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Opinion Paper

Information technology solutions, challenges, and suggestions for tackling the COVID-19 pandemic

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ABSTRACT

Various technology innovations and applications have been developed to fight the coronavirus pandemic. The pandemic also has implications for the design, development, and use of technologies. There is an urgent need for a greater understanding of what roles information systems and technology researchers can play in this global pandemic. This paper examines emerging technologies used to mitigate the threats of COVID-19 and relevant challenges related to technology design, development, and use. It also provides insights and suggestions into how information systems and technology scholars can help fight the COVID-19 pandemic. This paper helps promote future research and technology development to produce better solutions for tackling the COVID-19 pandemic and future pandemics.

1. Introduction

The COVID-19 pandemic has caused an immense impact on hospital systems, businesses, schools, and the economy. Telemedicine, telework, and online education become essential to help society slow down the spread of the coronavirus (Chavez & Kounang, 2020; Loh & Fishbane, 2020; Young, 2020). The pandemic has generated a rapid demand for efforts to use innovative technologies to cope with damage from COVID-19 on our life (O'Leary, 2020).

The pandemic has not only raised opportunities to advance technology-based solutions but also provided a rare opportunity to study the research and practice of technology, including information management, work practices, and design and use of technologies (Sein, 2020). The quick transition to telehealth, telework, and online education in response to the coronavirus threat is a reminder that digital technology brings many benefits and can play an essential role in managing and reducing the risks caused by the lockdown during the pandemic and even after the pandemic (Richter, 2020). It is well known that information systems and information technology (IS/IT) play an important role in healthcare, clinical decision support, emergency/crisis response, and risk management (Angst & Agarwal, 2009; Ben-Assuli & Padman, 2020; Chen, Sharman, Chakravarti, Rao, & Upadhyaya, 2008; Thompson, Whitaker, Kohli, & Jones, 2019). Many IS/IT professionals are working in various ways to help fight the pandemic, including developing products to combat the virus, tracking and predicting its spread, and protecting hospitals from cyberattacks (Mingis, 2020). Information systems and technology scholars should contribute to this global effort to fight the COVID-19 and future pandemics (Ågerfalk, Conboy, & Myers, 2020) by leveraging their previous experience and knowledge on responding to crises, decision making, remote working, managing virtual teams, analyzing large data sets, etc. There is currently a shortage of research contributions in the areas of information systems (IS) to help fight the COVID-19.

The pandemic has implications for the design, development, and use of information systems and technologies (Sein, 2020). Information systems and technology researchers and practitioners can help conduct an analysis of the COVID-19 pandemic data and engage in potential emerging research topics, such as facilitating work while social distancing, contactless commerce, face recognition when wearing masks or in other crises, COVID-19 apps in terms of privacy, crowdsourcing, donating data, and tracking cases, robotics and their impact on organizations, monitoring vulnerable vs. non-vulnerable for their impact on work, changing patterns of supply and demand for fragile supply chains and autonomic systems, virtual communication tools, online education breakthroughs, and separation of work and private life (O'Leary, 2020). Rai (2020) also identified some opportunities for IS research to contribute toward building resilience to pandemics and extreme events including (i) redesigning the public health system from reactive to

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proactive through the use of real-time surveillance systems and contact tracing tools to stem transmission, (ii) transforming organizations through enhancing crisis-driven agility and reducing crisis-revealed fragility, and (iii) empowering individuals and communities through adapting, coping, and stemming the infodemic. Dwivedi et al. (2020) present an assessment of critical challenges of COVID-19 through an information system and technological perspective and offer insights for research and recommendations studying the impact of COVID-19 on information management research and practice in transforming education, work, and life.

To reduce the overlap with O'Leary (2020) and Rai (2020), this paper primarily focuses on technology integration from the data, system, and people perspectives to discuss how information systems and technology scholars could contribute knowledge and insights to help fight the pandemic. As information systems and technologies are becoming foundational to society, information systems and technology scholars are in an excellent position to leverage their experience and knowledge with information systems and various technologies to improve existing systems and technology practice and help the society become digitally resilient to future large-scale disruptions.

2. Existing IT solutions

This paper uses the data-people-system framework to examine technology solutions to mitigate the impact of the COVID-19 pandemic. The data-people-system framework by Bardhan, Chen, and Karahanna (2020) demonstrates a multidisciplinary roadmap for controlling and managing chronic diseases by focusing on the following three components: (1) extraction, integration, and delivery of health data; (2) interoperability of systems; and (3) guidelines and interface to guide people's behavior. It must be noted that the original data-people-system framework was proposed for chronic disease management, which needs further development to be proactive and take account of the pandemic context.

