A Technology and Data Privacy Policy Framework for COVID-19 Contact Tracing

ABSTRACT

Global pandemics are widespread outbreaks of sickness which often result in many fatalities. With the ongoing COVID-19 pandemic, this paper aims to determine most effective strategies for combatting future outbreaks. The political, economic, social, technical, legal, and environmental impacts of the coronavirus are each detailed using the PESTLE framework. To minimize the spread of viruses, contact tracing serves as a valuable tool implemented by public health workers. The important aspects of digital and manual contact tracing are covered before going into specific contact tracing efforts within Asia, Europe, and North America. Data analysis is performed using information on forty COVID-19 contact tracing apps. The findings highlight the important considerations of app design and implementation. A review of technology and data privacy/security policy frameworks help to further understand the available options for maximizing technological capabilities while ensuring privacy.

INTRODUCTION

Knowledge Gap – Limited Research on technology and privacy for data usage.

Global health challenges such as the public health emergency of COVID-19 require science, technology, and innovation to reduce the negative impact of this pandemic. The European Commission launched several initiatives in 2020 that address epidemiology, preparedness and response to outbreaks, and the information and communication technology (ICT) infrastructure to enable this research and innovation on COVID-19 (European Commission, 2020).

Importance – Privacy/Security

On April 19, 2020, a statement on contact tracing was written and signed by representatives from twenty-five countries around the world. The joint statement includes warnings against centralized data collection in which powerful entities (i.e. governments) could conduct surveillance and exploit personal information. In fact, the English Parliament announced their approval of a decentralized system two days prior. Furthermore, Google and Apple are actively working to build infrastructure that supports the design of privacy protective Bluetooth applications. Signees acknowledge the significance of contact tracing systems that adhere to the privacy by design principles in addition to being transparent, privacy-protecting, and voluntary ("Joint Statement", 2020).

This Paper – Purpose

This paper reviews ICT for COVID-19, specifically the technological framework and data privacy policy framework around contact tracing for rapid and effective tools to address emerging health problems, and contain COVID-19 and other outbreaks on the scale of global healthcare.

LITERATURE REVIEW

COVID-19 Overview

Severe acute respiratory syndrome-coronavirus (SARS-CoV-2) led to the ongoing COVID-19 pandemic that broke out in Wuhan, China in December 2019 (Sauer, 2020). As of August 2, 2020, the total number of confirmed cases surpassed 18 million and the death toll reached 688,939 (Worldometer, 2020). The highly contagious disease mainly spreads via airborne droplets of saliva or discharge from an infected person. Another potential way of picking up the virus is by transferring from contaminated items or surfaces to one's face (CDC, 2020c). The incubation period of COVID-19 lasts 14 days, however symptoms typically appear within approximately five days after exposure. They include fever or chills, dry cough, fatigue, headache, diarrhea, and nausea or vomiting (Sauer, 2020; World Health Organization [WHO], 2020). Public health organizations recommend that people stay home if possible, wash hands frequently, practice physical distancing, and wear a face mask in public (CDC, 2020c; WHO, n.d.).

Impact of COVID-19: PESTLE Analysis

Political

In a National Bureau of Asian Research (NBR) interview, Thomas Pepinsky discussed the economic and political impacts of the coronavirus within Southeast Asia. He noted that Southeast Asian countries have experienced fewer COVID-19-related mortalities than Europe and North America. While the specific approaches varied from country to country, the leading factors in determining the outcomes involve response time and aggressiveness of policy implementations. Pepinsky acknowledged the success of Vietnam and Singapore with their social distance mandates and quarantining measures. Ultimately, the outcomes revealed the significance of government transparency in gaining public trust (Pepinsky, 2020).

Within the U.S., COVID-19 has raised controversial views on how powers and responsibilities should be divided amongst the different levels of government to best respond to the virus. Some argue in support for centralized decision-making in which the federal government passes down orders that would apply to entire nation. Others believe that local officials should be given more freedom to make decisions that would directly impact their communities. The best solution may be a combination of the two, but the specifics will need to be worked out in order to effectively battle against widespread outbreaks in the future (Dauba-Pantanace, 2020).

Economic

Global economies have been greatly affected by the pandemic. Increased rates of unemployment, poverty, and mortality continue to contribute to the status of the economy. Predictions indicate economic growth reductions will be between 3% and 6% during 2020. There are even concerns about the possibility of an upcoming worldwide economic recession (Congressional Research Service, 2020b). The International Monetary Fund (IMF) provides datasets for gaining a global perspective of the economy. As part of the World Economic Outlook (April 2020), the IMF shows statistics for the real gross domestic product growth (GDP) as an annual percent change. Values are as follows: Asia and Pacific -0.2%, East Asia -0.1%, Eastern Europe -5.4%, Europe -6.7%, North America -6%, South Asia 1.5%, Southeast Asia -0.7%, Western Europe -7.3%. In summary, most regions in Asia experienced minor declines while regions in Europe and North America faced major decreases (International Monetary Fund, 2020). To support their economies, many national governments have announced multi-billion-dollar stimulus packages. The funds will go towards helping citizens, businesses, and employees during the pandemic (Alpert, 2020).

Social
Many Asian countries share a collectivist culture in which the importance of the group outweighs individual needs. As a result, citizens have demonstrated a willingness to relinquish some control and privacy to their governments, who deployed data-collecting technology to assist in tracking the coronavirus. On the other hand, Western democracies, such as the United States, have not been so successful in flattening the curve. Data sovereignty and privacy pose as threats to the widespread adoption and implementation technologies intended to contain virus outbreaks. (Huang, Sun, & Sui, 2020).

Researchers set out to determine if individualistic culture had any correlations with the adherence to social distancing guidelines and crowdfunding efforts related to COVID-19. With the help of nearly one hundred computers, they analyzed big data from 18^{th} and 19^{th} century America. The data specifically pertained to the duration of time that different localities settled on the American frontier. The results indicated that "higher local levels of individualism reduced compliance with state lockdown orders by 41% and reduced pandemic-related fundraising by 48%" (Newman, 2020). By fully understanding the role that culture has on fighting the pandemic, policymakers can make more informed decisions (Newman, 2020).

