ICTs and Public Health in the Context of COVID-19

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Abstract

The globe is currently gripped by the deadliest and most widespread pandemic it has faced in over a century. Confronted by accelerating death tolls and widespread fear, societies around the world have also been forced to acknowledge points of stress in their economic and social fabrics that had long gone overlooked. In the midst of this turmoil, Information and Communications Technology (ICT) has played an essential role in facilitating the safe relief and treatment of affected populations. ICT has also shown itself to be essential both to bolstering long-term resiliency against future pandemics and to resolving the secondary challenges that emerge within a socially distanced environment. However, involving ICT in in pandemic relief and prevention carries with it its own set of challenges involving transparency, accountability, and privacy. Governments which apply ICT must ensure that far-reaching crisis measures do not become permanently entrenched in society, and that measures which are taken are deemed fair, proportional and just. In an annex, we summarize the best practices for ICT usage in a pandemic which have emerged during the global COVID-19 response.

Introduction

The COVID-19 pandemic represents a combined global economic, social and health crisis more acute than any such event so far this century. As of May 2020, over 5.5 million cases had been confirmed around the world, leaving at least 330,000 dead so far. These figures almost certainly underestimate the true toll, given the mass testing shortages which have hamstrung the worldwide response so far. Developing countries have fortunately not experienced the same toll as developed countries so far, but absent immediate measures to assemble a comprehensive pandemic management framework, they risk a similar or even greater magnitude of disaster given the existing stress on their medical systems.

Pandemics present challenges of an entirely different type than other disease outbreaks or the vast majority of other natural disasters. Because these diseases strike global populations which have no immunological experience with them, their spread is far more rapid, and frequently, more deadly than any comparable disease outbreaks. Essentially by definition, pandemics impact virtually every corner of society almost simultaneously, in contrast with the comparatively contained damage of other events. This leaves little room for the resiliency and flexible reapplication of resources which aids recovery from more localized types of disasters. Furthermore, unlike other types of disasters, pandemics target not physical infrastructure, but the very human infrastructure which is most necessary to combat them. The longer a disease rages on, and the more it kills and incapacitates vital personnel on the front lines of the response, the weaker the defenses societies can mount against an inferno which burns hotter the more fuel it consumes. These crippled medical systems must somehow find a way to hold the line over the months or even years it can take to develop treatments and vaccines from scratch, even assuming the pathogen does not mutate in a way which renders these efforts moot. And finally, as the disease causes fear to spread among the general public, it undermines institutional and societal trust, especially within the rapidly evolving and unreliable information environment which such an event creates. This trust is the most important ingredient for countries which hope to mount a cohesive, national response which halts the spread of the disease before it has the chance to rage through the entire population. The social contagion which a pandemic creates may not kill in the same way as a virus, but it is indirectly just as deadly.

A pandemic, at its heart, creates a monumental information and communications challenge. During the initial stages of an outbreak, novel diseases often spread rapidly before they can be widely recognized and contained by authorities. When such diseases are new and highly contagious, standard diagnostic techniques are frequently insufficient to highlight the new threat, while treatments for new diseases are developed too slowly to outpace the unchecked spread of the contagion among an immunologically naïve population. Once a new disease has been identified, its potential for danger must be communicated to officials at all levels of government in order to choreograph a containment response as rapidly as possible through contact mapping and tracing and strict enforcement of quarantines. If these measures fail and community spread begins to accelerate, authorities must shift gears from containment to mitigation by informing the population of the threat, communicating what steps people must take to minimize their risk. In the socially distanced environment that is necessitated during the mitigation phase of a pandemic, systems for distance communication and interaction must be instituted in order to replace the daily, normally face to face interactions that ordinarily keep a society running, but under such conditions represent unacceptable health risks. Similarly, systems must be put in place for individuals in isolation to communicate urgent needs and for society to meet these needs under conditions where in-person communication is extremely discouraged. Finally, once treatment has been developed which can be deployed to the population at large, the population must be informed how delivery will take place in a way which ensures the highest possible compliance. Most importantly, each of these steps must take place in a fashion which upholds institutional trust to the greatest possible degree so that the misinformation and conspiracies which flourish during times of uncertainty and fear do not undermine efforts to put the outbreak to an end as rapidly as possible.

Given the myriad of information and communications challenges which are presented by a pandemic, Information and Communications Technology (ICT) is particularly well-equipped to offer solutions to the problems that emerge over the course of these catastrophic events. Before a novel pathogen is even identified, ICT-based techniques such as search result correlation and mapping can flag the emergence of potentially deadly diseases before more traditional methods could alert disease control specialists to their presence, offering hope for immediate containment and near-total avoidance of an outbreak. Should containment need to take place at a more ambitious scale, mobile technology can aid these efforts by tracking and notifying individuals who have come in close proximity to suspected carriers, as Singapore has carried out to great effect, and GPS tracking can be used to enforce the quarantine of these individuals, as South Korea has successfully modeled. Throughout the treatment process, cognitive computing techniques can be applied to identify promising experimental treatments, risk factors and comorbidities in a way which helps society protect those who are most at risk. If an outbreak progresses to the point where containment must be abandoned in favor of mitigation, ICT can likewise play a key role by providing means for e-health checkups which relieve the pressure felt by overburdened hospitals and medical personnel. Adequate communications infrastructure also facilitates interpersonal connections at a stage when much of the population is likely to have been forced into isolation. This not only helps alleviate the personal stress which can negatively impact mental health during such times, but can also serve as a decentralized diagnostic network to flag potential new cases which would otherwise not be placed in contact with the relevant medical personnel. Finally, technology can facilitate economic resiliency by allowing employees

in certain sectors to work from home, facilitating direct payments to workers in more vulnerable industries to stave off mass unemployment, and helping deliver essential services while minimizing the required labor presence.

In section one of this paper, we survey the ways in which ICTs can strengthen the short-run medical and institutional response to COVID-19, including improving the testing and diagnosis regime, streamlining patient tracking, recordkeeping and case management, and ensuring the continuation of routine, yet still necessary medical procedures. Section two explores how ICTs can contribute to the long-term resiliency of society to pandemics and other similar disasters by making labor markets and supply chains more resilient, aiding the spread of accurate and quality information, and providing channels for direct economic support for the population. Third, we discuss the weaknesses and blind spots which ICT initiatives tend to fall victim to, and what this may mean for a public health response predicated on the use of ICT. Finally, we investigate what the countries which have most successfully contained the spread of COVID-19 have done, particularly regarding the use of ICT, and assess the best practices emerging from these experiences.

ICT for Immediate Relief and Medical Response

Testing and Diagnosis

Before any successful containment strategy can begin to take shape, medical personnel must gain an accurate portrait of who is infected and who they, in turn, have potentially infected. The first step in this process, and the step which has provided the most difficulty so far for nations dealing with this pandemic, has been the delivery of testing at a large enough scale to paint this portrait. ICT can do little directly to address the material shortage in testing, which has more to do with shortages of swabs and chemical reagents. If, however, enough tests can be manufactured to meet the demand of an entire population, ICT can play a significant role in addressing both human resources constraints and geographical challenges. For example, testing for COVID-19 involves conducting a simple genetic sequencing of the residue from a nasal swab, which seeks to identify the well-documented, telltale RNA patterns of the novel coronavirus. As this process requires no particularly specialized medical knowledge, batches of tests can easily be processed en masse at scale and on site with the aid of technology to identify these sequences.