The COVID-19 pandemic has revealed the urgent need to redesign the public health system from reactive to proactive and develop innovations that will provide real-time information for proactive decision-making at the local, state, and national levels of public health systems (Rai, 2020). COVID-19 is different from chronic diseases as it is highly contagious, can pass from people to people, and has a high mortality rate. Additionally, as COVID-19 is a new disease, scientific understanding of the virus that causes it, medical response, and actions by governments and organizations continue to evolve. The impact of COVID-19 on people and society is changing daily in ways that would have been unthinkable. As the current pandemic situation and its consequence continue to remain fluid, combating the COVID-19 pandemic requires strong coordination of various resources.

In response to the threats and risks posed by COVID-19, this paper adopts the data-people-system framework to examine the existing technology solutions for fighting against the COVID-19 pandemic and identify their challenges and potential opportunities for information systems and technology researchers. In particular, we have conducted an extensive search using academic databases and web search engines with a variety of queries related to technology, coronavirus, and COVID-19, synthesizing the related discussions in newspapers, news websites, blogs, white papers, practitioner websites, grey literature or academic literature to help understand the existing information systems and technology solutions and the roles that they could play in this challenging time of the pandemic.

Some new technology applications such as mobile COVID-19 contact tracing apps and chatbots have been recently developed to fight this pandemic. Applying these technologies can help reduce the impact of the coronavirus pandemic on people, organizations, and society. Effective and innovative use of emerging technologies can help identify community spread of the coronavirus, monitor the condition of the infected patients, improve the treatment of COVID-19 infected patients, and help develop medical treatments and vaccines (Johnstone, 2020). This section evaluates these technology applications based on the data-people-system framework by Bardhan et al. (2020).

Technologies powered by artificial intelligence (AI) including machine learning, image recognition, and deep learning algorithms can be used for early detection and diagnosis of the infection, more rapid drug discovery for developing new treatments (Brohi, Jhanjhi, Brohi, & Brohi, 2020). A few companies also repurposed existing AI systems that were initially designed for other areas to assist in social distancing enforcement and contract tracing (Sipior, 2020).

3D Printing Technology can help make face masks and other Personal Protective Equipment (PPE) for healthcare workers. Markforged has partnered with Neurophotometrics to produce 3D printed rayon wrapped nasopharyngeal (NP) swabs for COVID-19 testing. The swabs take less than three minutes to make, can be much quicker at collecting viral particles (Markforged, 2020).

Big Data Analytics can be used to identify people that need quarantine based on their travel history, predict the COVID-19 curve, speed up the development of antiviral drugs and vaccines, and advance the understanding of the COVID-19 spread across both time and space. In Taiwan, big data analytics has been successfully applied to help identify COVID-19 cases and generate real-time alerts through analyzing clinical visits, travel history, and clinical symptoms (Wang, Ng, & Brook, 2020; Wang, Zha, et al., 2020; Watson, Ives, & Piccoli, 2020).

HPC infrastructures and supercomputers are needed to address complex scientific problems and process big datasets in shorter time frames in order to develop new drugs and vaccines. The COVID-19 High-Performance Computing Consortium was launched to leverage the computing resources and supercomputers in the US. The consortium includes 16 public and private entities such as the US Department of Energy (DoE), IBM, and other academic and industry leaders (Woo, 2020).

Mobile apps via smartphones and video-conferencing tools can be used to track the movements of individuals, alert people from visiting COVID-19 hotspots, help doctors to diagnose patients through video services and telemedicine/telehealth, support people with online shopping, e-learning, online meetings, and telework (Marr B., 2020). Various phone and network-powered apps have been developed to help healthcare workers and ordinary people in this crisis. For example, the U.S. National Science Foundation funded an award to support researchers at Princeton University in developing a system to deploy a firmware update to mobile phones to provide proximity tracking ability for health officials. To preserve users' privacy, the key to the proximity data would be stored on the phone itself and could only be unlocked when the phone's owner voluntarily provided it to health officials. Suppose a person tests positive for a disease such as COVID-19. In that case, health officials could then use the system to automatically identify all other cellphone users who were within a certain distance of the infected person for a certain time. The time and distance could be determined by health officials based on knowledge of the disease. Healthcare departments can contact those potentially infected people, advise them of the exposure, and instruct them to get tested for the disease and self-quarantine as needed (WHO, 2020).

