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OVERVIEW AND INSIGHT: PERFORMANCE OF DIGITAL HEALTH SYSTEMS DURING THE COVID-19 PANDEMIC

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DEFINITIONS

Standards: Formally ratified standards created and adopted by one or more influential bodies such as governments or international organizations (WHO, UN, etc.). Also includes legislation and regulation adopted by governments.

Guidelines: Published guidelines created by relevant parties.

Toolkits: Prepackaged materials, either physical or digital, that provide actionable guidance. To be considered a toolkit, the materials must be readily available and multidimensional. For example, a downloadable notice about mask wearing would not be considered a toolkit. However, a guidebook on workplace safety for employers combined with safety posters and related forms/materials provided in a single package would be considered a toolkit.

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ACRONYMS

AI	Artificial Intelligence
APIs	Application Programming Interfaces
CDC	Centers for Disease Control
CEPI	Coalition for Epidemic Preparedness Innovations
CT	Computed Tomography
DP-3T	Decentralized Privacy-Preserving Proximity Tracing
EU	European Union
eWWG	eWorldwide Group
GHSI	Global Health Security Index
ICTs	Information and Communication Technologies
ICUs	Intensive Care Units
ITU	International Telecommunication Union
IVR	Interactive Voice Response
ML	Machine Learning
NHS	National Health Service
NLP	Natural Language Processing
OECD	Organisation for Economic Co-operation and Development
PACT	Private Automated Contact Tracing
PEPP-PT	Pan-European Privacy Preserving Proximity Tracing
PPE	Personal Protective Equipment
PSI	Private Set Intersection
RT-PCR	Reverse Transcription Polymerase Chain Reaction
SMS	Short Message Service
UNICEF	United Nations Children's Fund
US	United States
USSD	Unstructured Supplementary Service Data
W3C	World Wide Web Consortium
WEF	World Economic Forum
WHO	World Health Organization

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EXECUTIVE SUMMARY

With the onset of the COVID-19 pandemic, the eWorldwide Group (eWWG) and the IEEE began implementing a Global Digital Resilience Initiative in March 2020, bringing together stakeholders across multiple sectors to fast-track lessons learned and increase the ability of nations to mitigate the pandemic. The initiative aims to redefine and adopt a holistic strategic approach to digital resilience and focuses on developing frameworks, standards, guidelines, and toolkits for effective, ethical, and inclusive digital technologies for COVID-19 response, recovery, and mitigation.

More than 2 years after the World Health Organization (WHO) declared the COVID-19 outbreak a global pandemic, countries—regardless of development status or income group—continue to be engulfed by waves of infection, bringing to light the inadequacies of health systems around the world.

While countries have adopted different approaches to COVID-19 response and recovery, a clear trend is the accelerated adoption of all aspects of digital technologies, from the dissemination of critical health information to disease surveillance and contact tracing to treatment and vaccination. Countries around the world have adopted and adapted digital technologies to respond to, recover from, and mitigate the impact of the pandemic. The technologies include the following:

- SMS and instant messages for targeted public health messaging and other purposes
- Social media and online searches for syndromic surveillance
- Wearables and sensors
- Digital diagnostics and genomics
- Visualization tools such as interactive geospatial maps and data dashboards
- Smartphone apps for contact tracing, symptom reporting, chatbots, telemedicine, and mobility pattern analysis
- Computer vision and drones
- Machine learning (ML) and natural language processing, including web-based epidemic intelligence tools
- Privacy- and security-preserving technologies

These digital technologies have been applied to different aspects of pandemic response, recovery, and mitigation, including the following:

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- Communication and tackling misinformation and disinformation
- Detection and testing
- Reporting and mapping
- Contact tracing, tracking, and disease surveillance
- Alerts and rapid response
- Containment, isolation, and quarantine
- Treatment and monitoring
- Hospital load management
- Data collection, analytics, and destruction
- Data privacy, protection, security, and ethics
- Logistics and supply chain management, for example, personal protective equipment (PPE) and vaccines
- Vaccination and immunization, including the equitable distribution of vaccines

While the pandemic has been a catalyst in the rapid adoption of digital health tools—and digital technologies can improve the speed, reach, and cost efficiency of many health-care measures—challenges and gaps exist, particularly relating to digital exclusion and ethical, privacy, safety, and security concerns due to the large amounts of personal data being collected.

In all the countries studied, regardless of level of development, safeguards on personal data privacy, safety, and security have been insufficient. Moreover, the pandemic has resulted in the use of authoritarian power for mass surveillance and implementation of stringent measures that restrict civil liberties, which may accelerate the erosion of democracy.

As countries continue to experience successive COVID-19 waves, they clearly illustrate the urgent need for a holistic approach that considers all aspects of the digital health ecosystem and the importance of multidisciplinary and multilevel (local to global) collaborations to strengthen and sustain health-care resilience.

Moving forward, it is important to leverage best practices and lessons learned from the ongoing crisis to strengthen health-care resilience in a holistic manner to withstand future crises. They include the following:

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- Developing an integrated digital strategy for pandemic preparedness
- Adopting a holistic approach to health and well-being and establishing interagency collaboration mechanisms
- Promoting the engagement of an increasingly diverse group of stakeholders in digital health ecosystems
- Promoting public–private partnerships
- Developing and adopting global standards for data and applications for effective pandemic response
- Investing, strengthening, and building on existing digital health systems
- Establishing trust with multiple stakeholders
- Engaging with multiple stakeholders to build trustworthy artificial intelligence (AI)

Despite promising collaborative initiatives to develop principles, standards, and guidelines to help late adopters of digital health and developing nations catch up, policymakers are struggling to adopt and integrate digital technologies to their domestic health systems. With a large and growing selection of digital tools available, it is a challenge for countries to know what tools are both available and important and which tools best suit their context and needs for COVID-19 response and recovery and for building resilience to future crises.

Underlying the discussions in this paper is an urgent need to restore and build greater transparency and public trust. The public needs to have confidence that digital solutions to public health emergencies protect them, respect their rights and empower them, and do not normalize the deployment of mass surveillance as the only way to deal with a crisis. Some of the key risks to consider include the following:

- The digital and data divide exacerbating inequalities
- The power of tech companies and the lack of discussion regarding their accountability and liability
- Escalating privacy and security risks
- Rising mass surveillance
- Erosion of trust
- Lack of uptake of digital health technologies

A global standard is urgently needed to identify, systematize, assess, and exchange COVID-19 best practices for building resilient digital health ecosystems in a holistic manner. This standard should incorporate principles

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relating to equality, privacy, safety, security, interoperability, and ethical use of data. It should guide the adoption and integration of the best practices into national health-care systems based on countries' digital health readiness. The standard should be in alignment with the WHO's Global Strategy on Digital Health 2020–2025, which aims to create an interoperable, secure, and resilient digital health ecosystem that will enable fast response and recovery in future crises, sustained functioning of essential health services, and accelerated progress towards achieving the United Nation's Sustainable Development Goals.