In dense urban areas, where patients can easily provide samples for same-day testing, such a solution can and is currently being used to increase testing rates and accelerate turnaround time. In rural areas, however, lower population density and fewer equipped medical personnel make such a strategy unfeasible. For regions where frequent mass testing is unfeasible, ICT can again help fill the gap. Before mass testing was available in China, individuals who were concerned they had been exposed to the virus were asked to describe their symptoms on a government website. If their reported symptoms matched those of the coronavirus, they were directed to specialized fever clinics for further care and observation. To expand on this approach, a threat assessment app currently under development would use machine intelligence to analyze a mobile phone-based survey and identify those most likely to require a test based on history, exposure to

known infection clusters, risk factors and potential symptoms.[1] Were such individuals in a location where they could not easily reach a testing site, they could be sent of the several types of at-home tests currently in production and be linked digitally with a medical provider pending the results of the test.[2]

For medical teams working to trace clusters in the field, ICT can also lend an invaluable hand. Mobile technology allows for coordination between investigative teams and central authorities while providing for instant data analysis and correlation of observations to the known existing body of cases. During the initial outbreak in China, for example, technology played a critical role in managing data for the contact tracing of as many as 70,000 known cases, while simplifying the investigative role of field personnel and coordinating tracing efforts between these teams and central government.[3]

With the involvement of ICT, tracking a disease may not even require direct human involvement. Smart devices, or the "internet of things," can aid in the passive recognition of potential epidemics before they become a threat. For years, Kinsa Health, a company which manufacturers smart thermometers, has published an online map of recorded body temperatures which has successfully predicted the onset of the seasonal flu ahead of the CDC's own systems for the past two years. With over 90% of known coronavirus patients experiencing a fever, such an approach could theoretically be adopted in order to anticipate new localized disease outbreaks and contain them before they grow to reach larger scales. Given the high rate of adoption for wearables such as Fitbit that promote personal fitness in the past five years, the health data which could identify and locate an outbreak in progress may already exist, being collected passively from millions of smartwatch users per day. Research is currently taking place to determine whether the data collected by these devices is sufficient to identify likely cases, possibly even before the onset of symptoms.

Finally, internet users may generate sufficient data over the course of their ordinary online activities to identify emergent outbreaks, and even previously unknown symptoms of the disease, when analyzed in aggregate. Researchers at University College London have found a strong geographical correlation between Google searches for disease symptoms, such as fever, anosmia, and shortness of breath, and community outbreaks of COVID-19. Most intriguingly, the surges in these search results predated the public identification of these locations as infection clusters, meaning the same passive analytical tools could be applied to anticipate outbreaks and take preventative measures before they spiral into the public eye and out of control. Researchers even used search result correlation to identify a potential new symptom which had not previously been reported – eye pain. Although this outcome has not been definitively confirmed by medical professionals, if the results stand, they would imply that any unusual burst in search activity for medical symptoms confined to a geographic area could serve as evidence for the emergence of a pathogen, regardless of whether or not its presence was previously known. Such passive big data epidemiological analysis could even be automated by identifying a master list of symptom-

[1] Rao, A., & Vazquez, J. (2020). "Identification of COVID-19 Can be Quicker through Artificial Intelligence framework using a Mobile Phone-Based Survey in the Populations when Cities/Towns Are Under Quarantine." Infection Control & Hospital Epidemiology, 1-18.

[2] Brodwin, Erin. "At-home tests for coronavirus are here. Should you take them?" STAT News, March 20, 2020.

[3] McNeil Jr., Donald G. "Inside China's All-Out War on the Coronavirus." *The New York* Times, March 4, 2020.

related search results and designing an algorithm to track unusual spikes in search activity correlated by location.

Patient-Centric Record Keeping and Case Management

One component of e-health, Electronic Health Records (EHRs), is essential for tracking and treatment alike. Pandemics create enormous data management burdens which health systems must navigate swiftly in order to outflank the advance of the disease. For patients who have tested positive, providers must be ready to access health histories at a moment's notice to determine if the patient has any special risk factors or comorbidities, and if so, what specialized treatment if any may be appropriate. Epidemic trackers must also be prepared to pursue the primary, secondary, and tertiary contacts of those who have tested positive, a constantly shifting and evolving task which can only be completed rapidly enough to contain the advance of the disease with the assistance of data analytics and data management technology. Health systems reliant on obsolete paper records, which must be physically accessed any time any of the above information is required, cannot hope to access patient information or analyze it in conjunction with data on community spread rapidly enough to make a meaningful difference in the trajectory of the disease.

In the United States, obsolete records-keeping systems have dramatically hindered the public health response to the coronavirus outbreak on multiple fronts. Reliance on paper files, phone calls, and fax machines has slowed down processing of requests in the best of times. But now, the failure of many health providers to migrate their records to digital archives which can be accessed instantly regardless of time or location has served as a bottleneck for the exchange of vital health information between doctors, laboratories, and health officials. The health sector has seen significant IT upgrades over the past decade, but unfortunately, the public labs which were responsible for conducting the majority of testing in the early stages of the outbreak did not sufficiently upgrade doctor-lab communication systems as part of their investments in modernization. Namely, even though individual EHR systems were upgraded, competition between for-profit providers within the US healthcare system meant that little investment went into improving interoperability between EHR systems as a means of efficiently communicating complete, accurate information to support rapid decision making.[4] As a result, the backlog of missed calls, voicemails and even paper mailings which doctors have had to sift through in order to find out a patient's test results have crippled surveillance and outbreak intervention efforts – initiatives for which speed is of the essence.[5]

If there is a silver lining to this breakdown in the system, it has forced a reckoning over the hiccups which continue to slow down this response. A more resilient, fluid implementation of EHR is essentially being built in flight to meet the country's testing and health data management needs, lessons from which can and should be adopted by other countries as rapidly as possible in order to streamline their own testing pipelines before it is too late. For instance, practitioners at University of California San Diego Health (UCSDH) have developed a suite of EHR tools

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[4] Eddy, Nathan. "Coronavirus pandemic puts focus on strengths, weaknesses of EHRs." Healthcare IT News, March 26, 2020. https://www.healthcareitnews.com/news/coronavirus-pandemic-puts-focus-strengths-weaknesses-ehrs

[5] Tahir, Darius. "Coronavirus adds new stress to antiquated health record-keeping." Politico, March 11, 2020. https://www.politico.com/news/2020/03/11/coronavirus-health-record-keeping-125841

designed specifically to limit the spread of the virus through electronic systems for patient check-in, secure messaging, telemedicine, real-time data analytics, and test result communication.[6] Such integrated health platforms resolve the compatibility issues which hamper interoperability between EHR systems, and by extension, accelerate the entire testing and tracking response. By investing in such systems, health providers are adapting their disaster preparedness infrastructure to accommodate not just the physical and material burden of an influx of thousands of new patients, but the information and communications burden as well.