Robots have been applied to fight the coronavirus outbreak. For example, hospitals use robots as support systems to deliver food and medicine, disinfect rooms, and other hotspots without direct human interaction with patients. A CNN news report shows that doctors in Seattle have used a telepresence robot to treat the first confirmed patient who tests positive for coronavirus in the United States (Chavez & Kounang, 2020). Drones also are used to deliver medical supplies, patrol public areas, track non-compliance to quarantine mandates, and so on (Marr B., 2020; Marr N., 2020).

The Internet of Things (IoT) can be used for the surveillance of people infected by coronavirus to reduce the spread of the coronavirus (Kumar, Kumar, & Shah, 2020). IoT consists of several functional components: data collection, transfer, analytics, and storage. IoT sensors installed on mobile phones, robots, or health monitors can be used to collect data. Next, sensor data would be sent to the cloud server for processing, analytics, and decision-making. As an example, IoT helps check whether patients follow quarantine requirements. IoT can also be used to take the remote patients' temperatures and then transmit the data through mobile devices to the doctors to monitor, track, and alert while reducing the chance for coronavirus inflections (He, 2020). Additional roles of IoT technologies include the use of smart wearable devices in response to COVID-19 in early diagnosis, quarantine time, and after recovery (Nasajpour et al., 2020).

Blockchain is a distributed ledger technology that records online transactions. It is regulated through a consensus mechanism and is secured with cryptography (Chong, Lim, Hua, Zheng, & Tan, 2019). As an example, a smartphone app that leverages blockchain technology and AI was developed to help fight the coronavirus pandemic. Blockchain technology enables the app to give each participant a "digital identity" controlled by a private key that brings access to a digital version of paper certificates issued by the government. These allow the confirmed healthy people to leave home to buy food or to work (Sinclair, 2020). Blockchain has also been used to prevent the information from being manipulated by unauthorized parties. During the outbreak, a Chinese payment processor and financial services company used blockchain technology to monitor the process of processing claims and making payouts in a more secure and trustworthy way (News Staff, 2020). Blockchain technology has been applied to resolve the tension and trust issues between maintaining privacy and addressing public health needs, such as tracking infected patients in the fight against COVID-19 (Khurshid, 2020).

All the above technologies require the integration of data, people, and systems. Based on their primary focus and original design intention for use in practice, we broadly classify them into three categories. The data-centric technologies for combating COVID-19 include machine learning/deep learning, big data analytics, and HPC infrastructure. The people-centric technologies include robots and 3D printing technology; they are used to serve patients better and protect healthy people from infections with the support of specific systems. The system-centric technologies include digital contact tracing apps, the Internet of Things, and Blockchain; they are developed based on system concepts to monitor patients and prevent healthy people from contracting coronavirus. Some of these technologies are interrelated and may transcend multiple categories as they are being used in dealing with the pandemic, depending on how creative people are using them in varying contexts. For example, big data analytics that identify people who need quarantine could have system-centric or people-centric aspects depending on the specific purposes and use by different government agencies, health authorities, hospitals, and organizations. Table 1 summarizes the three categories of technologies and their required support from data, people, and systems.

Table 1
Summary of technology solutions for COVID-19.