We are at a critical crossroad today to steer towards a more inclusive, integrated, and resilient health-care system.

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1. INTRODUCTION

A Discrepancy Between Rhetoric and Reality

Two years after the World Health Organization (WHO) declared the COVID-19 outbreak a global pandemic, countries—regardless of development status or income group—continue to be engulfed by waves of infection, bringing to light the inadequacies of health systems around the world.

The Global Health Security Index (GHSI), which assesses countries' preparedness for epidemics and pandemics, ranked the United States (US) and the United Kingdom as the top two performers pre-COVID in 2019 (Figure 1).[1] Yet, the US has shown the highest COVID-19 case and death count globally. After the first confirmed case of COVID-19 in the US, it took the Centers for Disease Control (CDC) and Prevention more than 15 weeks to create a public website tracking the virus.[2] In contrast, it took Vietnam, ranked 50 on the GHSI, less than four weeks.[3] In fact, Vietnam is one of the few countries that has demonstrated a rapid and effective response to curbing the spread of the virus and has been able to keep the economy open enough to facilitate gross domestic product growth in 2020.[4,5]

This discrepancy between available data and country policies compiled by the GHSI and the reality of COVID-19 response and recovery sends a clear message that we need to reevaluate the metrics for pandemic preparedness in a holistic manner. More importantly, countries need to be open to learning lessons and adopting good practices for the global good as crises and pandemics are likely to increase in frequency and severity in the future. Rather than learning from science-based practices of COVID-19 control elsewhere in the world, the UK government initially pursued a discredited herd immunity strategy that led to a huge death toll.[6] With our increasing interconnectedness, cooperation and collaboration will be critical for fast and effective response and recovery from future crises and pandemics.

[1] Global Health Security Index, https://www.ghsindex.org/.
[2] McKillop, Matt, "Can the Pandemic Push U.S. Public Health in a Positive Direction?" *Greater Good Magazine*, Jun. 1, 2021, https://greatergood.berkeley.edu/article/item/can_the_pandemic_push_us_public_health_in_a_positive_direction.
[3] "COVID-19 pandemic in Vietnam," Wikipedia, https://en.wikipedia.org/wiki/COVID-19_pandemic_in_Vietnam.
[4] Pollack, Ted, et al., "Emerging COVID-19 success story: Vietnam's commitment to containment," Our World in Data, Mar. 5, 2021, https://ourworldindata.org/covid-exemplar-vietnam.
[5] Le, Sang Minh, "Containing the coronavirus (COVID-19): Lessons from Vietnam," World Bank Blogs, Apr. 30, 2020, https://blogs.worldbank.org/health/containing-coronavirus-covid-19-lessons-vietnam
[6] Yong, Ed, "The U.K.'s Coronavirus 'Herd Immunity' Debacle," *The Atlantic*, Mar. 16, 2020, https://www.theatlantic.com/health/archive/2020/03/coronavirus-pandemic-herd-immunity-uk-boris-johnson/608065/.

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FIGURE 1 Global Health Security Index Scores

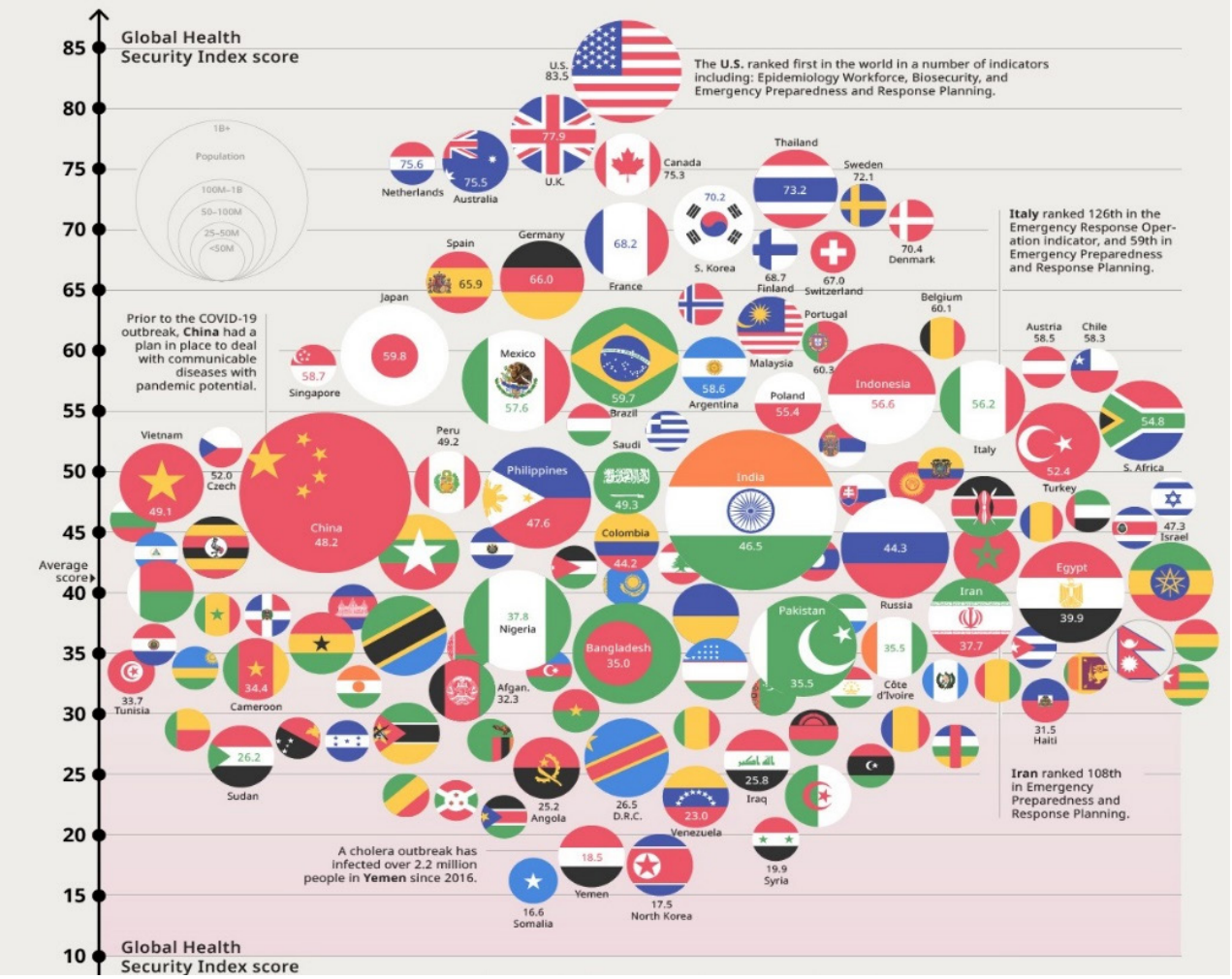


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Pandemic Response and Recovery Has Become Increasingly Digital

While countries have adopted different approaches to COVID-19 response and recovery, a clear trend is the accelerated adoption of all aspects of digital technologies, from the dissemination of critical health information to disease surveillance and contact tracing to treatment and vaccination. In fact, many countries that have been able to quickly and effectively leverage digital technologies for COVID-19 response and recovery, such as the Republic of Korea, Singapore, and Taiwan, have been recognized as successful models. A gap in the GHSI is the consideration for health system digital readiness.

