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Airport pandemic response: An assessment of impacts and strategies after one year with COVID-19

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ABSTRACT

The COVID-19 pandemic has caused an unprecedented crisis for the air transportation industry, affecting millions of aviation users and stakeholders. As the aviation sector has faced disease outbreaks and extreme events before—albeit not at the same scale—and will, in all likelihood, face them again, we provide an assessment in this study that a) gives an overview of the effects of the pandemic, b) categorizes the response mechanisms that were observed, and c) proposes a framework for a coordinated global response to future disease outbreaks. We highlight that of the many lessons, recommendations, and suggestions that emerged during previous outbreaks, few were introduced effectively into civil aviation practices and operations. Based on multiple data sources for passengers, cargo, and flight schedules, we assess the impact of COVID-19 on the global aviation industry and compare the data of some prominent airports to highlight the need for a coordinated response to effectively deal with future disruptions. As global aviation navigates its ongoing recovery, we discuss different responses during the pandemic including guidelines issued by bodies such as the International Civil Aviation Organization (ICAO), operational decisions such as closing terminals, increased cleaning frequencies, and mask mandates etc. We emphasize the need for resilience to accommodate disease outbreaks in future planning, design, and preparedness strategies for airports and airlines. We further argue that the existing civil aviation system needs a coordinated global response mechanism to combat future outbreaks and propose a framework with a threat response matrix to keep aviation safe and operational during future pandemics and mitigate socioeconomic fallout.

Introduction

On March 11, 2020, the World Health Organization (WHO) declared a coronavirus pandemic (WHO, Novel Coronavirus, 2019), after the emergence of a novel coronavirus, 2019-nCoV (i.e. SARS-CoV-2), in Wuhan, China, at the end of 2019 (Munster et al., 2020). In 14th century Europe, it took 3 years for the bubonic plague to diffuse from southern Italy to Britain on the backs of rats (Ozonoff and Pepper, 2005). In 1918, it took the Spanish flu less than 2 months to spread from the USA to France and a further 3 months to make it around the globe on the backs of the troops involved in World War I due to overcrowding of troops during transportation and the large-scale movement across countries (Barro et al., 2020). In 2019/20, it took less than 3 months for COVID-19 to spread across the globe on the backs of travelers. Soon after its emergence, human-to-human transmission was confirmed—the key to its global spread through modern routes of transportation, including air travel. As of early-August 2021, over 200 million people have been infected and close to 4.26 million have died across the globe (Dong et al., 2020).

After the severe acute respiratory syndrome coronavirus (SARS-CoV) outbreak in 2002 (Drosten et al., 2003; Peiris et al., 2003) and the Middle East respiratory syndrome coronavirus (MERS-CoV) outbreak in 2012 (Zaki et al., 2012; Memish et al., 2013), humanity is now suffering from a third coronavirus outbreak in just the past two decades. Several sources suggest that this will not be the last (Mason and Friese, 2020). A century after the devastating Spanish flu, which infected over one third of the world's population and caused over 40 million deaths (Barro et al., 2020; Lüthy et al., 2018), the COVID-19 pandemic remains the most severe outbreak with its devastating effects which have been described as an "unprecedented biopsychosocial crisis" leading to "great economic, social, and medical uncertainty" (Zagury-Orly and Schwartzstein, 2020). As the pandemic originated in one country, its initial spread (and that of subsequent variant COVID-19 strains later in 2020 and 2021) has been driven and/or facilitated by human movements via air transport. Due to rapid human-to-human transmission, various countries have declared travel bans, closed borders, and followed up with internal lockdowns, limiting public transport and non-essential activities (Le Quéré et al., 2020). Such restrictions have led to unprecedented (negative) impacts on global air transport, affecting the entire system including consumers, airlines, airports, and third-party service providers. Fifteen years ago, in a reference to the emerging H5N1 epidemic, Ozonoff and Pepper (2005) pointed out that it would just take a "ticket to ride" for diseases to spread globally, noting that "from a public-health standpoint, air travel is one of the most important kinds of interconnection." In the past, evidence of spread of disease outbreaks through air travel was widely investigated, e.g. following the outbreaks of H1N1 (Khan et al., 2009; Wagner et al., 2009), Ebola (Bogoch et al., 2015), Zika (Gardner et al., 2018; Bogoch et al., 2016), SARS (Wilder-

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Smith et al., 2020; Breugelmans et al., 2004; Wilder-Smith et al., 2006; Olsen et al., 2003), and MERS (Coburn and Blower, 2014; Gardner et al., 2016). Additionally, in-flight transmission has also been studied for other infectious diseases such as influenza, measles, smallpox, and tuberculosis (Mangili and Gendreau, 2005). Previous outbreaks were not as violent in their spread as COVID-19, but their existence paired with the severity, with which the current pandemic struck, leads to the question of whether lessons were not learned and why.

Travel restrictions across territories, particularly regarding air travel, seem to have played a positive role in delaying the pandemic progression by some days in China, and until mid-February 2020 through international travel restrictions, aiding the slower spread elsewhere in the world (Chinazzi et al., 2020). However, the timing of the outbreak, coinciding with the Lunar, or Chinese, New Year holidays, during which several billion person-trips are usually made in near full capacity flights, train and bus journeys, has played a detrimental role for both the transportation sector, public safety, and COVID-19′s eventual spread through (human) travel (Wu and McGoogan, 2020; McCloskey and Heymann, 2020; Chen et al., 2020; Wu et al., 2020). Several studies have now confirmed the crucial role of public and private transport in the spread of SARS-CoV-2 within and outside China (Zheng et al., 2020; Du et al., 2020; Kraemer et al., 2020).

Commercial civil aviation, as one of the most crucial modes of mobility with over 4.5 billion passenger journeys and 750 billion revenue passenger-kilometers (RPK) annual travel until 2019 (IATA, 2020a; IATA, 2020c), was thus both instrumental in the spread of COVID-19 (Nakamura and Managi, 2020) and among the industries hit hardest by the effects of the pandemic. Along with its socioeconomic importance, the current pandemic has raised several important considerations—about rethinking growth in the face of large scale demand shocks, or disease spread at different journey points, for example—for the air transport system including airports, airlines, and associated users and suppliers. This public health crisis, thus, sheds some light on the way the aviation industry is and has been prepared for such events. Even though previous lessons from disease outbreaks (Moon et al., 2015; Castillo-Chavez et al., 2015) were not acted upon systematically, a growing discourse has now emerged on global preparedness for such events in the near future (McCloskey and Heymann, 2020; Jacobsen, 2020; Jones, 2020; Ji, 2020). The COVID-19 pandemic has brought back to the forefront several systemic issues and exposed the hidden vulnerabilities which seem to have been ignored.

We will therefore a) revisit the current (at the time of writing) data of the impact on global air traffic, b) categorize the responses that have been observed in civil aviation, and then c) propose a response mechanism for future disease outbreaks based on areas where the current mechanisms appear to provide loopholes for further spread and thus damage to public health and the aviation industry. Overall, this study aims to highlight previously missed opportunities and lessons for the aviation sector, and proposes a systematic approach which, if adhered to or enforced, can minimize potential future risks and impacts, while providing a common ground for civil aviation to remain operational and mitigate economic fallout.

COVID-19 impacts on the civil aviation industry

Even though the pandemic has affected every aspect of the aviation industry, most of these effects originated from human-to-human transmission and associated health risks to passengers, crews, ground staff, cargo handlers and all stakeholders directly or indirectly involved. The immediate effects were, of course, reduced travel demand and government-initiated travel and immigration restrictions (Sun et al., 2021). As the initial epidemic spread across the globe from China, the 'lockdowns' of cities and airports led to a massive decline in air traffic (Fig. 1).

