Data-Driven Approach to Managing the COVID-19 Pandemic

White Paper

Table of

CONTENTS

ABSTRACT

The COVID-19 pandemic has exposed significant gaps in the public health response, not just in the United States, but internationally. The U.S. has been an epicenter of the pandemic, leading the world in COVID-19 cases. However, their response to the novel coronavirus has been marred by faulty operationalization of basic public health interventions, such as diagnostic testing and data collection and reporting. While it is critical to improve the nation's immediate response and speed up recovery in the short term, global health crises such as pandemics are an ever-present threat. Therefore, the U.S. public health infrastructure requires reforms to help leverage an effective response to similar future events.

An effective pandemic response should have many components, including, but not limited to leadership, political support, policies, resources, and budget. This white paper proposes a framework of adaptable, data-driven, "precision" public health to inform the strategic response to public health crises. Our proposed solutions include integrated use of both already-established and less-conventional data sources, as well as epidemiologic and economic modeling to create tailored responses at the national and local levels. These responses will include precise deployment of restrictive interventions, such as targeted lockdowns, and will account for trade-offs between health outcomes versus detrimental socioeconomic effects. A data-driven strategy across the U.S., coordinated with other nations and international bodies, will be essential to limit the impact of current and future pandemics and other health crises.

November 19, 2020

Introduction

THE COVID-19 PANDEMIC

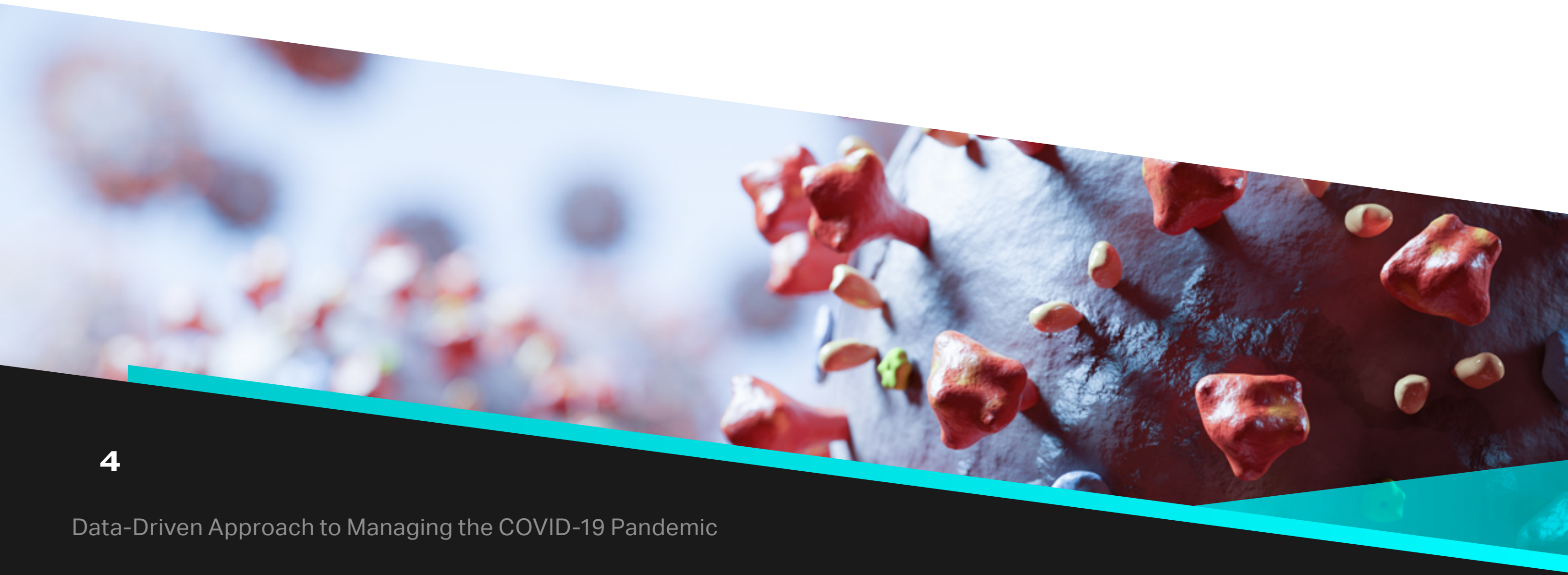
The first case of human COVID-19, caused by a novel coronavirus called SARS-CoV-2, was detected in Wuhan, China, in early December 2019.[1] The respiratory virus of zoonotic origin subsequently spread across the globe unevenly, affecting some countries more than others. The World Health Organization declared COVID-19 a global pandemic on March 11, 2020.[2]

The first COVID-19 case was identified in the United States on January 20, 2020, in Washington state. Early mitigation efforts consisted of travel restrictions and warnings, and on March 13, 2020, the U.S. federal government declared COVID-19 a national emergency.[3]

In absence of treatments or vaccines, non-pharmaceutical interventions (NPIs) have been the only available means to drive the public health response. NPIs, such as strictly-imposed travel restrictions, social-distancing measures, mask mandates, widespread use of handwashing and hand sanitizers, quarantine of exposed individuals, and isolation of the sick, proved effective in containing the impact of the outbreak when it first occurred in China.[1] Other countries, such as Australia, South Korea, Singapore, Taiwan, and Germany, also managed to contain the spread of the virus in the early stages of the pandemic through such NPIs.[4]

For many years, wide scientific consensus had indicated an increased risk for another significant pandemic, potentially with a large-population impact, such as the 1918 Spanish Flu.[5] Today's risk is even higher due to the significant growth of the human population in our increasingly globalized world. Humans' interference with the wild habitats (e.g., due to deforestation or climate change) has increased the overlap among human and wild animal ecosystems, allowing microbes to cross ecosystems easier.[6]

Yet, the U.S. was surprisingly one of the countries that was caught unprepared. By November 19th, at the time of this writing, the United States has been one of the most affected countries in the world, with close to 11.9 million diagnosed cases and more than 250,000 confirmed COVID-19 deaths.[7]



Problem

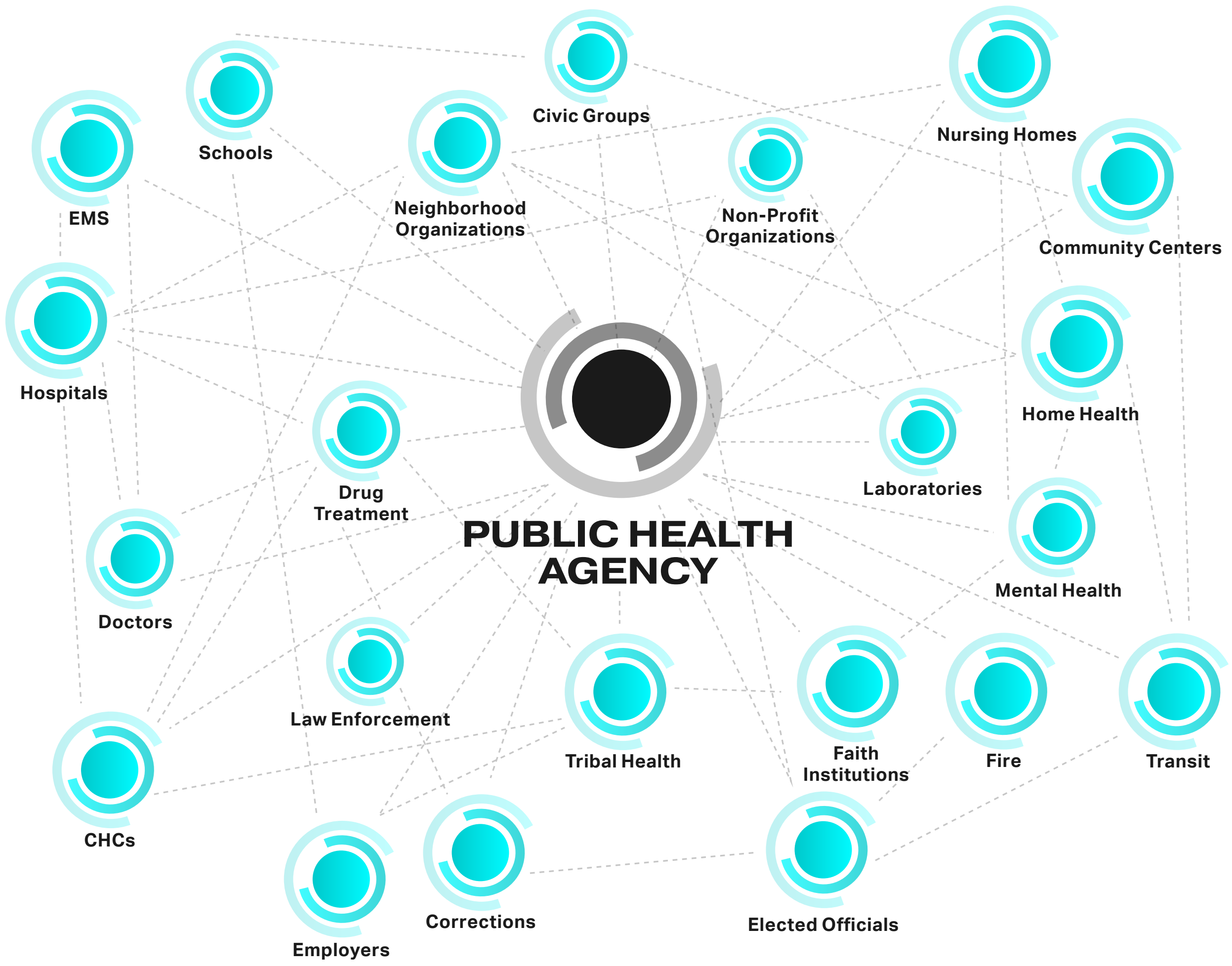
THE U.S. PUBLIC HEALTH SYSTEM'S COVID-19 RESPONSE