Technologies	COVID-19 Solutions	Data	System	People
Machine Learning/Deep Learning	Analyze epidemic situations (Punn, Sonbhadra, & Agarwal, 2020)	real-time information from the		
	Diagnostic and prognostic analysis (Wang, Ng, et al., 2020; Wang, Zha, et al., 2020; Watson, Ives, et al., 2020)	computed tomography images	fully automatic deep learning system	5372 patients
	Automatically detection of COVID-19 cases (Ozturk et al., 2020)	raw chest X-ray images		125 patients
	Early triage of critically ill COVID-19 patients (Liang et al., 2020)	medical records from laboratory-confirmed hospitalized cases		1590 patients, of which 131 developed critical illness, from 575 medical centers
Big Data Analytics	Early detection and diagnosis (Chen et al., 2020)	smart contact tracing–based mobile sensor data and other big sensor surveillance data		627,386 potential contact-persons in Taiwan
	Tracking movements of people, understanding epidemic trends, and control and regulate pharmaceutical supplies (Liu., 2020; Ting, Carin, Dzau, & Wong, 2020)	26.76 million sleep and resting heart rate data points from users' smart bracelets and watches	Baidu Migration Map	115,000 people in Hubei province and the nearby Anhui province
HPC Infrastructures	New drug and vaccine development (Wang, 2020)	screening 2201 approved drugs		
	Target exploration and drug selection (Liu, 2020)		Alibaba's super- computing power	
Robots	Deliver food and medicine; Disinfect rooms; Treat patients (Yang et al., 2020)		Robot-controlled noncontact ultraviolet (UV) surface disinfection; Mobile robots for temperature measurement; Automated or robot-assisted nasopharyngeal and oropharyngeal swabbing; Autonomous drones or ground vehicles; Automated camera systems; Social Robots	Patients; Healthcare workers
3D Printing Technology	Produce protective masks; Make test swabs (Choong et al., 2020)		Personal protection systems; Practice system for COVID-19 swab testing procedures; Temporary emergency dwelling	Patients; Healthcare workers
Digital Contact Tracing Technology	Track movements of individuals; Alert people from visiting COVID-19 hotspots (Budd et al., 2020)	Mobile data; Social media data	Smartphone tracing apps	Patients; Healthcare workers; Public
Internet of Things	Ensure patient compliance with quarantine requirements; Monitor patients remotely (Rahman et al., 2020)	Mobile data; Sensor data	IoT based smart disease surveillance systems	Patients; Public
Blockchain	Develop "digital identity" for healthy people; Process Claims and make buyouts (Bansal, Garg, & Padappayil, 2020)	COVID-19 related health data	Immunity certificate system	Public

3. Challenges

The COVID-19 pandemic has exposed the weaknesses of existing public health systems. The use of technologies to combat the pandemic raises challenges in many aspects. The specific nature of the COVID-19 pandemic requires strong coordination of connected data, people, and systems (Bardhan et al., 2020) to facilitate worldwide collaboration in fighting against it. Traditionally, public health agencies and healthcare stakeholders have not used the same systems, data formats, or standards, hampering the ability to identify trends and develop interventions against the pandemic. Public health researchers, epidemiologists, and government officials need to be connected via integrated systems with connected data to understand the evolving pandemic better and make collective decisions on addressing this crisis. As people play a crucial role in this fight against the COVID-19, it is essential to connect, coordinate, and support various stakeholders through innovative and integrated technologies.

3.1. Connecting systems to integrate technologies

Emerging technologies including the IoT, big-data analytics, AI, and blockchain can be integrated to develop smart strategies for addressing immediate challenges caused by the coronavirus. For example, Facebook has used artificial intelligence and big data technologies to tap into satellite imagery and census data to generate maps that display population density, demographics, and travel patterns in order to help decide where to send supplies or how to reduce the spread (Holt, 2020). Big data analysis of geographic information systems (GIS) and IoT sensor data collected from infected patients can assist epidemiologists to trace patient zero and help identify close contacts of the infected patients (He, 2020). The U.S. National Science Foundation recently funded a RAPID award that explores the capabilities and potential of integrating social media big data, geospatial data, and AI technologies to enable and transform spatial epidemiology research and risk communication. The emerging convergence of blockchain, the IoT, and AI holds great promise for addressing the issues of trust and security in public health (Gurgu, Andronie, Andronie, & Dijmarescu, 2019; Singh, Rathore, & Park, 2020). For example, medical device data and non-personal sensor data collected by IoT can be stored and shared on the blockchains. Patients' personal data can still be stored in the hospitals' enterprise systems due to privacy regulations such as the GDPR (Agbo, Mahmoud, & Eklund, 2019; Onik, Aich, Yang, Kim, & Kim, 2019). AI and big data technologies can be leveraged to analyze and visualize both on-chain and off-chain data and provide near real-time analytics and recommendations to relevant stakeholders through customized dashboards.

Currently, most systems and apps that have been used to deal with the pandemic are poorly inter-connected since they are developed by different government agencies, health authorities, and organizations. There is a lack of systematic frameworks and tools to accomplish systematic integration across various technologies in the global response against pandemic challenges.