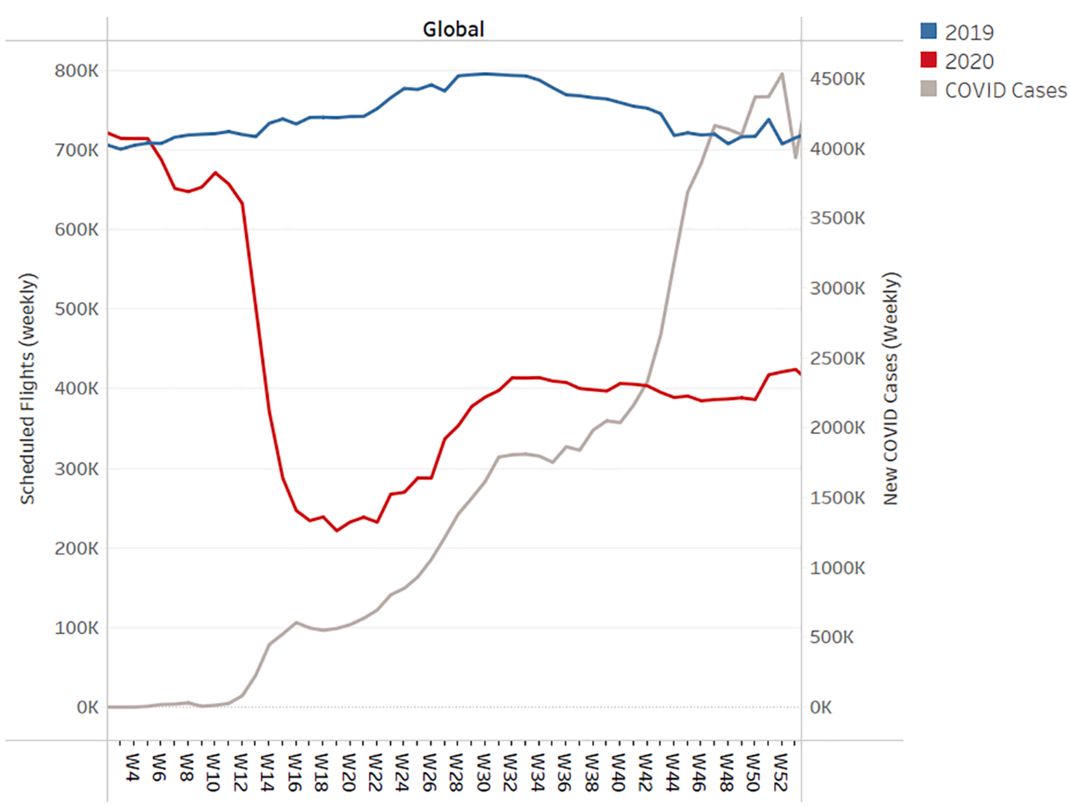

Fig. 1. Global scheduled weekly flights (in 2019 and 2020) and increase in new COVID-19 cases highlight first rapid decline in flights in April, and subsequent delayed recovery pathway. New COVID-19 cases had little impact on global flights recovery trend later on (Data from OAG, JHU and Authors).

Flight schedules and passenger movements

The real decline in passenger movements started to emerge in March 2020 (IATA, 2020a). Based on International Air Travel Association (IATA) (IATA, 2021) data, air travel demand remained significantly impacted by the Covid-19 pandemic, with all regions recording steep declines. Overall, 2020 was the worst year for the passenger traffic in aviation history with a 66% decline in the revenue passenger-kilometers (RPKs) from 2019 levels. The number of flights declined from 38.9 million in 2019 to 16.4 million in 2020. Based on the decline in scheduled flight capacity (Fig. 1), the available seat capacity (available seat-kilometers) declined by 56.5% in 2020 (IATA, 2021). Even though the recovery for scheduled flights started in April, continued to increase until August and remained steady until the year end, the overall passenger load factor decreased by 17.8% from 2019, reaching a 64.8% level—a record low. The new coronavirus strains in the UK and South Africa have affected travel demand, as well as restrictions, which led to about 70% of year-on-year decline in RPKs in the last months of 2020.

As individual countries control their respective pandemic outbreaks, domestic traffic has seen the largest recovery. Aviation hubs with low/no domestic traffic, thus, faced the most severe consequences of the pandemic primarily due to closed borders, travel restrictions, quarantine rules, and associated demand loss. At the peak of the crisis in April, international RPKs reached the lowest point with a 98.3% year-on-year decrease, while domestic RPKs saw a comparatively smaller decline of 86% (IATA, 2021). In comparison, by December 2020, international RPKs had only improved by 13%, still lower by 85.3% compared to 2019, but thanks to traffic within large countries, domestic RPKs improved by over 43%. Overall, 2020 saw a 48.8% decrease in domestic RPKs and a 75.6% decrease in international RPKs. Fig. 2 shows the different recovery rates and patterns of weekly scheduled flight capacity in different countries.

Based on the data from the past two years, it can be established from Fig. 2 that the recovery pathways for different countries were greatly influenced by the pandemic stage, aviation preparedness, regulatory restrictions, and passenger demand. Different driving factors led to varied recovery curves across specific countries and continue to influence the global recovery. Countries with more severe COVID outbreaks, including Spain, Italy, UK, United States and India, enforced strict lockdowns and domestic aviation capacity restrictions which affected the operations and recovery. Further, the differences between the patterns and numbers of new COVID-19 cases show that multiple factors determine the spread within a country. European countries seem to have followed a similar trajectory, with signs of recovery in traffic after a decrease in number of cases, and additional push of summer travel. However, aviation recovery in Europe was significantly suppressed when a renewed increase in COVID cases in the UK led to a general fear of second waves in other European countries such as France, Germany, and Italy. Unfortunately, this fear became reality with summer travel causing significant increase in COVID cases across the Europe starting July 2020 until end of the year (Hodcroft et al., 2020). A second much stronger wave hit countries where measures had been relaxed. One of the most challenging recovery futures seems to be for Hub Airports with no/low domestic traffic such as those in Singapore, the UAE, Hong Kong, and South Korea. Even though these countries have had significant success in containing the pandemic, air traffic remains minimal.

Looking at the progression of new COVID cases (Figs. 1 & 2), one can establish that the initial traffic decline during March-April 2020 was the