[7] Le Pan, Nicholas, "Ranked: Global Pandemic Preparedness by Country," Visual Capitalist, Mar. 20, 2020, https://www.visualcapitalist.com/global-pandemic-preparedness-ranked/.

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Countries have taken advantage of the benefits of digital technologies to improve the speed, reach, and cost efficiency of many health response measures and to help ease the burden and protect health-care workers. An often-cited example is telemedicine, which became a lifeline for many across the world in accessing medical advice and care when countries imposed lockdown and social distancing measures. Telemedicine has been used extensively to triage or screen patients and to provide care remotely for those who do not need medical intervention or can receive care at home. This technology helps to reduce the risk of virus transmission to other patients and health-care staff. Telemedicine also helps provide routine care for patients with chronic diseases who are at high risk if exposed to the virus. Additionally, physicians and health-care staff who have contracted COVID-19 and are being quarantined have the option to continue to see patients remotely.

The Digital Divide and Multiple and Complex Risks

Unfortunately, in a rush to adopt telemedicine and other digital health solutions, those who are not connected are being left behind. Almost half of the world's population remain unconnected and are unable to benefit from remote health services.[8] They are disproportionately those who are poor, women, persons with disabilities, ethnic minorities, migrants, refugees, and other vulnerable groups. Without access to digital technologies and telemedicine services, these groups are at higher risk of contracting the virus and have less access to resources for treatment and vaccination.

It is not a coincidence that the same people who are less likely to have internet service at home are also those at higher risk of severe illness and death from COVID-19.

Another widely discussed example is digital contact-tracing technologies that have been used in a number of countries as part of broader disease surveillance and containment strategies. Case studies have shown how East Asian countries have successfully used digital contact-tracing technologies to flatten the curve in early to mid-2020.[9] These technologies will not only become part of the COVID-19 response and recovery but also future pandemic prevention and control.

Yet, in the rush to rollout these technologies that collect a massive amount of personal data, they are raising ethical, privacy, and security concerns, infringing upon individuals' civil liberties, and exposing people to mass and constant surveillance. The Republic of Korea passed a law allowing the use of data from credit cards, global

[8] United Nations, "With Almost Half of World's Population Still Offline, Digital Divide Risks Becoming 'New Face of Inequality', Deputy Secretary-General Warns General Assembly," press release, Apr. 27, 2021, https://www.un.org/press/en/2021/dsgsm1579.doc.htm.

[9] Huang, Yasheng, Meicen Sun, and Yuze Sui, "How Digital Contact Tracing Slowed Covid-19 in East Asia," *Harvard Business Review*, Apr. 15 2020, https://hbr.org/2020/04/how-digital-contact-tracing-slowed-covid-19-in-east-asia.

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positioning system (GPS) data from vehicles and mobile phones, and closed-circuit television and facial recognition technology to trace people's movements and identify people who may have been exposed to the virus or may have breached quarantine orders. Vietnam uses Facebook and Instagram posts and mobile phone location data to check a person's movements against those reported to contact tracers. Israel, Armenia, Russia, Ecuador, and Taiwan gather mobile phone location data to aid contact-tracing efforts.[10]

However, studies show that digital contact-tracing technologies alone are insufficient to curb the spread of the virus. The ability for digital solutions to help rather than hinder depends on a country's digital readiness, such as the coverage and quality of its digital infrastructure, the digital competencies of health-care stakeholders and the population, and the data protection and cybersecurity measures that are in place. In addition, the provision of safe places and financial support for quarantine and the availability of widespread rapid testing and treatment are important conditions for successfully containing outbreaks. As countries continue to experience successive COVID-19 waves, they clearly illustrate the urgent need for a holistic approach that considers all aspects of the digital health ecosystem and the importance of multidisciplinary and multilevel (local to global) collaborations to strengthen and sustain health-care resilience. Vietnam, for example, was heralded for its successful initial handling of the pandemic but struggled to contain a new wave of COVID-19 infections and asked for public donations to purchase vaccines.[11]

More than 1.4 billion doses of the COVID-19 vaccine had been administered by late May 2021, yet less than 1% of the global supply is reaching low-income countries.[12] The inequitable distribution of the COVID-19 vaccine is threatening all lives. The longer the virus continues to spread unchecked, the higher the risk of more deadly or contagious variants emerging—placing everyone at risk. While well-supplied countries are vaccinating entire adult populations against COVID-19, others with very poor vaccination coverage are witnessing dangerous surges in infection rates and the emergence of new variants. The deadly second wave in India could be a precursor to what will happen across the region—and globally—if this inequality persists.

[10] Lewis, Dyani, "Why many countries failed at COVID contact-tracing — but some got it right," *Nature*, Dec. 14, 2020, https://www.nature.com/articles/d41586-020-03518-4.
[11] Agence France-Presse (AFP), "Vietnam begs public for 'vaccine fund' donations after COVID-19 surge," Channel News Asia, Jun. 8, 2021, https://www.channelnewsasia.com/news/asia/vietnam-covid-19-public-vaccination-donation-14971788
[12] UNICEF, "COVID-19 vaccines: 5 reasons why dose donations are essential," https://www.unicef.org/coronavirus/covid-19-vaccines-why-dose-donations-are-essential.

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Overview of the Report

This report provides an overview of the role of digital technologies in COVID-19 response, recovery, and mitigation, particularly the frontier technologies such as artificial intelligence (AI), ML and unpiloted systems, along with the data used to train algorithms (see section 2). The paper also unpacks the complexity of the issues and challenges around the application of these digital technologies during the pandemic (see section 3).

The report concludes with a summary of the good practices and lessons learned from different countries (see section 4) as well as the risks and vulnerabilities that must be urgently considered (see section 5) to ensure that efforts toward building digital health resilience are inclusive and protective of those most vulnerable.

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2. Digital Technologies in COVID-19 Response, Recovery, and Mitigation

Countries around the world have adopted and adapted digital technologies to respond to, recover from, and manage the COVID-19 pandemic. The technologies range from short message service (SMS), interactive voice response (IVR), and unstructured supplementary service data (USSD) systems to frontier technologies such as AI and robotics.

This section sets the stage by exploring the wide range of digital technologies that have been used in the public health response to COVID-19 (see Figure 2). Case studies of how the various digital technologies are used are presented.

Although the different technologies for COVID-19 response, recovery, and mitigation are reviewed separately, it is important to assess and deploy them in an integrated manner as part of a digital health strategy and ecosystem that considers their different purposes and functions and interoperability toward achieving health outcomes.