The U.S. public health system is largely composed of governmental authorities, such as the Centers for Disease Control and Prevention (CDC) and local public health offices, as well as healthcare providers and non-governmental organizations. In a federalized system, such as that in the United States, the COVID-19 response has been driven mainly by the local public health authorities, with guidance and support from the federal and state levels. The large number of players in the local public-health system, as well as the complexity of interactions among them can be observed in Figure[1]. While federalization should allow for a customized response based on local needs, the COVID-19 nationwide response has been deeply fragmented due to the lack of coordinated federal oversight, exposing heterogeneity in institutional capacities among different states.[8] In a decentralized model, local health agencies must have the necessary tools and information to mount an efficient response.

In a decentralized model, local health agencies must have the necessary tools and information to mount an efficient response.

The COVID-19 pandemic has exposed numerous deficiencies in the U.S. public health system. Per Bergquist et al,[6] the U.S. has failed to operationalize widespread COVID-19 testing due to at least three factors: initial reliability problems with tests distributed by the CDC; initially-delayed approvals of new tests by the FDA; and miscommunication between the Federal Administration and the White House Coronavirus Task Force, which spread confusion regarding COVID-19 mitigation best practices. Deficiencies in contact tracing capabilities due to a lack of personnel with

Figure 1. Stakeholders of the U.S. public health system engaged locally in the COVID-19 response.
The stakeholders include government organizations and elected officials, as well as health care providers, non-profits, and community organizations at federal, state, local, and tribal levels.



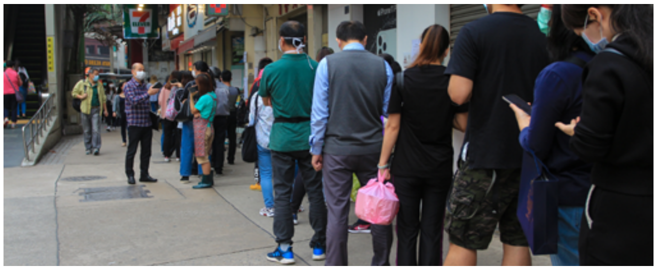
Source: CDC, 2017
Note: EMS: Emergency medical services; CHC: Community health centers.

appropriate training and lack of supportive digital health tools have compounded the viral spread.[9] This is unlike many other countries who have established a national contact-tracing registry and used mobile apps to notify people who might have been exposed to COVID-19. In addition to early failures with the diagnostic testing process, problems with data collection and reporting have also hindered the United States' pandemic response.[8] With no integrated public health information system to track supply and demand of essential public health goods (e.g., personal protective equipment [PPE] and ventilators), resource deployment is chronically suboptimal[9] both now and going into future months after the worst of the pandemic is behind us.[5]

To be fair, there have been some beneficial policy changes in the federal response to the pandemic as well. Examples include extending medical licenses across state borders and expanding the use of telemedicine, including reimbursement by insurance companies. Telemedicine has existed for decades; however, heavy regulation and subpar reimbursement had precluded its adoption and growth.[10] During the COVID-19 emergency, use of HIPAA non-compliant private communications has also been allowed to enable telehealth services. Several noteworthy digital public health initiatives have also been launched this year, in partnership with big tech companies, such as Microsoft, Apple, and Google.[11,12]

In contrast, other nations (e.g., Singapore, South Korea, Taiwan, Hong Kong, and Germany) appear to have been better prepared to adapt to the pandemic, including in their use of digital technologies. Figures 2 and 3 provide comparative trends of the pandemic in the U.S. versus selected other countries. The number of daily COVID-19 cases per million has

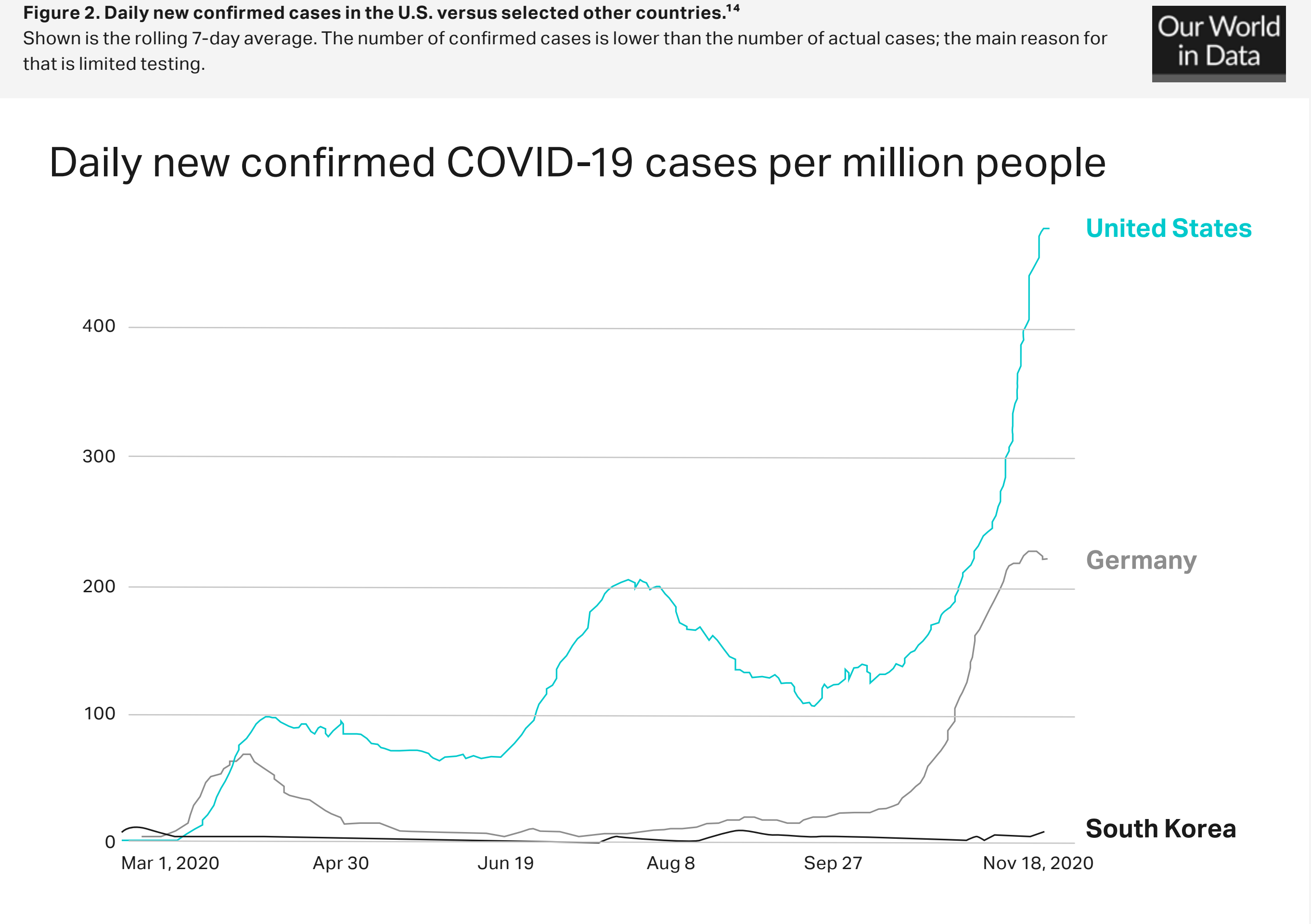
In addition to early failures with the diagnostic testing process, problems with data collection and reporting have also hindered the United States' pandemic response.