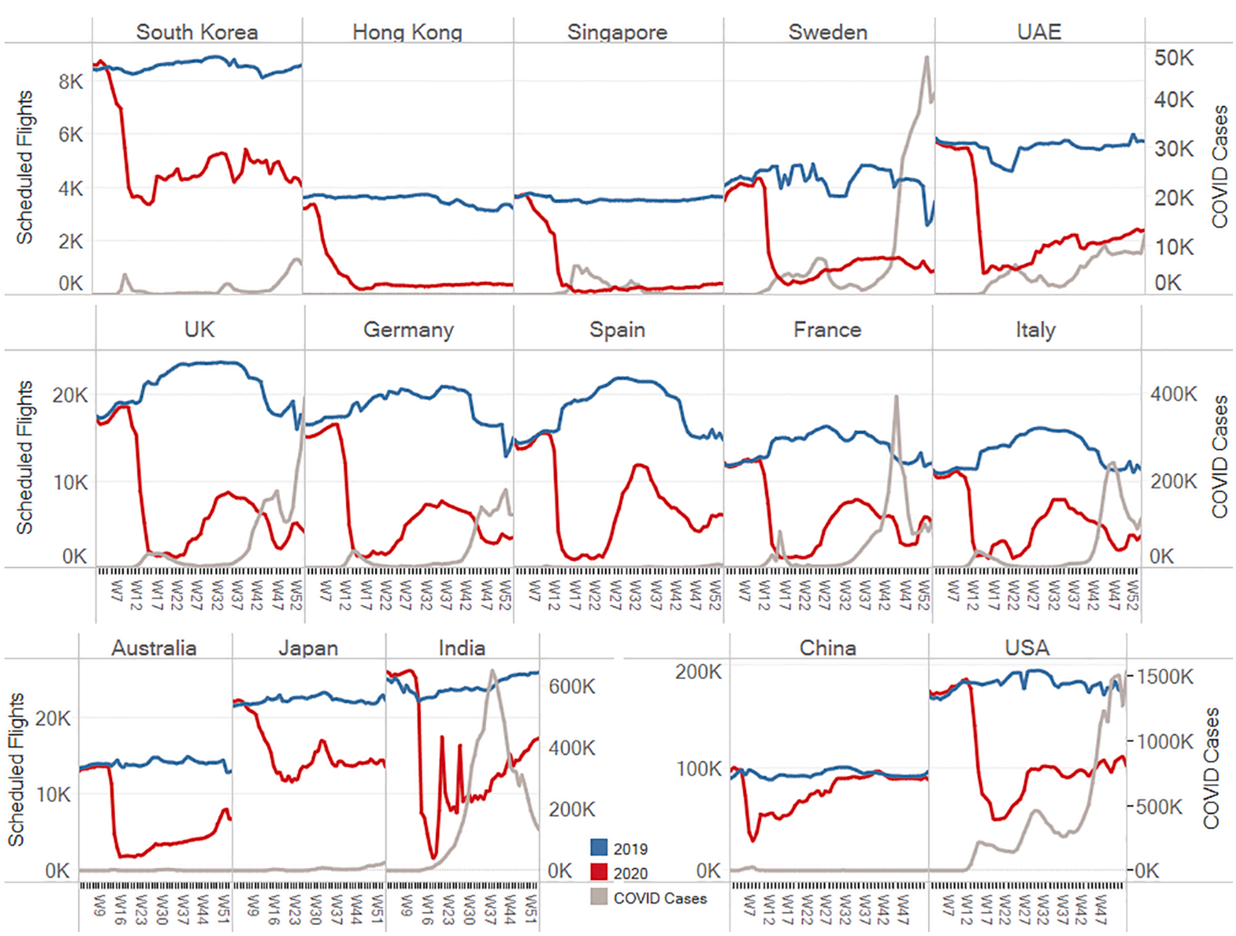

Fig. 2. Scheduled weekly flight capacity across selected countries during 2019 (Blue) and 2020 (Red) with weekly new COVID cases (Data from OAG, JHU). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

most severe even when the number of new COVID cases were disproportionally low. Even though daily COVID cases and deaths have reached a record high, as can be seen from the trends, the flight schedules continued to increase, albeit slowly, except in China which quickly gained ground on the way to its 2019 level due to unprecedented post-lockdown growth in domestic travel demand.

The initial recovery in each country and even at each airport was faced with several challenges including uncoordinated policy measures across airports, volatile measures, uncertain decision making and lack of robust recovery plans (Sun et al., 2021). For example, delays in putting the health screening and quarantine measures in place put the local population and airport staff at risk of being infected. Such challenges could have been avoided if an internationally coordinated response had been initiated at the beginning of the outbreak.

Freight movements and logistics

Annually, air transport is responsible for over 52 million tonnes of cargo movements, roughly 1% global trade by volume and over 30% by value (IATA, 2020b; IATA, 2020a). Air cargo provides significant income to airlines with up to 10–15% of total revenues before the pandemic. Air cargo fetched $102.4 billion, about 12.3% of total airline revenues in 2019 (IATA, 2020a). This sector, too, however, is not immune to a pandemic (Dube et al., 2021; Accenture, 2020). Based on an air cargo market analysis by the IATA (IATA, 2020), however, air cargo recovered significantly, in comparison to passenger traffic, with mere 0.5% year-on-year decrease in cargo tonne-kilometers (CTKs) in December 2020. Against the initial estimates of 14–31% CTKs decline in 2020, cargo recovery led to a lower than expected fall, but at 10.6% year-on-year decline, it was still much higher than the 6% global goods trade decrease. With a significant decrease in scheduled passenger flights and thus the unavailability of belly-hold capacity in passenger planes, the industry-wide available CTKs declined by 23.3% in 2020, but helped improve the load factors. The air freight and logistics sector has seen a consistent recovery since Q2 of 2020 with signs of robust performance across all regions. As the belly cargo capacity decreased due to the pandemic and its lockdowns and travel restrictions, these same factors led to an increase in e-commerce. The movement of dedicated freighters jumped up to ensure the necessary goods and mail movements. Lack of belly cargo capacity and lack of space in dedicated freighters thus led to elevated demand and fares. IATA reports the peak cargo season in Q4 has led to exceptionally high cargo revenues, up 75% year-on-year in December 2020. With the decline in passenger aircraft movements, continued lack of belly-hold space led to passenger aircraft being converted into freighters or '*preighters*' by some airlines—a term for passenger airplanes that are used to transport cargo, as a short- to medium-term agile strategy for revenue generation (Bouwer et al., 2021; Leopardi, 2021). *Preighters* played an important role in generating extra income for these airlines through dedicated cargo movements in the absence of passenger movements (Thorn, 2020; KPMG, 2021). Given the space constraints at certain airports, maintenance issues, and lack of flight hours for pilots, resulting from the grounding of large swathes of passenger fleets (Adrienne et al., 2020; Olaganathan and Amihan, 2021), the use of passenger aircraft for cargo also has benefits beyond direct airline revenue contributions. However, many argue that *preighters* are not a long-term solution given the logistical challenges, including safety issues (Kaminski-Morrow, 2021), and the need for cargo to be loaded by hand, making it costly and time consuming (KPMG, 2021). After a few months, some airlines began converting their *preighters* back to passenger aircraft, as long-haul passenger services started to gain traction in May-June 2021 (Flight Global, 2021). Given the predications of strong air cargo demand and revenues generated by air cargo as a lifeline for airlines, *preighters* will potentially cement a growing expansion of passenger airlines into the air freight business. As passenger traffic recovers, the belly-hold capacity will help ease the pressure on dedicated freighters.

Economic impacts

Global aviation revenues have been severely affected, facing a decline of over 60% in an $830 billion revenue stream last year (IATA, 2020a). Since the beginning of the pandemic, the IATA has revised its financial impact expectations several times. In June, the IATA forecast a 50% revenue decline to $419 billion and a loss of $84.3 billion. Towards the end of 2020, the IATA estimated revenues at $328 billion, with over $118 billion in losses for airlines in 2020 and >$20 billion in losses as an early estimate for 2021 (IATA, 2020a). However, there are several other independent estimates for the financial burden of the pandemic on the air transportation sector (Dube et al., 2021; Gudmundsson et al., 2021). Government support in the form of economic bailouts has also been an important issue. Globally, the aviation sector had received over $173 billion in relief measures (IATA, 2020a) by the end of 2020.