Contact Tracing and Investigation

Once positive cases have been identified through a scaled-up, widespread testing program, the next phase of preventative measures within a containment program involves identifying those individuals who have potentially contracted the disease by coming into contact with a carrier. Traditionally, this process involves a highly labor-intensive in-person investigative program. Such programs are not only time-consuming, wasting one of the most precious resources available to health officials when combatting a disease outbreak. In addition, these investigators often must don extensive full-body Personal Protective Equipment (PPE) to guard against traveling to potentially infectious environments, risking their own health, and possibly even becoming vectors for the disease themselves. In cases such as the 2014 West African Ebola outbreak, the sight of investigators wearing such equipment so scared local communities that many, fearing a virus which may have already been circulating in their communities, barred the entry of these perceived dangerous outsiders. As a result, the institutional trust which was necessary to promulgate disease prevention efforts advocated for by the authorities was undermined by the very actions intended to slow the spread of the virus, potentially prolonging the outbreak. Fortunately, advances in ICT have made contact tracing without the invasive presence of these medical teams far more feasible. Where personal technology such as smartphones are widespread and institutional trust is high, as in the East Asian countries which have most successfully battled the coronavirus so far, the tracing process can almost entirely be automated. Where such technology is not prevalent, or where low levels of societal trust may inhibit compliance with quarantine measures, low-tech applications of ICT can augment more traditional tracing approaches. By adding a human touch to what would otherwise be a highly impersonal process, these approaches can bolster a sense of social solidarity and personalized care which is essential for maintaining the cohesiveness of society throughout the long trajectory of the crisis.

Early in the course of the pandemic, Singapore released the TraceTogether app, setting a standard which few countries have been able to meet with one of the most visionary applications of ICT to the problem of contact tracing to have emerged from the global health crisis so far. After users download TraceTogether, smartphones equipped with the app utilize their Bluetooth capability to catalogue the physical proximity of other users. If a user tests positive for the virus, all users of the app who came within close physical proximity of that user, and potentially contracted the virus as a result, are sent a notification and a set of instructions for self-isolation.

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[6] J Jeffery Reeves, MD, Hannah M Hollandsworth, MD, Francesca J Torriani, MD, Randy Taplitz, MD, Shira Abeles, MD, Ming Tai-Seale, PhD, MPH, Marlene Millen, MD, Brian J Clay, MD, Christopher A Longhurst, MD, Rapid Response to COVID-19: Health Informatics Support for Outbreak Management in an Academic Health System, *Journal of the American Medical Informatics Association*, , ocaa037, https://doi.org/10.1093/jamia/ocaa037

If mimicry is the greatest form of flattery, then the number of countries which have begun piloting their own tracing apps after witnessing Singapore's success with TraceTogether should stand as testament to the benefits of this approach. India, for instance, is currently piloting its own Bluetooth-powered tracking app, termed CoWin-20, and Israel has unveiled its own app, called HaMagen, or "The Shield."

TraceTogether and its siblings have experienced significant adoption and success, but they are not a perfect solution to the challenge of contact tracing. Their main weakness is that as third-party apps, they do not have seamless interoperability with Android or iOS devices. As a result, the app causes phones to consume more battery life when operating in the background and can on occasion fail to begin functioning at startup, or may experience interruptions in Bluetooth connectivity. This weakness is a minor, but significant hole in what would otherwise be a tight surveillance network. Far more significant of a weakness is the fact that the app is not mandatory, and is offered on an opt-in rather than an opt-out basis. This significantly shrinks the user base, and as a result, the proportion of society which the app can successfully serve. Moreover, since those who have paid little heed to health guidelines are both less likely to download the app and may be more likely to carry the virus, the app's userbase may self-select away from likely carriers of the disease in a way which underestimates the level of social distancing required to stop the spread of the illness. To address these shortcomings, Google and Apple have partnered to design tracing software for direct incorporation into the operating systems of their smartphones. This software, which would allow users to opt out in deference to privacy concerns, would be more reliable and efficient than an external app and would create a denser surveillance network by virtue of a larger user base. Direct integration into mobile operating systems may also increase coverage in the developing world by reducing barriers to uptake. However, regardless of the virtues of the underlying technology, such techniques will do little good if they are not paired with digital records of test results which can be seamlessly communicated between laboratories, the medical officials who maintain testing databases, and the software companies which would forward any necessary alerts to end users.

Furthermore, such a centralized surveillance approach runs into serious obstacles in countries with highly individualistic cultures and an endemic distrust of government. It was for this reason that Massachusetts, when presented with the opportunity to apply a technology-forward method of contact tracing similar to what was applied in these East Asian success stories, instead opted for what at first seems like a low-tech approach for a developed country, and one ill-suited to the level of technology the general population has access to. Rather than automating contact tracing digitally, the state has enlisted over 1000 people in a contact tracing program in which tracers make personal calls to the cell phones of those identified as contacts through traditional means. Such a system is highly labor intensive, and has the seeming disadvantage of missing casual interactions between strangers in public places which nonetheless have the potential to spread the virus. However, what this method lacks in thoroughness, it makes up in interaction quality. The system, in which phone bankers call up an average of ten contacts per newly identified case, was pioneered by Partners in Health (PiH), a nonprofit famed for its successful initiatives against infectious diseases, namely tuberculosis, in some of the world's poorest countries. According to PiH's founder, Paul Farmer, nothing ensures compliance with an epidemiological program so much as a bond of trust. In compliance with this principle, over the course of a half hour on the phone, contacts receive not only reassurance from their tracers, but have the opportunity to voice

any specific concerns and needs for social support they will require over the course of their time in isolation. The result is a more holistic approach to the challenges posed by the need for strict quarantine, and one which leverages ICT to enlist thousands of new health workers and safely engage them in the constructive work of cornering the disease.[7]

Other observers have witnessed the success of the phone banking approach and proposed that it be taken to an entirely new scale. Jeffrey Sachs, acknowledging the need for mass identification, tracing, and isolation of the infected as a prerequisite to slowing and eventually halting the advance of the disease, has proposed the organization of mass phone banks at national and subnational levels around the world. These phone bankers would check in on a daily basis with confirmed cases in order to follow symptoms, trace family and work contacts, and identify any needs these individuals have for public services in order to ensure they remain in social isolation. Contacts who reported any symptoms would be placed on a priority list for testing, be placed under the same temporary isolation, and receive the same assertive social support.An aggressive intervention along these lines which successfully resulted in the self-isolation of all infected individuals within the first day of reporting symptoms, as illustrated in a technical demonstration which Sachs contributed to, would dramatically reduce the r-value of the disease, or rate of new infections per new case, below one, and lead to the organic decline of the epidemic.[8] [9]

Telemedicine during a Pandemic

Regardless of the symptoms, characteristics or deadliness of any particular disease, the greatest challenge faced by any health system during a pandemic is the sheer number of cases which must be processed within a short amount of time. The threat of hospitals being overwhelmed by a surge of life-threatening cases beyond their capacity to treat has been the motivating force behind appeals to "flatten the curve," or slow the spread of the disease enough that the peak number of cases where hospitalization is necessary remains below the ceiling of total hospital treatment capacity. Even so, however, in the worst hotspots, the universal shortage of hospital space means that routine and nonessential consultations must be done outside of traditional spaces. Even for a disease as potentially severe as COVID-19, patients who have not come down with symptoms which absolutely require hospitalization have been requested to remain home in order to preserve space for the worst cases. Likewise, going to the hospital now poses such a significant risk of exposure that many patients wishing to undertake nonessential procedures have been turned away both for their own safety and to reduce the risk of further spread.

