A Multi-Layered Air Defense Model to Protect Shared Air in Critical Infrastructure Sectors

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This publication is part of a partnership between Auburn University's McCrary Institute and Air University pursuant to which challenges related to cyber and critical infrastructure security are examined for the purpose of advancing U.S. national security.

ABOUT US

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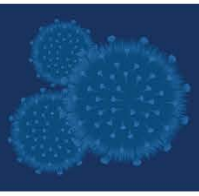
FOREWORD



During my career spanning over 50 years as an Airman and as a Surgeon, I have studied how we can best prepare our society to deal with emerging disasters, both manmade and natural. The President has declared a war against a hidden, invisible enemy that has now reached our homeland. Through my experiences, I've grown to appreciate how military principles, strategy, and tactics have proven beneficial to the delivery of care for our citizens during a crisis. They are applicable to any war, including the war we come together to face as a nation today. By coupling these military principles with learnings from our civilian partners, we can fight this war with new and innovative strategies and technologies to help heal our country so we emerge stronger and better prepared for pandemics to follow.

As we study the Coronavirus pandemic, we now recognize, like the Influenza viruses or other common respiratory pathogens, the disease is spread predominantly from person-to-person in our communities through "shared air." Certainly, much of this community spread is through droplet nuclei shared from an infected person's coughs or sneezes. However, a far more difficult and insidious problem is that we understand people who do not hsave any symptoms of the disease can, and do, infect "shared air" of those around them, especially in close quarters such as indoor gathering spaces or transportation modes. If we protect this "shared air" we can significantly decrease the risk of transmission and stop the virus, while ensuring all 16 of our Critical Infrastructure Sectors function for our society.

This strategic white paper, crafted and influenced by a research team spanning civilian, military, academia, and application science, is based upon the best information we have to date. It is my opinion that a focus on protecting the air we all must breathe will provide the critical solution allowing us to sensibly reopen and sustain our society, avoiding the false choice between "lives" and "livelihoods" some believe we must make. While all of us hope this virus will go away as rapidly as it arrived, hope is not a strategy when dealing with the very fabric of our society and the infrastructure sectors that must work together to support our country.

The authors advocate for all traditional public health controls including at-scale testing and contact tracing, isolation of infected or exposed people, and personal protective equipment for high risk workers and others in our society. They support the unprecedented, accelerated research schedules for vaccines and cures for this terrible disease; however, there will be no silver bullet in our country's fight against COVID-19 until we have a vaccine. They recognize these actions are not enough now to protect our infrastructures and the people who support them. The authors advocate for a similar national priority, with both focus and funding, to rapidly survey, study, and simultaneous deploy, at-scale, several promising engineering solutions and policies. If these interventions are applied together, I believe they show great promise in controlling the person-to-person spread by protecting the "shared air" we all must breathe, allowing our nation to survive and operate until we find a cure and a vaccine.

During this past Fourth of July weekend, as I reflected on our country's current challenges, I was reminded of the sacrifices of all generations who came before, fighting to ensure our children can live in a free country. As we come together again for the common defense, with inspiration from our founding documents, I know the American people are gracious, generous, and innovative. In the same way previous generations have out-innovated an adversary, we can out-innovate the COVID-19 virus. This will not be easy, but we as a country have never backed away from doing the right thing … together.

May God continue to bless America,

Lt Gen (ret) Dr P. K. CARLTON Jr, MD
Surgeon General, U.S. Air Force (1999-2002)

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We would like to especially recognize the sustained leadership and ongoing contributions of Lt Gen (ret) Dr P.K. Carlton, Jr, the 17th Surgeon General of the United States Air Force, part of the first cadre of Air University Visiting Scholars. Since the emergence of the COVID-19 pandemic in early 2020 and through the present, he has provided tireless advocacy to focus on creative multi-domain and multi-layered solutions to these vexing challenges across the American society. We were honored when he agreed to write this paper's foreword, and have based many of the ideas of this paper on his concepts and research.

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We recommend that America adopt a multilayered air protection and mitigation strategy to provide safe fresh indoor air across the 16 designated critical infrastructures. Coupled with traditional public health guidance including testing, contact tracing, social distancing, and isolation of people with known disease or exposure, we further recommend a focus on engineering solutions and administrative controls. These controls, applied in a multilayered and redundant model, at-scale, could provide the public confidence to allow America to fully reopen the economy and sustain our critical infrastructures. Together with personal protective equipment for our most vulnerable populations, we can sustain our country economically while protecting public health and those most vulnerable to this or future diseases.

America's ability to survive the COVID-19 (Coronavirus, SARS-CoV-2) pandemic as a society depends on our ability to protect our citizens while we simultaneously protect the critical infrastructure sectors that support our economy, and ultimately, the American way of life. Until we achieve a herd immunity either through a vaccine, a profound natural disease spread (a costly and painful prospect involving significant suffering and loss of life), or some combination thereof, the country's only weapon to slow the progress of COVID-19 are restrictions on gathering together, particularly in enclosed spaces (restaurants, businesses, transportation systems, schools and colleges, etc). Until the risk of spreading infection can be mitigated, an unintended but very real side effect is the paralysis of our economy and the threat to our nation's ability to sensibly reopen critical infrastructure sectors.

Restoring the confidence of people, customers, workers, and producers is the critical opportunity we must seize to ensure each critical infrastructure sector can reliably support our society. As our understanding of COVID-19 is refined, we now recognize that a majority of the disease transmissions occur through an airborne spread. As of now, there is no single solution to eliminating airborne spread of the pathogen or of an unrecognized, asymptomatic individual contaminating the shared air in an enclosed space, thus passing the virus to a population. Until we fix this, the American people and industry sectors will not have confidence to embrace, at-scale, a robust movement to return to work.

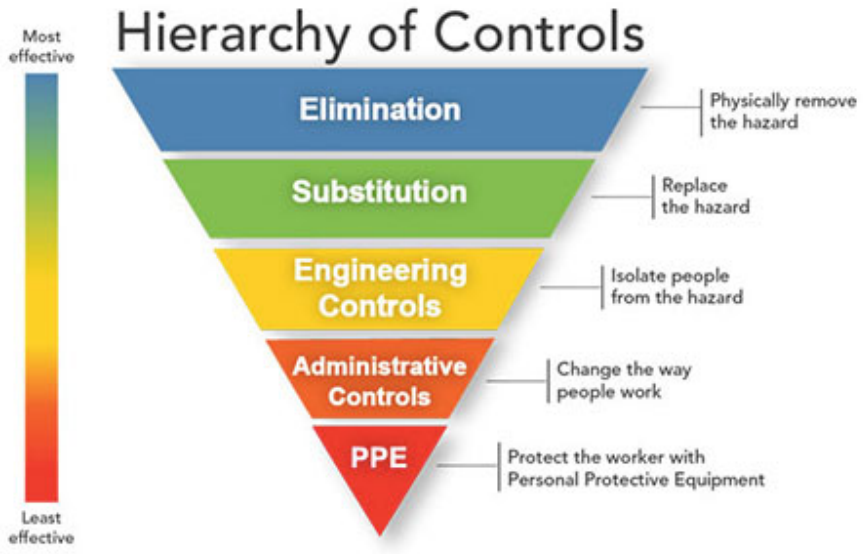
The traditional models of public health should be followed as a starting point to prevent community spread. They include:

- Traditional social distancing, testing, contact tracing, and isolating cases and contacts
- Aggressive surface cleaning and disinfecting
- Personal protective equipment (PPE) including N95 respirators and face shields for high risk workers and others who are at risk due to underlying health conditions

However, by themselves, current traditional public health measures, with an overreliance on fomite elimination, will be ineffective in managing a contagious airborne illness to a degree that will allow infrastructures to return to pre-pandemic productivity until a vaccine is tested,

produced and widely distributed. The authors argue for a multilayered and redundant model, focused on the shared air we breathe, using established or emerging technologies when available, applied systematically across each infrastructure, and modified to both the requirements of the workplace or gathering, as well as, tailored to a population at risk. This model should continuously evolve as we discover keys to efficiency and effectiveness. With modifications based upon processes and workforce, such a model should be applied across each sector of infrastructure in order to accelerate national productivity and leave us better prepared for future man-made and natural airborne threats.