The financial implications of the pandemic directly affect the workforce employed in the industry. According to various estimates, air transportation supports around 65.5 million jobs globally (IATA, 2020a; IATA, 2019). It provides 10.2 million direct jobs and 55.3 million indirect, induced, and tourism-related jobs. Terminal closures and flight suspension as well as health risks in the case of a pandemic thus affected many more than those directly employed. Many reports only highlight major airlines' staff job losses (Sobieralski, 2020) (the Lufthansa Group, for example, which owns several airlines across Germany, Austria, Switzerland, and Belgium announced 22,000 job cuts) which is a fraction of the overall employment numbers in jeopardy. At Rolls-Royce, for example, the restructuring and cancellations of aircraft orders affected demand for their jet engines and related services, resulting in cutting of at least 9,000 jobs across the company, and a record £5.4bn loss for the first half of the year. Rolls-Royce expects that the business will eventually return to normal now that vaccines have been developed, but that this shock to the whole of commercial aviation is going to take years to recover. The company does not expect orders to recover to pre-COVID levels until 2025. The IATA expects over 25 million direct and indirect jobs at high risk due to airline shutdowns. Beyond the directly associated air transportation jobs, the millions of jobs at stake are from aviation-dependent fields such as tourism in general, e.g. hotel staff, catering, retail at airports, private-hire drivers, and car rental services. The pandemic has also affected aviation related capital investment schemes, airport expansion programs and upcoming new projects which have been put on hold, with direct economic consequences to the construction industry, and investors with committed capital (Avanzi and Zerjav, 2020). From the capital investment and infrastructure development perspective, the social cost of the pandemic and saved costs due to slower pace of investments may lead to optimized renovation and expansion programs in transportation sector. Complex issues such as travel demand and behavior will become more relevant and continue to play an important role in economic trajectory due to changes in work locations, reduced business travel etc. post-pandemic (Colonna and Intini, 2020). Overall, significant direct and indirect economic loss has been caused by the pandemic to the global aviation ecosystem with little social cost savings due to the compensation effect.

Environmental impacts

Aviation activity reduction has resulted in a reduction of the environmental impacts associated with the sector (Le Quéré et al., 2020; Liu et al., 2020; Calderon-Tellez and Herrera, 2021). With aircraft movements reduced by over 80% globally in April 2020, carbon emissions and global warming impacts of aviation were significantly reduced, contributing towards the Paris agreement climate targets. Before 2020, the aviation sector contributed 2.8% of the global carbon emissions (Le Quéré et al., 2020), and remains a highly carbon intensive mode of transportation even though efforts for cleaner fuels are being explored. Compared to a total of 945.5 million tons (Mt) of CO_2 emissions in 2019, a decrease of 254.5 Mt CO_2 emissions in the first seven months of 2020 was reported (Liu et al., 2020), however, due to the increase in air traffic towards the end of the year the emissions rose slightly in later months. Overall, emissions associated with global aviation in 2020 reached 512.5 Mt, suggesting a 48% decrease in CO_2 emissions from the previous year (Liu et al., 2020). The overall aviation emissions averaged 2.59 Mt of CO_2 per day in 2019 but were reduced to an average of 1.4 Mt per day in 2020. Lowered emissions due to flight reductions seem to be among the only robust and positive world-wide implications of COVID-19. Discussions are ongoing as to whether this will be a mere, insignificant blip to be cancelled out once pre-COVID air travel resumes—-whether travel behavior will change long term is not clear. Although there an opportunity for the transportation sector to develop clean aviation fuel alternatives, the economic impact of the pandemic may slow these efforts.

Modes of responding

In order for airports and airlines to react to the challenges of the pandemic and keep air transportation safe from disease spread, there are different levels at which the response can take place. We have categorized these as follows:

Policy level

The highest response level which coordinates and dictates all subsequent levels, is the policy response to the pandemic. In the case of civil aviation, the highest authority in this domain is the International Civil Aviation Organization (ICAO). With the ratification of the Chicago Convention, establishing the ICAO, member states agreed to uphold article 14: "Each contracting State agrees to take effective measures to prevent the spread by means of air navigation of cholera, typhus (epidemic), smallpox, yellow fever, plague, and such other communicable diseases as the contracting States shall from time to time decide to designate, and to that end contracting States will keep in close consultation with the agencies concerned with international regulations relating to sanitary measures applicable to aircraft. Such consultation shall be without prejudice to the application of any existing international convention on this subject to which the contracting States may be parties".

Globally, much has been written, deliberated, and recommended not just by the ICAO, but also by the IATA, as well as the Airports Council International (ACI), not least via the ICAO's Collaborative Arrangement for the Prevention and Management of Public Health Events in Civil Aviation (CAPSCA) program (CAPSCA), which brings together the aforementioned agencies, as well as the WHO, United Nations World Tourism Organization (UNWTO), among others (Alonso Tabares, 2021), to raise global preparedness for global disease outbreaks (Dube et al., 2021; Chung, 2015). The CAPSCA framework includes the Chicago Convention's articles relevant to disease spread/control, i.e. 13, 14, and 22, relevant standards and recommended practices (SARPs) from the ICAO's technical annexes, as well as relevant assembly resolutions, and WHO International Health Regulations (IHR 2015).

The ACI and ICAO also jointly published "Airport preparedness guidelines for outbreaks of communicable disease," stating that "[e]ach airport operator, together with its national authorities, should play its part towards achieving greater predictability and international coordination of preparedness measures, as this is the key to success in reducing the risk of spread of any communicable disease." (Airports Council International (ACI), 2009). The paper outlines several avenues for communication and details areas response plans need to address, such as "screening, logistics (transport of travellers to health facilities), equipment, entry/exit controls, and coordination with the local/regional/national public health authority", even stressing the need to keep a steady supply of Personal Protective Equipment (PPE) and sanitizers for airport staff (Airports Council International (ACI), 2009).

While both CAPSCA and the *airport preparedness guidelines* have been a response to previous pandemic situations, COVID-19 has also brought forth new global initiatives. Specifically tailored to the response to COVID-19 and outlining the recovery from it, the ICAO has circulated reports to member states issued by the Council's Aviation Recovery Task Force (CART) with broad recommendations and listing specific measures for the modules *Airport*, *Aircraft*, *Crew*, and *Cargo* (ICAO, 2020; CART, 2020).

Among the measures recommended in the second edition of the CART recommendations, is a concept and training series for the establishment of "public health corridors" by the ICAO, an initiative aimed at ensuring "clean crew, clean aircraft, clean airport facilities[,] and clean cargo to mitigate the spread of COVID-19 through air travel" (Alonso Tabares, 2021; CART, 2020). Meanwhile, the IATA has proposed and is currently trialing a "travel pass" solution that uses an app to communicate testing and immigration requirements for a trip to passengers, as well as test results for the said trip to the relevant authorities by registering health requirements and testing/vaccination centers (Travel Pass, 2021). Both measures are geared towards ensuring to continue international air travel in a safe manner.

Processing and operations level

Concrete manifestations of the policy level, or even the local management decisions can be observed in daily airport and airline operations. Processes needed to be changed to ensure safe distancing, separation of passenger flows, screenings, more frequent and more extensive cleaning routines, and so on. Even entire terminals were closed. Singapore's Changi Airport, for example, closed two of its four terminals in the first half of 2020 (Toh, 2020; Eber, 2020), representing a large-scale operational response to the changing landscape of tighter controls and dwindling flight and passenger numbers. In this case the airport benefited from its modular layout allowing the operational flexibility to take such measures.

Within the terminals, Changi Airport furthermore adopted a concept of Transit Holding Areas (THA) as part of its pandemic response to allow the airport to remain open for business. As the data showed, hub airports such as Singapore Changi, with no domestic offerings were particularly hard-hit by the pandemic. As such, it is essential to keep transit traffic going. Under the THA scheme, transit passengers disembark after passengers headed for arrivals and are then channeled to a holding area equipped with basic amenities to wait for their next flight. This is meant to keep both the airport's staff and other passengers safe, by not intermingling flows of passengers. Ultimately, however, flows of passengers will mix, as they will join different flights from the transit airports.

The boarding process itself remains a high risk and high cost step in air travel. Milne and Kelly (Milne and Kelly, 2014) highlighted how the boarding speed has slowed from 20 passengers per minute in 1970 to 9 passengers per minute in 1998. The process remains one of the crucial hot-spots during air travel and continues to pose the higher risk of human-to-human COVID-19 exposure (Sun et al., 2021). The mode of processing passengers at the gate is largely in the hands of the airline and based on the boarding method used, several of which exist and have been recommended to minimize the risk of disease spread, e.g. back-to-front by row—WilMA (Windows Middle Aisle, i.e. passengers with window seats board first, followed by those with aisle seats, etc.) (Milne et al., 2021). On the terminal side, the available measures are largely reduced to safe distancing, mask wearing and the enforcement thereof (Harvard T.H. Chan School of Public Health, 2020). Here, as with other journey points that require queueing, e.g. security/passport checks, the airport and the stakeholders involved, need to ensure efficient processing of passengers, i.e. queue management, and also provide ample space for safe distancing to minimize the risk of disease spread.