been significantly higher in the U.S. versus Germany, for instance, at least during the initial wave of the pandemic (Figure 2).

Excess mortality trends also suggest a much larger initial impact of the pandemic in the U.S. when compared to Germany (Figure 3). However, the second wave of the pandemic, which is occurring this fall, appears to have impacted Europe more significantly, including Germany. Furthermore, while the daily number of confirmed COVID-19 cases has increased during the fall, the case fatality rate is decreasing globally compared to earlier this year. Explanations may include better treatment, but also increased diagnostic testing and the different age mix of the affected populations.[13]

Figure 2. Daily new confirmed cases in the U.S. versus selected other countries.[14]
Shown is the rolling 7-day average. The number of confirmed cases is lower than the number of actual cases; the main reason for that is limited testing.

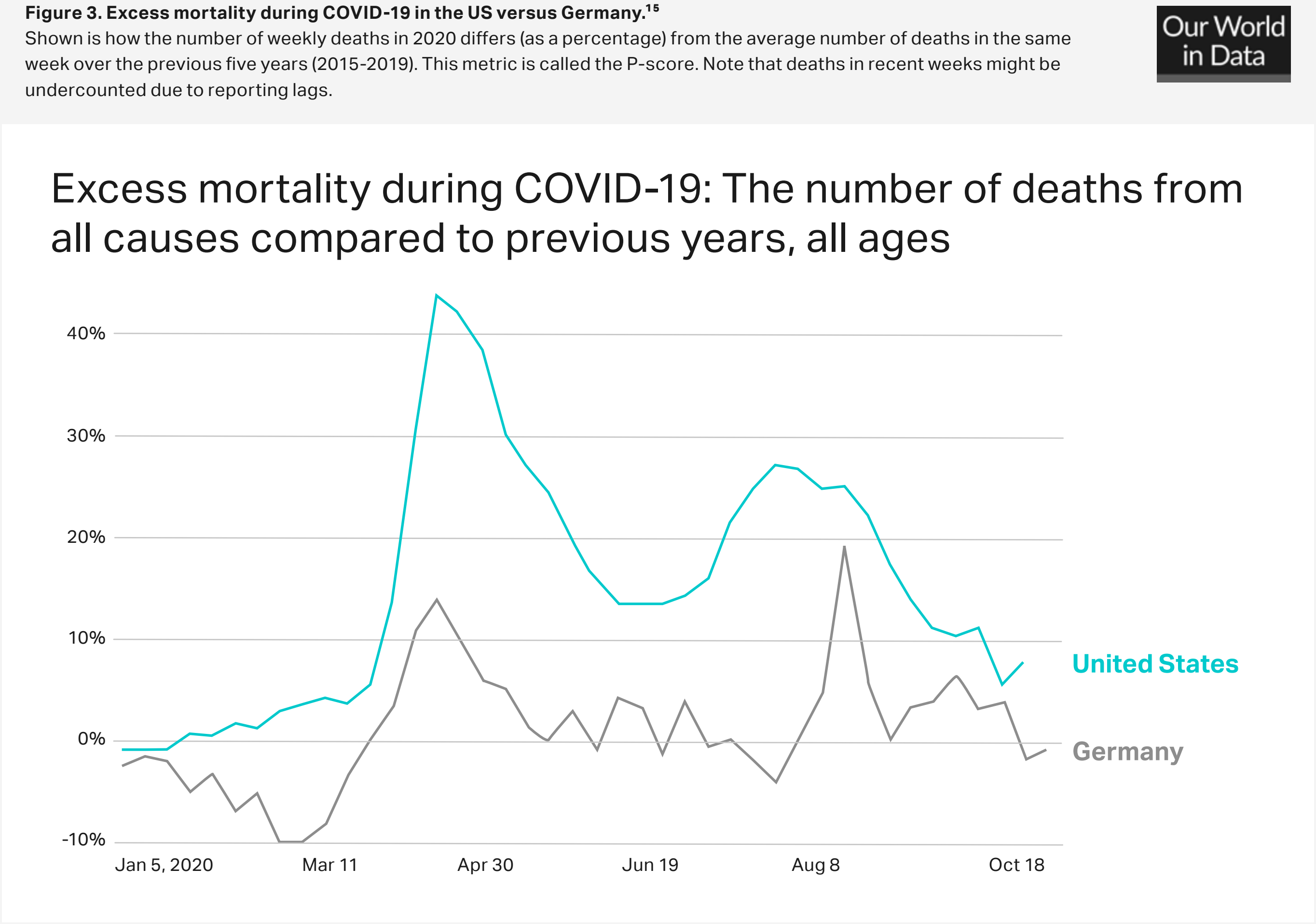


Source: European CDC - Situation Update Worldwide - Last updated 18 November 13:05 (London time)

Reduced economic productivity, factory closures, and disruptions in global supply chains are putting strain on the world economy, leading to negative supply shock.[16] Although the economic risk may not necessarily be closely correlated with the health risk,[17] the stock market indices, as measures of consumer and business confidence in the economy, have been indeed negatively correlated with the daily number of COVID-19 cases.[16] The U.S. economy has been significantly affected, as have many other largely service-based economies,[17] even if a nationwide lockdown had not occurred in the U.S.

Why has the pandemic varied in timing and magnitude of impact among different nations? This is still poorly understood, but data is emerging that can help inform our future preparedness. Germany, for instance, has benefited from autonomous local public health decision making with efficient central coordination. Recent reform and appropriate funding have

Figure 3. Excess mortality during COVID-19 in the US versus Germany.[15]
Shown is how the number of weekly deaths in 2020 differs (as a percentage) from the average number of deaths in the same week over the previous five years (2015-2019). This metric is called the P-score. Note that deaths in recent weeks might be undercounted due to reporting lags.



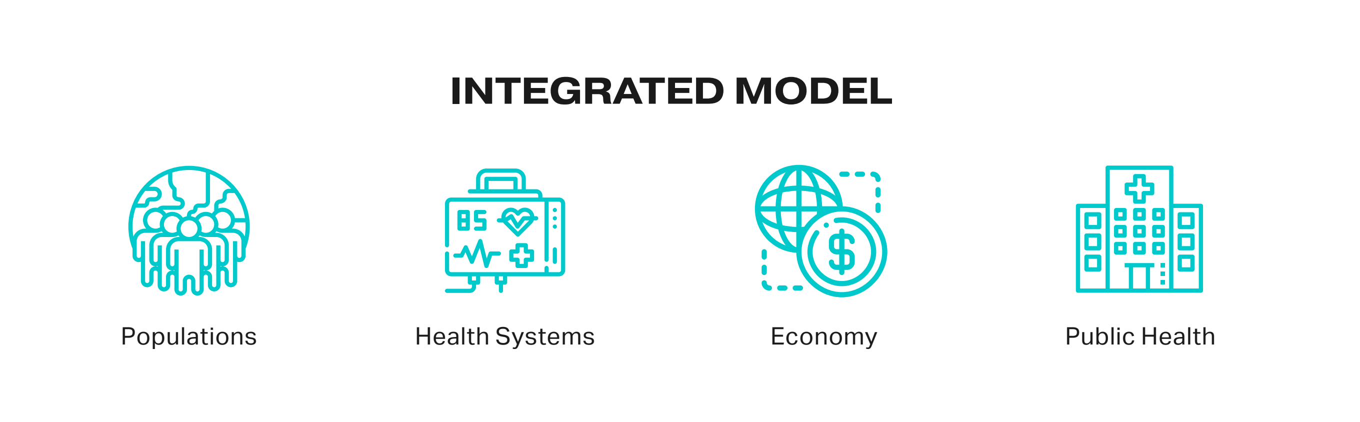
Source: Human Mortality Database (2020), UK Office for National Statistics (2020)
Note: Dates refer to the last day in each week for most but not all countries. More details can be found in the Source tab.