Technical
A report by Deloitte explains the impacts of COVID-19 on the technology sector. Many factories in Asia had temporary shutdowns causing disruptions in the supply chain, therefore raw materials (i.e. aluminum and copper) are currently experiencing delays. It will inevitably take time for production to recover. The pandemic also caused a shift in the workforce as many employees started to work remotely. Consequently, hardware companies are expected to see a rising sales due to laptop purchases. IT cloud infrastructure services, communications equipment, and security software will also be in high demand as businesses continue to adapt to the changing work environment (Deloitte, 2020).

Legal
The pandemic has brought about significant challenges for employees, especial low-income workers. Although laws were in place to protect workers prior to the coronavirus, many workers and employers are unaware that such laws or programs exist. For example, the Families First Coronavirus Response Act was passed by the national government to provide sick workers compensation during leave, however, "a lack of outreach has undermined the law's critical goals (Goldman, 2020). In a collaboration effort, a toolkit called "Protecting Workers through Publicity: Promoting Workplace Law Compliance through Strategic Communication" was released to emphasis the use of the media in raising public awareness about policies. Labor enforcement agencies, policymakers, and worker advocates play a powerful role in helping advocate for legal compliance (Goldman, 2020).

Environmental
Pollution and greenhouse gas levels have decreased around the world due to lockdowns imposed during COVID-19. According to Kimberly Nicholas, a sustainability science researcher, transportation contributes to nearly 25% of global carbon emissions; vehicle and airplane produce over 80% of greenhouse gas emissions in the transportation sector. (Henriques, 2020). Data captured by NASA satellites revealed substantially less nitrogen dioxide in the atmosphere.

In fact, China experienced nitrogen dioxide reductions between 10-30% in January and February compared with the same time during the previous year. Delhi, India also saw a decline of approximately 55% between late March until late April (BBC, 2020). Similarly, data collected by the European Space Agency's Copernicus Sentinel-5P satellite revealed a significant reduction in nitrogen dioxide concentrations above Italy and other European countries (The European Space Agency, 2020). With the lifting of restrictions, the air pollution seems to be on the rise again. The important question remains as to what the status of the environment will be post-pandemic (Gardiner, 2020).

Table 1 PESTLE Analysis

Political	• Fewer COVID-19 mortalities in Asian countries compared to Europe and North America • USA government federal, state, and local: Powers and responsibilities at different levels
Economic	• Overall economic growth rates expected to drop by 3-6% • Possible global recession • Real GDP as an annual % change • Multi-billion-dollar stimulus packages
Social	• Collectivist culture: Asia • Individualistic culture: USA
Technical	• Temporary factory shutdowns • Disruptions in supply chains • Employees work remotely • IT spending for hardware, cloud infrastructure services, communications equipment, and software security
Legal	• Families First Coronavirus Response Act • Protecting Workers through Publicity: Promoting Workplace Law Compliance through Strategic Communication" toolkit
Environmental	• Global decline in pollution and greenhouse gas during lockdowns • Rising levels due to lifted restrictions

Contact Tracing Overview

Contact tracing is a public health tool used to keep the spread of viruses under control.
The two forms of contact tracing include manual and digital. With both types, the goal is to intercept transmission routes by tracking confirmed cases and their close contacts. Manual contact tracing relies on trained workers, who conduct over-the-phone interviews. Digital contact tracing can also be implemented to assist with manual tracing. During the COVID-19 pandemic, countries around the world have taken various approaches in terms of deploying contact tracing tools. Many have focused their efforts on developing smartphone applications with built in technologies such as Bluetooth signals and/or global positioning system (GPS). The system stores data on app users every time they come into a certain proximity of another user. If an app user tests positive, he or she reports this update, which enables the app to notify their close contacts (Shachar, 2020).

To gain a clearer understanding of the implemented tools, the advantages and disadvantages are detailed as follows. Digital contact tracing eliminates the need to train and pay workers to manually track the virus spread by automating the tracing process. People with smartphones can download the app and be alerted if they come into contact with an infected individual. It is important to recognize that not all people own smartphones. That said, the effectiveness of digital contact tracing depends on widespread adoption and properly functioning technology. Additionally, individuals take on the responsibly for following through with appropriate measures of getting tested and/or quarantining. On the other hand, manual contact tracing allows for over the phone interactions between the tracer and individual. The process can be time-consuming. Furthermore, the outcomes depend on the case’s willingness to cooperate with human tracers as well as their ability to accurately recall the people they encountered. Unlike digital contact tracing, manual contact tracing avoids complications associated with technical glitches and does not raise major privacy concerns regarding personal data security and usage (Kleinman & Merkel, 2020; TechDispatch, 2020).

Table 2 Digital versus Manual Contact Tracing

Digital Contact Tracing		**Manual Contact Tracing**	
Advantages	Disadvantages	Advantages	Disadvantages
• Automates the tracing process • Easy for users with a smartphone to download app • Does not require confirmed cases to recall their close contacts • Provides immediate alert to close contacts • Close contacts can quarantine and/or receive testing	• Raises privacy concerns surrounding personal data security and usage • Requires smartphones • Effectiveness depends on adoption and technology • Relies on individuals to follow through with appropriate measures • Less personable without human interaction	• Human interaction between the tracer and individual • Lacks privacy concerns associated with digital contact tracing • Do not have to worry about technology issues	• Requires lots of time and money (training and paying workers) to implement • Time consuming process to carry out • Depends on people’s willingness to cooperate with human tracers • Relies on an individual’s memory to recall interactions

Contact Tracing by Region

Asia

Digital contact tracing has been highly effective in slowing the spread of Covid-19 as seen in many East Asian countries, including China, Taiwan, South Korea, and Singapore. This article focuses on, technology adoption, digital infrastructure, and data sharing, the three essential conditions for digital contact tracing to work effectively. Technology adoption involves the release and widespread use of digital applications. Several apps and their respective countries are StayHomeSafe (Hong Kong), TraceTogether (Singapore), and Corona 100m and Corona Map (South Korea). Secondly, digital infrastructure refers to the governmental systems in place for handling outbreaks. SARS in 2003 led South Korea and Taiwan to actively prepare for the next unexpected natural disaster. Lastly, data sharing between corporations and government is pivotal to determine the best course of action in critical situations. Only the future will determine the extent to which the individualistic ideologies of Western democracies will impact the development of technological advancements relating to public safety (Huang et al., 2020).