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[7] Barry, Ellen. "An Army of Virus Tracers Takes Shape in Massachusetts." *The New York Times*, April 16, 2020. https://www.nytimes.com/2020/04/16/us/coronavirus-massachusetts-contact-tracing.html
[8] Sachs, Jeffrey. "This is how we conquer COVID-19." CNN, April 6, 2020.
[9] Moghadas, Seyed et al. "Projecting hospital utilization during the COVID-19 outbreaks in the United States." Proceedings of the National Academy of Sciences, April 2020. https://doi.org/10.1073/pnas.2004064117
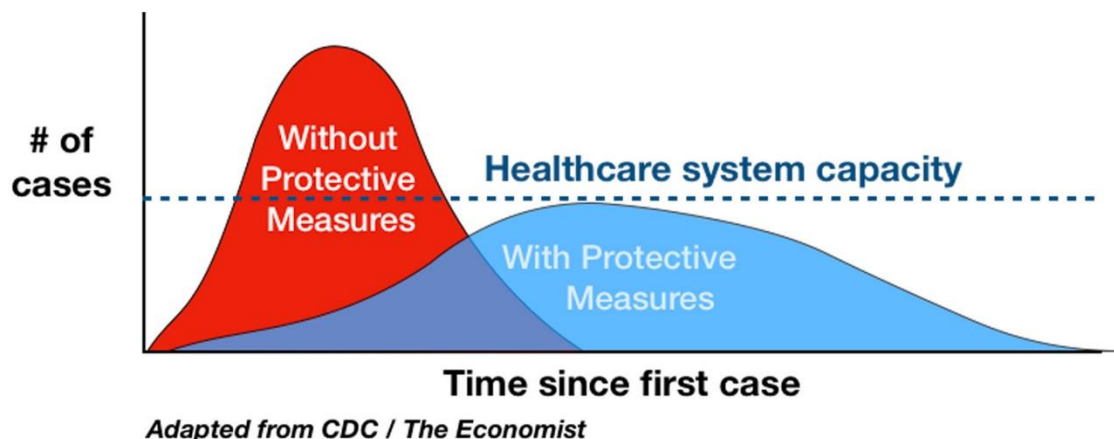
Figure 1: Slowing the rate of spread through protective measures, or "flattening the curve," is an essential part of maintaining the capacity of hospitals to manage an outbreak. Telemedicine plays an important role both in promoting the distancing necessary for this and in opening hospital space desperately needed for urgent treatment. Source: ABC News.

In such a constrained environment, telemedicine becomes an essential tool for maintaining public health, for those who have tested positive for the disease and for those with more routine conditions alike. Telemedicine is an umbrella term referring to the many ways in which ICT can be engaged in the service of health care without necessitating personal contact between physicians and the sick. This ranges from the low-tech, such as phone calls and text messaging between patients and doctors, to more advanced techniques involving wearable medical devices and high-resolution imaging software.[10] For all but those cases requiring the most immediate medical intervention, telemedicine can serve as an adequate stopgap which maintains normal standards of care while allowing physical hospitals to focus on crisis management.

Telemedicine has experienced a global boom during the current coronavirus outbreak. Over the course of its epidemic trajectory, China has been able to move 50% of all medical care online, opening space in its medical facilities to treat COVID-19 patients while maintaining safe distance for ordinary patients. Among the normal procedures of these remote checkups, temperature monitoring was conducted over the phone twice a day for suspected positive cases in

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[10] For an overview of the current extent of telemedicine and other e-health and m-health services within India, please refer to ICT India Working Paper #4, "ICT Interventions for Improved Health Service Quality and Delivery in India: A Literature Review."

order to track the emergence of any fever and, if necessary, identify patients who may need to be sent to special fever wards. Nor has the rise of a policy preference for telemedicine been limited to Asia. New York State, to provide one example, has eliminated co-pays for telehealth services for the duration of the crisis.[11]

More public-facing telemedicine initiatives have gained currency around the world, not just those involving the private relationship between patients and doctors. Monthly consultations on JD Health, one of China's largest online pharmaceutical platforms, grew tenfold to over two million over the first two months of the outbreak, growing even more once the platform rolled out a free online medical consultation tool linking overseas Chinese to physicians through the platform. Similarly, Alibaba's health arm, Ali Health, provided 100,000 remote consultations for Hubei residents under lockdown within five days, and Tencent's WeDoctor app connected 20,000 physicians to patients on a volunteer basis. The boom in online telemedicine hasn't been limited to for-profit companies, either. Dingxiang Yuan, China's largest online community of medical professionals, experienced a large surge both in visits and online users, created a heat map of COVID-19 infections which has been viewed over 2.5 billion times, and has published a multilingual set of guidelines both for home isolation and prevention procedures and for treating coronavirus patients in hospital settings which have since gone viral.

Treatment

Enforcing Quarantines and Social Distancing

Once positive cases have been definitively identified, sick individuals must be placed into social isolation to allow them to recover from the disease without the possibility of infecting anybody else. Without strict enforcement of quarantines, there is little prospect of the r-value of a disease dropping low enough for the overall number of cases to decline until enough people fall ill and recover that some degree of herd immunity can be achieved. Such an approach constitutes not only a deadly roll of the dice for the millions of people who would become dangerously sick as a result, but also a tenuous bet on the so far unproven theory that those who recover from the disease maintain their immunity in the long term. In other words, quarantining the sick and making sure they stay isolated, while providing them with the resources they need, adds up to a moral obligation regardless of the infringements on liberty involved which would otherwise be unacceptable in normal circumstances. ICT can contribute to the enforcement of quarantines for the sick, and ICT tools have seen successful applications in various East Asian nations so far. However, a careful balance must still be struck between transparency of information provided and protection of privacy, should the social stigma resulting from becoming a publicized patient and potential spreader prove as deadly as the disease.

South Korea has, to this point, been the global leader in using ICT to aid the enforcement of quarantines for sick individuals. Following the mass testing of segments of the population suspected to have come in contact with spreaders, including the asymptomatic, those who test positive are ordered to self-quarantine and directed to download a smartphone app which

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[11] Press Release, NYS Department of Financial Services.
https://www.dfs.ny.gov/reports_and_publications/press_releases/pr20203171

continuously tracks their location. If the GPS data generated by the patient's movements indicates that they leave their residence during the quarantine period, police are automatically notified, the patient's movements are cross-referenced using CCTV footage and credit card records, and the individual faces a fine of up to 8000 USD. At the nation's most recent peak, over 30,000 suspected carriers in South Korea had been ordered to self-quarantine under these restrictions. Taiwan has taken the South Korean approach a step further by treating the boundaries of a patient's home as an "electronic fence" under direct enforcement by the police. Within 15 minutes of a quarantined individual traveling beyond this boundary as determined by their location data, they are contacted or even directly visited by the authorities to investigate, with the potential for an additional fine. No Western countries have yet taken the step of implementing such a severe system. However, the United Kingdom, after initial gestures toward the herd immunity approach, has considered using location data to track people's movements in a similar fashion.