On board the planes, where safe distancing is much harder (and less economical) to accomplish, reducing the likelihood of infection is an important topic, too. During the H1N1 outbreak, for example, 25 passengers were infected on an Air China flight up to as far as 5 rows ahead and 7 rows behind. This should have resulted in the rethinking of safe distancing measures during travel (De Vos, 2020). Initially, proposals emerged to keep adjacent seats and/or rows in commercial flight vacant. However, the IATA remarked that keeping many seats vacant would have made most flights in losses at the last year's vehicle load factors. Moreover, as the above example shows, the proposed distancing would have been insufficient. IATA has maintained its view that gloves and masks can be the best alternative to ensure non-loss-making flights. It is largely up to the airlines to decide at which capacity they want to stop issuing tickets. In February 2021, Delta Air Lines was reported to be the only US carrier to continuing to ensure empty middle seats to boost travelers' confidence (Thompson, 2021), although it began selling all seats again in May 2021 (Singh, 2021). Besides empty seats, airlines (and catering companies) have also had to alter their processes for in-flight services. Measures taken range from slight adjustments to minimizing touchpoints, e.g. passing drinks on trays or using single-use plastics instead of reusable tableware, to the cancellations of certain service offerings altogether (Sillers, 2021).

Technology level

To help alleviate operational challenges, responses also have to be and have been introduced at the technology level. Journey points such as security screening entail a number of touch points and close contacts (Gillen and Morrison, 2015) between passengers and personnel. In the case of a pandemic, this increases the risk of disease transmission, not only for the passengers, but also for the front-line personnel, who will be in contact with thousands of people in just one shift. As such, where possible, no-touch options have been introduced. Changi Airport introduced touchless self-service check-in machines, touchless elevator buttons, touchless biometric passport check lanes, as well as other measures such us autonomous cleaning robots that mist carpets with disinfectant (CNA, 2020).

On board of airplanes, HEPA filters are widely used. This technology manages to contribute towards curbing in-flight disease spread by cleaning out over 99% of particulate matter that could transmit COVID-19 from the cabin air; overall, the air that crew and passengers breathe aboard an aircraft is replaced every 2–3 min (Bielecki et al., 2021; Harvard T.H. Chan School of Public Health, 2020). However, besides the air, airplanes—even more so than airports—offer a variety of touchpoints, such as tray tables, toilet doors, or overhead lockers. Therefore, innovation in cleaning technology is also vital, and UV-cleaning technology is reportedly seeing an increase in demand by airlines (Reuters, 2020; Moore, 2020). Singapore's Changi Airport was also reported to have tested UV-cleaning (CNA, 2020).

Technology is not only used to eliminate touchpoints or virus cells, but also to actively detect infected persons. Screening methods, such as rapid tests have been developed and existing ones, such as temperature screenings, intensified. Temperature screening methods, however, were unfortunately shown to be not very effective with estimates that 46% (95% confidence interval: 36 to 58) of infected passengers may not be detected, depending on the incubation period, the sensitivity of exit and entry screening, and the proportion of asymptomatic cases (Quilty et al., 2020). Thermal screening alone is thus unlikely to be an effective screening method for SARS-CoV-2 infected passengers (Bielecki et al., 2021) and hence requires other or additional testing. Since none of these measures offer absolute certainty, a layered approach, i.e. combining multiple non-pharmaceutical interventions such as HEPA filters, disinfection, mask wearing, etc. for multiple layers of protection, is advisable (Harvard T.H. Chan School of Public Health, 2020).

Individual level

Ultimately, measures have to be implemented and followed at the individual level. Many news reports throughout 2020 highlighted unruly passengers who refused to wear masks; albeit a global problem, it seemed to be particularly pronounced in the US (Ortile, 2020; The Japan Times, 2020; Wong, 2020). Aeroflot even resorted to creating zones for these passengers to minimize service interruptions (McMahon, 2020). This brings the passengers' risk awareness and willingness to take risks into the picture. Individual perceptions of the pandemic influence peoples' behavior and thus the safety of others, passengers as well as employees.

Although passengers take the media spotlight, employees at the world's airports and airlines also play a role, not only in ensuring passengers adhere to rules and regulations, but also in adhering to these themselves. Just as one unruly passenger can endanger those around them, non-compliant security screeners can endanger everyone at the checkpoint. The same goes for baggage handlers, check-in agents, flight attendants, shopkeepers, and cleaners among others. Compliance by employees may be contractually required, but still requires measures and provisions that ensure that employees are able to, and indeed do, comply. For example, an employee at the check-in desk is in a very vulnerable position relative to the passengers, as is an employee who assists passengers with special needs. Special solutions are needed that allow operations not only to be performed, but also maintain a positive experience for employees and passengers alike.

Challenges resulting from response mechanisms

The measures taken by airports can be evaluated independently and studied based on their respective efficacy and merit in fighting the pandemic, similarly to what has been done for items such as screening measures (Quilty et al., 2020). A wide variety of measures has been proposed and discussed in literature (Sun et al., 2021; Dube et al., 2021; Alonso Tabares, 2021; Bielecki et al., 2021), even the ACI's response guidelines provide details on some measures (Airports Council International (ACI), 2009). The measures are virtually uncountable and every week reports of additional steps and adjustments surface—many are new and may not necessarily be evidence-based. The COVID-19 pandemic has clearly exposed weaknesses in airport planning and operation throughout all domains. Decisions such as centralizing HVAC systems, for example, may now mean that these cannot be turned off for unused parts of the building, thus causing significant burdens for airport operators.

The level of detail required to assess all measures and implications is beyond the scope of this paper— Bielecki et al. (2021) have taken a thorough look. Given the global nature of this (and any) pandemic, we instead take a broader look at the policy level and how airports' measures fare collectively regarding the existing global initiatives mentioned in section 3.1, and, in particular, article 14 of the Chicago Convention.

The burden of testing requirements

While a pandemic is clearly a global problem, the focus in fighting it appears to be much more local. For measures relating to cleaning and entry screenings, for example, this is perfectly reasonable. After all, to fight the pandemic, the airport and its staff members need to be protected from potential carriers of a virus or infectious disease. Upon closer inspection, however, measures such as the establishment of THAs and others related to transit traffic, reveal themselves to be also mainly aimed at protecting the airport (and by extension of the employees, the country's border), despite having global implications – i.e., limiting the spread locally but doing little to limit the spread via the global air transportation system.

Singapore Changi Airport may separate transit passengers from the flow of departing and arriving passengers by means of THAs, but only in a few isolated cases are these travelers required to take pre-departure PCR-test.[1] This, in theory and global immigration regulations notwithstanding, allows Changi Airport to be effectively a "node" (see Chung, 2015) in global disease spread.

A sample booking (see Fig. 3A), made on January 11, 2021, reveals that it would have, in fact, been possible to fly from Kuala Lumpur in Malaysia to Hannover in Germany without any COVID-19 PCR-test. Neither Singapore Changi Airport nor Frankfurt Airport require tests for transit passengers. Germany's Robert Koch Institute (www.rki.de) did not consider Malaysia a risk area (Risikogebiet), therefore allowing quarantine-free entry into the country. A similar sample booking was made for a flight from Kuala Lumpur to Los Angeles (Fig. 3B), where, prior to the Biden Administration taking office, a similar spread could have occurred. Looking at other airports shows that this is not an isolated occurrence. Doha's Hamad International Airport in Qatar, to list another example, also has little requirements for transit passengers.[2]

As of May 5, 2021, the booking is still possible, but passengers arriving in or transiting through Germany are now, according to the Singapore Airlines booking page, required to have a negative PCR-test result from within 48 h of arriving. Changi Airport's "node status" is therefore now limited by requirements from Germany in this particular case. The burden of putting barriers in place to curb the global spread is therefore clearly on nation states, with the burden of proof for tests—so to speak—having to be enforced by airlines and their respective ground handlers prior to granting a traveler passage.