After the outbreak of SARS-CoV-2 in Wuhan, China, the city of Shenzhen turned to surveillance as a means of tracking the virus. A combination of symptom-based surveillance and contact tracing helped the Shenzhen Center for Disease Control and Prevention collect data on 391 COVID-19 cases and over one thousand close contacts between January 14 and February 12. Researchers used the data to perform analyses on case identification and transmission. With symptomatic surveillance, there was a lead time of 4.6 days between symptom onset and identification and isolation. The implementation of contact tracing was able to decrease the time gap to 2.7 days. They concluded that both contact tracing and isolation reduce the community's exposure to the infection, but asymptomatic cases add another level of complexity to determining the overall effectiveness (Qifang et al., 2020).

Another contact tracing study in Taiwan focused on the transmissibility of COVID-19 at varying exposure time periods. The study, lasting from January 15 to March 18, 2020, included 100 confirmed cases and 2,761 of their contacts. The results revealed that the highest risk for exposure spanned the first five days of a case being symptomatic. On the contrary, none of the 852 contacts with later exposure, day six and beyond, tested positive. None of the 852 contacts with later exposure, day six and beyond, tested positive. Additionally, the group of 299 contacts who were solely exposed to presymptomatic cases faced a greater risk of infection. The researchers concluded that merely quarantining symptomatic patients will not suffice in fighting the virus, therefore other measures like social distancing need to be implemented (Cheng, Jian, Liu, Huang, & Lin, 2020).

Europe

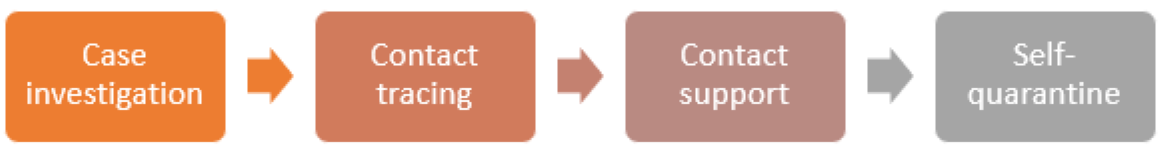
The European Commission (EC) has embraced digital technologies in the combat against COVID-19. In February 2020, the Commission adopted its Digital Strategy. This action was followed by a Recommendation adoption on April 8th "support[ing] the gradual lifting of coronavirus containment measures through mobile data and apps" (European Commission, 2020). The goal of the Recommendation was for the European Union (EU) to follow a standardized approach for COVID-related mobile applications. On April 16th, the EC released guidelines pertaining to contact tracing app development to protect the privacy of users. More specifically, the guidelines asserted that digital technologies must adhere to data protection and privacy rules of the General Data Protection Regulation (GDPR) and the ePrivacy Directive. The GDPR protects health data and only permits the processing of personal health data in limited cases (i.e. epidemics and pandemics) where access to and analysis of private data serves in the best interest of the public health (European Commission, 2020).

The EU recommended nations within Europe to reopen their internal borders by mid-June (Amaro, 2020). Around the same time, digital contact tracing apps started to become available for download in several European countries. Italy led the way with Immuni followed by France's StopCovid app and Germany's Corona-Warn-App. Despite the apps being made voluntary, a new set of concerns arose surrounding user privacy. Other areas of question relate to the future of technological implementations and the rights of individual nations versus Europe as a whole (Horowitz & Santariano, 2020).

North America

The Centers for Disease Control and Prevention (CDC) has published an array of resources on contact tracing and continue to release updated documentations to reflect the ongoing research and findings. The United States public health agency asserts that "Contact tracing is a key strategy to prevent the further spread of COVID-19" (Centers for Disease Control and Prevention [CDC], 2020a). Amongst the key principles of contact tracing are case investigation and contact tracing. Case investigation centers around patients who test positive for COVID-19, whereas contact tracing focuses on individuals who have been exposed to the virus via infected patients. Both principles have been implemented for many years prior to fight infectious diseases including Ebola, HIV, and tuberculosis (CDC, 2020a; Joseph, 2020).

Figure 1 Core Principles of Contact Tracing



During case investigation, public health workers communicate with the patient and help them to recall their close contacts – anyone within 6 feet of the infected individual for 15 minutes or longer beginning 2 days prior to the individual's symptoms until isolation. Next, public health staff conduct contact tracing by reaching out to the identified contacts to inform them of their potential exposure. It is important to note that the staff members are required to preserve the anonymity of the original source. Once the contacts are notified, they are given useful education and information about the risks involved with the virus as well as ways they can avoid exposing others and self-monitor. Lastly, contacts are advised to self-quarantine at home for 14 days since their most recent exposure.

COVIDTracer, a spreadsheet-oriented tool, enables public health officials and policy makers to evaluate multiple contact tracing strategies. The excel spreadsheet (COVIDTracer Spreadsheet CDC) is available for download on the CDC website. To begin, users must provide details about the population, total number of cases, and number of cases over the past two weeks. Additional information needed involves predictions of how many contacts per case and how many hours that contact tracers would work each day. Based on the data inputs, the COVIDTracer tool provides detailed results comparing three case identification/contact tracing approaches, which helps public health officials determine the most effective plan for controlling the virus (CDC, 2020b).