FIGURE 2 Digital Technologies Used in the Public Health Response to COVID-19

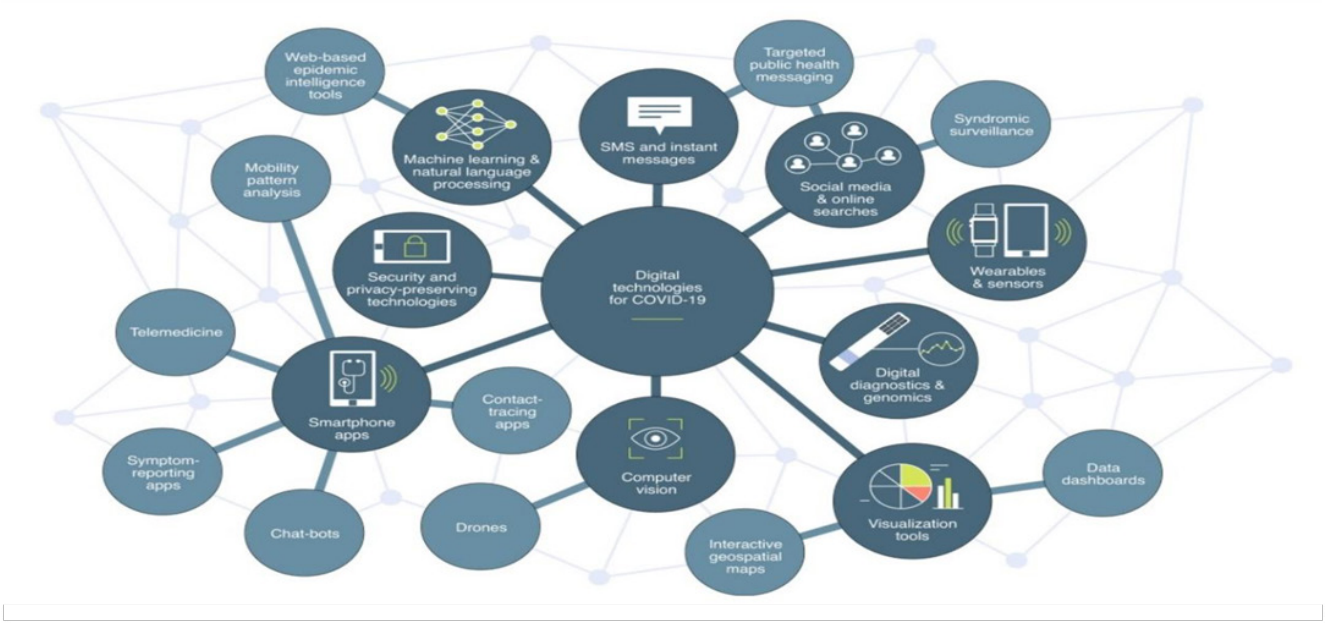


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[13] Budd, Jobie, et al., "Digital technologies in the public-health response to COVID-19," *Nature Medicine*, vol. 26, no. 7, Aug. 2020, https://www.nature.com/articles/s41591-020-1011-4.

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2.1. SMS AND INSTANT MESSAGES FOR TARGETED PUBLIC HEALTH MESSAGING AND OTHER PURPOSES

SMS and instant messaging apps, such as WhatsApp, Telegram, and Viber, have been widely used by governments and health-care systems in low-, middle- and high-income countries alike[14,15] to provide accurate public health information and counter fake news, send emergency alerts, boost participation in COVID-19 response measures, and promote preventive behavior. Countries like the Republic of Korea,[16] New Zealand,[17] and Taiwan[18] have been lauded for their ability to contain the spread of COVID-19, in part through their intensive use of mobile alerting. In some cases, the SMS and instant messages include links to websites, social media platforms, and videos. Videos are especially useful for those who are not literate, but an internet connection is often required to access them. Another problem with SMS links is the high incidence of malware associated with messages claiming to be from official sources[19,20,21] (see section 3.10 for a discussion on the rising incidents of cyberattacks during COVID-19). There also have been instances of the creative use of SMS to track, monitor, and communicate with at-home patients (see case study 1).

In issuing SMS alerts and messages related to the pandemic, governments have made use of preestablished emergency alert channels used for disaster warnings and other emergencies. With cell broadcasting technology, it is possible to send location-specific alerts using network operators' cellular towers and radio cells to push messages without officials needing access to any specific information on SIM cards or phones, as in the case of the Republic of Korea where residents receive emergency SMS alerts about new COVID-19 cases in their locality and regular reminders and instructions on how to prevent the virus from spreading.[22] This system can typically

[14] Lee, Minjung, and Myoungsoon You, "Effects of COVID-19 Emergency Alert Text Messages on Practicing Preventive Behaviors: Cross-sectional Web-Based Survey in South Korea," *Journal of Medical Internet Research*, vol. 23, no. 2, Feb. 2021, https://www.jmir.org/2021/2/e24165/ and

[15] Bateman, James, Diarmuid Mulherin, George Hirsch, Srinivasan Venkatachalam, and Tom Sheeran, "Rapid distribution of information by SMS-embedded video link to patients during a pandemic," *The Lancet*, May 6, 2020, https://www.thelancet.com/pdfs/journals/lanrhe/PIIS2665-9913(20)30126-0.pdf.

[16] Gold, Hadas, "How governments are using text alerts to fight the coronavirus pandemic," CNN, Mar. 27, 2020, https://edition.cnn.com/2020/03/27/tech/text-alert-coronavirus/index.html

[17] Matthews, Alex, "Coronavirus: 5 things New Zealand got right," Deutsche Welle, Jun. 8, 2020, https://www.dw.com/en/jacinda-ardern-leadership-in-coronavirus-response/a-53733397

[18] Chen, Chun-Mei, "Public health messages about COVID-19 prevention in multilingual Taiwan," *Multilingua*, vol. 39, no. 5, Aug. 26, 2020, https://www.degruyter.com/document/doi/10.1515/multi-2020-0092/html.

[19] Australian Cyber Security Centre, "COVID-19 scam messages," Mar. 16, 2020, https://www.cyber.gov.au/acsc/view-all-content/advisories/covid-19-scam-messages.

[20] Tressler, Colleen, "COVID-19 contact tracing text message scams," Federal Trade Commission, May 19, 2020, https://www.consumer.ftc.gov/blog/2020/05/covid-19-contact-tracing-text-message-scams

[21] "SMS malware acts like Covid-19 vaccine registration app, targets users in India and spreads via text messages," India Today, May 4, 2021, https://www.indiatoday.in/technology/news/story/sms-malware-acts-like-covid-19-vaccine-registration-app-targets-users-in-india-and-spreads-via-text-messages-1798633-2021-05-04

[22] Hadas Gold, "How governments are using text alerts," CNN.