As such, it is questionable whether the duties laid out by Article 14 of the Chicago Convention are sufficiently carried out by the member states' airports/relevant authorities, despite all efforts of extensive cleaning and protecting staff members behind acrylic screens and through various forms of PPE.

Standardization and coordination

Passenger numbers and global COVID-19 case counts, as well as deaths, indicate that the initial measures taken did not effectively limit the spread of the pandemic. Section 3 showed that there was no shortage in responses across all levels. Yet, there appears to have been ample opportunity for COVID-19 to spread through aviation and eclipse passenger numbers. While some measures may contain loopholes such as the screening, or lack of transit passengers, the issue appears to lie in the coordination of responses and orchestrating a concerted global effort.

Despite numerous documents published and measures examined, even before the current coronavirus pandemic, the response by global airports has been shown to vary greatly from country to country, both in terms of timeliness of the response and regarding the specific measures and the enforcement thereof. To provide an effective response for a potential future pandemic, response plans and measures must account for a timeframe (airports must respond at the same time), a level of response and the individual measures. Only then can a response be sufficiently uniform on the global scale to curb disease spread. More importantly the burden of putting testing, and now, in all likelihood, vaccination, requirements in place, cannot be solely be on individual nations, with the international air transportation industry assuming, by all appearances, little direct responsibility and being motivated chiefly by self-protection.

Framework for a global airport pandemic response mechanism

In the following section, we propose a concept for a response mechanism that would lead to better coordination and more control after a disease outbreak. The resulting response would therefore aid in curbing disease spread, while keeping air travel safe and providing regulations that are easier to navigate for travelers.

Learning from security regulations

Given the 'lessons not learned' and the widespread discrepancies in airport reactions to the pandemic, both temporal and in terms of actual measures, we propose a global pandemic response mechanism that is similar in essence to how security regulations are already implemented. The ICAO's technical annex no. 17 to the Chicago Convention lays out the standards and recommended practices (SARPs) to ensure uniformity in the field of aviation security. National or regional authorities then adapt and enforce these SARPs locally as regulations (see Fig. 4).

Naturally, the security procedures are not entirely uniform across the entire global aviation network. However, as the European Commission, for example, stated in regulation No 300/2008: "It is desirable, in the interests of civil aviation security generally, to provide the basis for a common interpretation of Annex 17 to the Chicago Convention on International Civil Aviation of 7 December 1944." It is noteworthy that the civil aviation industry has made significant capital investments in safety and security infrastructure following the 9/11 terror events (Blalock et al., 2007). Security risks also helped in developing equivalent security standards. As such, the ICAO's SARPs provide a common baseline for local authorities and legislators to not only draft their own regulations, but also evaluate practices in other countries/regions. In 2018, for example, Singapore was newly added to a list of third countries "recognized as applying security standards equivalent to the common basic standards on civil aviation security." (EU 2018/55) Passengers travelling from Singapore to Hannover in Germany via Frankfurt, to give one example, therefore no longer have to undergo a security screening in Frankfurt.

Through the mechanisms in place, airports and authorities are part of an effective system that increases global aviation security. To make up for potential security deficits at other airports, i.e., from countries not on the same list as Singapore in the case of the European Union, airports then conduct security checks for transit passengers, even though these have already undergone a security screening at their departure airport. An added benefit is furthermore that, given the degree of standardization, travellers know what to expect, despite minor difference—no liquids, remove electronics, etc.

One disadvantage of the security standards implementation is the time it can take to achieve global consistency. When a plot involving liquid explosives was uncovered in the UK in August 2006, individual policies were quickly put into place restricting liquids in carry-on baggage. Two days after the event, *The New York Times* already reported on new TSA regulations (Peters and Kanter, 2006), while in Europe a regulation (EC 1546/2006) was passed two months later. The

[1] As of May 5, 2021 only passengers who have been to Indonesia or the Philippines within 14 days of departing are required to have pre-departure COVID-19 PCR-test to transit via Singapore Changi Airport. Passengers who have been to Bangladesh, India, Nepal, Pakistan, or Sri Lanka within 14 days of departing are not allowed to transit in Singapore. In January 2021 passengers who had been to India, Indonesia, the Philippines, or the UK were required to have a pre-departure COVID-19 PCR-test. https://www.singaporeair.com/en_UK/us/travel-info/covid-19/

[2] As of January 27, 2021 PCR-tests were required for transit passengers who have been in Armenia, Bangladesh, Brazil, India, Iran, Iraq, Nepal, Nigeria, Pakistan, the Philippines, Russia, or Sri Lanka within the past 14 days. https://qatarairways.zendesk.com/hc/en-us/articles/360011691817-Is-the-PCR-test-mandatory-for-all-countries. As of March 16, the list of countries was updated and 13 countries, for which a PCR-test was previously required, were removed from the list https://www.qatarairways.com/tradepartner/en/press-releases/2021/Update-on-PCR-Test-Requirements-for-Qatar-Airways-Flights.html

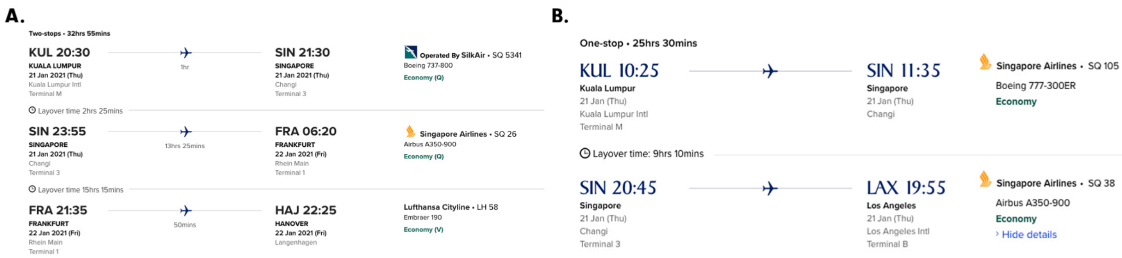

Fig. 3. Sample booking for trip in January 2021 a) from Kuala Lumpur to Hannover, via Singapore Airlines; b) Sample booking for trip from Kuala Lumpur to Los Angeles, via Singapore Airlines.

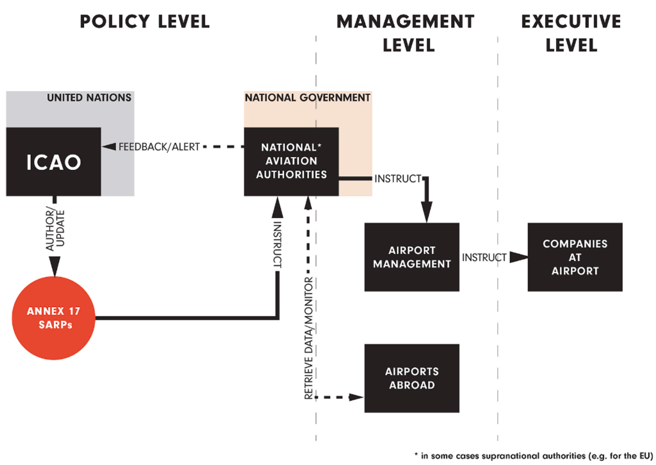

Fig. 4. Communication of security standards from the ICAO to airports.