equipped Germany's public health system to respond more adequately to the COVID-19 challenge.[18] Asian countries or territories, such as Singapore, South Korea, China, Hong Kong, and Taiwan, had previously dealt with viral outbreaks, such as the 2003 SARS and 2012 MERS crises. These previous health emergencies prepared the Asian nations by creating strong surveillance systems which could meet citizens' needs in the COVID-19 pandemic.[18] In China, for instance, the 2003 SARS outbreak necessitated the implementation of a new, web-based reporting system that replaced their former antiquated, paper-based disease reporting. This new system has shortened reporting times for life-threatening infectious diseases to the Chinese CDC from 29 days to under 2 hours.[19] Even some less affluent countries, like Cuba and Vietnam, have been able to implement effective local public health responses to COVID-19 with more traditional methods, like door-to-door testing and targeted lockdowns.[18]

THE MAIN U.S. STAKEHOLDERS INVOLVED IN THE PANDEMIC RESPONSE

We have identified four major U.S. stakeholders that are largely responsible for an appropriate pandemic response: populations, health systems, public health organizations, and the economy (Figure 4). These stakeholders, which have all been affected by the pandemic, are also highly interdependent, creating unique challenges for the U.S. COVID-19 response. Therefore, it has been difficult to launch and coordinate the pandemic response while, at the same time, anticipating and mitigating the undesired side effects of corrective interventions on these interrelated stakeholders. We will discuss each stakeholder, and their unique challenges, below.

Figure 4. Four main types of stakeholders are involved in pandemic response: populations, health systems, public health, and the economy. An integrated pandemic response model should consider and coordinate efforts among all these stakeholders while recognizing that they are highly interconnected.



Populations

In the early days of the pandemic, the clear choice was to shut down everything and put a stop to globalization; yet, that also had profound effects on the economy and society. Population movement restrictions affected all aspects of life as we knew it, especially when entire countries first shut down their borders. Regular clinical care for other medical conditions was also halted.[20] Modeling of intervention trade-offs and related cost-benefit analyses should be considered in supporting future public health decision making. Indeed, Acemoglu et al have found that more targeted policies could have led to overall better socioeconomic outcomes, while maintaining COVID-19 health outcomes.[22]

Restrictive, generalized public health interventions have also deepened socioeconomic disparities, disproportionately affecting the less fortunate from both socioeconomic and healthcare perspectives. For example, starting in April 2020, there has been a much higher unemployment rate for minority populations compared to non-minority populations. Therefore, improved approaches to combating COVID-19 have great importance to the socioeconomic landscape just as they do for health outcomes. Platforms can collect real-time data from individuals, and can provide guidance back to the public from public health officials. This improved communication can benefit individuals, health systems, businesses, and others by facilitating a more coordinated COVID-19 response which reduces the need for economically detrimental lockdowns of entire communities by providing convenient, tailored public health information to citizens.

Health systems

While pandemics are rare — the U.S. has not seen such an event in over a century — effective preparedness for such major events should allow for appropriate capacity planning within the health system. With COVID-19, U.S. hospitals have been overwhelmed by sick patients. In heavily-affected areas, such as New York City, there were not enough testing kits, PPE, or hospital beds.[23] Established local supply chains for essential goods and services have been missing in the COVID-19 pandemic, and so have optimization models to help deploy various resources, such as PPE, based on local demand. These would help to ensure resource scalability in the future. Lack of integration with centralized public health epidemiological data and modeling outputs also posed huge challenges in the capacity planning of the health systems.

Public health agencies

Despite political rhetoric on the value of prevention, public health spending has actually progressively decreased in the U.S. as a share of the overall healthcare spending. Importantly, fixation on clinical care delivery and underinvestment in population-based activities have neglected a key avenue to improve the nation's health.[24,25] State and local-level public health systems are underfunded and suffer from infrastructure heterogeneity.[8] Appropriate funding for the CDC and the local public health infrastructure, including laboratories, is essential. Making public funding more flexible by the braiding and blending of public funds can also help address this problem.[26] Expanding the role of hospitals and other institutions as hubs could be an initial approach to tackle the infrastructure heterogeneity.[26]

> Despite political rhetoric on the value of prevention, spending on public health has actually progressively decreased in the U.S. as a share of the overall healthcare spending.

Economy

Lockdowns and other restrictions have had a detrimental impact on most countries' economies. Generalized lockdowns are counterproductive for the local economy because they can lead to furloughs and layoffs, and shut down entire sectors of the economy (e.g., retail, travel, entertainment). In the second quarter of 2020, the U.S. economy contracted at the steepest pace since the Great Depression.[27] Ensuring stakeholder coordination, with attention to economic activities, including education, has proven challenging. It would have been useful to use multi-source data and support the economy by guiding local businesses to selectively open or close based on their industrial sector and the expected effects of such actions on predicted or actual outbreaks. How could this be implemented efficiently in the future?

Leveraging available data to coordinate the pandemic response and mitigate its negative effects would ensure a balanced approach that optimizes health outcomes while avoiding unnecessary damage to the economy, and detrimental impacts on the population, health systems, and public health resources.

Solution

PRECISION PUBLIC HEALTH FOR U.S. PANDEMIC PREPAREDNESS & RESPONSE

John Snow famously investigated the 1854 cholera outbreak on Broad Street in London, leading to the first data-driven insights, which indicated that cholera was probably due to a communicable agent transmitted in drinking water.[28] Today, 166 years later, systemic reforms are being proposed to modernize U.S. public health so that we can benefit from technological progress and new data sources. Table 1 lists some of the challenges during the COVID-19 response, along with corresponding potential solutions. Of note, all these solutions have a data analytics component.

Use of data from existing healthcare information systems has been operationalized for a long time to help public health surveillance. Previously, there have been many different, independent surveillance systems to monitor specific infectious diseases and other health conditions. However, data collection relied on voluntary participation and the data was often incomplete with only selected data elements being collected. The analysis had traditionally been quite simple, looking most often for changes in disease incidence.[31] Traditional data sources used in U.S. public health have been typically health-system based, and include laboratories, clinicians, and syndromic surveillance networks (i.e., hospitals and other selected sentinel healthcare facilities).[30] Data is then typically reported to local and state departments and the CDC.

Precision medicine is an established concept, used typically in the context of genomics. It refers to a personalized, “precise” approach to pharmacotherapeutic decision making in clinical medicine. This concept of “precision” has been expanded to public health as well. Precision public health approaches leverage big data and analytics to deploy more targeted population-level interventions, including less conventional sources, such as search engine or social networking data.[32] With chronic diseases, for instance, this includes genomic data, but it also applies to other non-genetic types of information, such as disease surveillance data.[32] Personalized public health has been cited as a potentially useful approach in tackling the COVID-19 crisis, in order to support improved customization of public health interventions.[33] In this context, specific data types can add value. For example, viral strain sequencing data or population mobility data have been used.[34,35] Although proposed in the academic literature and shown to be of demonstrated value in limited-use cases, precision public health has not been widely implemented yet.

There is a growing body of scientific literature relevant to data-driven, precision public health. Chinese researchers have proposed a practical architecture displaying actual data inflows and outputs among different stakeholders for syndromic

Table 1. Deficiencies in the U.S. public health system exposed by COVID-19 and potential solutions supported by digital health.