Arguably, the more information that is published about the identity and backgrounds of carriers, the more likely those who have traveled within the same circles will consider themselves at risk of contracting the disease and take the appropriate steps to get tested and, if necessary, self-isolate. However, excessive publishing of information about the infected can easily cross the line from the marginally useful to the downright invasive, especially when fear and the power of stigma mobilizes online mobs to seek out the identities of these individuals. Initially, South Korea took a maximalist approach to publicizing data about the identities of patients, in concordance with a suite of additional measures which may have seemed draconian in the moment but were, in hindsight, necessary. However, the information published by the South Korea authorities, which went beyond data such as age, sex, and location to include potentially embarrassing details such as the place of presumed infection (in one man's case, while attending a sexual harassment class) which, in some cases, revealed the identity of the individual. The result was a wave of cyberbullying of the infected which some patients described as "scarier than coronavirus." In a society which already suffered from widespread online harassment, the effective publicization of patients' identities, in addition with unnecessary and often misleading details about adulterous relationships, plastic surgery appointments, alleged prostitution and the like, has caused sufferers of the disease to report anxiety, feelings of guilt, and even suicidal thoughts.[12]

When a pandemic moves beyond the initial containment phase, detailed information about individual patients ceases to serve any public benefit. This is particularly true because anonymized location data collected over the course of normal tracking, tracing and quarantine surveillance efforts is perfectly adequate to provide an accurate portrait of geographical risk. Hong Kong has published perhaps the world's best example of caseload mapping, publishing a building-by-building map illustrating the number of cases at every single address in the entire city without any additional identifying information.[13] Few other locales have made such detailed, granular and useful information public, but some have attempted to use the location data they have at their disposal to generate anonymized, yet useful illustrations of the virus' progress

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[12] "Coronavirus privacy: Are South Korea's alerts too revealing?" BBC, March 5, 2020. https://www.bbc.com/news/world-asia-51733145
[13] Map available at https://chp-dashboard.geodata.gov.hk/covid-19/en.html

throughout their communities. New York City, for instance, currently the global epicenter of the pandemic, recently published a map of the number of verified cases in each of the city's ZIP codes.

Applied AI and Machine Learning for Tracking and Treatment

Months into the global pandemic, medical professionals around the world remain in the dark about what sorts of treatments are useful for patients suffering from COVID-19. Drugs for other disease such as the anti-malarial hydroxychloroquine and the antibacterial azithromycin have shown some murky promise in limiting the worst symptoms of the disease, such as the deadly autoimmune response known as a cytokine storm in which the body begins attacking its own cells in a futile attempt to hunt down the virus. However, other medical professionals believe that administering these drugs could be even more harmful than going without. Through this point, doctors and researchers alike remain in the dark on how to medicinally confront a disease whose disparate and seemingly unrelated complications have ranged from acute respiratory distress to sudden cardiac arrest to liver failure, and in at least one case, a blood clot necessitating the amputation of a leg.

In other opaque and complicated drug development scenarios, AI and machine learning techniques have provided a way forward for identifying new compounds or preexisting drugs which could meet the need for a new treatment. In the normal drug development pipeline, biologically useful compounds are systematically modified using techniques such as 3D molecular structure prediction, ligand design, and docking. With sufficient provision of data, AI offers the chance to accelerate this pipeline through deep analysis of data from research results, clinical trials, and even the biology of the cell itself. Current AI methods, such as Bayesian network analysis, lack the sophistication to interpret findings for more complex disease, especially when high-quality, clean data is scarce. But new, cutting-edge algorithms offer the promise of replicating the pharmaceutical development pipeline, and possibly gaining new insights human researchers would not have naturally reached, through virtual analysis. If there is one thing the pandemic will not create a shortage of, it will be clean, high-quality, medically relevant data from millions of patients with the same disease. The prospects of AI playing a role in developing treatments and an ultimate cure should therefore be seen as quite bright.

Hospital Management

As discussed, improved implementation of ICT plays a clear role in the testing and tracking process, specifically in streamlining the communication of EHRs between patients, laboratories and medical providers. But ICT will also play a critical part in assuring that hospitals themselves continue to run smoothly, and that doctors are insulated to the greatest degree possible from the stress of rapidly rising caseloads, insufficient resources, and heartbreaking moral dilemmas. By fully integrating EHRs into patient care, clinicians can keep consistent track of specific patients' needs without having to waste valuable time pulling information from an opaque system. Digital schedule management can adaptively shift staffing to surge personnel during times of high anticipated need while giving doctors and nurses much-needed rest during anticipated lulls. And should hospitals reach the point where triage of patients becomes necessary, clinical algorithms can help make objective, humane decisions about which resources to direct to which patients in a

way which avoids any extra psychological burden on those of whom so much has already been asked.

ICT for Prevention and Long-Term Resiliency

The COVID-19 pandemic will eventually pass, and with its conclusion, medical systems around the world will be relieved from a crucible of months or even years of constant strain and pressure. But societies must be careful not to forget the many difficult lessons the pandemic will have taught about the vulnerabilities and holes which continue to exist in the social fabric. As a means of survival, societies will be forced to adjust to supplementary institutions which could serve as the seed of an institutional immune response to the shock of the inevitable future outbreaks and similar disasters to come. The utmost care must be taken to ensure that these sources of resiliency, many of which have ICT at the core of their functionality, are not simply discarded when this crisis comes to an end.

More Robust and Elastic Medical Supply Chains

One of the most striking characteristics of this pandemic has been the mass shortages of PPE and other essential equipment, such as ventilators, that medical personnel have had to deal with. Doctors on the front lines have been reduced to wearing ski goggles, homemade face masks and even rain ponchos from canceled sports matches in an effort to give themselves some degree of protection against this highly contagious virus, particularly during dangerous procedures such as intubation which are necessary for the treatment of severe cases. Hospitals in the New York area have had to begin experimenting with using ventilators for multiple patients at once, and have even been forced into uncomfortable discussions about how and whether to repurpose veterinary ventilators for human patients. Despite warnings years in advance about the threat of a flulike pandemic, the national strategic stockpile in the United States proved utterly inadequate to meet the magnitude of the crisis. Other countries which are unable to successfully contain their outbreaks and have medical systems more materially lacking than the American system will inevitably face similarly inelastic medical supply chains in the near future.

Yet in times of crisis, help comes from unexpected places, and ICT has facilitated coordination between unlikely industries across sectors to create ad-hoc supply chains out of whole cloth. Sewing cooperatives, responding to urgent online appeals by hospitals, have manufactured face masks from material found at home according to patterns published online and distributed them directly to first responders. Perfumeries and whiskey distilleries have converted their facilities over to the production of hand sanitizer. The Ford Motor Company, in partnership with GE, has begun building ventilators out of F-150 seat fans to help meet the national shortage. And 3D printing enthusiasts and makers across the country have used templates shared through social media to manufacture everything from face shields to ventilator valves from scratch.

Such a response is moving, but it remains uncoordinated in the absence of a centralized consortium to identify shortages, assign production, and distribute output to centers of need. In fact, in the United States, the lack of such a purchase consortium has forced states to bid against each other for essential supplies in a counterproductive parody of federalized government. A national digital platform for managing the production, purchase and distribution of all essential

medical supplies, open to all who could demonstrate a basic ability to manufacture the required goods, would be an ideal tool for connecting nontraditional suppliers within a collaborative, patent-free marketplace while incentivizing and coordinating the distribution of the most needed supplies. If data from epidemiological tracing efforts were incorporated into the platform's contract award system, including the types of big data discussed above with the potential to anticipate outbreaks, the platform could even predictively coordinate the manufacture and delivery of supplies to new recipients before they were hit with a wave of hospitalizations, not after the fact.