According to Dr. Ashish Jha, “If we don’t have extensive contact tracing in every community in America, it’s going to be hard not to see this virus when we open back up” (Santhanam, 2020). Manual contact tracing follows a two-step process: 1) Test all persons who are believed to have contracted the virus and 2) Identify and alert everybody who the people in step one have come into contact with and recommend they be tested and quarantine to prevent further spreading (Santhanam, 2020). States have arranged for contact tracers to correspond with both the infected individuals and their contacts. Their duties involve educating infected individuals about COVID-19, collecting information on their recent whereabouts and whom they have come in contact with, reaching out to those contacts and advising them to quarantine (Joseph, 2020). The United States faces potential barriers to curtailing COVID-19 through contact tracers are rampant cases, limited testing availability, and American views about privacy (Temple, 2020).

In a recent study, a group of researchers take a quantitative approach to help explain the intricacies of COVID-19. They identify the different ways that the virus spreads 1) symptomatic transmission 2) presymptomatic transmission 3) asymptomatic transmission 4) environmental transmission and use the four transmission routes to develop a model explaining the contribution of each route to the spread of the coronavirus. Based on their findings, the researchers recommend deploying an instantaneous contact tracing app. Everyone with the mobile application downloaded on their devices would receive an alert if they were potentially exposed to the virus by means of an infected individual. The publication also highlights major ethical considerations in response to the concerns surrounding digital technologies. To establish public trust and uphold ethical standards, the proposed requirements involve an advisory board, guiding ethical principles and moral values, data protection measures, and knowledge sharing (Ferretti et al., 2020).

METHODOLOGY

Background
In response to the coronavirus, numerous contact tracing applications have been launched with technologies ranging from voluntary and unobtrusive to mandatory and invasive. The authors of an MIT Technology Review article explained how they began to wonder about the overall impact of the apps on society. Unable to find the proper answers to their questions, they decided to the create a “Covid Tracing Tracker” database. The first version of the database consisted of information gathered on twenty-five different contact tracing applications. Over time, more apps and data have been added to a Google Excel read-only spreadsheet. General information included the app name, country, developer, status, technologies used, number of users and penetration level. Furthermore, each app received a rating on a scale of zero to five based on the following measures: voluntary, limited, data destruction, minimized, and transparent. The purpose of measuring these factors was to gain a greater understanding into data usage and privacy protection (O’Neill, Ryan-Mosely, & Johnson, 2020).

Data Analysis
The database created by MIT Technology Review provided data for analyzing technology and privacy frameworks of digital contact tracing. The relevant data was based on the most recent update, 7/30 3:15pm ET, and consisted of a total of 40 apps in Asia, Europe, and North America (O’Neill, Ryan-Mosely, & Johnson, 2020).

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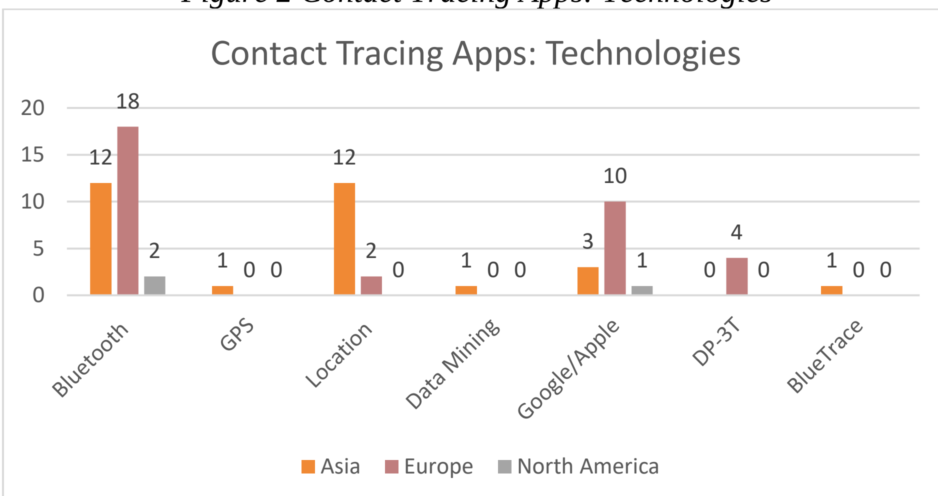
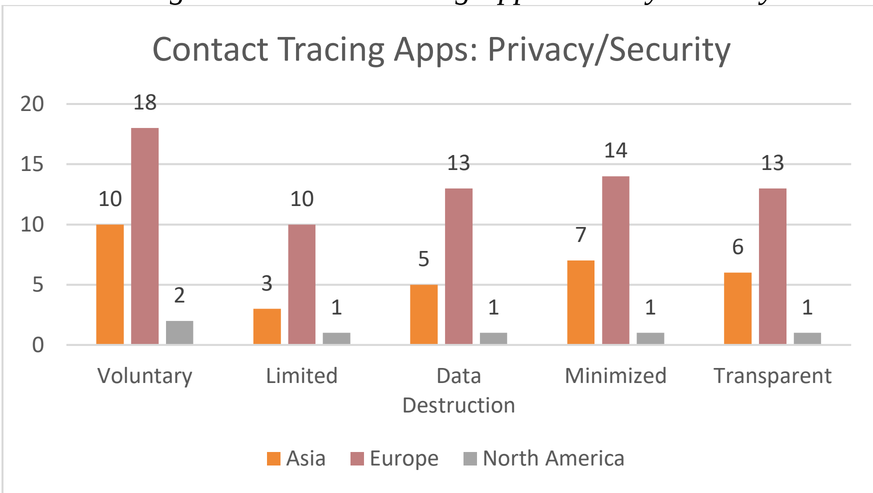
- Asian countries: Bahrain, China, Cyprus, India, Indonesia, Iran, Israel, Japan, Kuwait, Malaysia, Philippines, Qatar, Saudi Arabia (2), Singapore, Thailand, Turkey, United Arab Emirates (UAE), and Vietnam
- European countries: Austria, Belgium, Bulgaria, Czech, Denmark, Estonia, Finland, France, Germany, Gibraltar, Hungary, Ireland, Italy, North Macedonia, Northern Ireland, Norway, Poland, Switzerland, and UK
- North America: Canada and Mexico