ICAO confirmed the measures in a state letter (AS 8/11-06/100 Confidential) almost 4 months after the incident and it took almost one year for the European regulations (EC 915/2007) to achieve full consistency with the ICAO's state letters (ICAO, 2007). However, this slow process further proves why a standard response for pandemics should have been formulated or drafted, at the latest during the SARS outbreak in 2003, to ensure optimal preparedness for the next pandemic.

A standardized pandemic response mechanism

The proposed pandemic response mechanism would distribute SARPs from the policy-level to the airports and companies involved in airport operations, similarly to what happens with security regulations. However, the flow diagram (see Fig. 5) now includes health authorities, both national and the WHO, highlighting their importance in disseminating information and communicating recommendations to the aviation authorities. As security screenings and measures are rather constant—more so than one would hope the rapidly changing responses needed to combat a pandemic to be—we have included threat levels to be issued by the ICAO. These threat levels would determine exactly which SARPs are to put in place depending on the spread, to account for the response level mentioned in section 2.3. As opposed to the security diagram (Fig. 4), user behaviour is important and therefore also included, as everybody plays an integral part (Tuchen et al., 2020)—as opposed to terrorism, where not every passenger could by means of neglect become a terrorist. Furthermore, given the dynamic nature of human behaviour, considerations of user behavior are critical for a robust pandemic response mechanism (Tuchen et al., 2020) under varying aviation demand and capacity management strategies (Jacquillat and Odoni, 2018).

Essentially, many components for this kind of response already exist.

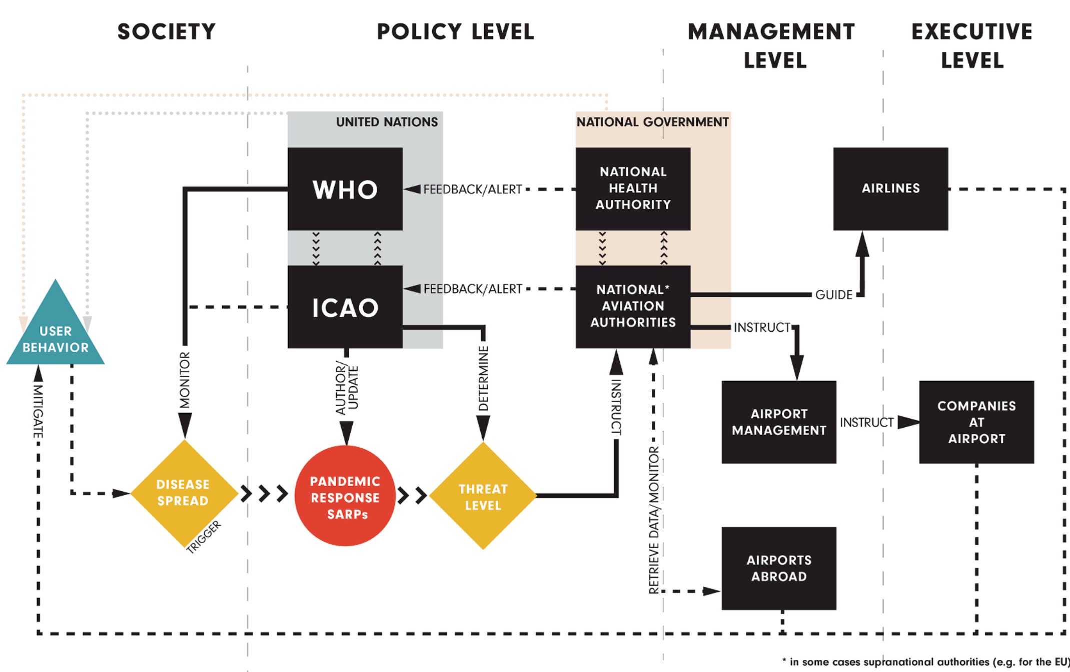

Fig. 5. Holistic Pandemic response mechanism to curb disease transmission.

The technical annexes to the Chicago Convention already include several relevant SARPs that are part of the CAPSCA framework. Furthermore, the CART documents and reports contain essential recommendations. However, the multiplicity of solution avenues and nature of most recommendations being not binding render the global response to curbing disease spread in civil aviation ineffective. Our proposal would be a mechanism in which the SARPs for a pandemic response take a position within the mechanism that puts them on equal footing with annex 17.

Some of the current measures—i.e. protecting an airport's workforce and the country it provides a gateway to, while allowing passengers to transit with few restrictions—no doubt contribute towards keep airports operational in a deep economic crisis for the aviation industry. As Chung (2015), argued, "the more efficient the airport pandemic control plan, the less severe the economic impact on the airport during a pandemic." Our flow diagram, however, implicitly suggests that focusing these measures solely on the airport (and country) that implements them, is shortsighted. A coordinated global response to curb the spread, on the other hand, not only keeps air travel as a whole safe(r), but also works towards regaining passenger trust, and generally making the system at large more resilient against economic fallout by keeping airports and airlines in more regular operation (see e.g. Alonso Tabares, 2021). Furthermore, it would potentially limit the lifetime of a pandemic, paving the way to a speedier recovery.

Threat levels and response matrix

The threat levels are detailed in a response matrix (see Table 1), which outlines what kind of measures could be taken as part of a concerted global effort. The color levels are chosen based on Singapore's color-coded 'Disease Outbreak Response System Conditions' (DORSCON). The measures listed are indicative and used only to illustrate the severity of the threat level. We are not arguing for detailed measures as outlined in several ICAO documents, but rather for the systematic enactment of measures based on a standardized severity measure.

Threat level green could be compared to the pre-pandemic situation, i.e. prior to December 2019. There are no specific requirements for screening or to alter processes. However, SARPs from annex 9 to the Chicago convention, for example, such as the immediate reporting of suspected communicable diseases by pilots (8.15), would still apply. Furthermore, constant vigilance is highly recommended.

Threat level yellow would be used for heightened vigilance in case a disease outbreak is suspected in a particular region, similarly to when reports of a "mystery pneumonia" surfaced in 2019 (Zuo et al., 2019).

Threat level orange is meant to apply to situations where an epidemic has been confirmed in a certain country/region and should feature much tougher measures at airports to curb the spread before an outbreak turns into a pandemic. It is of vital importance that international airports act decisively and uniformly on the issued SARPs at this

Table 1
Proposed Threat Levels and pandemic response matrix.

Threat Level	Health Screening Measures	Hygiene	Protective Equipment	Terminal Zoning	Passenger Processing	Discretionary Activities	Additional Advice
Green No known communicable disease spread	No recommendation, potential normal temperature screening on arrival based on local discretion (e.g. China, Taiwan, etc.)	Regular cleaning operations	No requirement	Normal	Normal	Normal	None
Yellow Potential communicable disease spread (e.g. COVID-19 in Decemeber 2019)	Minor screening for passengers arriving on flights from affected region (screening method based on communicable disease properties)	Increased cleaning frequency in arrival and transit areas	Recommended for personnel conducting the screening, security staff, and customs/immigration	None	Depending on type of communicable disease, safe-distancing in transit security queues might be advisable	Normal	None
Orange Confirmed (controlled) communicable disease spread, epidemic (e.g. COVID-19 in January 2020)	Screening for passengers arriving on flights from affected region (screening method based on communicable disease properties), Minor screening for departing passengers, regular screening method for frontline staff	Increased cleaning frequency throughout terminal, mandatory frequent disinfection of touchpoints, self-disinfecting coating for touchscreens, etc. recommended	Mandatory mask wearing inside the terminal, additional PPE for screening personnel	Separation of flights from affected regions at designated gates for increased screening of passengers before release into transit/arrival area	Travel advisories etc. to be communicated to check-in staff, safe-distancing in all queues, security personnel to change gloves after pat-downs/luggage inspections, frequent disinfecting of luggage bins, boarding by zones	Safe distancing in shops and restaurants/cafes, maximum number of occupants to be enforced	It may be advisable to implement a shift system (e.g. team A, team B), to avoid cross-contamination of personnel
Red Uncontrolled communicable disease spread, pandemic	Mandatory pre-departure testing (e.g. COVID-19 PCR), for all passengers, including transit passengers, regular testing for all staff, boarding passes for transit passengers only to be issued after pre-transit screening (potentially rapid tests), not at departure airport	Strict hygiene regiment throughout entire airport, building on concept from threat level orange, including disinfecting of checked luggage	***Same as threat level orange plus*** counters equipped with Perspex/acrylic screens	Establishment of transit holding areas, separation of departing/arriving/transit passengers, in extreme cases, parts of terminal gate areas could be turned into arrival test centers for pre-arrival, pre-transit screening, establishment of secure area in departures area	***Same as threat level orange plus*** check-in staff to check for negative test result before issuing boarding pass (i.e. admitting passengers to secure area), boarding passes for transit passengers only to be issued after pre-transit screening, not at departure airport	***Same as threat level orange plus*** non-essential shop closures may be advisable (depending on the pandemic situation in the respective country)	***Same as threat level orange plus*** admitting only traveling customers to the airport premises may be advisable (depending on the pandemic situation in the respective country)