The authors advocate taking all steps currently available to decrease the number of potential airborne viral particles in the "shared air" of our critical infrastructure sectors. They define "shared air" as the air that exists in or around gathering spaces (public or private) such as workplaces, houses of worship, entertainment venues, and dining facilities. They further recommend a multilayered approach to protecting the public from "shared air" that potentially contains infectious viral particles using the NIOSH "Hierarchy of Controls" model of hazard mitigation. The interventions discussed focus first on engineering solutions, then policy guidance, and finally on personal protective equipment. We recommend adoption of all current public health interventions, and add the following:



Engineering Controls to consider for indoor/enclosed "shared air":

1) Increasing air turnover with fresh outdoor air using open windows
2) Increasing air turnover with fresh air using HVAC room turnover
3) Installing physical barriers between people where they share air
4) Providing directional air flow as a virtual barrier between "shared" and "personal" air.
5) Surveying/mapping/mitigating air flow hazards in high risk public indoor spaces (bathrooms, elevators, etc)
6) Filtering shared indoor air with virus/bacteria/mold killing through UV or ceramic filtration
7) Installing pathogen-scavenging (virus, but potentially also bacteria and mold) technology that provides a continuous level of protection using ionized compounds (vaporized low-level Hydrogen Peroxide, Hypochlorous Acid, etc.), repurposed to target aerosolized or vaporized COVID-19, as well as other pathogens that may be encountered in the future

Administrative controls:

1) Developing and executing mandatory mask use in populated indoor/enclosed areas
2) Decreasing numbers of people in indoor/enclosed areas
3) Developing and executing plans to decrease personal traffic through high risk areas
4) Developing and executing terminal cleaning of high risk areas between use, decreasing surface re-aersolization potential

Personal protective equipment:

1) N95 mask and googles/face shields when available to protect high risk individuals, populations, or critical workers who could become single point failures. (consider virus scavenging tech PPE)
2) PPE expanded to general population when more supplies are available, but not at expense of high risk groups
3) Explore new virus scavenging technologies that could either be worn or deployed as portable units for workstation use (personal clean air zone)

Since all sectors of American society (industry, business, government, civil society) benefit, all should have a stake in success. Therefore, understanding this model, implementing it at-scale, studying the results, and refining it as a matter of national survival should be organized, prioritized, and funded in the same way that effective vaccine and treatment strategies are supported. Unlike vaccine and treatment strategies, clean air technology has the potential to mitigate risk and impact the current crisis as well as serve as a known line of defense for future airborne threats. The role of government is critical, but collaboration and funding should transcend all stakeholders, including government, military, civil society, business, industry, and academia. Of note, because the military is reliant on each of the national infrastructure sectors, the Department of Defense should be involved in this partnership but should not be the primary driver of dual-use technology development.

Recommended immediate next steps:

1) National commitment to identify/study all engineering tech to mitigate airborne pathogens
2) Execute rapid public private partnership funding for research across sectors (Gov/Mil/Business)
3) Execute third party validation of technologies individually for multilayered airborne defense
4) Execute large-scale, rapid education campaign for airborne defense implementation strategy
5) Rapidly deploy promising engineering solutions in layered approach, with formal ongoing study
6) Invest at-scale nationally across critical infrastructure sectors, continuously refining models
7) Recommended focus on Healthcare/Public Health, Transportation, Commercial Service and Government Facilities Sectors
8) Recommend additional emphasis on education and child-care environments to speed recovery of business sectors

INTRODUCTION

We recommend that America adopt a multilayered air protection and mitigation strategy to provide safe fresh indoor air across the 16 designated critical infrastructures. Coupled with traditional public health guidance including testing, contact tracing, social distancing, and isolation of people with known disease or exposure, we further recommend a focus on engineering solutions and administrative controls. These controls, applied in a multilayered and redundant model, at-scale, could provide the public confidence to allow America to fully reopen the economy and sustain our critical infrastructures. Together with personal protective equipment for our most vulnerable populations, we can sustain our country economically while protecting public health and those most vulnerable to this or future diseases.

America's ability to survive the COVID-19 pandemic depends on our ability to protect the health of our citizens while we simultaneously sustain the critical infrastructure sectors that support our economy, and ultimately, the American way of life. The current debate between "lives" and "livelihood" is a false choice for the American public. If America, as a world leader, chooses to balance these challenges effectively, then through science and evidence best practices, both considerations can be served responsibly, consistently, and methodically across our sectors of critical infrastructure. In the process, the nation can emerge from the pandemic stronger and more resilient to threats from future natural or man-made infectious diseases.

Until the risk of spreading infection can be mitigated, an unintended but very real side effect of our actions is the paralysis of our economy and the threat to our nation's ability to sensibly sustain and reopen critical infrastructure sectors. However, like all threats, COVID-19 presents a unique opportunity to manage the dilemma of the current pandemic, and actually build a stronger, more resilient nation going forward.

Dependence upon people, both as customer and producer, is the one common vulnerability each critical infrastructure sector shares. Certainly the pandemic will likely accelerate certain trends toward automation, remote working, and on-line commerce. The ability to work remotely may transition many knowledge-work activities at least partially or temporarily. However, for the present and foreseeable future, each infrastructure sector is still dependent at varying levels for groups of individuals to come together to work, learn, produce, and consume at a common location while sharing the same air.

As our understanding of COVID-19 is refined, we now believe that a majority of the disease transmissions likely occur through airborne spread.[1] Retrospectively this makes sense based upon the transmission of other respiratory illnesses. The CDC's acknowledgement that there is significant airborne spread of virus (we will use this term to include both droplet nuclei and vaporization, even though these are two discreet but interrelated phenomenon) was

[1] Source: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html

significant because it brought into question whether our current public health measures have potentially given us a false sense of security due to an overreliance on fomite control procedures. Additionally and impressively, 239 international scientists are now on record in an upcoming letter to the World Health Organization emphasizing their analysis and synthesis of the science that has led them to support the airborne route as the primary route of transmission for COVID-19.[2]

As of now, there is no single solution to the issue of airborne spread of the pathogen.

The authors argue for a multilayered and redundant model, applied systematically across each infrastructure. These protections should be modified to both the requirements the work or gathering requires and are also tailorable to the population at risk. This model, which must continuously evolve as we learn more, should be applied across each infrastructure. Taking these actions collectively will allow us as a nation to survive, ultimately emerging stronger and more protected against infectious pathogens in the future, regardless of the cause.

Since all sectors of American society benefit – industry, business, government and civil society – all should have a stake in success, and all should contribute toward a shared public value; therefore, understanding this model, implementing it at-scale, studying the results, and refining it as a matter of national survival should be organized, prioritized, and funded in the same way that effective vaccine and treatment strategies are. The role of the government is critical, but collaboration and funding should transcend all stakeholders, including government, military, civil society, academia, business and industry.