Figure 2 Contact Tracing Apps: Technologies



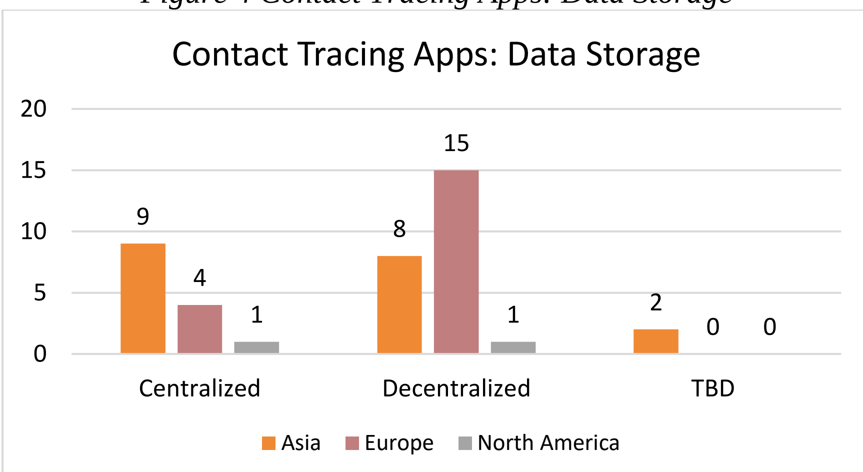
Contact tracing apps gather data of users' interactions with various smartphone technologies: Bluetooth, GPS, Location, Data mining. They can be further classified based on their privacy protocols such as Google/Apple, DP-3T, and BlueTrace. In Asia, twelve apps were built to function using Bluetooth including six also using location, two following Google/Apple protocol, one with BlueTrace protocol. There are four apps that solely use location. A few unique technologies and their respective countries are location and data mining (China) and location and GPS (Cyprus). All but one European app operate with Bluetooth: one also using location, ten follow Google/Apple protocol, four with DP-3T protocol. Bulgaria chose to go with location technology. Both apps in North America work with Bluetooth and Canada's follows Google/Apple protocol.

Figure 3 Contact Tracing Apps: Privacy/Security



The only app to receive five stars in Asia was Singapore's TraceTogether. CovTracer (Cyprus), HaMagen (Israel), and COCOA (Japan) had four-star ratings while the remaining apps were given between zero and two stars. Nine out of the nineteen European apps received the maximum possible ratings. The other apps had the status of TBD for several criteria, which explains the lower scores. In North America, Canada's COVIDAlert received full rating. CovidRadar by Mexico was given one star for being voluntary.

Figure 4 Contact Tracing Apps: Data Storage



Each app was classified as either centralized, decentralized, or TBD depending on their data storage approach. Asia has nine centralized, eight decentralized, and two unidentified apps. Over 75% of European apps use decentralized systems while the remaining 21% of use centralized systems. Canada's app was classified as decentralized, and Mexico's app used the centralized approach.

Figure 5 Heat Map
Calculations based on data as of August 3, 2020

Country	# App Users/Pop	Total Cases/Pop
Austria	6.659%	0.236%
Bahrain	23.449%	2.415%
Bulgaria	0.792%	0.170%
Cyprus	0.745%	0.095%
Czech	2.586%	0.156%
France	2.910%	0.288%
Germany	16.705%	0.252%
Gibraltar	26.714%	0.558%
Hungary	0.104%	0.047%
India	7.240%	0.131%
Indonesia	6.940%	0.041%
Iran	4.757%	0.368%
Israel	21.745%	0.789%
Italy	3.639%	0.410%
Japan	3.164%	0.028%
Malaysia	0.309%	0.028%
Norway	26.305%	0.171%
Philippines	1.094%	0.094%
Poland	0.110%	0.124%
Qatar	90.164%	3.957%
Singapore	35.871%	0.902%
Switzerland	5.774%	0.411%
Thailand	0.508%	0.005%
Turkey	16.805%	0.276%
Vietnam	0.392%	0.001%

The heat map shows the strengths of the relationships between the variables. For 25 out of the 40 apps, there was data on the number of app users. The worldometer website provided additional data, total cases and population sizes for each country. Two calculations were performed in Excel: # App Users/Pop and Total Cases/Pop. The results from the first calculation indicate that the highest percentage for app downloads took place in Qatar 90.164% followed by Singapore 35.871% and Gibraltar 26.714%. Countries with the lowest app download rate include Hungry 0.104%, Poland 0.110%, Malaysia 0.309%, and Vietnam 0.392%. Apps from all of the aforementioned countries, except for Qatar, were voluntary. Based on the second calculation, countries with the lowest percentage of COVID-19 cases were Vietnam 0.001%, Thailand 0.005%, Japan and Malaysia 0.028% and Indonesia 0.041%. The opposite end of the spectrum included Qatar 3.957%, Bahrain 2.415%, Singapore 0.902%, and Israel 0.789%.

MODEL & RESEARCH DESIGN

MOBILE Devices and Apps

Mobile devices and applications continue to revolutionize the healthcare industry. They are replacing the traditional pager, cellphone, and personal digital assistants. The rise in mobile devices in medical settings can be attributed to the development of medical software applications, also referred to as apps. Apps assist health care professionals (HCPs) with duties related to "administration, health record maintenance and access, communications and consulting, reference and information gathering, and medical education" (Ventola, 2014). One of the most noteworthy benefits of mobile devices is their ease of access to resources at the point-of-care. The main resources needed at the point-of-care include hospital information systems, clinical software applications, and informational resources. It is essential to understand that mobile apps are intended to provide additional capabilities complementary with desktop applications. That said, not all HCPs are eager to incorporate mobile technologies into their everyday practices, and there is still a need for the establishment of best-practice standards for app developers and HCPs alike (Ventola, 2014).