To integrate these different technologies, guidelines and systematic efforts are required to coordinate the collection of large amounts of quality data related to coronavirus cases. The design of effective big data analytics and AI algorithms requires public health departments and hospitals to provide a large amount of reliable and high-quality data. Due to a lack of standards, the integration of multiple data sources for promoting interoperability is challenging. Some data sources may be well structured, while others are not (Pham, Nguyen, Huynh-The, Hwang, & Pathirana, 2020). There is also a need to generate standardized protocols to facilitate communication across systems without compromising data security. Governments, leading tech firms, health organizations, and other relevant stakeholders need to collaborate efficiently and effectively to define the standard, protocols, data formats and types, etc.

Information systems and technology scholars have been examining system integration in enterprise or organizational environments over the past several decades (Henningsson, Yetton, & Wynne, 2018; Ravichandran & Rai, 2000; Xu, 2011). Information systems and technology scholars also studied the role of information systems in crisis, disaster, and emergency response (Chen et al., 2008; Pan, Pan, & Leidner, 2012; Valecha, Rao, Upadhyaya, & Sharman, 2019). Information systems and technology researchers should take the opportunity to offer their expertise in system integration and experience with emergency or crisis response systems to provide recommendations and strategies to help developers with various systems and technology integration efforts.

3.2. Connecting data to share best practices

As the World Health Organization (2020) suggests, new collaboration and knowledge sharing are needed to deliver targeted solutions through a coordinated effort to support countries facing stages of this epidemic in different ways and at different times. Faced with a global pandemic, countries need to work together to share data, information, resources, effective practices, and strategies to combat the coronavirus. In addition, global collaboration among relevant stakeholders between organizations and governments will be crucial to coordinating the sharing and use of data and knowledge to solve the problems we encountered during this pandemic. For example, China took extraordinary measures for the shutdown of Wuhan, a large city with millions of people, to control the spread of the coronavirus (Lin et al., 2020). Useful experience and lessons related to its efficacy as a containment measure could be valuable for other countries who are considering similar measures. Data integration and knowledge management (KM) technologies such as web portals, knowledge repositories, and online communities of practice can be used to empower data connections to leverage resources more effectively and efficiently at a lower cost (Bardhan et al., 2020; Pan, Cui, & Qian, 2020).

Knowledge-based systems such as expert systems and intelligent decision technologies have been used to support health workers in detecting and diagnosing patients, and providing decision-making support for relevant healthcare stakeholders and decision-makers in a pandemic crisis (O'Leary, 2020; Rehfuess et al., 2019). Data mining and visualization technologies have been used to discover and visualize knowledge evolution across time and locations as the coronavirus outbreak continues to evolve. Online health communities have been established to help healthcare workers, patients, and other stakeholders learn about COVID-19, symptoms, and the effectiveness of treatments (Yan & Tan, 2014; Ziebland et al., 2004). However, these systems often operate in a silo, and the data, information, and knowledge stored in their systems are not widely shared. To allow various systems and stakeholders in different communities of practice to share knowledge within and across their individual areas, we need to create an environment to encourage people across countries to share knowledge instead of keeping or holding the knowledge. In the context of a coronavirus outbreak, strategies could be developed to assess the quality of the knowledge and help systems break down silos that hinder communication and sharing data more efficiently.

Besides, behavioral issues need to be addressed to facilitate the sharing of data and best practices among stakeholders. Over the years, there have been a number of calls for information systems and technology researchers to consider the unintended or negative consequences of technologies (Chiasson, Davidson, & Winter, 2018). IT professionals have been rushing to build apps, services, and systems for contact tracing, tracking, and quarantine monitoring. Some of these technologies are lightweight for short-term use, while others are pervasive and invasive (O'Neill, Ryan-Mosley, & Johnson, 2020). For example, many researchers have advocated the use of digital contact tracing and health code apps (Oxford Analytica, 2020) to reduce the spread of the disease. Some people are concerned that short-term fixes such as monitoring of infected people via an app could lead to a permanent state of surveillance by the government (Lin & Martin, 2020). Digital contact tracing can be effective but is controversial because it could have disastrous consequences if not implemented with proper privacy checks and encryption (Huang, Sun, & Sui, 2020). For example, some experts are questioning how anonymous the data is and whether it can be easily de-anonymized to identify or infer the personal identity of infected persons (Lee & Roberts, 2020). Healthy authorities may misuse or abuse the data they collected from digital tracing mobile apps for long-term and other purposes. Many people are concerned about whether these coronavirus-fighting apps are secure to use, how these apps will preserve privacy, and what policies are needed to prevent the abuse (O'Neill et al., 2020). These concerns are likely to undermine public trust and affect people's adoption of emerging technologies. There is also a need for further research to investigate security, privacy, and ethics issues related to technologies developed for fighting this pandemic.