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reach more than 80% of the population.[23] For emergency alerts, public announcements, and mass communication, the use of short codes and zero-rated messages are good practices. Short codes should have reverse-billing capacity so that charges for messages sent over the system are borne by an agency and not by individuals receiving and sending responses. For example, in Niger, the short code 701 is used by the Ministry of Health to broadcast information regarding COVID-19 prevention and diagnosis to its citizens in five local languages at no cost to them.[24]

Case Study 1: France User SMS For At-Home Covid-19 Patient Management

An SMS communication program was implemented by French physicians to monitor COVID-19 patients after discharge from outpatient or emergency care. The aim of the SMS tracking is to advise patients about their need for medical reassessment if reporting worsening of COVID-19 symptoms. Every morning, patients received four follow-up questions. Daily responses were converted to green, orange or red trees, analysed in real time by physicians. "Red" patients were called immediately to check their condition and organise transfer to hospital if needed. "Orange" patients were called within two hours to verify whether the specific instructions following the SMS had been followed. SMS tracking platforms could be useful as an early warning system to refer patients with worsening clinical status to hospital-based care or additional clinician advice.

Source: Paul Loubet et al., "Use of short message service in at-home COVID-19 patient management." BMC Medicine, Vol. 18(2020), https://bmcmedicine.biomedcentral.com/articles/10.1186/s12916-020-01863-9

Although the technology may be in place, care needs to be taken to ensure that the messaging is clear and inclusive (e.g., available in multiple languages)[25] and with clear indication of its sender. In the US, nearly half of early COVID-19-related alerts left out this latter information,[26] which can lead to confusion about the trustworthiness of messages, hesitancy to take them seriously, and the proliferation of fake news and scams (these issues are discussed in section 3.1).

[23] Hadas Gold, "How governments are using text alerts," CNN.
[24] ITU, "Interactive Voice Response: Delivering life-saving information amid COVID-19 in Niger," ITU News, Jan. 19, 2021 https://www.itu.int/en/myitu/News/2021/01/19/08/29/Interactive-Voice-Response-life-saving-information-COVID-19-Niger.
[25] WHO maintains a COVID-19 SMS Message Library with templates that can be translated into multiple languages.
[26] Bean, Hamilton, et al., "Exploring the Use of Wireless Emergency Alerts for Notifications Regarding COVID-19: Initial Lines of Inquiry," *Natural Hazards Review*, vol. 22, no. 2, May 2021, https://ascelibrary.org/doi/full/10.1061/%28ASCE%29NH.1527-6996.0000472.

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2.2. SOCIAL MEDIA AND ONLINE SEARCHES FOR SYNDROMIC SURVEILLANCE

Throughout the pandemic, people have turned to social media and online search engines for information. Social media is one of the top online activities—often people's first online experience and sometimes people's *only* online experience. Globally, social media adoption jumped by more than 12% during the first past 12 months of the pandemic, which translates to approximately 14 people starting to use social media every second. [27] As a result, governments and organizations have used social media platforms as one of the communication channels to disseminate information to the public.

Social media has also become the platform of choice for public opinions, perceptions, and attitudes toward public health policies regarding COVID-19.[28] Health authorities, therefore, have used the data generated from social media platforms and online searches to complement traditional syndromic surveillance, which includes early detection and prediction of COVID-19 clusters or hotspots and real-time monitoring. Social media and online searches have also been used for gauging public attitudes, assessing mental health, and analyzing government responses to the pandemic. Data aggregation systems—including ProMED-mail, GPHIN, HealthMap, and EIOS, which use natural language processing (NLP) and ML to process and filter online data have been developed to provide epidemiological insights. Several of these systems have claimed detection of early disease reports for COVID-19 before WHO released a statement about the outbreak.[29] As the pandemic wears on, social media and online search engines continue to be crucial in keeping people informed. However, the "walled garden" ecosystem of these sites applies algorithms to determine what users see. As the algorithms tend to boost sensational and emotive content that raises online engagement metrics, this has primed the social media space for disinformation and propaganda efforts. For low-income users depending on zero-rated access to specific sites, their access to accurate and reliable information is further hindered.

These are serious problems on their own and can result in significant harm, but they also raise concerns regarding the quality of data for syndromic surveillance. Relying on these sets of data can lead to bias, as trending topics are self-perpetuating and can be manipulated (see section 3.9).[30]

[27] Kemp, Simon, "Digital 2020: October Global Statshot," DataReportal, Oct. 20, 2020, https://datareportal.com/reports/digital-2020-october-global-statshot.
[28] Tsao, Shu-Feng, et al., "What social media told us in the time of COVID-19: a scoping review," *The Lancet*, vol. 3, no. 3, Jan. 28, 2021, https://www.thelancet.com/journals/landig/article/PIIS2589-7500(20)30315-0/fulltext.
[29] Budd, Jobie, et al., "Digital technologies in the public-health response," *Nature Medicine*.
[30] Samaras, Loukas, et al., "Syndromic surveillance using web data: a systematic review," *Innovation in Health Informatics,* 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7153324/.

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Another serious concern is the protection of privacy and security rights. Digital systems used for syndromic surveillance generally lack mechanisms for obtaining informed consent from individuals[31] (see section 3.10).

2.3. WEARABLES AND SENSORS

Wearables and sensors are being used to support all aspects of COVID-19 response, recovery, and mitigation, including detection, tracking, surveillance, contact tracing, monitoring adherence to quarantine and social distancing, treatment and remote patient monitoring, hospital load management, and vaccine delivery. Sensors, including thermal imaging cameras and infrared sensors, are deployed to detect potential cases on the basis of febrile symptoms (e.g., at airports). However, their accuracy is questionable, which can undermine detection efforts.[32]

On a wider scale, sensors have been deployed as part of smart homes and smart cities and are significant drivers for ML because they generate vast quantities of data from their surroundings, including audio, images, and videos, which also have been used in monitoring and controlling COVID-19 (see section 2.7 on Computer Vision). Hospitals are using sensors to monitor and manage bed availability. With vaccine distribution, sensors are important, particularly in tracking temperature of vials across the vaccine cold chain.

Smartwatches and fitness trackers are showing promise in predicting COVID-19 outbreaks. Scripps Research published a study showing that data from smartwatches on changes to normal sleep, activity level, or resting heart rate (which typically increases before an abnormal body temperature or fever) can predict clusters of COVID-19 outbreak using AI. This can help promote precision quarantine and better containment.[33]

In Germany, the Corona Data Donation App gathers the vital signs (pulse, temperature, and sleep) of volunteers and analyzes the probability of testing positive for COVID-19 using wearable technology. An online interactive map is generated based on this information to depict the geographical spread of the virus.[34] These wearable initiatives are currently enterprise driven or investigational. These initiatives have raised privacy and security concerns. The Corona Data Donation App enables volunteers to transfer their personal data pseudonymously (i.e., without providing a name), while allowing researchers to allocate the data to an individual user. However, pseudonymized data can still be attributed to an individual through the use of additional information.[35] This can

[31] Aiello, Allison E., Audrey Renson, and Paul N. Zivich, "Social Media–and Internet-Based Disease Surveillance for Public Health," *Annual Review of Public Health*, 2020, https://www.annualreviews.org/doi/full/10.1146/annurev-publhealth-040119-094402.
[32] Beall, Erik B., "Infrared Fever Detectors Used for COVID-19 Aren't As Accurate As You Think," *IEEE Spectrum*, Dec. 11 2020, https://spectrum.ieee.org/news-from-around-ieee/the-institute/ieee-member-news/infrared-fever-detectors-used-for-covid19-arent-as-accurate-as-you-think.
[33] Scripps Research, "Can a Wearable Detect COVID-19 Before Symptoms Appear?" DETECT, https://www.detectstudy.org/.
[34] Corona-Datenspende, https://corona-datenspende.de/science/en/.
[35] Spajic, Daniela, "The German corona-data-donation-app as an example of the concept of data donation," CiTiP Blog, Ku Leuven Centre for IT & IP Law, Apr. 20, 2021, https://www.law.kuleuven.be/citip/blog/the-german-corona-data-donation-app-as-an-example-of-the-concept-of-data-donation/.