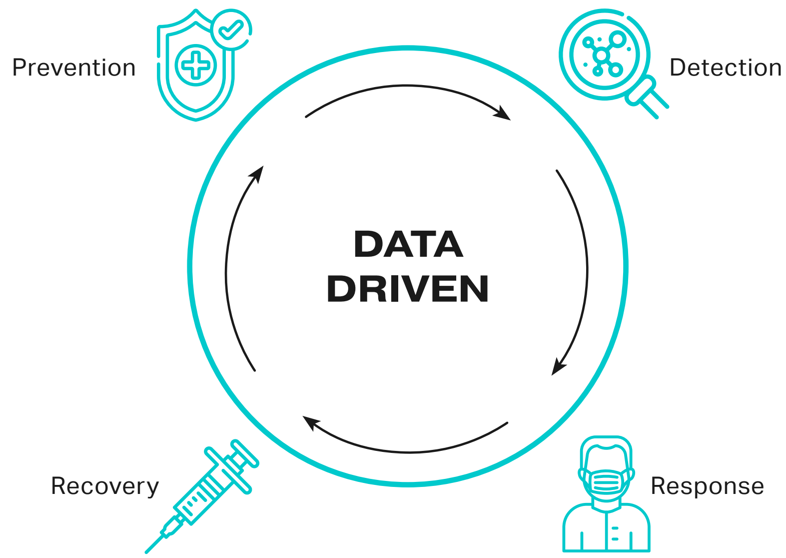
Deficiencies in US public health system	Potential digital health-supported solutions
Miscommunication & lack of communication.	Automate deployment process for federal and local public health guidelines. Prioritize reliable information sources.
Insufficient resources & overdependence on global supply chains.	Create local supply chains for essential goods and services. Build and implement optimization models to help deploy these resources, based on criticality of local needs.
Inability to learn quickly from other countries and from own accumulated data.	Facilitate the use of artificial intelligence in automating and accelerating the learning process.
Lack of established models & strategy to make trade-offs between public health restrictions versus socioeconomic effects.	Create federal and state guidelines for making such trade-offs and fund public & private efforts to generate appropriate software tools.
Data collected does not include disparities-related information (e.g., racial, socioeconomic data).	Fund and implement this data's collection infrastructure at the local level. Incorporate disparities information in public health decision making.
Since digital tools and platforms, such as telemedicine, can support appropriate interventions, addressing the digital divide is also important in order to protect all social groups.[29]	Beginning with something as basic as facilitating internet access can help; however, a multifaceted approach will be needed.[29]
Care for other medical conditions has been hampered by lockdowns and "brick-and-mortar" clinic and hospital closures.[20]	Expand telehealth.[26] Expand role of remote disease monitoring and "hospital at home."
Restrictive regulation that had suppressed adoption and growth of digital health.[10]	Payment reform, regulatory relief and evaluation of digital health tools.[10]

surveillance in China; however, this system is generalizable to any health system, including that of the U.S.[19] Additionally, other useful data-driven public health frameworks are available from the recent literature.[30,36] Examples of visual outbreak analytics that would be useful to have available in a pandemic command center were summarized by Polonsky et al in 2019.[37] However, a modern, synthetic view of a data-driven public health system has not been available. Ensuring a common understanding would assist problem solving and subsequent operationalization of data-driven tools and related interventions.

PRECISION HEALTH FRAMEWORK

We are thus proposing a precision public health framework, displayed conceptually in Figure 5. In summary, our precision framework restructures public health to increase cohesiveness of data sources, focusing on data analytics, including visual analytics, predictive modeling, and artificial intelligence. We envision a data-driven, precision public health cycle that has four proposed phases: detection, response, recovery, and prevention. At the core of this model is a powerful data engine that will capture and integrate numerous data feeds from all the stakeholders above and beyond (e.g., environment), generate timely and relevant insights for each of the four main types of stakeholders described above, in real time, and allow coordination of proactive responses. The cyclical nature of the proposed model attempts to capture the need for an adaptive, recurring, and continuously improving public health response. This is essential in light of multiple waves of infections that differ in their timing and severity across local communities, as we have seen in the past nine months. The framework also applies in the longer term, if we assumed that we would face other pandemics in the future.

Figure 5. Conceptual model of precision public health. A continuous, data-driven, precision public health improvement cycle has four proposed phases: detection, response, recovery, and prevention.



Detection

Early detection of outbreaks is crucial for the most effective response.[38] To date, fragmented data collection and reporting has hindered the public health response during the current pandemic.[8] Additionally, most of the traditional data sources rely on patient-provider interactions. Waiting for medical visits to occur adds an inherent delay to case identification, and also removes from consideration many cases where individuals do not seek medical care. This is particularly relevant for COVID-19, where a large proportion of infected individuals are only mildly symptomatic or asymptomatic.[39]

Unfortunately, public health has lagged behind other areas in healthcare when it comes to wide adoption of digital tools.[30] Some of these digital tools use data sources that are upstream of medical encounters. Examples include search engine data on user queries for related symptoms. For example, one New York Times op-ed discussed the fact that COVID-19 local hot spots could potentially be predicted by determining which communities were searching for information about "loss of smell," a common COVID-19 symptom.[40] Additionally, data sources, such as population-mobility data collected from cell phones, can inform predictive models. This latter information has the potential to be even further upstream in the epidemiological chain. Identifying and reporting early population level signals via internet surveys and analyses of social networking and search engine data would be intuitively helpful in enhancing disease surveillance at the community level. Leveraging Google Flu Trends for influenza syndromic surveillance is now notorious.[41]

At the employers' level, we envision implementation of disease surveillance via employee surveys of exposure history and symptoms, as well as body temperature monitoring.

Health systems are also part of early disease surveillance for initial outbreaks through reporting of suspicious new-symptomatic cases to public health authorities. Diagnostic testing, when available, is important for designing an effective response and should be coordinated by public health agencies with support from the health systems. Investing now in the public health information technology (IT) infrastructure will enhance our ability to collect and make use of all this data more efficiently in the future.

Response

In absence of therapeutics and vaccines, non-pharmaceutical interventions are key to response and control. At the population level, actions as simple as social distancing, using face masks in crowded public spaces, following hand washing guidelines, and complying with population mobility restrictions are effective means at our disposal to fight pandemics. Effective communication with public health agencies is critical. Although dissemination of best practices to the population via social media has been suggested as a solution, that approach also has some limitations.[42] Dedicated channels (e.g., apps) are likely more appropriate.

Using technology to disseminate clear, actionable policies and guidelines specific to each business area (e.g., bars, restaurants, or malls), accompanied by tools to monitor compliance, has been lacking from the COVID-19 response to date. One area in which this approach could have been useful is in the enforcement of business lockdowns to reduce the spread of COVID-19. Businesses have been important in monitoring and enforcing the implementation of public health policies (e.g., occupancy requirements, mask mandates), as well as collecting related data for public health agencies. Selectively closing businesses based on the data collected by the locality as well as individual businesses can help reduce detrimental economic effects. A more precise approach to lockdowns would have protected businesses from closing down unnecessarily while still ensuring public safety.

Real-time data from these businesses and the local community is very important in order to create a practical effort. Creating bidirectional feedback loops where the business community provides information to the local public health authorities on existing and new cases or outbreaks among their employees, while receiving customized expert guidance and operational support, should be at the core of any local pandemic response. Additional data types, such as data on the status of policy implementation at bars, restaurants, gyms, schools, and other locales, would be helpful in the context of this strategy. Real-time data collected from the community (see Table 2 for examples) can support predictive modeling and disease surveillance efforts, allowing for preemptive intervention at a much earlier time frame. This preemptive data provides an advantage compared to data collected later from clinical, patient-provider encounters.

Public health agencies, through enforcement of isolation, quarantine, and targeted lockdowns, informed by disease surveillance and contact

Table 2. Examples of less conventional data types and potential use cases for infectious disease outbreak response.