Knowing about coronavirus exposures is important for containing the spread of COVID-19. Governments around the world are introducing technologies such as mobile apps to help health officials trace contacts of people newly infected with the coronavirus. These mobile apps work by recording whom a person comes close to—then alerting those people if a person contracts COVID-19. Out of precaution to protect people's privacy and reduce people's concern on increased surveillance, Australia made it illegal for non-health officials to access data collected on smartphone software to trace the spread of the coronavirus. The European Data Protection Board (EDPB) has published guidance for the use of location data and contact tracing tools in order to mitigate privacy and security concerns. Apple and Google disclosed a series of changes including stronger privacy protections and accuracy to their COVID-19 contact tracing initiative.

On the other hand, some researchers think that it is justified to temporarily relax privacy measures for such technologies in the hopes of possibly saving lives, serving the public good, and protecting public health under pandemic circumstances. Many people have been engaged in self-disclosure on social media to share personal information such as health status and preventive behaviors (e.g., wearing masks and buying sanitizing products) because sharing such information contributes to the public good (Nabity-Grover, Cheung, & Thatcher, 2020). Some researchers hold that privacy concerns should not decrease the usefulness of technology to protect public health (Cho, Ippolito, & Yu, 2020). They do not think such technologies were designed to make a permanent change to society (Ferretti et al., 2020). The lack of a consensus on privacy protection in technologies against COVID-19 indicates a strong need for establishing best practice guidelines to reassure citizens on data collection (Fahey & Hino, 2020).

Public trust and confidence are necessary to people's adoption of various technologies including sharing their data to address the challenges caused by this pandemic (Ferretti et al., 2020). Currently, the adoption of digital contact tracing apps is voluntary in western countries. It has been recognized that these issues cause more controversy in Western countries with a culture of individualism such as Europe and the U.S. than in countries with a culture of collectivism. However, at least 60 percent of people with smartphones would need to opt-in for such apps to be effective (Scott, 2020). How to incentivize mass user adoption of these apps is a challenge. In the context of this coronavirus pandemic with a lot of loss of life, information systems and technology scholars can help evaluate the use of digital data and technologies including AI-related algorithms in a responsible manner, provide oversight for user-related data, develop ways to incentivize users to share relevant data as needed, help develop mechanisms to ensure that technology design and use are guided by ethical principles in order to ensure transparency, equity, and security and increase public trust and confidence (Ienca & Vayena, 2020; Lee & Roberts, 2020). Information systems and technology scholars can also help identify best practices to implement responsible data-collection and data-processing, and achieve a balance between privacy and utility of the proposed technologies.

3.3. Connecting people with enhanced collaborative tools and IT infrastructures

The COVID-19 outbreak is rapidly changing the workplace. Millions of people are moving their workspaces to their homes through teleworking. Many industries benefit as knowledge workers learn to operate virtually, work from home, and use cloud services to process and store files. We are witnessing wider acceptance of online services by people and diverse types of industries during this pandemic. The importance of IT infrastructure in enabling teleworking, online learning, e-government, e-commerce, and other online activities has been widely recognized. The pandemic is forcing a record number of employees to work remotely for an extended duration, which results in heavy traffic on remote connectivity networks. There are vital needs for society to continue investing in IT infrastructure and accelerate digital transformation efforts to deal with the impact of COVID-19 and future public health crises (Watson, Ives, et al., 2020). Companies need to enhance their investments in tools such as video conferencing and group decision-making support systems (Xu, Du, & Chen, 2015) to enable personnel and distributed teams to work remotely and collaborate virtually. On the other hand, costs for IT infrastructure are exploding as employees practice teleworking and students take online classes in light of the COVID-19 outbreak. It is necessary to understand the rise in hard costs of IT infrastructure associated with meeting spiking demand. As the pandemic continues to evolve, IT infrastructures need to be enhanced for workers to perform their duties safely and healthily (CISA, 2020). Some critical tasks may not be executable from home, and workarounds need to be identified. It is particularly necessary to identify the factors that drive the cost of serving the increased demand due to teleworking, such as cloud server costs, video conferencing costs, additional licenses for support products. Cloud services should be further leveraged through existing infrastructures such as Google Cloud, Azure, AWS, or Salesforce. Strategies need to be developed to keep essential functions and services up and running. CIOs need to think about retrofitting the present for the new needs or creating new systems for new situations (Watson, Ives, et al., 2020). Finally, digital infrastructure readiness and resilience are also important areas to explore (Papagiannidis, Harris, & Morton, 2020).

