RT-PCR	Reverse Transcription Polymerase Chain Reaction
SARS	Severe Acute Respiratory Syndrome
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
SHASE	Society of Heating, Air-Conditioning and Sanitary Engineers of Japan
SOP	Solid Oxygen-Purifying
ULPA	Ultra-Low Penetration Air
UNWTO	World Tourism Organization
UV	Ultarviolet
UVGI	Ultraviolet Germicidal Irradiation
VR	Ventilation Rate
VSP	Vessel Sanitation program
WBE	Wastewater-Based Epidemiology
WTTC	World Trade travel and tourism council

9.3. Appendix C: Glossary of Definitions

The following terminology was consistently used in the section *8.1. Built-Environment characteristics of cruise ships* of this report:

- **Airborne droplets.** Droplets which have not completed evaporation and remains suspended within the puff/cloud (Balachandar *et al.*, 2020).
- **(Airborne) droplet nuclei.** Droplets that remain in the air within the puff/cloud and that have fully evaporated, also called ***aerosols*** (Balachandar *et al.*, 2020).
- **Airborne transmission.** Infection that can be spread by exposure to smaller or comprised virus-laden respiratory droplets and particles that can linger in the air over long distances and time (typically, for minutes to hours) (CDC, 2020).
- **Close contacts.** Someone who has been within 6 feet of an infected person (laboratory-confirmed or a clinically compatible illness) for a cumulative total of 15 minutes or more over a 24-hour period (CDC, 2021).
- **Cloud.** The distribution of ejected droplets that remain suspended (in the airborne) even after the puff has lost its coherence. The cloud is advected by the air currents and is dispersed by environment turbulence (Balachandar *et al.*, 2020).
- **Contact transmission.** Infection spread through direct contact with an infected person (i.e. touching) or with a surface that has become contaminated, also called fomite transmission (CDC, 2020).
- **Displacement ventilation.** An efficient mechanical ventilation method that supplies cool fresh air from the floor level, forcing the movement of the air up when it meets the heating in the room at the ceiling, and then out of the indoor space through exhaust panels (Smart Building Systems for Architects, Owners and Builders, 2010).
- **Droplet transmission.** Infection spread by exposure to larger and smaller virus-laden respiratory droplets exhaled by an infected person (CDC, 2020).
- **Exited droplets.** Droplets that have either overshot the puff/cloud or settled down due to gravity forces (Balachandar *et al.*, 2020).
- **Puff.** Warm, moist air exhaled during breathing, speaking, coughing or sneezing, which remains consistent and goes down during early times after exhaling (Balachandar *et al.*, 2020).

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10.1. Scientific Evidence

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10.2. Guidelines

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