A Matter of National Survival in Defense of the Nation

The COVID-19 pandemic provides a case study in what total war against an unseen enemy in the 21st century may look like for the United States as an aging superpower. It has left every part of the American population feeling vulnerable to what is an existential threat to how our society operates. Further, it has highlighted multiple interrelated vulnerabilities across society in America's increasingly interdependent society. The Healthcare and Public Health and the Emergency Services sectors were initially and appropriately identified as particularly vulnerable to such a global pandemic. However, for the economy or society to function, each of our 16 critical infrastructures must survive to operate at a certain base level; otherwise, the entire state and society will fail.

The importance of sustaining these critical, interrelated infrastructures was clearly articulated by the Executive Branch's "Updated Coronavirus Guidance for America[3]" on March 16th, 2020. The Cybersecurity and Infrastructure Security Agency (CISA) issued a more extensive memorandum three days later articulating which American workers were deemed

[2] Source: https://www.nytimes.com/2020/07/04/health/239-experts-with-one-big-claim-the-coronavirus-is-airborne.html
[3] Source: "30 Days to Slow the Spread". Link: https://www.whitehouse.gov/wp-content/uploads/2020/03/03.16.20_coronavirus-guidance_8.5x11_315PM.pdf

strategically critical to the function of our nation.[4] CISA was established formally in 2018 as the nation's lead component of the US Department of Homeland Security in the protection of the nation's physical and cybersecurity infrastructures, regardless of whether the threat is natural or man-made.

As stated earlier, the nation initially focused much attention in March and early April 2020, on both the Emergency Services and the Healthcare and Public Health sectors in the initial American response to the pandemic. Many of the other sectors continued to function without signs of visible degradation to the average American. If there was a degradation, many people likely assumed it was a merely a lack of demand for the service. For example, while the Transportation and Logistics System sector saw a significant decrease in demand for passenger transportation, most Americans likely believed any strain on the financial viability of the passenger mass transportation system (air, rail, transit, boat) was due to aggressive local and state orders to shelter in place which restricted much non-essential travel. In spite of specific shortages (toilet paper, for example), supply chain logistics was never visibly threatened to the average American citizen regardless of where they lived. Few Americans thought about the Dams, Water and Wastewater Systems, or Communications Sectors, and if they did, saw no visible significant impact from COVID-19.

The full-page ad released by Tyson Foods[5] warning that America's food security was threatened under the strain of COVID-19 served as a wake-up call for much of the nation. Over the past several decades, America's processing of animal-based protein has become concentrated in a relatively small number of plants.[6] For example, 98% of beef processing is now carried out in only 50 American plants. Therefore, partial or full shutdown of any meat processing facility threatened not just the immediate processing of animals, but the entire animal protein supply chain, from farmer to table. More importantly, Americans, for the first time in many generations, gave serious consideration to a threat to the entire food and agricultural supply chain.

Compounding the anxiety from outbreaks in the heartland of rural America, far away from the cosmopolitan melting pots that define our major cities, was the concern about rural Healthcare and Public Health infrastructure investment. As rural hospitals have closed and consolidated into regional markets, this heightened sense of vulnerability was compounded by the perennial lack of capacity in rural Public Health support and expertise.

The President took action implementing the Defense Production Act (DPA).[7] This action was recognition of a critical choke point vulnerability in the food supply chain. In doing so, he elevated the discussion of critical infrastructure vulnerabilities to the current pandemic in a

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[4] Source: https://www.cisa.gov/news/2020/03/19/cisa-releases-guidance-essential-critical-infrastructure-workers-during-covid-19
[5] Source: "Tyson Foods takes out full-page ad: 'The food supply chain is breaking'" Link: https://thehill.com/policy/healthcare/494772-tyson-foods-takes-out-full-page-ad-the-food-supply-chain-is-breaking
[6] Source: Coronavirus: "Meat-Packer Concentration – The Weak Link in Livestock Industry" Link: https://agfax.com/2020/04/29/coronavirus-meat-packer-concentration-the-weak-link-in-livestock-industry/
[7] Source: https://www.federalregister.gov/documents/2020/05/01/2020-09536/delegating-authority-under-the-defense-production-act-with-respect-to-food-supply-chain-resources

way that had not been done. The action also served to drive a sustained national dialogue on the balance between "lives" and "livelihoods." On one side of the debate are those who advocate for the same aggressive public health measures identified early in the outbreak, regardless of the impact on the fabric of society or the economy. On the other side are those who advocate for sacrificing public health interventions likely to save lives in the interest of getting the economy up and running as soon as possible. Unfortunately, this debate has unnecessarily devolved into a false choice between one perspective or the other, a divisive place for the American public to be. In reality, we must do both sensibly.

Anatomy and Transmission of an Illness

As a newly identified virus, we have much to learn about COVID-19, the Coronavirus that is causing the current pandemic. In the past 35 years since the HIV-AIDS epidemic, we have had the luxury of time to gather facts and methodically study disease pathogens, their control, and effective treatments. Today, in the case of COVID-19, we do not have the luxury of time and are learning while simultaneously having to take mitigating action. Both public and political leaders have grown increasingly frustrated with the evolution of professional gaps in the scientific understanding of the disease. It is on the shoulders of scientific professionals we all stand as we strive to educate the public on this process. However, all professionals should temper expectations that information on clinical course, basic epidemiology, transmission, and control measures will change as we study and learn using the scientific method.

As with the Severe Acute Respiratory Syndrome (SARS) outbreak in 2003, but more importantly seasonal Influenza (of which the American population has far more experience), we now recognize COVID-19 is an illness spread through the respiratory route. Our understanding of COVID-19 has evolved as we have studied the disease, and we now recognize that viral transmission from person to person occurs primarily through the air, either through respiratory droplet nuclei (larger particles which tend to fall out of the air within 6 feet of dissemination)[8] or aerosolized particles which may be more insidious, persist longer, and travel further from a point source of infection.[9]

Incubation periods are thought to be less than 14 days, with most cases becoming symptomatic within the first week of exposure.[10] We are currently unsure of how many COVID-19 particles a normal host would need to be exposed to (the viral load) to cause infection. Initial reports over the past several months, starting in China, have suggested that severity of infections may be related to a dose and mechanism dependency from viral load, especially those small virus-containing aerosols that could be transferred deep into the alveolar region of the lungs.[11] These findings, if validated, would be generally consistent with studies of other respiratory airborne illnesses.

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[8] Source: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html
[9] Source: https://wwwnc.cdc.gov/eid/article/26/7/20-0885_article
[10] Source: https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html
[11] Source: Prather, Kimberly A., Wang, Chia C., Schooley, Robert T (2020). "Reducing transmission of SARS-CoV-2". Science. 27 May 2020. Link: https://science.sciencemag.org/content/sci/early/2020/05/27/science.abc6197.full.pdf; Wu Z, McGoogan JM.

Disease manifestations and host specific risk factors for serious complications are well described elsewhere, disproportionately impacting certain demographics, socioeconomic statuses, as well as persons with co-morbid conditions.[12] These disease characteristics should all be considered as we define populations at risk and as we begin to reopen critical infrastructure sectors to mitigate the impact on the most vulnerable populations. Further, a certain unknown percentage of the population appears to be asymptomatic (or pre-symptomatic) shedders,[13] which is especially concerning because of the impact that these apparently healthy shedders could have on community spread as we begin to congregate again professionally and socially in confined, shared air spaces.