Group decision-making is often needed for complicated situations involving much uncertainty and time constraints. Information systems and technology scholars can share their experience with group decision support systems to support collective decision making regarding the evolving pandemic, help connect stakeholders at different levels to build consensus, and support governments, health authorities, organizations, and the public to make culturally appropriate and sensitive decisions regarding the infection detection, infection prediction, and infection avoidance and when to reopen the economy. Information systems and technology scholars can also help build collaborative information systems, community-based information systems, talent, and volunteer networks to leverage the expertise and time of various stakeholders. As an example, an innovative application is a wastewater COVID-19 early warning detection system. Wastewater detection of COVID-19 could act not only as a supplement to medical testing but as an early warning system for community monitoring and prevention. Continued wastewater-based monitoring could alert public health officials whether the coronavirus is still circulating in a community (Chakradhar, 2020). A lot of volunteers are needed to make the wastewater COVID-19 early warning detection system successful. Information systems and technology scholars can contribute by providing expertise to help the government, authorities, and local communities to design and develop a volunteer network to engage and organize a large number of volunteers, and help build a collaborative information system to deliver a national program in this area (Thomas & Bertsch, 2020). As Rai (2020) points out, swift deployment of grassroots innovation could develop rapid solutions to meet urgent needs.

3.4. Studying human behavior with technologies and digital divide

It is important to study human behavior when designing, building, and using technologies as more COVID-19 related technologies are being developed, integrated, and used by governments, organizations, and people. Lots of efforts to combat the pandemic incorporate new technological advances and approaches in integrating various systems and innovations. However, we need to acknowledge that people's misbehavior with technologies may reduce the eff ;ectiveness of the technology-related interventions or countermeasures on containing the coronavirus break. Information systems and technology scholars can contribute by incorporating their understanding of human behavior into the technology design and development process, leading to more effective technology (Pfleeger & Caputo, 2012). A large number of theories and models such as the technology acceptance model, innovation diffusion theory, the theory of reasoned action, health belief models and theory of planned behavior, social cognitive theory, and motivation theory can be used to explore the acceptance and use of COVID-19 related technologies such as telehealth technologies, study the strategic role of various technologies in dealing with the COVID-19 pandemic, and also examine unintended consequences of using technologies. For example, information systems and technology scholars can examine online users' information sharing behavior, study how online patient communities should be engaged and incentivized to share information and support COVID-19 patients and caregivers, and how to analyze data to reveal new insights to support policy-making for health departments and medical knowledge discovery (Bardhan et al., 2020).

We have also witnessed a digital divide during the pandemic. The digital divide broadly refers to the uneven access to digital content and connection because of some people who do not own or have easy access to technology. People's ability to use technologies effectively remains inequitable (Newman, Browne-Yung, Raghavendra, Wood, & Grace, 2017). As emerging technologies such as mobile apps, AI, IoT, and big data analytics are increasingly used to fight the pandemic, existing disparities, inequality, and biases are further reinforced (Park & Humphry, 2019). As people spent more time working, learning, socializing, and shopping online at home, this pandemic provides a chance to assess the issues and challenges faced by the rapid digital transformation of organizations and how the digital divide impacts people (e.g., underprivileged populations, women, workers in healthcare, elderly and those at-risk) (Venkatesh, 2020). Therefore, information systems and technology scholars need to help develop strategies and approaches to addressing digital inequality and disparity, especially when the governments need to flatten the curve of infection.