Preserving Labor-Intensive Supply Chains

Other industries and sectors are just as important to the normal functioning of society, such as agriculture, public transportation, and package delivery. Yet either these industries themselves or the supply chains backing them up are labor-intensive in a way which makes them extremely vulnerable to collapse under social distancing guidelines. Taking agriculture as an example, in America, crops have been left rotting in the fields for want of harvesting. In India, stoppage of work on farms has led some to start asking about food security in a country whose rural sector was already reeling.[14] For these industries or any others whose workers have been classified as "essential" due to the nature of their work and the need for their physical presence on the job, reforms must take place to minimize the amount of onsite labor required for these jobs to be completed successfully and for society to continue functioning smoothly.

It need not be said that automation, or conversion of a job to a task which can be completed remotely from home, should be the end goal of any resiliency efforts targeted at workers in essential industries for future pandemics. But given current technology, not all essential work can be successfully automated or distributed. In this case, employers should endeavor to organize their employees' schedules and divide their workforces into smaller, entirely segregated units so that contact between groups is minimized or eliminated and divisions report on a staggered schedule incorporating periods of isolation to allow any potential symptoms to reveal themselves. Such an approach, designed to maintain minimum necessary levels of labor while minimizing transmission at the workplace to the fullest extent possible, would likely be most easily managed through digital schedule management software, which could be integrated with the central digital testing databases so that all employees who may have had contact with a carrier are immediately notified. In the case of agriculture, ICT innovations have the potential to improve inventory management for perishable goods, reducing food waste and improving food security.

Mitigating Economic Impacts

Small businesses are likely to take a body blow as a result of long-term national lockdowns. Without revenue or access to customers, many will soon find themselves unable to pay their bills and will be forced into insolvency. Employees face an equally catastrophic scenario. After the first month of formal social distancing in the United States, over 22 million American workers

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[14] Biswas, Soutik. "Will coronavirus lockdown cause food shortages in India?" BBC, April 7, 2020. https://www.bbc.com/news/world-asia-india-52176564

had filed for unemployment, or as many as at the height of the Great Depression. With layoffs having just begun, and millions more workers unable to connect to antiquated state unemployment systems to sign up, what has been recorded to date is sure to be the mere tip of the iceberg, with Goldman Sachs projecting an ultimate unemployment rate of 32.1%. For perspective, a rate this high would exceed the 27.5% unemployment rate which staggered Greece during the depths of the eurozone crisis. And yet American workers, thanks to the high level of formalization within the economy, have been able to benefit from reasonably rapid and direct financial support from the federal government. What measures have been passed so far, including wage support for businesses struggling to keep employees on payroll and direct cash payments to independent adults, may have been insufficient to date to meet the needs of the present moment. But beyond lapses which are nearly unavoidable in such a massive program which was rolled out so quickly, there were no major logistical obstacles to the legislative intent of providing direct financial support to struggling Americans.

The same cannot be said for countries such as India for whom vast swaths of the population are dependent on an informal, cash-based economy. For workers in the informal sector, who are often insufficiently banked and lack registration with the government by definition, a national lockdown doesn't just mean losing customers. It means losing any means to offer or receive payment that don't involve making physical contact and breaking social distancing. If these individuals do not have any financial information on file with the government, information which the formally employed would have no trouble furnishing, then it becomes that much harder for the government to provide them with any sort of direct financial relief.

In preparation for the economic pain resulting from future crises, governments must work to maintain up to date financial information on as many citizens as possible to streamline the delivery of financial relief. For the unbanked, governments should consider incorporating novel financial institutions under the authority of their central banks and linked to national identification numbers in order to provide a swift and reliable means of providing financial support to those who are the most difficult to reach. India's Aadhaar system would provide a particularly convenient foundation for such a system. Governments should also prioritize moving as many businesses into the formal sector as possible in order to provide not just formal wage relief, but to assist in placing holds on interest and loan payments which would otherwise come due. For informal enterprises, whose access to capital is often governed by moneylenders and relational networks, no such official guarantee would be possible.

Social Media and Disinformation

When the next pandemic arrives, just like this one, the public will be immersed in a soup of fear, anxiety and hyperbole which causes misinformation to ferment and spread. In countries where such misinformation gained traction, particularly through social media, it fed conspiracy theories which ultimately undermined public health efforts. Such conspiracies are particularly dangerous when they are stirred up by bad-faith actors which view pandemics as opportunities to weaken geopolitical rivals, which troll farms have reportedly engaged in during the present outbreak.[15]

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[15] "Is Russia running a coronavirus disinformation campaign?" Deutsche Welle. https://www.dw.com/en/is-russia-running-a-coronavirus-disinformation-campaign/a-52864106

Given the potential for disinformation online to spiral into a public health risk, social media companies have a responsibility to tamp down naïve and malicious falsehoods and conspiracies alike. At the same time, their platforms provide public health researchers, epidemiologists, and public response coordinators a golden opportunity to spread their messages and findings to the public. Social media companies, acknowledging their inescapable place in public discourse, should prepare to proactively elevate the good information over the bad when the next crisis occurs. In the interim, they should rethink algorithms which prioritize engagement over quality, which has proven time and time again to be a recipe for toxic, polarized, and manipulative portrayals of issues in the public space which affect us all.

Challenges and Pitfalls

ICT should be no means be viewed as a cure-all to a pandemic. A complete public health response requires both adequate material provisions and the proper coordination of said resources, only one of which ICT can provide. With that being said, leaning on ICT as a pillar of a public health strategy introduces a number of short-term and long-term risks which must be taken into account. If a society relies on ICT as the primary means of outreach during a pandemic, then its response is likely to leave out the poor and elderly, coincidentally the two groups which have been the most exposed to danger during the COVID-19 outbreak. Such a response would not only threaten the health of these groups, but also the health of society as a whole. Failure to account for such challenges has already threatened to unravel the entire public health response in countries otherwise considered among the most competent and successful in managing the outbreak, such as Singapore, which has experienced a recent surge in infections among migrant workers. On the other hand, governments may be tempted to make temporary ICT interventions which prove too successful, particularly in the fields of surveillance and contact tracing, permanent. These innovations, while initially intended for the protection of public health, can easily be applied for nefarious means as well. If the technological advances which help societies emerge from this pandemic also lead to a permanent erosion of privacy and political freedoms, then such a development would represent a permanent and unnecessary cost to this pandemic which governments and civil organizations seeking to maintain free and open societies should strive to avoid.

Inclusion for the Poor and Elderly

For reasons both similar and disparate, the poor and the elderly have proven themselves to be the most vulnerable populations to COVID-19. The coronavirus has an estimated lethality rate of 13.4% for patients 80 and older, more than ten times higher than the rate for the rest of the population. The working poor, on the other hand, are vulnerable because they have neither the means nor the physical space to practice the social distancing which would otherwise shield them from exposure. The poor and lower classes are disproportionately in employment which requires them to show up in person, often via means of transport which put them in close proximity with others. Due to their poverty, they often lack the financial security to leave these jobs in order to protect their health. If they have the means to shelter in place, they often must do so in crowded conditions with multiple family members or roommates – who themselves may need to continue risking exposure to support themselves. Recent moves by certain American states to cut

unemployment benefit eligibility for blue-collar workers who remain at home after stay at home orders are lifted, likely prematurely, will heighten the stakes of this impossible choice between health and sustenance, exposing the poor to even more danger. Finally, the coronavirus has exhibited an affinity for victims with preexisting conditions disproportionately represented among the poor and elderly alike. Asthma patients, people with serious heart conditions, the immunocompromised, including AIDS patients, the obese, and those with diabetes, liver, or chronic kidney disease have all been shown to be at high risk for severe illness and complications from COVID-19.