Droplet nuclei containing virus particles are at the highest concentration when a potential host is in close proximity to a symptomatic person who sneezes or coughs. The fact that in non-flowing, still air a majority of these heavy droplets fall out onto surfaces within 6-feet has led to reasonable preventive medicine and public health recommendations that we practice social distancing by maintaining a 6-foot perimeter and cleaning exposed surfaces to decrease transmission. However, as alluded to earlier, there is nothing magic about the 6-foot perimeter. Recent studies have suggested that some droplets can carry 20 or more feet with forceful sneezes, and viral aerosols can persist longer and potentially transmit further than droplet nuclei. Even these studies exclude the implications of airflow patterns in enclosed spaces which may serve to carry the virus well beyond the recommended social distancing, 6-foot perimeter or even the 20-foot range of a forceful sneeze.[14]

Many of our public health sanitation efforts have been focused on surface cleaning to eliminate fomite transmission. However, over the past several months, as we have recognized the importance of airborne spread (droplet or aerosols), this surface transmission of virus particles through fomites is now felt to be less common and therefore less important in the control of the spread of the disease. The CDC has recently acknowledged this growing body of evidence, while expert opinion has consolidated around the idea of controlling airborne spread as the primary mode of controlling the virus outbreak.[15]

Characteristics of and Important Lessons From the Coronavirus Disease 2019 (COVID-19) Outbreak in China: Summary of a Report of 72 314 Cases From the Chinese Center for Disease Control and Prevention. JAMA**.** 2020;323(13):1239–1242. doi:10.1001/jama.2020.2648. Link: https://jamanetwork.com/journals/jama/fullarticle/2762130; Henegan, C., Brassey J., Jefferson, T (2020). "SARS-CoV-2 viral load and the severity of COVID-19". Center for Evidence Based Medicine. Link: https://www.cebm.net/covid-19/sars-cov-2-viral-load-and-the-severity-of-covid-19/

[12] Source: https://www.cdc.gov/coronavirus/2019-ncov/need-extra-precautions/groups-at-higher-risk.html

[13] Sources: Yang, R., Gui, X., Xiong, Y (2020). Comparison of Clinical Characteristic of Patients with Asymptomatic vs Symptomatic Coronavirus Disease 2019 in Wuhan, China. JAMA. Published online May 27, 2020. Link: https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2766237, Wei, W.E., Li, Z., Chiew, C.J., Yong, S.E., Toh, M.P., Lee, V.J (2020). "Presymptomatic Transmission of SARS-CoV-2 – Singapore, January 23 – March 16, 2020". Link: https://www.cdc.gov/mmwr/volumes/69/wr/mm6914e1.htm

[14] Source: Bourouiba, Lydia (2020). Turbulent Gas Clouds and Respiratory Pathogen Emissions: Potential Implications for Reducing Transmission of COVID-19. JAMA. Published Online March 26, 2020. Link: https://jamanetwork.com/journals/jama/fullarticle/2763852

[15] Source: "We cannot keep ignoring the possibility of airborne transmission. Here's how to address it." Joseph Allen, Washington Post. 26 May 2020. Link: https://www.washingtonpost.com/opinions/2020/05/26/key-stopping-covid-19-addressing-airborne-transmission/

We additionally acknowledge that particles from a surface can, under certain conditions, be re-aerosolized, and transmission from surface to mucous membranes (eyes, nose, mouth) is still a potential risk. Finally, fecal oral transmission, or aerosolized fecal material delivered as respiratory droplets through a toilet flush, appear to be possible routes of transmission, but their significance is as of now unclear. Because of the ability of high flush toilets to aerosolize and create droplet nuclei at-scale, this is a potentially serious concern that should be acknowledged, mitigated, and further studied, particularly in heavily used public restroom settings such as airports, entertainment venues, and schools.[16]

Limitations of Traditional Public Health Measures to Combat COVID-19

Since the initial widespread control efforts in the United States in February 2020, current American public health measures have been, until very recently, focused principally on decreasing community spread by three major mechanisms executed simultaneously whenever possible – these include traditional public measures such as social distancing, testing and contact tracing, aggressive cleaning and disinfection, and use of personal protective equipment reserved for selected high-risk populations (currently limited to groups such as medical care teams or first responders due to a lack of supplies). Each of these strategic mechanisms is important and valuable as the nation has worked to "flatten the curve," helping to protect workers and controlling several, highly visible and destructive outbreaks – both regionally and locally.

The scientific community has long recognized a component of airborne spread of COVID-19 (either through droplet nuclei or aerosolized viral particles) and has insisted on universal precautions (including respiratory protection and negative pressure isolation rooms) as part of good infection control in our healthcare system. Early in the pandemic, however, there was not consensus that these measures should be applied to non-healthcare settings. Legitimate concern persisted that scarce PPE should be reserved only for first responders and medical workers in the highest risk settings.

We recognize the effectiveness of each of these measures has been limited either by supply (testing, and personal protective equipment), compliance (cleaning) or organizational capacity (contract tracing and supply chain). However, even if executed simultaneously, reproducibly, and at-scale, these measures alone do not fully and adequately address the key mode of transmission for this respiratory illness: an unrecognized, symptomatic or asymptomatic person spreading viral particles through shared air (either through droplet nuclei or by airborne spread) to individuals or groups of vulnerable people, especially in confined spaces over a sustained time period.

[16] Source: Johnson, D. L., Mead, K. R., Lynch, R. A., & Hirst, D. V. (2013). Lifting the lid on toilet plume aerosol: a literature review with suggestions for future research. American journal of infection control, 41(3), 254–258. https://doi.org/10.1016/j.ajic.2012.04.330. Link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4692156/

Critical Viral Vulnerabilities that Support Airborne Targeting of Community Viral Spread

The COVID-19 virus likely has two characteristics that make it vulnerable to a multilayered defense strategy targeting airborne distribution, building upon traditional public health measures. First, the capsule of the virus, compared to other biologically active particles, appears relatively vulnerable to disruption. Since the viral capsule is critical for survival and infection of a host, this represents a vulnerability to target. Second, because COVID-19 appears to behave like other respiratory illnesses, there is, as yet, an undefined medium infectious dose (ID-50)[17] where 50% of an exposed population would be expected to develop an illness if exposed to that number of viral particles over a particular time. If we can lower the absolute concentration of active viral particles in the air or lower the time of exposure to those particles, we could, theoretically, dramatically decrease the spread of the virus in a population.

[17] Source: "What We Do and Do Not Know About COVID-19's Infectious Dose and Viral Load". Seema Lakdawala and Marta Gaglia, Discover. 18 April 2020. Link: https://www.discovermagazine.com/health/what-we-do-and-do-not-know-about-covid-19s-infectious-dose-and-viral-load

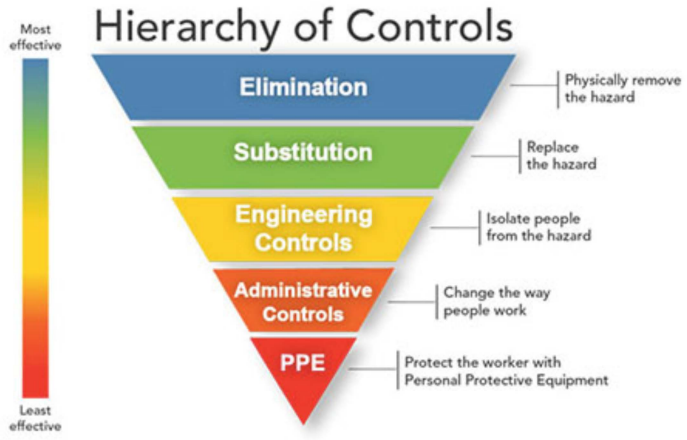
A Fourth Leg of a Multilayered Defense Against Respiratory Pathogens

Our current public health efforts are focused on identification of cases, contract tracing, and isolation of active and potential viral shedders. This is only a partially effective strategy to decrease the risk that viral shedders contaminate the air with infectious viral particles in areas populated by vulnerable populations in a high enough concentration to cause community spread. For situations where people must interact with infected individuals, such as first responders or hospital settings, we provide personal protective equipment for "universal precautions," including medical grade N-95 masks and face shields. We have moved screening activities out-of-doors whenever possible to take advantage of the diffusion capacity of the open air, and, drawing upon the lessons of the 1918 Influenza epidemic, have advocated for fresh air as part of the treatment for those who are infected.[18] All these efforts are good, but they are not enough to realistically reduce the risk to individuals who work, shop, or socialize in densely populated indoor environments