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potentially have a negative impact on individuals. Moreover, as this is a public–private partnership involving multiple entities, including Germany's public health authority and manufacturers of wearables, clarity is needed on where the data is stored, who has access to data and for how long, how data is transferred and used, and what are the protocols in case of a data breach (see section 3.9 and 3.10). Another caution related to bias in data (raised in the previous section) applies: in particular, the representativeness to the larger population of the people who are able to afford smartwatches and who are also interested in purchasing and wearing smartwatches.

Controversy has arisen related to the use of wearables for wrists or ankles to remotely monitor those in quarantine at home. Users may have even less control over how these wearables work (compared to smartphones, which can be switched off), especially when they are made mandatory and users are not able to stop the wearables from collecting and broadcasting data (see section 3.6 for examples).

Currently under development for mass consumption are low-cost wearable sensors in the form of electronic epidermal tattoos (to track cortisol levels associated with stress), electronic textiles (temperature and metabolites), smart face masks (breathing pattern, airborne pathogens, and inflammation markers), and smart wristbands and patches that can collect previously inaccessible physical and biochemical signals and can be used to detect cases in future pandemics. The wearables also can be used to remotely monitor the recovery of individuals undergoing treatment or self-isolating at home.[36]

As wearables produce ever-larger data sets, reliance on ML will increase. This raises ethical, privacy, and security concerns due to the large amount of personal data being collected. Unlike conventional testing in a clinical setting, which may occur once or a few times a year, wearables provide continuous access to real-time physiological data of individuals.

2.4. DIGITAL DIAGNOSTICS AND GENOMICS

Genomics involves the study of the structure, function, evolution, and mapping of genomes or DNA. Genome sequencing enables researchers and public health authorities to identify and track emerging variants. Variant surveillance is important to determine if emerging mutations are rendering the virus more contagious, more potent, or resistant to existing vaccines and medicines.

[36] Ates, H. Ceren, et al., "Wearable devices for the detection of COVID-19," *Nature Electronics*, vol. 4, no. 13-14, 2021, https://www.nature.com/articles/s41928-020-00533-1.

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With the rise of genomic data, digital platforms have helped to manage large amounts of data, and AI has been used to process and analyze genomic data and spot variations in the code. Fast genome sequencing is important because most tests for the COVID-19 virus in patients rely on identifying part of the virus genome in a nose or throat swab, thus contributing to the rapid development of kits for COVID-19 testing (see case study 2).

Nextstrain[37] is an open-source project that analyzes all virus genomes from around the world to track the spread of the epidemic. It has collated thousands of genomes for COVID-19, including maps showing how different strains are spreading.

Case Study 2: Seegene Uses AI to Develop COVID-19 Test Kit

Seegene, a Korean molecular diagnostic company, developed the real-time RT-PCR test kit using AI algorithms, significantly reducing development time and costs. Seegene's test kit obtained European certification in February 2020; since then, 10 million tests have been exported to nearly 60 countries in Europe and Southeast Asia.

The task of developing a PCR reagent, which would normally take a group of 100 experts 3 months to accomplish, could be completed in only 3 hours using AI. The AI-developed diagnosis reagents enabled an accurate and rapid diagnosis to be made from a single test. The time to get the test results was also greatly reduced, from 24 hours to 6 hours.

Source: *Ministry of Science and ICT, Republic of Korea, "How We Fought COVID-19: A Perspective from Science & ICT," Jul. 2020, https://mofa.go.kr/eng/brd/m_22742/down.do?brd_id=20543&seq=28&data_tp=A&file_seq=1.*

Besides genomic sequencing, AI has been used for other aspects of diagnosis, for example, in the recognition of patterns and anomalies in images to detect cases of COVID-19 from X-rays and computed tomography (CT) scans of patients' chests—especially before the wide availability and accuracy of reverse transcription polymerase chain reaction (RT-PCR) test kits. An AI-based deep-learning model known as COVNet has been able to accurately distinguish between patients with COVID-19 and other community-acquired pneumonia and lung diseases from chest X-rays and CT scans.[38]

Medical AI solution developers such as Vuno, Lunit, and Medical IP have made their AI-based chest X-ray and CT scan reading solutions available on their websites free of charge. Hospitals and health centers around the world have installed their software to enhance diagnosis efficiency. Results can be obtained within five seconds of uploading a chest X-ray and within one minute of uploading a CT scan image.[39]

[37] Nextstrain, https://nextstrain.org/.
[38] Kedia, Priyansh, et al., "CoVNet-19: A Deep Learning model for the detection and analysis of COVID-19 patients," *Applied Soft Computing*, vol. 104, Jun. 2021, https://www.sciencedirect.com/science/article/pii/S1568494621001071.
[39] Ministry of Science and ICT, Republic of Korea, "How we Fought COVID-19: A Perspective from Science & ICT," Jul. 2020, https://mofa.go.kr/eng/brd/m_22742/down.do?brd_id=20543&seq=28&data_tp=A&file_seq=1.

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In recent years, there have been developments in integrating smartphones and diagnostic technologies, such as the use of forward-looking infrared radar for the thermal detection of fever and a smartphone-based microscope that transfers diagnostic results to a database for analysis. Smartphones can also be leveraged to coordinate, and report point-of-care testing used to diagnose patients without sending samples to centralized facilities, thereby enabling communities without a laboratory infrastructure to detect infected patients.

From the start of the pandemic, Iceland collected data on patient-reported symptoms through smartphone apps and combined these data with other data sets, such as clinical and genomic sequencing data, to reveal information about the pathology and spread of the virus. This approach has added to the knowledge base regarding the prevalence and transmission of asymptomatic COVID-19.[40]

2.5. VISUALIZATION TOOLS SUCH AS INTERACTIVE GEOSPATIAL MAPS AND DATA DASHBOARDS

The need to track COVID-19 has fueled the innovation of interactive geospatial maps and data dashboards that visually display data collected. Customizable and automatically updated dashboards allow rapid visualization of data collected from various sources to facilitate disease monitoring and surveillance and statistical and trend analysis for different groups working on different aspects of COVID-19 response.