Less conventional data types		Potential use cases
Detection	Search engine queries	Inform disease surveillance
	IoT (sensors, wearables) e.g., heart rate as collected by fitness trackers,[33] fever as indicated by infrared sensors in airports,[30] blood oxygen saturation as measured by iWatch Series 6	
	Patient surveys (apps, web)	
	Absenteeism (e.g., from school, work)[38]	
	Monitoring of sewage for SARS-CoV-2 virus[33]	
	Instant messaging platforms	
Response	Mobile tracking via dedicated apps[30]	Inform contact tracing
	Mobile tracking (e.g., Google Mobility, Unacast Social Mobility Scoreboard, Safegraph's cell phone mobility measures, Baidu Maps)[43]	Measure population mobility to assess compliance with mobility restriction policies
	Social networking platforms; dedicated apps	Communication of public health guidelines
	Status of policy implementation at bars, restaurants, gyms, schools	Monitor operationalization of public health guidelines in the local communities
	Viral strain sequencing geodata[34]	Inform epidemiological modeling
Recovery	Clinical trial and/or post-marketing data[44]	Gauge outcomes of new treatments and vaccines
	Vaccine administration data	Measure and optimize vaccine deployment
Prevention	Veterinary (e.g., avian deaths)[38]	Predict occurrence of disease outbreaks
	Meteorologic[45]	
	Transportation[46]	
	Over-the-counter medication sales[38]	
	Mobile tracking[47]	

tracing, are essential drivers of the pandemic response. Public health agencies can improve data collection for surveillance, monitoring, contact tracing, and forecasting capabilities using the powerful insights gleaned from big data and data analytics. Health systems, on the other hand, treat the sick, while informing the assessment of treatment outcomes at the population level.

Recovery

The recovery process, accelerated through widespread vaccination and "herd" immunity, also needs participation from the four major types of stakeholders described above. Populations must comply with vaccination guidelines once COVID-19 vaccines become available. Public health agencies will be important in monitoring population-level vaccination outcomes as well as recurring disease outbreaks. Along with health care facilities, and despite acknowledged implementation challenges, they may be issuing vaccination certificates and even immunity passports that will potentially help circumvent travel restrictions for "certified" individuals.[48] Health systems will resume regular care and elective procedures, a process ideally prioritized by patient clinical need. Businesses will reopen in accordance with guidance from public health authorities.

Operationalizing precision public health would be of immediate impact, given that the post-COVID recovery should also be data driven. The COVID-19 pandemic may not resolve completely in the near future, and instead follow a protracted course with recurring outbreaks. This is likely, especially if immunity after either having the disease or potential vaccination would not be long lasting.[49] It is important to have a long-term strategy for this type of more pessimistic, but still quite possible, scenario. In particular, nationwide vaccination efforts will prove to be a complex task. Information systems will be critical to track, analyze, and optimize implementation. Multiple vaccine manufacturers, different dosing schedules, multiple-care settings in an already fragmented health system, the need to prioritize initial doses to persons at higher risk, potential requirements for testing of antibody response, and monitoring of adverse events will increase the complexity of this task.

After vaccines enter the commercial market, relevant example use cases may include monitoring of vaccine outcomes, including needs for revaccination, detecting early potential disease outbreaks, and measuring case seasonality, among others. Data-driven approaches, along with digital tools that can facilitate these approaches, will need to be integrated into the existing public health infrastructure. Monitoring of circulating viral strains, including genetic mutations that may render current vaccines ineffective or increase virulence of circulating strains, will be key. Such near-to-real-time viral strain genomic sequence data has already been used successfully in the Netherlands to supplement traditional epidemiology methods in order to inform earlier decision making and more effective control of the viral transmission.[34]

Prevention

Prevention of other pandemics implies, from a population perspective, following public health guidelines, such as ensuring proper hand hygiene recommendations and avoiding close contact with wildlife or consumption of exotic meats.[50] Businesses will need to avoid overcrowding of work spaces and implement regular disinfection of the work environment, under guidance from public health agencies.

Creating and maintaining such efficient information flows among different stakeholders will benefit our society for the foreseeable future. Public health agencies will guide efforts for development of new vaccines and therapeutics. Health systems should work beyond just preparedness training to ensure appropriate staffing and reliable supply chains for personal protective equipment and other essential goods. Monitoring veterinary outbreaks of infectious disease, along with other variables, may allow the prediction of other potential human pandemics.[38] Human resources (HR) preparedness training is also important, as employers are a key stakeholder that can help manage that part of the population, which constitutes the active workforce. Monitoring veterinary outbreaks of infectious disease may allow, along with other variables, the prediction of other potential human pandemics.[3]

It will take time to translate ideas for novel sources of data and their potential use cases (Table 2), from isolated efforts to broader digital strategies. Improved funding and policy support could accelerate the adoption of these digital tools. In addition, ensuring data quality and addressing data fragmentation will be ongoing challenges that will need to be addressed separately from the mere creation of digital tools.

HOW ARTIFICIAL INTELLIGENCE CAN HELP

Artificial intelligence software applications are already being used in clinical care to support COVID-19 diagnosis. In one example, AI algorithms accelerated COVID-19 diagnosis by integrating clinical symptomatology, exposure history, chest CT imaging, and laboratory test results.[51] Other potential applications could be envisioned specifically for public health. In any public health emergency, the key is to be prepared and proactive rather than reactive. Historical data from past epidemics or even COVID-19 in other geographic locations could be useful in training prediction models (e.g., by using baseline R0 and case fatality, intervention type and timing, and economic or societal indicators as predictors and the outbreak duration, economic, societal impact or overall mortality as outcome variables). Similar approaches have been reported in the recent published literature using COVID-19 data from different countries.[52,53]

Deep learning, a form of artificial intelligence that has generated significant breakthroughs in tasks such as image, video, audio, speech and text processing,[54] could be employed to facilitate the development and implementation of AI models. Deep learning does not require manual creation of features.[55] This could be particularly useful due to the complexity of data feeds and fast-changing data landscape during a pandemic, in direct clinical care, public health and beyond. Many different types of models will be needed, however, to address different facets of the pandemic response.

AI-enabled optimization models could potentially help gauge trade-offs between advantages and disadvantages of public health interventions.

Constraint-based simulations could thus aim to optimize outcome variables, such as number of businesses closed or total business revenue, while enforcing desired constraints for health outcome variables and available public health resources. The learning component can make the simulation more efficient the next time it is run.[56]

This approach could better inform where and for how long measures such as isolation, quarantine, or lockdowns should be imposed. The ultimate goal should be for these interventions to become more precise in scope, including their timing, geography, type of restrictions, as well as the specific population involved.

Depending upon individual AI use cases, other IT solutions can operate synergistically with artificial intelligence models. For instance, blockchain is a technology that creates distributed networks of computers with data encryption and advanced security protocols. Blockchain, along with AI, could help to operationalize the vaccine distribution from multiple manufacturers, while maintaining data security and patient privacy.[57] Imagine an integrated IT platform that allows secure data transfers and processing, while employing artificial intelligence and simulations to efficiently generate best scenarios for optimal resource allocation for vaccine distribution.

The outcome variables to be optimized could consist of the number of at-risk individuals successfully vaccinated, or the time to complete vaccination of a certain population, while constraints could be imposed, for example, to match currently-available staffing or the vaccine supply. Such a blockchain platform could also monitor the global progress on vaccination efforts and issuance of “vaccination certificates,” such as for travel purposes, irrespective of country of origin or vaccine manufacturer. That would allow for protection of individuals’ privacy regarding their health information, as well as protection of commercial proprietary information among different vaccine manufacturers, while still supporting the global vaccination monitoring efforts. The World Health Organization has already initiated a preliminary initiative, in collaboration with the private sector, to build such a blockchain platform that will support the issuance of vaccination certificates. This will first be deployed only in Estonia; however, if validated, the initiative will become global.[58]

CONCLUSION

The COVID-19 pandemic is a major international public health challenge. The U.S. has been affected disproportionately more than other countries due to poor leadership, system fragmentation, and long-term underfunding and neglect of its public health system. While the hope is that new therapeutics and vaccines can reduce COVID-19's negative impact, this crisis has illuminated the need for change in U.S. public health. A multifaceted approach including improved funding, revamped legislation, and infrastructure changes is necessary to improve pandemic preparedness and response. In a highly-connected world, one in which overpopulation and increasingly overlapping human and wild animal habitats is becoming an issue, infectious disease outbreaks such as the COVID-19 pandemic are likely to occur more frequently with an even larger impact. Advances in computing infrastructure, data collection, and reporting create new avenues to predict, prevent, and contain the spread of future infectious disease outbreaks.