In April, the CDC recommended that asymptomatic persons consider covering their mouth and nose with a non-medical grade mask or cloth covering (preserving PPE for those in highest risk activities) when social distancing (6 feet) is not possible as a way to prevent community spread.[19] Industries are now providing clear plexiglass barriers for front facing positions where people must interact with the general public (such as checkers in stores) or for people who must gather together to work (such as those on assembly lines) to decrease the risk of viral spread by droplet nuclei. These actions are acknowledgements that with our current layered testing (and for that matter any testing in the foreseeable future), we will not be able to keep all viral shedders out of the general population. We agree with these efforts as initial steps, but do not believe they fully leverage all the policy and engineering controls that allow us to aggressively move to methodically reopen and protect each of our 16 critical infrastructures. Further, these minimal efforts, even implemented at-scale, may not alone inspire the needed worker or consumer confidence in a sustained way, and improper wear of PPE may actually do more harm than good by providing a false sense of security.

[18] Source: https://ajph.aphapublications.org/doi/pdf/10.2105/AJPH.8.10.787

[19] Source: Davies, A., K. Thompson, K. Giri, G. Kafatos, J. Walker, A. Bennett (2013). Testing the Efficacy of Homemade Masks: Would They Protect in an Influenza Pandemic? Disaster Medicine and Public Health Preparedness. Aug 2013, pp. 413-418. Link: https://www.cambridge.org/core/journals/disaster-medicine-and-public-health-preparedness/article/testing-the-efficacy-of-homemade-masks-would-they-protect-in-an-influenza-pandemic/0921A05A69A9419C862FA2F35F819D55/core-reader



Defining "Shared Air"

For practical purposes, "shared air" is air in an enclosed space (building, vehicle, etc) where people congregate in a density that person-to-person spread can occur. While theoretically all of our air is shared, outdoor air, with air currents, UV light, and nearly limitless dilution capacity, especially when people are not closely clustered together, appears unlikely to cause person-to-person transmission in emerging research from China.[20] We are defining "shared air" as air that has a high likelihood of becoming contaminated with viral or other pathogens and then spreading those pathogens at a high enough concentration to reliably cause person-to-person spread.

We recognize people share air in the home and in private vehicles, away from professional or recreational activities. Person-to-person transmission of disease brought into the home setting represents a significant threat of infectious spread outside of the workplace in certain infrastructure settings. For example, some have postulated that person-to-person spread may actually originate from shared or public transit vehicles while commuting to the workplace or in shared living arrangements (especially multigenerational households)[21] resulting in the introduction of COVID-19 into the workplace environment. These concerns highlight the challenges demographics, healthcare indicators, and socioeconomic status may have in mitigating the virus. Fortunately, many of our recommendations can be applied in a home or vehicle to reduce the risk to both household members and fellow passengers.

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[20] Source: Qian, H., T. Miao, L. Kiu, X. Zheng. D. Luo, Y. Li (2020). "Indoor transmission of SARS-CoV-2". doi: https://doi.org/10.1101/2020.04.04.20053058 Link: https://www.medrxiv.org/content/10.1101/2020.04.04.20053058v1.full.pdf+html

[21] Source: Qian, H., T. Miao, L. Kiu, X. Zheng. D. Luo, Y. Li (2020). "Indoor transmission of SARS-CoV-2". doi: https://doi.org/10.1101/2020.04.04.20053058 Link: https://www.medrxiv.org/content/10.1101/2020.04.04.20053058v1.full.pdf+html

A Basic Equation to Understand Risk of Respiratory Spread of Illness

Theoretically, people can spread respiratory viruses in the open air or through incidental contact with fomite on surfaces; however, most current data suggests the majority of people who develop COVID-19 do so through respiratory inhalation of a threshold (as yet undefined) exceeding viral load during sustained exposure to an infected person or persons in an enclosed area.[22] Further, we have seen evidence of a dose-dependent risk of developing more severe manifestations of the disease. These manifestations include the ominous bilateral, lower respiratory findings related to higher risk of hypoxia, respiratory failure, intubation, and ultimately death. We propose the following equation to describe the inhaled dose of viral particles that an uninfected person is exposed to:

(Concentration of viral particles in air) x (Volume of respiration/time) x (Time of exposure) =

(Inhaled dose of viral particles)

Therefore, using this model, should we wish to reduce the viral load exposure below the ID50 and therefore the risk of disease to individuals and populations, we must focus not only on viral density in shared air environments (with engineering, administrative, and personal protective equipment solutions) but also the length of exposure to these environments (where the focus would be on elimination or substitution of activities, as well as administrative controls).

[22] Source: Somsen, G., C. van Rijn, S. Kooij, R. Bem, D. Bonn (2020). Small droplet aerosols in poorly ventilated spaces and SARS-CoV-2 transmission. The Lancet. Published online May 27, 2020. doi.org/10.1016/S2213-2600(20)30245-9 https://www.thelancet.com/journals/lanres/article/PIIS2213-2600(20)30245-9/fulltext

Why "Multilayered" Matters

We are defining potentially infectious "shared air" as the primary hazard and are focused on these engineering controls, administrative controls, and personal protective equipment in a multilayered way in mitigation control. The goal is to decrease the risk of virus-dense shared air to individuals and to the population as a whole.

The benefits of a multilayered approach are significant.[23] Partially successful intervention may not, by itself, provide definitive protection or public confidence in infrastructure sectors; however, in a multilayered approach, these same interventions, could theoretically provide an exponentially decreased risk of disease transmission. For example, if we combine three environmental interventions that act independently of each other, one that provids a 60% risk reduction (allowing a 40% risk of disease transmission), one that provids a 70% risk reduction, and a third with an 80% risk reduction, the risk of transmission could be decreased by roughly 97%.

Where "Risk of Transmission" (RT) is defined by $RT^1 \times RT^2 \times RT^3 = RT^{Total}$

Example $(0.4) \times (0.3) \times (0.2) = 0.024$

While in reality some of the interventions will likely depend upon each other and not be independent and the mathematical modeling currently applied would be far more rigorous, the basic concept is sound with compounding interventions leading to decreased risk. In addition, a multi-layered, clean-air strategy allows different layering solutions best suited to each environment's unique threats and needs to be employed to create an effective as well as a cost efficient return on investment.

[23] Source: https://www.sciencedirect.com/science/article/pii/S0025556420300560.

RECOMMENDATIONS

We recommend the following additional considerations, adopted at-scale, as a multilayered approach to provide safe shared air, allowing the United States to protect its 16 critical infrastructures. The American Society of Heating, Refrigeration and Air-Conditioning Engineers evidenced-based position paper from April 2020, provides a foundation for the first six engineering controls.[24] The recommendations to repurpose Commercial Off-the-Shelf (COTS) or Government-Owned Technology (GOT) in a pathogen-scavenging role shows promise, and the authors recommend implementation while simultaneously studying these technologies as part of a multi-layered control model.