At the global level, the WHO COVID-19 Dashboard,[41] Johns Hopkins University COVID-19 Dashboard,[42] Organisation for Economic Co-operation and Development (OECD). AI COVID-19 Watch,[43] and the COVID-19 resources of Our World in Data[44] make use of the open data sets shared by governments and other organizations to provide up-to-date maps and visuals that track COVID-19 cases, deaths, recoveries, testing, and vaccine dose administered as well as analysis of trends and insights on the state of the pandemic and public health response.

There are also efforts to capture the spread of COVID-19-related misinformation and disinformation online.[45] The platform reviews hundreds of millions of social media messages to interpret changes in public sentiment, the proliferation of bots, and the reliability of information being shared online.

[40] Hjelmgaard, Kim, "Iceland has tested more of its population for coronavirus than anywhere else. Here's what it learned," *USA Today*, Apr. 10, 2020, https://www.usatoday.com/story/news/world/2020/04/10/coronavirus-covid-19-small-nations-iceland-big-data/2959797001/.
[41] WHO, "Coronavirus (COVID-19) Dashboard," https://covid19.who.int/.
[42] Johns Hopkins University, COVID-19 Dashboard, https://coronavirus.jhu.edu/map.html.
[43] OECD.AI, "AI-powered COVID-19 watch," OECD AI Policy Observatory, https://www.oecd.ai/covid-19.
[44] Our World in Data, "Statistics and Research: Coronavirus Pandemic (COVID-19)," https://ourworldindata.org/coronavirus.
[45] An example of this is CoMuNe Lab, "COVID-19 Infodemic Observatory," https://covid19obs.fbk.eu/#/.

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With increasing availability of geospatial data from satellites, aircrafts, and drones, geographic information systems (GIS) are combining geospatial data and technologies to strengthen health systems. Companies with expertise in geospatial mapping such as CARTO,[46] Esri[47] and MapBox[48] have compiled expansive repositories of mapping tools and dashboards to help governments, businesses, health organizations, and civil society in COVID-19 response and recovery.

There are a number of maps and dashboards developed by governments, academic institutions, nonprofit organizations, and volunteers that visualize country- and local-level situations.[49] Case study 3 shows how Bangladesh has leveraged data from a variety of sources, displayed on a national COVID-19 dashboard, to track the spread of COVID-19 and aid decision-making in resources allocation.

In the US, there is the US COVID Risk and Vaccine Tracker with maps and dashboards developed by Covid Act Now, a nonprofit founded by volunteers in March 2020.[50] In the US, all states have a dashboard. A key problem is that the data provided are not consistent and comparable between states.

The US does not have standard national data on COVID-19. The US also lacks standards for state-, county-, and city-level public reporting on COVID-19 information (see section 3.3). Vital Strategies, a public health organization, has been working with governments across the US to improve the reporting of COVID-19 data using consistent indicators that can be compared across states over time. A model COVID-19 dashboard has been developed that can be adapted with state or county data to generate a color-coordinated dashboard for embedding in a website.[51] Efforts to promote commitment to responsible and ethical visualization and mapping are important, as such tools can easily be manipulated to mislead, contribute to misinformation and disinformation, and result in real-world consequences affecting human health and societal stability.[52, 53]

[46] Rushton, Dan, "CARTO Provides Free Visualization Software for Organizations Fighting COVID-19," CARTO, Mar. 11, 2020, https://carto.com/blog/carto-free-for-fight-against-coronavirus/.
[47] Esri, "COVID-19 GIS Hub," https://coronavirus-disasterresponse.hub.arcgis.com/.
[48] MapBox, "COVID-19 Response," https://blog.mapbox.com/covid19-response/home.
[49] Muggah, Robert, "Why maps matter in our response to COVID-19," World Economic Forum, Aug. 19, 2020, https://www.weforum.org/agenda/2020/08/covid-19-maps-tracking/.
[50] COVID Act Now, "U.S. COVID Risk & Vaccine Tracker," https://covidactnow.org/?s=1945861&utm_campaign=dec2020&utm_medium=banner&utm_source=ces.
[51] Prevent Epidemics, "Essential Indicators Dashboard," https://preventepidemics.org/covid19/indicators/dashboard/.
[52] Field, Kenneth, "Mapping coronavirus, responsibly," ArcGIS Blog, Feb. 25, 2020, https://www.esri.com/arcgis-blog/products/product/mapping/mapping-coronavirus-responsibly/
[53] Mooney, Peter, and Levente Juhász, "Mapping COVID-19: How web-based maps contribute to the infodemic," *Dialogues in Human Geography*, Jun. 23 2020, https://journals.sagepub.com/doi/full/10.1177/2043820620934926.

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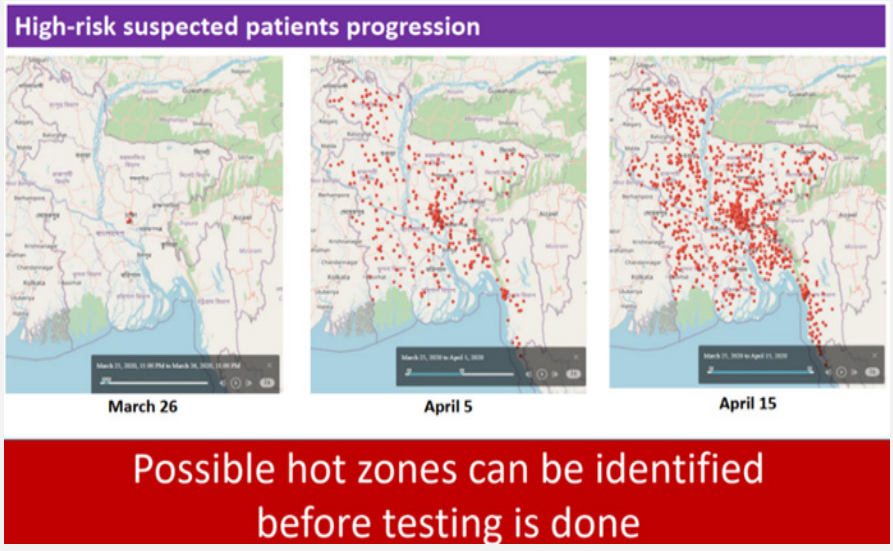
Case Study 3: Bangladesh's COVID-19 Collective Intelligence System

The system combines data from various sources to create a dashboard for supporting decision-making. Data sources include the following:

- Citizen self-reporting of symptoms through the telephone hotline, IVR and USSD systems, and app and web services;
- Reports from community health-care workers and physicians;
- Reports from teachers, religious leaders, postal workers, and social safety net workers;
- Reports from COVID-19 tests;
- DHIS2 national health information system data;
- DGHS hospital management data; and
- Access to location data and mobility patterns through collaboration with all mobile network operators.

With the data, visualizations were created on dashboards for health-care providers, government administration, and the public (see https://covid19bd.idare.io/).