We have discussed the supporting arguments and critical need for a targeted "precision" public health infrastructure to provide tailored solutions to reduce the negative impacts of disease mitigation strategies. We have also proposed a framework to help operationalize this concept in the U.S., leveraging solutions based on big data and analytics that are powered by artificial intelligence. Advancing precision public health will be an ongoing, iterative process that creates a continuously adaptive system as a way to effectively tackle upcoming challenges in pandemic preparedness and response.

The future of precision public health would see digital tools and public health interventions seamlessly integrated, with intervention scope and deployment informed by AI. A few more developments are required for a fully-functional, data-driven system. Over time, regulatory and scientific vetting of the digital tools' and related interventions' effectiveness should also occur. To protect individuals' privacy, data security protocols and appropriate protective legislation are necessary, as well as an ethics' framework for data collection and sharing. Furthermore, technology alone will not be sufficient without appropriate staffing in the public health system's hinterland. A coordinated international data strategy is strongly needed, especially given the global nature of the pandemic.

In conclusion, a solution that integrates multiple sources of data is imperative for effective pandemic response. We are thus proposing here the development of a technology-enabled ecosystem that allows public health agencies to coordinate the pandemic response, while taking into account the impact of their interventions on the economy, populations, and health systems.

> This is far more than just an aspiration; it is a profound necessity in order to save lives and protect livelihoods. This is the future of public health.

REFERENCES

1. Pan, A. et al. Association of Public Health Interventions with the Epidemiology of the COVID-19 Outbreak in Wuhan, China. JAMA 323, 1915–1923 (2020).
2. Ducharme, J. World Health Organization Declares COVID-19 a 'Pandemic.' Here's What That Means. Time https:// time. com/5791661/who-coronavirus-pandemic-declaration/ (2020).
3. Bergquist, S., Otten, T. & Sarich, N. COVID-19 Pandemic in the United States. SSRN Electronic Journal doi:10.2139/ssrn.3657404.
4. Schneider, E. C. Failing the Test — The Tragic Data Gap Undermining the U.S. Pandemic Response. New England Journal of Medicine vol. 383 299–302 (2020).
5. Osterholm, M. T. Preparing for the Next Pandemic. N. Engl. J. Med. 352, 1839–1842 (2005).
6. Bedford, J. et al. A New Twenty-First Century Science for Effective Epidemic Response. Nature 575, 130–136 (2019).
7. United States Coronavirus: 6,788,147 Cases and 200,197 Deaths - Worldometer. https://www.worldometers.info/ coronavirus/country/us/.
8. Xu, H. D., Daniel Xu, H. & Basu, R. How the United States Flunked the COVID-19 Test: Some Observations and Several Lessons. The American Review of Public Administration vol. 50 568–576 (2020).
9. Blumenthal, D., Fowler, E. J., Abrams, M. & Collins, S. R. Covid-19 — Implications for the Health Care System. New England Journal of Medicine (2020) doi:10.1056/nejmsb2021088.
10. Keesara, S., Jonas, A. & Schulman, K. Covid-19 and Health Care's Digital Revolution. New England Journal of Medicine vol. 382 e82 (2020).
11. Apple and Google partner on COVID-19 contact tracing technology. https://www.apple.com/ newsroom/2020/04/apple-and-google-partner-on-covid-19-contact-tracing-technology/.
12. Apple releases new COVID-19 app and website based on CDC guidance. https://www.apple.com/ newsroom/2020/03/apple-releases-new-covid-19-app-and-website-based-on-CDC-guidance/.
13. COVID-19: Implications for business. https://www.mckinsey.com (2020).
14. Our World in Data. https://ourworldindata.org.
15. Our World in Data. https://ourworldindata.org.
16. Pak, A. et al. Economic Consequences of the COVID-19 Outbreak: The Need for Epidemic Preparedness. Front Public Health 8, 241 (2020).
17. Fernandes, N. Economic Effects of Coronavirus Outbreak (COVID-19) on the World Economy. SSRN Electronic Journal doi:10.2139/ ssrn.3557504.
18. Kirchhelle, C. Giants On Clay Feet – COVID-19, infection control, and public health laboratory networks in England, the US, and (West-) Germany (1945-2020). doi:10.31235/osf.io/uv57t.
19. Jia, P. & Yang, S. China needs a national intelligent syndromic surveillance system. Nature Medicine vol. 26 990–990 (2020).
20. Kamp, J. Death Toll From Covid-19 Pandemic Extends Far Beyond Virus Victims. The Wall Street Journal (2020).
21. Russonello, G. Why Most Americans Support the Protests. The New York Times (2020).
22. Acemoglu, D., Chernozhukov, V., Werning, I. & Whinston, M. Optimal Targeted Lockdowns in a Multi-Group SIR Model. (2020) doi:10.3386/w27102.
23. Honan, K. New York City Weighs Turning Hotels Into Hospitals. The Wall Street Journal (2020).
24. Himmelstein, D. U. & Woolhandler, S. Public Health's Falling Share of US Health Spending. Am. J. Public Health 106, (2016).