MOBILE Contact-Tracing Technology Framework

A major challenge faced within the healthcare industry is effectively transferring clinical care, patient safety, and quality improvement data between systems. For systems to work together effectively, data standards must be implemented. "Data standards encompass methods, protocols, terminologies, and specifications for the collection, exchange, storage, and retrieval of information associated with health care applications" (Institute of Medicine (US) Committee, et al., 2020). The process of standardizing medical data requires 1) defining the data to be gathered and shared, 2) selecting the format for the data, and 3) figuring out a way to encode the data for sending. Data elements are fundamental information, each with their own meaning and groups of distinct values. Several examples are patient name, age, gender, diagnosis, and lab results, and medications. Data types pertain to the format of the data elements and range in complexity from the date and time to name and address. Universal data types are essential for data usability amongst healthcare workers in addition to common scientific units. Ultimately, data standards enable information systems to work as a unified enterprise (Institute of Medicine (US) Committee, et al., 2020).

Heath data sharing between organizations involves complex, scalable systems. Within the U.S. healthcare system, three information technology standards used to assist with interoperability include direct, fast healthcare interoperability resources (FHIR), and cloud fax (J2 Global, 2019). Each is outlined below.

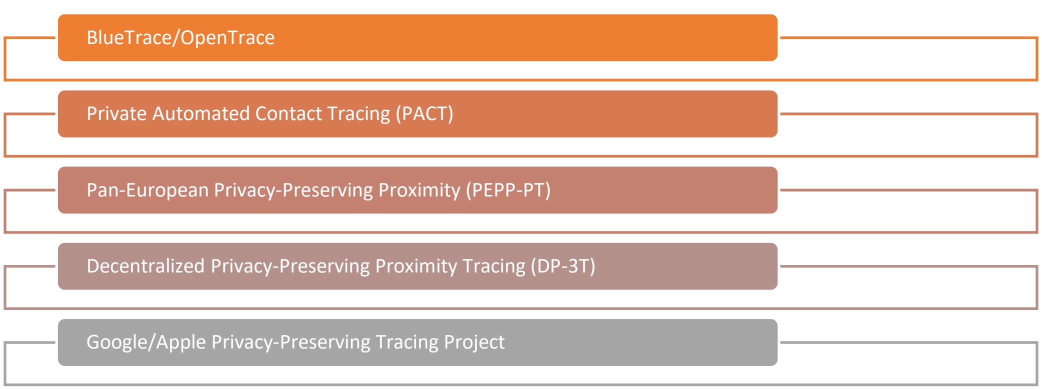
1. **Direct**, a document-based exchange standard, was created in 2010 and improved in later years. The non-profit called DirectTrust also developed a security and trust framework and ensures that direct messaging exchanges follow the Direct standards. Direct messaging is often compared to email with additional security. The process requires a Health Internet Service Provider (HISP) to handle exchanges. Additionally, the HISP manages encryption/decryption and digital signing. In November 2019, DirectTrust reported that upwards of 1.2 billion Direct exchanges had occurred during the year (J2 Global, 2019).
2. **FHIR** is a widely used an internet-based exchange standard developed by Health Level Seven organization, or HL7. FHIR messaging serves as a versatile solution for a variety of situations involving "mobile phone apps, cloud communications, EHR-based data sharing, server communication in large institutional healthcare providers, and much more" (J2 Global, 2019).
3. **Cloud fax** standards provide a secure method of faxing that complies with the Health Insurance Portability and Accountability Act (HIPAA). Hosting often takes place in a private cloud or in a hosted environment located offsite. Cloud fax services are replacing the physical fax machines which lack capabilities such as encryption, access control and audit control (J2 Global, 2019).

There are five common limitations associated with digital contact tracing. Firstly, the level of app adoption determines the effectiveness of application. If only a small percentage of a population opts to use the service, then many interactions between an infected person(s) and their exposed contacts would go undetected (Kleinman & Merkel, 2020). In terms of coverage, epidemiologists estimate that 60%-80% of a country's population should be using the app to stop the spread of COVID-19 (Congressional Research Service, 2020a). Secondly, technologies are not without fault. They can provide erroneous measurements especially with many factors in effect as with Bluetooth-based apps (Kleinman & Merkel, 2020). Bluetooth applications rely on strong signals between devices, which can be greatly impacted by the smartphone make, distance between smartphones, and physical location of the phone. For maximized app performance, calibrations cannot be overly sensitive or completely insensitive, therefore it is ideal to conduct signal processing and testing hardware (Congressional Research Service, 2020a). Thirdly, Bluetooth app scanning, particularly on iOS devices, face detection restrictions if they are not based on Apple-Google protocol. Fourthly, the ongoing, extensive monitoring raises privacy concerns. While protocols are designed to protect consumer privacy as much as possible, restrictions on data collection limits efforts by public health organizations to test and improve quality of exposure notification technologies. Other worries surround third parties using data to collect information on people. Lastly, the overall effectiveness of the apps currently in use remains undetermined. Each of these limitations should be fully recognized and understood by countries considering digital contact tracing (Kleinman & Merkel, 2020).

MOBILE Contact-Tracing Privacy/Security Framework

A key privacy/security consideration is whether contact tracing data will be stored using centralized or decentralized systems. Apps with centralized systems collect and store user data on a single, central server. Public health officials often support centralization because it allows for massive data collection. With access to this data, epidemiologists are better equipped to understanding the path of the virus (Rivero, 2020). The downside of the approach is the risk of "government surveillance and potential data breaches" (Khalid, 2020). Decentralization involves storing of data of interactions on a user's personal device. Only if that person were to become infected would they be asked permission to allow their data to be sent to a central database (Mitchell, 2020). The decentralized approach has been integrated into several privacy-preserving protocols detailed below.