The recommendations follow the NIOSH Hierarchy of Controls model. (Appendix 2)

A further key component of execution of this plan will be a public education campaign. (Appendix 3)

Engineering Controls to consider for indoor/enclosed "shared air":

1) Increasing air turnover with fresh outdoor air using open windows
2) Increasing air turnover with fresh air using HVAC room turnover
3) Installing physical barriers between people where they share air
4) Providing directional air flow as a virtual barrier between "shared" and "personal" air
5) Surveying/mapping/mitigating air flow hazards in high risk public indoor spaces (bathrooms, elevators, etc)
6) Filtering shared indoor air with virus/bacteria/mold killing through UV or ceramic filtration
7) Installing pathogen-scavenging (virus, but potentially also bacteria and mold) technology that provides a continuous level of protection using ionized compounds (vaporized low-level Hydrogen Peroxide, Hypochlorous Acid, etc.), repurposed to target aerosolized or vaporized COVID-19, as well as other pathogens that may be encountered in the future

Administrative controls:

1) Developing and executing mandatory mask use in populated indoor/enclosed areas
2) Decreasing numbers of people in indoor/enclosed areas
3) Developing and executing plans to decrease personal traffic through high risk areas
4) Developing and executing terminal cleaning of high risk areas between use, decreasing surface re-aersolization potential

[24] Source: https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

Personal protective equipment:

1) N95 mask and googles/face shields when available to protect high risk individuals, populations, or critical workers who could become single point failures. (consider virus scavenging tech PPE)
2) PPE expanded to general population when more supplies are available, but not at expense of high risk groups
3) Explore new virus scavenging technologies that could either be worn or deployed as portable units for workstation use (personal clean air zone)

Transdisciplinary Study and Implementation

One of the largest barriers toward implementation is how our nation's professional organizations, such as medicine, public health, and engineering, are aligned and funded. The business of medicine and how our system is funded is a bewildering mix of public and private funding arranged in stovepipes to produce a profit for the private sector. Indoor air quality has primarily been the domain of engineering disciplines. Preventive medicine and the delivery of health care have largely been the domain of healthcare professionals, including doctors, nurses, and other specialists. Much of the effort regarding indoor air quality in the past has been focused on protection from the elements, maintaining basic temperature and humidity of the buildings, and ensuring sufficient air turnover to allow humans to survive and interact comfortably.

Certainly, there are instances where medical and engineering disciplines have worked together, but these are not the default position, and this action is often crisis driven. For example, the initial well-documented Legionnaire's outbreak in 1976 emphasized the impact of building design and maintenance; this disease outbreak and the work to contain it highlighted the relationship of disease clustering associated with engineering on a national stage. Similarly, certain natural events such as hurricanes and floods have triggered significant concerns of mold and other health impacts.

Certain clinicians, such as occupational, pulmonary, allergy, and other medical specialists, have, at times, connected indoor air quality to clusters of medical problems. For example, medical conditions related to sick building syndrome is a recognized, albeit controversial, risk for certain disease manifestations, especially in patients with underlying conditions. Generally, however, indoor air quality has largely resided in the engineering domain, removed from public health, clinical, and infectious medicine domains.

Most of these prior events have been focal in nature, centered on a unique structural defect that once discovered, could be resolved in isolation. The national threat from COVID-19 forces us to examine our current ventilation codes and social engineering paradigms to determine whether they are overwhelmed with the introduction of disease-causing organisms within indoor air spaces.[25] In reality, the threat of infectious shared air has always had a negative impact on the nation's productivity when considering the annual burden of lost work-days to influenza and other more common respiratory illnesses. If medical and engineering experts can successfully explore, innovate, and employ clean air solutions, the economic and public health impact of their work could pay dividends for the foreseeable future in reducing natural and man-made respiratory illness transmission.

[25] Source: "Pandemic COVID-19 and Airborne Transmission". Link: https://www.ashrae.org/file%20library/technical%20resources/covid-19/eiband-airbornetransmission.pdf

Lack of Shared Funding Streams Across the Infrastructure Sectors

Each of the 16 critical infrastructures is unique with either public, private, or most commonly, a blended model of ownership and investment. Some are designed almost completely for profit (such as the food and agriculture sector), but almost all the sectors are supported directly or indirectly by some form of public funding. For example, while certain modes of mass transportation are privately owned and operated (air, truck, freight rail, shipping, and over the road trucks), and some are government owned (passenger rail and transit), almost all depend primarily on government owned infrastructure, excluding small projects such as toll or private roads. The most important exception in transportation is the freight rail industry where a majority of the infrastructure is privately held and funded. All are enabled by profit with little redundancy or excess capacity for research and development that may cross sectors. Further, protection of intellectual property, a legitimate concern, may actually inhibit collaboration during crises.

Department of Defense Funding Streams

While the defense industrial sector is privately owned, it is, by nature, entirely dependent on investment by the public sector. Further compounding this confusing set of relationships is that all of our national defense is reliant on the 16, mostly civilian, infrastructures, and each of these is profit driven. For example, military troops depend upon the same food and agriculture sector as their civilian counterparts, generally use the same water and power sources, and travel and ship using the same civilian transportation systems. While there are funding mechanisms authorized by Congress to develop shared-use technology (beneficial to military and civilian use), collaboration with industry to develop shared-use is not the default position for most Department of Defense investments.

Public Distrust in Institutions

The nation faces a crisis in public confidence in the very institutions we must depend upon in times demanding collective action for both public and private good. As we work to reopen and sustain our infrastructure sectors, alternate political narratives, distrust of traditional news media, and low confidence of elected bodies is at an all-time high. This distrust extends to other groups such as big business, religious institutions, and public schools, which together with public institutions, threaten to derail our ability to act collectively. Public confidence, fortunately, remains relatively high in the military, small business, healthcare, and the emergency services sectors, which should be leveraged across the critical infrastructures to instill high public confidence.[26]

[26] Source: "Confidence in Institutions." Link: https://news.gallup.com/poll/1597/confidence-institutions.aspx

Public Expectations, Distrust and Misunderstanding of Science

Just as trust in public institutions broadly is at historical lows or near lows, distrust and misunderstanding of science, especially in certain sectors of society, is also low. This will prove problematic as we move toward a consistent scaled implementation of a multilayered airborne defense strategy.[27] This distrust has been compounded by rapidly changing projections from the scientific community, as well as public health and medical recommendations that continue to evolve as we actively learn from this rapidly changing pandemic environment.

Distribution and Visibility of Critical Infrastructure Sectors

Certain infrastructures are disproportionately concentrated regionally, creating an environment that highlights the deep partisan and regional divides in the nation. For example, the Food and Agriculture sector disproportionately depends upon rural America, while the Financial Services sector is concentrated in urban sections of the country. Other sectors function out of view of the American public, such as the Dams or Water and Wastewater Systems sectors.

Some sectors, however, are both highly visible and ubiquitous across the nation, such as the Healthcare and Public Health, Emergency Services, Transportation Services,[28] Commercial Facilities and Government Facilities Sectors. We recommend paying special attention to these additional sectors along with the Public Health and Healthcare sectors because they cross all regions of the country, impact all Americans, and are highly visible. They also serve as one of the biggest challenges since they are highly dependent upon consumer demand and the ability to come together safely in large groups of uncontrolled people. This demand is highly elastic during a crisis; public confidence in regard to safety measures oscillates across the political spectrum almost daily. If we are able to restore confidence in these sectors and operate safely, American public confidence will grow and be sustained throughout our reopening processes. Our opinion is that confidence in all other sectors will follow if we get the multilayered, disease defense right in the Transportation Systems, Commercial Facilities, and Government Facilities Sectors implemented immediately.

While gathering in houses of worship is not technically a "Commercial Service" the challenges of participating in these activities in times of COVID-19 are similar to those experienced by for profit businesses. Additionally, whether public or private, educational environments share the same challenges of safe operations. We recommend working with these organizations and stakeholders to bring disparate portions of society together safely for a common purpose.