The dashboard for health authorities is used to identify "hot zones"—where there is a high prevalence of infections—for COVID-19 testing since it is not possible to conduct mass testing due to the lack of test kits and the high cost of such mass testing.



The dashboard is also used to manage hospital load and monitor compliance with quarantine and self-isolation measures. Measures for ensuring data privacy and security, however, are not elaborated.

Source: *Chowdhury, Anir, "COVID-19 Data Intelligence System in Bangladesh," presentation, 2020.*

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2.6. SMARTPHONE APPS FOR CONTACT TRACING, SYMPTOM REPORTING, CHATBOTS, TELEMEDICINE, AND MOBILITY PATTERN ANALYSIS

A wide array of smartphone apps has been developed for pandemic management, specifically for contact tracing, symptom checking and reporting, telemedicine, and more. In the Republic of Korea, the government release of open data related to COVID-19 spurred the rapid development of a variety of smartphone apps to help the public access real-time information and cope during the pandemic (see case study 4).

Case Study 4: Republic of Korea Releases Open Data for App Development

The release of open data related to COVID-19 (https://www.data.go.kr/en/index.do), including in the form of open application programming interfaces (APIs) for developers, led to many local enterprises developing relevant apps for the public to cope with the pandemic. For example, real-time data of the supply of publicly distributed face masks at pharmacies and other distribution points were provided to people through mobile apps and web services, reducing confusion and inconvenience while raising distribution efficiency.

Source: *Government of the Republic of Korea, "How Korea responded to a pandemic using ICT: Flattening the curve on COVID-19," Apr. 15, 2020, http://www.moef.go.kr/com/cmm/fms/FileDown.do?atchFileId=ATCH_000000000013739&fileSn=2.*

Contact Tracing

Since the onset of the pandemic, many countries have developed apps for contact tracing. The MIT Contact Tracing App Database referenced 48 countries with contact-tracing apps.[54] Contact tracing (discussed in more detail in section 3.4) is the identification of those who may have been infected by known carriers. Using the sensor technology within smartphones, if a user tests positive, it is possible to check back and inform *all* contacts of this—not only those the user knows but all who have been within an infectible distance while a carrier was contagious. Different groups around the globe have worked to develop the technologies for contact tracing, usually with either GPS information or Bluetooth, and countries have used either a centralized server structure for storing data or a decentralized structure focused on users' devices. Some of the solutions are open source and others are proprietary (see case study 5).

[54] Flourish, "MIT Technology Review Covid Tracing Tracker," Mar. 16, 2021, https://public.flourish.studio/visualisation/2241702/.

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Case Study 5: Singapore's TraceTogether Contact-Tracing App and Token

In Singapore, a mobile app called TraceTogether was launched that exchanges Bluetooth signals when individuals are in proximity to each other. The app records these encounters and stores the encrypted data in their respective mobile phones for 21 days. If an individual is diagnosed with COVID-19, Singapore's Ministry of Health accesses the data, following the user's consent, to identify contacts of the infected person. Subsequently, a TraceTogether Token was designed for those who may not own or prefer not to use a smartphone to participate in digital contact-tracing efforts. Like the TraceTogether app, the Token only captures proximity data via Bluetooth signals. The encrypted data is kept on the device until the user consents to share it with the Ministry of Health for contact tracing.

Source: *Government of Singapore, "Token Go Where," https://token.gowhere.gov.sg/.*

Despite countries such as China, the Republic of Korea, Singapore, and Vietnam attributing their success in controlling the spread of the virus to contact-tracing apps, research studies show that there has been little scientific evidence of their efficacy. Moreover, in the absence of standardized validation tests and protocols for contact-tracing technologies, it is difficult to accurately engage in a robust risk-benefit analysis.[55]

Contact-tracing apps have been developed that provide additional functions, such as alerting users when they have come into contact with a COVID-19 positive person and advising them of next steps. In Vietnam, a number of contact-tracing apps have been developed for a variety of purposes (see case study 6).

[55] Gasser, Urs, "Digital tools against COVID-19: taxonomy, ethical challenges, and navigation aid," *The Lancet*, Aug. 1, 2020, https://www.thelancet.com/journals/landig/article/PIIS2589-7500(20)30137-0/fulltext.

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Case Study 6: Vietnam's Digital Contact-Tracing Efforts

Within days after the first case was detected in Vietnam in January 2020, the central government established a subcommittee involving telecom companies to mobilize their collaboration in supporting a COVID-19 response. By March 2020, a number of apps were launched to support detection, reporting, contact training, alerting, containment, and treatment.

The NVOCI app, for example, is multipurpose and allows users to declare their own and their families' health status and report suspected cases. It also includes a real-time map of detected cases and clusters of infections and serves as the official channel for state agencies to deliver rapid updates and public health recommendations to users. The Hanoi SmartCity App helps authorities track and monitor people who have been infected and isolated, sending a notification to the heads of districts if the patient moves more than 30 meters from the designated quarantine area. Installation of the two above-mentioned apps is optional, but the Vietnam Health Declaration App is mandatory to track and trace travelers entering Vietnam.

These apps have raised concerns about privacy and mass surveillance, especially after identities of infected individuals were leaked on social media. In response, the government leveraged its tech startup ecosystem and launched Bluezone within a month. Bluezone is an open-source, low-energy Bluetooth-enabled mobile app that notifies users if they have been in close contact with someone who tested positive for COVID-19. The use of Bluetooth is generally more privacy friendly than tracking techniques that use GPS or mobile phone data. Rather, it creates a log of interactions that remain on the phone, so users' names and numbers are not disclosed. Nevertheless, the system is centralized, and the data is accessible by health authorities. When a new case of COVID-19 is confirmed, health authorities enter this data into the system, which then sends a notification to other smartphone users with Bluezone installed. The app analyzes and compares users' history of exposure (within two meters of a positive case in the last 14 days). If it finds a match, Bluezone will alert users at risk of infection and instruct them to contact health authorities to seek assistance. Unlike other Bluetooth-enabled contact-tracing apps that consume a lot of energy, Bluezone consumes only about 10% of battery life when enabled for a full day. These apps are all designed for smartphone users, yet only 45% of the population in Vietnam has access to smartphones, limiting the scale of these apps. Nevertheless, the information collected by these apps has given health authorities nearly real-time access to data for monitoring and identifying hotspots for increasing COVID-19 testing. Data from all the apps synchronize to one large database managed by the Ministry of Health.

Sources: *Exemplars in Global Health, "NCOVI and Bluezone in Vietnam: Govt. Launches Digital Apps to Contain COVID-19," https://www.exemplars.health/emerging-topics/epidemic-preparedness-and-response/digital-health-tools/ncovi-and-bluezone-in-vietnam; Pollack, Todd, et al., "Emerging COVID-19 Success Story: Vietnam's Commitment to Containment," Exemplars in Global Health, https://www.exemplars.health/emerging-topics/epidemic-preparedness-and-response/covid-19/vietnam .*

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