The coronavirus may be more likely to impact these vulnerable groups, but an ICT-driven intervention is simultaneously the least likely to reach them. The elderly are less likely to use much of the technology which would serve as the backbone of an ICT-powered public health initiative, not just due to lack of familiarity but also due to physical disability. Visual and auditory impairment severely restricts the ability of those who suffer from such conditions to engage with any sort of electronic device, regardless of its purpose, and therefore to fully benefit from e-health programs relying on these devices. For the part of the poor, particularly in developing countries, devices such as smartphones which have increasingly served as primary platforms for notification, monitoring, and information dissemination during the pandemic may simply be out of financial reach.

ICT can and should be used as the backbone of a public health response during a pandemic, due to its facility in managing the many diverse needs for information sharing presented by such a crisis. However, if a country chooses to ground its approach in the use of ICT, it must prioritize finding ways to reach those vulnerable populations which may be excluded by that very strategy. One way of doing this could be to maintain a sense of appropriate technology for ICT interventions involving such populations. This would involve maintaining a high degree of sophistication for technology on the back end of the response in order to preserve the integrity of tracking and tracing while simplifying the technology used for outreach services according to the means of the target population. Such an approach would inevitably require a greater investment of manpower in these communities to ensure an adequate degree of trust and compliance compared to a nondifferentiated approach. However, given how one vulnerable group makes the entire population more vulnerable in a pandemic, the public health dividends from such an investment would be more than worth the cost.

Finally, if a country chooses to turn to ICT and big data in order to coordinate its public health strategy, it must remain conscious and mindful of the ways in which unconscious biases can be laundered through big data with negative outcomes for excluded populations. Machine learning algorithms have the potential to predictively prescribe the most effective courses of treatment for specific patients according to their histories and symptoms, and could lead to the developments of treatments or even vaccines. However, such algorithms are only as good as the data they are based upon. If medical records are incomplete or inaccurate for specific socioeconomic groups, and this data is used to train a treatment or drug development algorithm, the outcomes are likely to replicate the same unconscious biases found in the underlying data. This could lead to treatments which work for certain groups but not others, chronic insufficiency of care for those

belonging to disadvantaged groups, and misclassification of risk for vulnerable patients.[16] One can even imagine a nightmare scenario in an overburdened hospital which has turned to an AI to make objective decisions on patient triage, only to have the AI systematically deprioritize patients from excluded social or racial groups due to faults in the underlying data used in its design. If automation of any sort is incorporated into the treatment strategies applied by public health authorities, which is increasingly likely given the emerging importance of universal EHRs as a tool for fighting this disease, then special care must be taken to ensure that the inevitable omissions and errors contained within do not propagate and replicate themselves in the form of systematic, automated socioeconomic disparities in treatment.

Privacy and Maintaining the Social Contract

The actions of the countries which have been most successful at containing the coronavirus have demonstrated that some infringement of privacy and normal freedoms is a necessary part of a public health response to a universal threat. Data sharing between public and private entities would often be seen as an unnecessary infringement on privacy in ordinary times, but during a pandemic, doing so enables the smooth transmission and communication of public health information about specific individuals to authorities and the community at large. Likewise, automated contact tracing would typically be seen as uninvited invasion of the government or the corporate world into personal space, but it solves a time-sensitive problem in a pandemic that can only go ignored at great cost. And while automatic location monitoring by the government would normally be viewed as a Big Brother-style intrusion with little judicial justification in ordinary circumstances, under the extraordinary conditions we are currently living in, it is simply an expeditious and effective means of preserving public health while available manpower is scarce.

However, applications of ICT for tracking and controlling the movements and actions of the population will not only cease to be of public health benefit once this crisis passes, they will become actively detrimental to the cause of fair and open societies. Unlimited private-public data sharing leads to profiling by corporations and governments alike and moves society further away from realizing equality of opportunity by making past actions impossible to move beyond and forget. Contact and location tracing sets a precedent for following the movements of political opponents, identifying their associates, and taking unjustified legal or extralegal action against them in order to maintain incumbents' hold on power. And the "digital fence" could serve as a frightening prelude for a society in which dissidents or other undesirables could have their movements forcibly restricted at a whim.

Preventing these developments shouldn't just be seen as maintaining the guardrails of democracies around the world. It should also be viewed as a public health imperative, given how authoritarian actions such as these have undermined public trust in the pandemic response where they have taken place. Therefore, while such applications of ICT have a role to play, they should be paired with a strict sunset clause causing them to expire once the public health emergency comes to an end. Additionally, when they are applied, the reasoning behind each individual action should be made as transparent as possible to avoid public speculation about nefarious intentions and maintain a sufficient level of institutional trust.

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[16] Gianfrancesco, Milena A et al. "Potential Biases in Machine Learning Algorithms Using Electronic Health Record Data." *JAMA internal medicine* vol. 178,11 (2018): 1544-1547. doi:10.1001/jamainternmed.2018.3763

Annex: Best ICT Practices from East Asia

In the current crisis, certain East Asian nations and dependencies such as South Korea, Taiwan, Hong Kong, and Singapore have performed leaps and bounds ahead of the rest of the world. In large part, this has been due to their superior application of ICT across all dimensions of their public health response. ICT has helped these countries intervene more quickly and squelch emergent outbreaks. ICT has also aided these countries in performing safer, earlier and more frequent testing, strengthening information about where resources should be directed to combat the virus. Furthermore, ICT has played an irreplaceable part in the contact tracing efforts of these governments, while making the enforcement of quarantine for sick individuals and suspected carriers smoother and less labor intensive. Finally, ICT has enabled more widespread public participation in disease containment efforts. By achieving nearly unblemished success while following very similar scripts to fighting the disease, these countries have realized a blueprint for pandemic suppression which other countries both today and in the future can and should follow to the best of their abilities in order to maintain the health and prosperity of their societies through this crisis and similar ones to come.

Rapid Intervention and Prevention

South Korea's rapid response to its first reported cases of COVID-19 was essential to moving the public health infrastructure into place to combat the pandemic within the country before the disease spread beyond the reach of containment measures. While simple good governance gave the country's early recognition of the disease weight in determining policy, ICT innovations also accelerated the speed at which this infrastructure could be mobilized. The South Korean government directed medical companies to begin developing potential testing kits for the coronavirus in late January, only a week after the country confirmed its first case. Even before this, though, as early as January 16, the Korean biotechnology company Seegene had begun focusing on developing diagnostic techniques according to the information which had been made publicly available at the time. Using AI and big data analytics, Seegene was able to optimize the chemical composition of its prototype tests according to the published genome of the virus by February 5, compressing a process which normally takes 2-3 months to a matter of weeks. Furthermore, the company was able to follow the insights yielded by this automated data analysis to begin producing its tests without even having a sample of the virus available for testing. The Korean CDC (KCDC) approved the test within less than a week of its initial development, paving the way for the mass production of tests before the virus had gained an untraceable foothold.