Figure 6 Protocols: Privacy Preserving Contact Tracing



Singapore's TraceTogether application was co-developed by the nation's Government Technology Agency and the Ministry of Health. The contact tracing app uses BlueTrace protocol along with OpenTrace reference implementation. BlueTrace functions on mobile devices by communicating over Bluetooth. The protocol design includes four specific measures to protect data and safeguard user privacy. Firstly, health officials receive only one piece of personally identifiable information (PII), a telephone number. Additionally, an individual's encounter history is stored locally on their personal device. The data will only be shared with health officials if they receive permission in the case that the person becomes infected. To avoid interference from third parties, the device functions with an identifier that changes periodically. Finally, users may choose to opt out of the tracing application at any point in time. The decision to no longer give consent results in the deletion of any PII and encounter history (Bay et al., 2020).

Private Automated Contact Tracing, also known as PACT, began in mid-March 2020 as a collaboration headed by MIT Computer Science and Artificial Intelligence Laboratory (CSAIL). PACT aims to integrate exposure detection capabilities within mobile devices to improve contact tracing and health outcomes while continuing to protect privacy. The protocol specifications of PACT rely on Bluetooth Low Energy signaling carried out in a decentralized manner. There are four key components: proximity detection efficacy, privacy, integration, and public health efficacy (Rivest, Weitzner, Ivers, Soibelman, & Zissman, 2020).

Pan-European Privacy-Preserving Proximity Tracing (PEPP-PT) protocol launched on April 1, 2020. According to the PEPP-PT website, the initiative aims to "provide standards, technology, and services to countries and developers" while following a "privacy-preserving approach" (Pan-European Privacy-Preserving Proximity Tracing [PEPP-PT], 2020). It supports both centralized and decentralized systems. The PEPP-PT team, as of March 31st, consisted of over 130 members from eight European countries with expertise in areas including but are not limited to artificial intelligence, communication, proximity tracing, encryption, privacy, security, and scalable systems (PEPP-PT, 2020).

Decentralized privacy-preserving proximity tracing, or DP-3T, is an open source protocol designed by a team of European researchers and scientists. DP-3T performs with Bluetooth Low Energy and protects users' data by allowing processing to take place locally on their personal device. The decentralized protocol is available for viewing on github ("DP3T," 2020).

On April 10, 2020, the public was informed of the Apple-Google partnership in developing protocol for Bluetooth-based apps designed to notify users of exposure. The companies announced the following month that over twenty countries spanning five continents chose to build apps following Apple-Google protocol (Congressional Research Service, 2020a). Apple published draft documentation for the Exposure Notification System on their website. In addressing privacy measures, they emphasize that they do not collect any locational data and base proximity solely on Bluetooth. Additionally, users must opt-in if they wish to participate in exposure notifications and consent to how their data would be shared if they test positive. Each user has a Rolling Proximity Identifier associated with their Temporary Exposure Key. The identification number switches frequently to protect their privacy (Apple & Google, 2020).

Researchers built a prototype peer-to-peer mobile app based on the transmission graph model. The transmission graph is made up of nodes (contact points) and directed edges (transmission vectors) used to depict a system of connections between individuals. The network continues to increase in size and complexity with the addition of transmission vectors linking nodes to one another. To model different situations, the researchers also designed a computer simulation using R programming language. They compared the proportion of a population infected over time using adoption rates of 0%, 25%, 50%, and 75%. In the discussion section, the researchers address key characteristics of their proposed app. They describe the peer-to-peer aspect as “joint participation of their peers” in which users scan QR codes to build networks. There is a potential that users may be turned off by the setup, and app users may get tired of the process. However, the app avoids collecting locational data often viewed as invasive of personal privacy. They go on to explain how transmission graph data is located on a central server. That said, users do not need to register or provide any personal details. The purpose of a centralized system is for creating confirmation codes. The confirmation codes enable proper reporting of the positive status for contact points in the transmission graph. The researchers expect for some diagnoses to go without being reported by users, but their simulations demonstrate how the app’s effectiveness does not depend on complete participation (Yasaka, Lehrich, & Sahyouni, 2020).

CONCLUSION AND CONTRIBUTIONS

Contact tracing has been a commonly used tool to assist in the process of tracking transmission routes. Recent publications on COVID-19 studies conclude that detecting positive cases as soon as possible is advantageous in curtailing the virus spread. Digital contact tracing can help overcome some of the limitations of the traditional manual contact tracing. Meanwhile, it also brings about a new set of complications surrounding user data privacy and security. Based on a data analysis of the available contact tracing apps, most countries developed their apps to function with Bluetooth or location and follow Google/Apple or DP-3T protocols. According to the heat map, there was not a strong indication that higher percentages of app users yielded lower percentages of total cases. The recommended solution is to utilize Bluetooth technologies and a decentralized privacy preserving protocol such as Google/Apple. People should also be given the choice about whether to download in the app. In addition to contact tracing, solidarity is an especially crucial during a health crisis. National governments can help to unify its citizens by sending clear, consistent messages on how to prevent spreading. The group mentally will help governments enforce temporary lockdowns, quarantine measures, and contact tracing without significant backlash from citizens. State and local governments should also collaborate with healthcare workers to ensure the proper resources are available to support citizens.

The threat of global pandemics requires advanced preparation by government officials, public health workers, researchers, scientists, engineers, and other experts. When an outbreak starts, interventions must be quickly implemented. COVID-19 provides a significant amount of insight into the approaches taken by different continents and countries. The findings reveal that no easy solution exists, but instead, multiple efforts are necessary for fighting the virus.