25. Committee on Public Health Strategies to Improve Health, Board on Population Health and Public Health Practice & Institute of Medicine. For the Public's Health: Investing in a Healthier Future. (National Academies Press, 2012).
26. Butler, S. M. After COVID-19: Thinking Differently About Running the Health Care System. JAMA 323, 2450–2451 (2020).
27. Reuters Staff. U.S. second-quarter GDP falls at steepest rate since Great Depression. Reuters https://www. reuters.com/article/us-usa-economy-instant-idUSKCN24V2GJ (2020).
28. Paneth, N., Vinten-Johansen, P., Brody, H. & Rip, M. A rivalry of foulness: official and unofficial investigations of the London cholera epidemic of 1854. Am. J. Public Health 88, 1545–1553 (1998).
29. Ramsetty, A. & Adams, C. Impact of the digital divide in the age of COVID-19. J. Am. Med. Inform. Assoc. 27, 1147–1148 (2020).
30. Budd, J. et al. Digital technologies in the public-health response to COVID-19. Nat. Med. 26, 1183–1192 (2020).
31. Thacker, S. B. & Berkelman, R. L. PUBLIC HEALTH SURVEILLANCE IN THE UNITED STATES. Epidemiologic Reviews vol. 10 164–190 (1988).
32. Khoury, M. J., Engelgau, M., Chambers, D. A. & Mensah, G. A. Beyond Public Health Genomics: Can Big Data and Predictive Analytics Deliver Precision Public Health? Public Health Genomics 21, 244–250 (2018).
33. Rasmussen, S. A., Khoury, M. J. & Del Rio, C. Precision Public Health as a Key Tool in the COVID-19 Response. JAMA 324, 933–934 (2020).
34. Oude Munnink, B. B. et al. Rapid SARS-CoV-2 whole-genome sequencing and analysis for informed public health decision-making in the Netherlands. Nat. Med. 26, 1405–1410 (2020).
35. Kraemer, M. U. G. et al. The effect of human mobility and control measures on the COVID-19 epidemic in China. medRxiv (2020) doi:10. 1101/2020.03.02.20026708.
36. Jia, Q., Guo, Y., Wang, G. & Barnes, S. J. Big Data Analytics in the Fight against Major Public Health Incidents (Including COVID-19): A Conceptual Framework. International Journal of Environmental Research and Public Health vol. 17 6161 (2020).
37. Polonsky, J. A. et al. Outbreak analytics: a developing data science for informing the response to emerging pathogens. Philosophical Transactions of the Royal Society B: Biological Sciences vol. 374 20180276 (2019).
38. Henning, K. J. What is Syndromic Surveillance? PsycEXTRA Dataset (2004) doi:10.1037/e307182005-001.
39. Gudbjartsson, D. F. et al. Spread of SARS-CoV-2 in the Icelandic Population. N. Engl. J. Med. 382, 2302–2315 (2020).
40. Stephens-Davidowitz, S. Google Searches Can Help Us Find Emerging Covid-19 Outbreaks. The New York Times (2020).
41. Dugas, A. F. et al. Influenza Forecasting with Google Flu Trends. Online Journal of Public Health Informatics vol. 5 (2013).
42. Chan, A. K. M., Nickson, C. P., Rudolph, J. W., Lee, A. & Joynt, G. M. Social media for rapid knowledge dissemination: early experience from the COVID-19 pandemic. Anaesthesia (2020) doi:10.1111/ anae.15057.
43. A Literature Review of the Economics of COVID-19. https://www.iza. org/publications/dp/13411/a-literature-review-of- the-economics-of-covid-19.
44. Thorlund, K. et al. A real-time dashboard of clinical trials for COVID-19. Lancet Digit Health 2, e286–e287 (2020).
45. EPI-BRAIN. https://www.epi-brain.com/.
46. Wu, J. T., Leung, K. & Leung, G. M. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. Lancet 395, 689–697 (2020).
47. Jia, J. S. et al. Population flow drives spatio-temporal distribution of COVID-19 in China. Nature 582, 389–394 (2020).
48. Phelan, A. L. COVID-19 immunity passports and vaccination certificates: scientific, equitable, and legal challenges. Lancet 395, 1595–1598 (2020).
49. Scudellari, M. How the pandemic might play out in 2021 and beyond. Nature 584, 22–25 (2020).
50. Aguirre, A. A., Alonso Aguirre, A., Catherina, R., Frye, H. & Shelley, L. Illicit Wildlife Trade, Wet Markets, and COVID-19: Preventing Future Pandemics. World Medical & Health Policy vol. 12 256–265 (2020).
51. Mei, X. et al. Artificial intelligence-enabled rapid diagnosis of patients with COVID-19. Nat. Med. 26, 1224–1228 (2020).
52. Chaudhry, R., Dranitsaris, G., Mubashir, T., Bartoszko, J. & Riazi, S. A country level analysis measuring the impact of government actions, country preparedness and socioeconomic factors on COVID-19 mortality and related health outcomes. EClinicalMedicine 25, 100464 (2020).
53. Primc, K. & Slabe-Erker, R. The Success of Public Health Measures in Europe during the COVID-19 Pandemic. Sustainability vol. 12 4321 (2020).
54. Ting, D. S. W. et al. AI for medical imaging goes deep. Nature Medicine vol. 24 539–540 (2018).
55. LeCun, Y., Bengio, Y. & Hinton, G. Deep learning. Nature 521, 436–444 (2015).
56. Monostori, L., Kádár, B., Viharos, Z., Mezgár, I. & Stefán, P. AI and ML techniques combined with simulation for designing and controlling manufacturing processes and systems. IFAC Proceedings Volumes vol. 33 181–186 (2000).
57. Ting, D. S. W., Carin, L., Dzau, V. & Wong, T. Y. Digital technology and COVID-19. Nat. Med. 26, 459–461 (2020).
58. Bloomberg. https://www.bloomberg.com/news/articles/2020-10-01/ blockchain-app-from-eu-tech-hub-may-solve- virus-passport-puzzle.

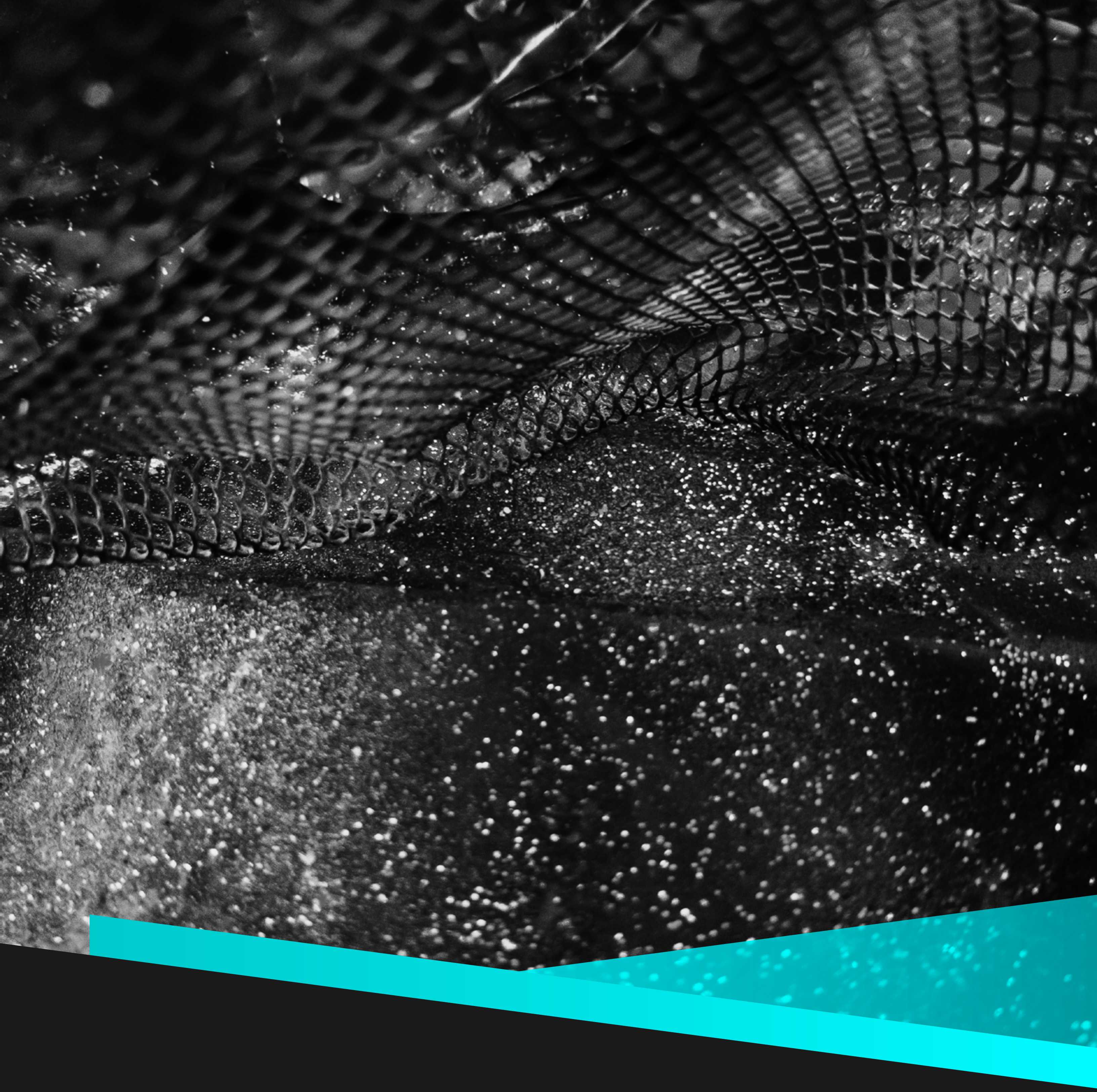
ABOUT PROJILE

We are a group of technology development and implementation industry leaders, with special focus on business strategy. We believe in starting with a strategy, not the technology. That is why we call ourselves is the Aqua team. If blue stands for business and green represents innovation, we are a perfect blend of both. Our hands-on team understands the business and technological needs of healthcare. We are not clinicians, but we collaborate with clinician teams and programs to help implement the right digital health strategy for the circumstances.

Because healthcare is our sole focus, we can quickly integrate knowledge from our digital health, data, and business perspectives to provide strategic insights that help you make more confident investment decisions. If you are technology innovator, investor, or a healthcare organization, we would like to hear from you about your challenges and goals. After a short assessment, we can provide you an engagement model that best meets your needs. We will assemble the right team and get to work.

The world has changed. We want to be your change agent in transforming healthcare using digital technology.

For more information, visit:
projile.com



Disclaimer

In some cases, some of the references to companies or products herein may include companies or products which Projile supports or provides services to. Projile is in no way promoting or intending to market any one particular company, solution or product or otherwise offer or market a medical device or clinical solution or services.