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[27] Source: "Trust and Mistrust in Americans' Views of Scientific Experts" Cary Funk, M. Hefferson, B. Kennedy, C. Johnson. Pew Research Center. Published online August 2, 2019. Link: https://www.pewresearch.org/science/2019/08/02/trust-and-mistrust-in-americans-views-of-scientific-experts/

[28] Source: The Multi-Layered Clean Air Defense: Practical Transportation System Considerations. Jim Mathews, Rail Passenger Association. Unpublished Air University White Paper, March 2020. This was the first article which addressed one of the critical infrastructure sectors using the layered clean air methodology.

OVERCOMING BARRIERS

A Whole of Society Implementation Strategy to Protect Shared Air

The authors argue that the at-scale implementation of a ***multilayered airborne defense strategy*** will enable our nation to sustainably reopen the economy and protect the 16 critical infrastructures from the COVID-19 pandemic. Every day we delay this action is measured not only in lives and economics but also opportunity costs. Further, if we get this right, we will rapidly recover not only from the current pandemic, but we will harden all aspects of society against future airborne spreads of infectious diseases, strengthening us against both natural and man-made threats in the future. The economic and humanitarian opportunities before us are enormous, and national resiliency and confidence in defeating this threat will be an example not only to our citizens, but also to all citizens of the world. Through our actions, we will demonstrate that the United States can overcome most any enemy or threat; therefore, we recommend these actions be elevated to the highest level of national dialogue for consideration and action.

Recommended immediate implementation steps:

1) National commitment to identify/study all engineering technologies to mitigate airborne pathogens
2) Execute rapid public-private partnership funding for research across sectors (Government/Military/Business)
3) Execute third-party validation of technologies individually for multilayered airborne defense
4) Execute large-scale rapid education campaign for airborne defense implementation strategy
5) Rapidly deploy promising engineering solutions in layered approach, with formal ongoing study
6) Invest, at-scale, nationally across critical infrastructure sectors, continuously refining models
7) Recommended focus on Healthcare/Public Health, Transportation, Commercial Service and Government Facilities sectors
8) Recommend additional emphasis on education and child-care environments to speed recovery of business sectors

Making Shared Air Everyone's Responsibility

Just as every sector of society and every infrastructure sector has been threatened during the pandemic, each will tremendously benefit when we develop sustainable solutions. Finding these solutions will benefit and bridge multiple disciplines, crossing multiple funding streams. For this strategy to succeed a national, bipartisan consensus will be required, as well as leadership at the federal level, bringing stakeholders together for solutions. We should commit to rapidly funding the research that will identify, evaluate, and prioritize possible emerging technological solutions involved in a multilayered airborne defense strategy. Ideally, because of the shared public/private benefit, the research should be funded through public-private partnerships, with full access to, and commitment by, Federal labs - paying special attention to the protection of intellectual property and business interests. Supply chain and domestic manufacturing issues are a significant concern while implementing at-scale, so all mechanisms should be considered during an implementation plan.

As we focus on necessary sectors of society that must work together and be exposed to the threat of shared air, we are simultaneously focusing on several institutions that still inspire a high level of public confidence. This includes not only first responders and the health care workers but also the military. The military and our nation's first responders expect to be placed in harm's way as a precondition of service. This acknowledged risk to front-line health care workers is now more broadly visible in our communities. As a society, we have insisted on the best protective safety equipment and protected work environments for both military and first responders. We clearly must now expand this for all our healthcare workers as they have become part of our nation's first line of defense in this nationwide threat.

As the personnel who work and frequent these sectors develop confidence in their equipment and the multilayered implementation and execution strategy, front-line health care workers will continue to instill confidence in the technologies and concepts with the American people. Further justifications for the military's aggressive involvement in these dual-use concepts and technologies include the reliance of the military on all 16 of the civilian critical infrastructures, and an opportunity to develop defenses against potential biowarfare threats our military could face on the battlefield of the future.[29]

The authors recommend focusing initial efforts on the Emergency Services, Healthcare and Public Health, Transportation, Commercial Services and Government Facilities sectors. These sectors are ubiquitous across all regions and demographics of the country, and in the case of the Government Facilities sector, the government (federal, state, and local) has near total control over implementation. These sectors also provide some of the most challenging problems of shared air where the likelihood of asymptomatic or sick individuals shedding viral load into contained or enclosed spaces is the greatest. Further, the last three infrastructure sectors depend upon consumer confidence to reopen at-scale; therefore, we believe if the nation can successfully reopen these infrastructure sectors, then all other sectors should be able to incorporate these strategies to successfully mitigate their unique

[29] Source: https://www.businessinsider.com/coronavirus-brings-7th-warfare-domain-top-navy-officer-europe-says-2020-4

risks caused by the global pandemic. A public education strategy should include not only clear directions ("what" and "how") but also include a basic understanding of the science behind the "why" of these recommendations.

Final Thoughts: A Multilayered Defense Plan and Adoption by the American People

How we "Fight the war on Coronavirus" will define who we are as a nation. Excluding fringe populations, we believe a majority of the American people will do the right thing when information is presented in thoughtful ways, acknowledging we are continuously learning as we face this challenge together. This dialogue must not only address valid concerns about the spread of disease, but also civil liberty, freedom, self-determination, and transparency. We recommend special attention be paid to a public information campaign, executed in an apolitical way where shared understanding of the problems and solutions are coupled with shared societal values and commonalities, rising above partisanship, socioeconomic status, and regional differences. Sensible public policy based upon a foundation of both good science, sound business, and shared values and experiences will help us transcend the moment of crisis we now face - through these experiences we will emerge stronger *together* - as a people and as a country, not just against COVID-19, but against any other current or future threat.

APPENDIX ONE

Listing of 16 Designated Critical Infrastructures[30]

There are 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof. Presidential Policy Directive 21 (PPD-21): Critical Infrastructure Security and Resilience advances a national policy to strengthen and maintain secure, functioning, and resilient critical infrastructure.

- Chemical Sector
- *Commercial Facilities Sector**
- Communications Sector
- Critical Manufacturing Sector
- Dams Sector
- Defense Industrial Base Sector
- Emergency Services Sector
- Energy Sector
- Financial Services Sector
- Food and Agriculture Sector
- *Government Facilities Sector**
- *Healthcare and Public Health Sector**
- Information Technology Sector
- Nuclear Reactors, Materials, and Waste Sector
- *Transportation Systems Sector**
- Water and Wastewater Systems Sector

* Recommended infrastructures that should be a focal point in the initial implementation plan as discussed in this paper.

[30] Source: https://www.cisa.gov/critical-infrastructure-sectors
Original release date: March 05, 2013 | Last revised: March 24, 2020 Retrieved 25 May 2020