Information systems and technology can play a significant role in improving the visibility of digital inequality and disparity at organizations and communities (Bardhan et al., 2020). Data shows Black and Hispanic populations face higher exposure to coronavirus and more significant hurdles for medical treatment and level of care (Nemo, 2020). People of color communities tend to have relatively lower public health literacy and less experience in finding and evaluating healthcare information. Information systems and technology scholars can investigate to what extent the marginalized, women, elderly, and people of color are engaged, included, and impacted by these COVID-19 technology-related applications and systems, including health information seeking tools, mobile contact tracing, and tracking apps, COVID-19 self-checking chatbots, quarantine monitors, and telemedicine in a sustainable manner. It would be valuable to understand the short, medium, and long-term impacts of the digital divide during the COVID-19 pandemic response on marginalized groups, women, the elderly, people of color and people in rural settings. Information systems and technology scholars can do their part to improve technology design and processes to promote digital inclusion, assist with efficient development and sustainable implementation of the proposed technology, particularly in underserved populations. For example, Goh, Gao, and Agarwal (2016)) showed that technology-mediated online health communities could share information and alleviate rural-urban health disparities. Online health communities can also support the most vulnerable family caregivers (Friedman, Trail, Vaughan, & Tanielian, 2018). Information systems and technology scholars can explore factors affecting underserved populations and communities to adopt and effectively use emerging technologies, encourage information sharing behavior during this crisis, and identify strategies to incentivize the mass adoption of relevant coronavirus-fighting technologies by underserved populations. Understanding the underserved population's unique perspectives in this coronavirus outbreak can provide guidelines for future IT systems and applications design, development, and potentially improve the adoption and use of novel IT systems.

4. Conclusion

The COVID-19 pandemic has produced significant impacts on people, businesses, and society. The pandemic also has implications for the design, development, and use of technologies (Sein, 2020). Technologies can be useful for reducing the severity of the coronavirus pandemic's impact on people, organizations, and society. However, the use of technologies to combat the pandemic raises challenges such as security, privacy, biases, ethics, and the digital divide. This paper evaluates the technology applications based on the data-people-system framework and suggests that the specific nature of the COVID-19 pandemic requires strong coordination for connected data, people, and systems to facilitate worldwide collaboration.

Future pandemics are likely to come. While information systems and technology scholars might not be able to help with the scientific aspect of developing vaccination and treatment directly, we can contribute knowledge, experiences, and time to help society better prepare for future pandemics. To mitigate future pandemics' costs and improve data sharing during global public health crises, Chin and Chin (2020) called for establishing a global common data space for highly infectious diseases. While it is very challenging to establish a global common data space for public health data sharing due to various reasons such as technical, geopolitical, and ethical barriers, we support this call for its promising benefits and broader social good. At this stage, information systems and technology scholars can at least help advocate and build a national common data space or health information systems for public health data sharing.

Solving grand challenges facing society requires significant financial and human resources. To increase the importance and relevance of information systems and technology research, we encourage scholars to actively apply for various government and industry grants, including various COVID-19 funding opportunities, to get financial support to put some of their research ideas into practice. For example, the U.S. National Science Foundation and National Institutes of Health have grants programs that support technology-related research to develop solutions to addressing challenges caused by the coronavirus. Information systems and technology scholars should get involved by leading or joining an interdisciplinary team to write grant proposals and get funding to directly work on some of these research ideas. Furthermore, many students including undergraduate and graduate students in information systems and technology are looking for internship opportunities. Since many small businesses in industries such as tourism, food service, and retail are being hit hardest by the pandemic, information systems and technology faculty could collect student resumes, put them on a Google drive or a website, and share the resumes with interested small business owners. This would help match information systems and technology students with interested small businesses or non-profit organizations to solve the technology and other issues they may have during the pandemic. We are glad that some of the information systems and technology faculty are doing this and mentoring small business owners on deploying digital technologies to deal with the challenges of business continuity (Papadopoulos, Baltas, & Balta, 2020). Some professors were involved in digital solution development projects (e.g., tackling misinformation) and helped to organize events such as online hackathons to gather people with diverse skills to work on solutions to help society fight COVID-19 (Bacq, Geoghegan, Josefy, Stevenson, & Williams, 2020; Pan & Zhang, 2020). We hope to see more information systems and technology scholars involved in building and expanding technology volunteer networks and mobilizing community resources and services to fight COVID-19. At last, some of the developed technologies and application for this pandemic may cease to be useful after the pandemic ends, but many will likely be retained, enhanced, or repurposed for other uses (Oxford Analytica, 2020), in which information systems and technology scholars can continue to play a role after the pandemic. For example, will data collected from mobile contact tracing be destroyed after this pandemic? What data management policies are needed to prevent the abuse of the user data and guide the improved design, development, and use of future mobile contact tracing and tracking tools?

CRediT authorship contribution statement

Wu He: Conceptualization, Investigation, Writing - original draft, Writing - review & editing. **Zuopeng (Justin) Zhang:** Writing - original draft, Writing - review & editing. **Wenzhuo Li:** Writing - original draft, Writing - review & editing.

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