Taiwan took advantage of the lessons it had learned during the 2003 SARS outbreak to implement specific prevention strategies ahead of the arrival of the virus. The country was able to leverage ICT to almost entirely get ahead of its outbreak through pragmatic application of its existing data management systems for border control. On January 27, six days after its first reported case, Taiwan's National Health Insurance Administration (NHIA) took advantage of the interoperability of its patient identification systems with data from the National Immigration Agency (NIA) to compile a list of citizens and foreign residents alike, whether hospitalized or not, who had a travel history in affected areas within the past 14 days. Those identified through the new system were then directed via mobile phone notification to go into quarantine. By

February 14, the system was made even more proactive through the introduction of the Entry Quarantine System, which used a mobile survey linked to a QR code to accelerate immigration clearance for individuals at low risk. Finally, by February 18, the government once again took advantage of the interoperability of its digitized records to automatically provide access to travel histories for all patients to every hospital, clinic, and pharmacy in the country. At every step of the development of this system, Taiwan modeled the successful mobilization of existing government data in the coordination of a preventative health response.

Safe and Frequent Testing

Without exception, the countries which have distinguished themselves by their responses to the coronavirus outbreak have done so by building high-volume testing regimes capable of handling the demands of an entire population before infection rates began accelerating out of control. One aspect of this is completing the development of testing kits early enough in the trajectory of the crisis to allow for mass production and delivery before symptoms begin manifesting themselves, but another part involves completing tests rapidly, reporting results quickly and directly to patients, and providing for the safety of health personnel throughout this process. ICT can lend a valuable hand to improving the safety, frequency and reporting efficiency of testing, as these countries have demonstrated.

South Korea has gained renown for its creative uses of ICT throughout the diagnostic process. First and foremost, South Korea was a pioneer in the implementation of automatic testing methods. These techniques, which involve a robot mixing the testing solution with multiple samples at once, have been shown to proceed up to four times faster than manual methods, in which a technician must pipette the testing solution into each individual test tube. By doing so, South Korea has eased testing bottlenecks, accelerated reporting of results, and shielded scarce medical personnel from potentially infectious sample. KCDC has also deployed a suite of additional ICT tools to mitigate risk and prioritize treatment according to the anticipated risk for each individual case. A number of image analysis tools currently in use, such as the VUNO Chest X-Ray AI Image Support Tool and JLK Inspection, are capable of classifying ICU patients by risk category according to AI analyses of chest X-rays which identify and highlight abnormal lesions within the chest cavity in as little as three seconds.

In addition to boosting the capacity of the testing process, successful countries have also applied ICT to direct more potentially infectious people toward testing. Upon entry into South Korea, new visitors are required to download an app on their smartphones which walks them through a set of potential symptoms and guides them to testing sites in case of a potential match. More interactive self-diagnosis symptoms have been put in use elsewhere, such as the Tencent Health portal on WeChat, which allows users to look up nearby positive cases, learn about potential symptoms, and review information on self-protection, and a chatbot launched by the Government of Singapore allowing users to learn about the disease and what resources the government has made available to combat it.

Contact Tracing and Quarantine Enforcement

Taiwan, South Korea and Singapore have all set themselves apart by the efficiency and thoroughness of their contact tracing and quarantine measures, made possible through the judicious use of ICT. The most effective uses of technology for the tracking of infection statuses, the movements of the infected, and chains of contact have three basic traits in common: near-universal or mandatory adoption, a strong public digital infrastructure on the back end, and seamless data sharing and interoperability between publicly and privately stored data.

Singapore has demonstrated both how ICT can be used to direct exposed individuals into home isolation and how to use e-health tools to improve contact tracing. As early as February 10, Singapore developed and introduced a texting and web-based platform through which individuals under home quarantine could report their location to the government. Several weeks later, by February 27, the country began combining data from serological testing with contact tracing efforts to build a sophisticated map of transmission linkages through the population, improving the efficiency and efficacy of home quarantines, an initiative which would not be possible without the capacity to seamlessly track patients through digital health records. Singapore has gained even more publicity for its TraceTogether app, which directly applies mobile technology to decentralize contact tracing with the aid of these digitized testing records. TraceTogether uses Bluetooth to ping other users of the app within a specific physical radius of the user's mobile device. If a user is later reported to have tested positive for COVID-19, all users who have recently come within close physical proximity of that user are sent a notification and directed to take the appropriate preventive measures. TraceTogether has been successfully replicated in numerous other countries, including India, and Apple and Google recently announced joint efforts to improve upon this approach by integrating Bluetooth contact tracing into their own mobile operating systems.

In Taiwan, individuals who test positive and are placed in mandatory home quarantine are kept there with the help of their phones. All who are placed under quarantine have their location monitored via the location data on their phone, and are required to stay within a "digital fence" encompassing the bounds of their property. If their location as reported by their device moves beyond this fence, or stops being received, then automatic alerts are sent and police are dispatched to investigate whether quarantine was broken. In one case, a man whose phone battery died overnight woke up to the sound of two police officers knocking on his door, dispatched to determine whether he had left his house or not. South Korea has adopted a similar app, which sends location alerts to a designated case officer for each individual under enforced isolation. Hong Kong takes the "digital fence" approach one step further by pairing an app which all new arrivals must download with a wearable device which reports location data back to authorities.

Public Participation

Finally, the most successful countries have used ICT to interactively engage with the public during the outbreak. The most successful ICT tools are used not just to notify or to compel action, but to build avenues for decentralized action and contribution of time, information, and other resources by the general public. Relevant human resources are as scarce a resource as face masks in a global outbreak, and these tools allow citizens to start closing the vast gap between what is needed and what can be provided on all fronts.

In this case, Taiwan has provided the model on how to promote mass voluntary civic engagement. Avoiding the twin extremes of a laissez-faire, opt-in approach which is sunk by low rates of adoption and follow-through and an authoritarian approach which foments mistrust and boxes out the potential contributions of civil society, Taiwan has built an overlapping network of databases shared directly between government and activists and coordinated through the open democracy portal vTaiwan in order to direct the production and distribution of all relevant resources and information. Over half of Taiwan's population participates in vTaiwan, which by coordinating public-private partnerships, "hacktivism," and mass collective action, has been responsible for the implementation of 124 separate health policy interventions according to a study by the Stanford University School of Medicine. One tool developed through this creative approach mapped face mask supply and demand, as reported by producers, medical personnel and ordinary citizens alike, in order to direct new shipments to where they were most needed. In another example, activists worked directly with the digital ministry to build a participatory tool for symptom report sharing, verification, and location history analysis to notify individuals who had likely been exposed.

Through this unique e-government approach, despite having had its access to WHO data on the coronavirus blocked due to its dubious international status, Taiwan was able to accomplish similar scale and coverage as similar efforts in more authoritarian states without compromising user privacy. Taiwan further built up transparency and public trust through the use of ICT through measures such as livestreaming meetings tied to the health crisis response, which additionally avoided the coordination and misallocation challenges which have plagued countries with a less sophisticated digital response while highlighting challenges the government had encountered which a decentralized approach could help solve. By limiting the use of ICT for force and compulsion only where absolutely necessary, and applying an approach to data and information which emphasizes transparency and collaboration, Taiwan has built its capacity for a truly *public* health response which is flexible, creative, and most importantly, exportable.

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