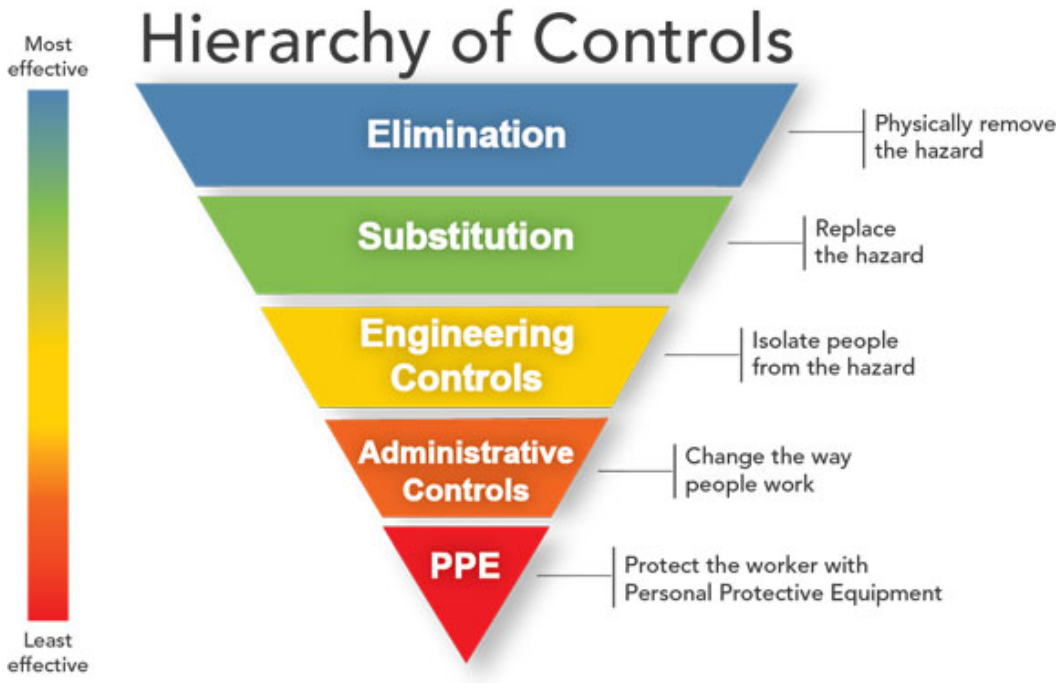
APPENDIX TWO

The National Institute for Occupational Safety and Health (NIOSH) Hierarchy of Controls

Overview

Controlling exposures to occupational hazards is the fundamental method of protecting workers. Traditionally, a hierarchy of controls has been used as a means of determining how to implement feasible and effective control solutions.

One representation of this hierarchy is as follows:



The idea behind this hierarchy is the control methods at the top of graphic are potentially more effective and protective than those at the bottom. Following this hierarchy normally leads to the implementation of inherently safer systems, where the risk of illness or injury has been substantially reduced.

NIOSH leads a national initiative called Prevention through Design (PtD) to prevent or reduce occupational injuries, illnesses, and fatalities through the inclusion of prevention considerations in all designs that impact workers. Hierarchy of controls is a PtD strategy. To learn more, visit the PtD website.

Elimination and Substitution

Elimination and substitution, while most effective at reducing hazards, also tend to be the most difficult to implement in an existing process. If the process is still at the design or development stage, elimination and substitution of hazards may be inexpensive and simple to implement. For an existing process, major changes in equipment and procedures may be required to eliminate or substitute for a hazard.

Engineering Controls

Engineering controls are favored over administrative and personal protective equipment (PPE) for controlling existing worker exposures in the workplace because they are designed to remove the hazard at the source before it comes in contact with the worker. Well-designed engineering controls can be highly effective in protecting workers and will typically be independent of worker interactions to provide this high level of protection. The initial cost of engineering controls can be higher than the cost of administrative controls or PPE, but over the longer term, operating costs are frequently lower, and in some instances, can provide ~~a~~ cost savings in other areas of the process.

For descriptions of engineering control technologies researched by NIOSH, and information on the control details and their effectiveness, visit the Engineering Controls Database. The engineering controls contained in the database are beneficial for users who need control solutions to reduce or eliminate worker exposures.

Administrative Controls and PPE

Administrative controls and PPE are frequently used with existing processes where hazards are not particularly well controlled. Administrative controls and PPE programs may be relatively inexpensive to establish but, over the long term, can be very costly to sustain. These methods for protecting workers have also proven to be less effective than other measures, requiring significant effort by the affected workers.

Source: https://www.cdc.gov/niosh/topics/hierarchy/default.html
Page last reviewed: January 13, 2015
Retrieved 2 June, 2020

APPENDIX THREE

COVID-19 Communications Strategy

Transitioning the nation from lockdown to the new business "normal" will take a disciplined, science-based approach to continue to ensure public safety. Person-to-person transfer remains one the highest means of germ transmittal, not only for COVID-19, but for many pathogens. Adopting a layered approach strategy, with you at the center and working your way outward from your home, mode of transportation, work environment and larger public gatherings is a key strategy to focus protection against this invisible enemy.

Every American will have decisions each day they will make to allow them to both survive the pandemic and carry on meaningful personal and professional lives as part of our society. Using education-focused, on-key messages based on the best science available, we can adapt these concepts in our day-to-day lives so we can all survive the pandemic stronger together at the end as we adjust to whatever new normal we will be confronted with. All of us should refer to the current CDC guidelines for the most up-to-date recommendations to keep you, your family, and your friends and neighbors safe.

KEY MESSAGES

Personal protection: You are ultimately responsible for ensuring a pathogen doesn't get to you. Whether you are following social distancing, bumping elbows, taking care of a small cut on your hand, rubbing your eyes or nose with dirty hands, or sharing utensils when dining, you are ultimately responsible for your health and those around you who depend upon you.

> ***Key Message 1:*** Make sure you wash your hands and use hand sanitizer frequently, and keep surfaces around you clean. If you or a member of your family has special health conditions making you particularly vulnerable to COVID-19, you may need extra protection.

Home and transportation protection: We spend the majority of our time either at home, at work, or commuting. In many cases, your work and commute will be the highest risk activities. Whenever possible, work from home or stagger your commuting times to decrease your exposure to shared community air.

> ***Key Message 2***: Apply the concepts of a multi-layered air defense strategy to all the environments you frequent. This will not only keep the air clean in your environment but may decrease the risk of re-infection among household occupants.

> ***Key Message 3:*** Physical distancing remains a recommended defense against the spreading of airborne pathogens. Following the most current CDC guidelines, maintaining a minimum of six feet between non-family members, must be the norm. When personal protective equipment is available for the general population, you may consider this if you need to travel or work in environments that do not allow social distancing, especially if you or your family member are considered high-risk from COVID-19.

Workplace and Public Gatherings: Worker and customer safety is key to getting the economy running again. Public gatherings may include such activities as shopping, social events, school, and religious services. Continue to follow all CDC guidelines including six-foot social distancing whenever possible. Stay home when you are sick.

The wearing of face masks or scarves must become the norm. These masks must not to be confused with personal protective equipment (such as N-95 face masks and shields) used in the medical and first responder communities.

The general public should utilize face masks to protect others from you: wearing a face scarf should be viewed as a sign of respect for others. Regardless of how healthy we think we are, we could still be one of the many asymptomatic carriers who is sharing an infectious disease like COVID-19 to our friends, family, and neighbors. If you are in public and are sharing public

air, wear a face mask. Recognize, of course, if you are in an outdoor environment where there is little contact with others, when you are driving alone, or when you are with family members only, face masks are not required.

> ***Key Message #4:*** When in public and sharing air, especially indoors, follow six-foot physical distancing whenever possible while additionally wearing a mask.
>
> ***Key message #5:*** Until COVID-19 abates or effective prophylactics and immunizations developed, the wearing of face masks in the work-place and in public gatherings needs to be considered normal and considerate.
>
> ***Key Message #6:*** Out of courtesy to your neighbor, save the N-95 masks and face shields until such time as we have plenty for all our first responders, health care workers, and those who require extra protection from COVID-19.

Final and Most Important Key Message #7

We must continue to be respectful of others as we transition into a running economy while protecting those most vulnerable among us from this assault by an invisible enemy. Your actions today may save the life of somebody's loved one…maybe a special person in your life. We are all in this together.[31]

[31] The Key Messages section was authored by Lt Col Rick "Sonic" Johnson. He is a Visiting Scholar at the Air University, and recently retired after serving 37 years in the Air Force. He spent nearly 23 years as a pilot including two instructor pilot tours and an assignment at the Air University. After retirement from active duty in 2004, he entered Air Force Civil Service as a Public Affairs Officer at Columbus Air Force Base where he served for over 14 years. He is currently a co-owner in an air purification business.