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APPENDIX

Figure 1 Contact Tracing Apps: ASIA

Contact Tracing Apps: ASIA

Application	Country	Users/Downloads	Tech	Rating	Voluntary	Limited	Data Destruction	Minimized	Transparent	Centralized
BeAware	Bahrain	400000	Bluetooth, Location	1	Y	Y	TBD	N	N	Centralized
Chinese health code system	China	TBD	Location, Data Mining	0	N	N	N	N	N	Centralized
CovTracer	Cyprus	9000	Location, GPS	4	Y	N	Y	Y	Y	Decentralized
Aarogya Setu	India	100000000	Bluetooth, Location	2	N	N	Y	N	Y	Centralized
PeduliLindungi	Indonesia	19000000	Bluetooth, Location	1	N	N	N	N	N	Centralized
Mask.ir	Iran	4000000	Location	1	Y	TBD	TBD	N	N	TBD
HaMagen	Israel	2000000	Location	4	N	Y	Y	Y	Y	Centralized
COCOA	Japan	4000000	Google/Apple	4	Y	TBD	Y	Y	Y	Decentralized
Shlonik	Kuwait	TBD	Location	1	Y	TBD	N	N	N	Centralized
MyTrace	Malaysia	100000	Bluetooth, Google/Apple	1	Y	TBD	N	N	N	Decentralized
StaySafe	Philippines	1200000	Bluetooth	1	Y	TBD	TBD	N	N	Decentralized
Ehteraz	Qatar	2531630	Bluetooth, Location	0	N	TBD	N	N	N	Centralized
Tawakkalna	Saudi Arabia	TBD	Location	0	TBD	TBD	TBD	N	N	TBD
Tabaud	Saudi Arabia	TBD	Bluetooth, Google/Apple	2	Y	TBD	TBD	Y	N	Decentralized
TraceTogether	Singapore	2100000	Bluetooth, Blue Trace	5	Y	Y	Y	Y	Y	Centralized
MorChana	Thailand	355000	Bluetooth, Location	0	TBD	TBD	TBD	N	N	Decentralized
Hayat Eve Sigar	Turkey	14186000	Bluetooth, Location	1	N	N	N	Y	N	Centralized
TraceCovid	UAE	TBD	Bluetooth	1	N	TBD	TBD	Y	TBD	Decentralized
BlueZone	Vietnam	382160	Bluetooth	2	Y	TBD	N	N	Y	Decentralized

Figure 2 Contact Tracing Apps: EUROPE

Contact Tracing Apps: Europe

Application	Country	Users/Downloads	Tech	Rating	Voluntary	Limited	Data Destruction	Minimized	Transparent	Centralized
Stopp Corona	Austria	600000	Bluetooth, Google/Apple	5	Y	Y	Y	Y	Y	Decentralized
Belgium's apap*	Belgium	NA	Bluetooth, Google/Apple, DP-3T	1	Y	TBD	TBD	TBD	TBD	Decentralized
ViruSafe	Bulgaria	55000	Location	5	Y	Y	Y	Y	Y	Centralized
eRouska	Czech	277000	Bluetooth	5	Y	Y	Y	Y	Y	Decentralized
Smittestop	Denmark	TBD	Bluetooth, Google/Apple	5	Y	Y	Y	Y	Y	Decentralized
Estonia's app*	Estonia	NA	Bluetooth, DP-3T, Google/Apple	2	Y	TBD	TBD	Y	TBD	Decentralized
Ketju	Finland	NA	Bluetooth, DP-3T	3	Y	TBD	TBD	Y	Y	Decentralized
StopCovid	France	1900000	Bluetooth	1	Y	TBD	TBD	TBD	TBD	Centralized
Corona-Warn-App	Germany	14000000	Bluetooth, Google/Apple	4	Y	TBD	Y	Y	Y	Decentralized
Beat Covid Gibraltar	Gibraltar	9000	Bluetooth	5	Y	Y	Y	Y	Y	Decentralized
VirusRadar	Hungary	10000	Bluetooth	4	Y	TBD	Y	Y	Y	Centralized
CovidTracker	Ireland	NA	Bluetooth, Google/Apple	5	Y	Y	Y	Y	Y	Decentralized
Immuni	Italy	2200000	Bluetooth, Google/Apple	5	Y	Y	Y	Y	Y	Decentralized
StopKorona	North Maced	TBD	Bluetooth	5	Y	Y	Y	Y	Y	Decentralized
Northern Ireland's app*	Northern Irel	TBD	Bluetooth, Google/Apple	1	Y	TBD	TBD	TBD	TBD	Decentralized
Smittestop	Norway	1427000	Bluetooth, Location	3	Y	Y	Y	N	N	Centralized
ProteGO	Poland	41665	Bluetooth	4	Y	TBD	Y	Y	Y	Decentralized
Swiss Contact Tracing App	Switzerland	500000	Bluetooth, DP-3T, Google/Apple	5	Y	Y	Y	Y	Y	Decentralized
NHS COVID-19 App	UK	NA	Bluetooth, Google/Apple		TBD	TBD	TBD	TBD	TBD	Decentralized

Figure 3 Contact Tracing Apps: North America

Contact Tracing Apps: North America

Application	Country	Users/Downloads	Tech	Rating	Voluntary	Limited	Data Destruction	Minimized	Transparent	Centralized
COVIDAlert	Canada	NA	Bluetooth, Google/Apple	5	Y	Y	Y	Y	Y	Decentralized
CovidRadar	Mexico	TBD	Bluetooth	1	Y	TBD	N	N	N	Centralized

Table 1 Contact Tracing Apps: Technologies

Continent	Bluetooth	GPS	Location	Data Mining	Google/Apple	DP-3T	BlueTrace
Asia	12	1	12	1	3	0	1
Europe	18	0	2	0	10	4	0
North America	2	0	0	0	1	0	0

Table 2 Contact Tracing Apps: Privacy/Security

Continent	Voluntary	Limited	Data Destruction	Minimized	Transparent
Asia	10	3	5	7	6
Europe	18	10	13	14	13
North America	2	1	1	1	1

Table 3 Contact Tracing Apps: Data Storage

Continent	Centralized	Decentralized	TBD
Asia	9	8	2
Europe	4	15	0
North America	1	1	0