stage to prevent the lagging and varied responses observed all over the globe in early 2020.

Threat level red could, finally, be compared to the pandemic situation at the time of writing, May 2021 (despite the global vaccine rollout). The airport response recommended in the matrix being in line with the "pandemic free airport" proposed by Alonso Tabares (Alonso Tabares, 2021), which is based on ICAO's public health corridors (PHC).

Implementation: Potential, challenges, and limitations

Combining this threat level and measure matrix approach with the implementation mechanism illustrated in the conceptual flow model (Fig. 5) would urge airports and aviation authorities to react simultaneously with comparable measures and provide the tools to evaluate other countries'/airports' measures and act, if necessary. This would move some of the burden of disease control from mere domestic measures and highly localized border control mechanisms to the global air transportation system and its nodes that accelerate global disease spread. In addition, it would create multiple transparent layers of screening throughout the journey, regardless of immigration regulations. Standardized measures, coupled with the use of the IATA travel pass to facilitate the checking of travel requirements, would also let travelers know what expect, no matter the threat level. Instead of a variety of testing requirements (48 h prior to arrival, 72h prior to departure, etc.), there should exist certain procedures that are uniform across the board, much like the liquid ban for security.

The proposed response mechanism and framework primarily focus on safety from disease spread to address shortcomings in the current practices. Several other potential safety concerns in aviation linked to the pandemic are indirectly covered by the proposed strategy. For example, as a result of the lack of demand, many airplanes had (and still have) to be parked/stored for long periods of time, leading to maintenance issues (Adrienne et al., 2020). Similarly, many pilots are not flying at all or not as regularly, in turn causing training challenges to maintain pilot proficiency (Olaganathan and Amihan, 2021). While the framework does not directly provide solutions to issues like this, its strategy for a coordinated fight against the spread of pandemics and thereby much greater safety from disease spread, would keep more routes operational and indirectly reduce problems resulting from large parts of airlines' fleets being grounded.

Despite this potential, there are challenges regarding the implementation of such a mechanism and framework that are worth addressing. While the mechanism diagram includes the monitoring of airports abroad, in practice this step would be far from simple, yet crucial. Part of the problems described—leading to the need for a coordinated global response—stem from the fact that each country responds differently to the pandemic at the national level. In part, this is due to cultural differences and/or differences in political administrations, but it is also due to different impacts and pandemic trajectories. Therefore, the global framework would need to account for differences in local perceptions and threat levels. One country's stipulated threat level, e.g. based on community transmission, despite relatively few border restrictions, might be lower than the one specified by the ICAO under the proposed framework. A country's health authorities or administration might also generally regard the global situation as less threatening than the ICAO and WHO. In either case, it might prove difficult to convince the respective local authorities to enact certain measures which, from their perspective, could be too extreme. However, this challenge could be mitigated by a "critical mass" of participating countries/authorities. The monitoring of airports abroad would thereby identify the unconvinced countries as weak links and impose stricter measures on arriving passengers from there, thus either incentivizing the countries to comply with the measures entailed within the global threat level, or mitigating the effects of their non-compliance. Naturally, some countries could also determine a higher threat level than assumed by the ICAO under this scheme. In this case, however, the overall goal would not be in jeopardy and the measures recommended under the framework could function as the recommended minimum, although communicating the stricter requirements to the passengers might be a slight challenge. Nevertheless, there are again general similarities to the implementation of security SARPs, where some countries may have stricter or less strict requirements than the norm. What is lacking in the pandemic-case, as mentioned, is the common baseline.

The key in tapping into the potential of a global framework for a coordinated response lies in the effective monitoring of the situation across borders and in reaching a critical mass of participating countries/airport authorities to break the implementation barrier posed by individual local government assessments and decisions. These implementation challenges are not to be trivialized and the details of overcoming them surpass the scope of this paper. However, talks about enabling vaccinated travelers from the US to visit Europe (New York Times, 2021), mutual recognition of vaccination records in general (Iwamoto, 2021; Xinhua, 2021), talks about travel bubbles between Asian nations (Choon, 2021) and even Australia (Schofield, 2021; Cusmano, 2021), and in particular the setting of markers for community transmission for these bubbles, among others, all show that monitoring of other countries' measures, as well as the desire to cooperate to promote safe air travel exist in-principle. Coordinating these plans at the global level, albeit challenging, is therefore a viable undertaking.

Conclusion

As global COVID-19 case counts rose due to the connectivity of our globalized world, civil aviation both contributed towards the spread of the pandemic and suffered from its effects. This paper has shown that this unprecedented crisis occurred despite numerous measures taken across different domains. One problem appears to be the local and individual nature as evidenced, for example, by transit airports protecting themselves but not the destination country, effectively pushing the responsibility of disease spread to national border agencies. When it comes to disease spread, airports and airlines do not directly benefit from screening passengers or imposing their own stricter regulations on passengers. On the contrary, too strict a response might cost an airport valuable transit traffic in a crisis. Key in implementing a global crackdown on disease spread as advocated here is to make airports and aviation authorities realize the indirect long-term benefits thereof. If an airport allows infected passengers to transit freely to any destination, the burden of disease control (apart from exceptions for countries with extreme case counts) being solely on the immigration authority of the final destination, it may contribute to the disease spread in the destination country, worsening the global situation and ultimately cutting off its own supply of passengers. Accepting responsibility as potential nodes for disease spread, on the other hand, limits the global spread by adding additional layers of security. By extension, this ensures more safety in air transportation, creates a travel landscape that, thanks to uniformity across airports and airlines, is easier for travellers to navigate, and ensures speedier recovery from pandemic situations. Ultimately, this would make a positive contribution to passenger numbers at the airport in question. As such, we presented a conceptual framework for a coordinated global response that would promote more responsibility and ultimately resilience across airports. To overcome implementation challenges, future work needs to focus on detailing the monitoring mechanisms at the global and local level, and developing concrete steps towards determining and reaching a critical mass of participating authorities in such a global framework to make it effective, while the ongoing work on tools such as the IATA travel pass makes the global coordination of the proof of tests and vaccinations tangible.

CRediT authorship contribution statement

Mohit Arora: Conceptualization, Investigation, Methodology, Data curation, Formal analysis, Visualization, Writing – original draft, Writing - review & editing. **Stefan Tuchen:** Conceptualization, Investigation, Methodology, Visualization, Writing – original draft, Writing - review & editing. **Mohsen Nazemi:** Conceptualization, Writing - review & editing. **Lucienne Blessing:** Supervision, Funding acquisition, Conceptualization, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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