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# Digital Contact Tracing for COVID-19:
## A Review of Its Application to the Global Pandemic

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### ABSTRACT

The spread of the COVID-19 virus across the globe has permanently changed life for billions of people. Manual contact tracing has been utilized to assist in limiting the spread of contagious diseases for many years. The ubiquitous use of smartphones and similar wireless devices has allowed this process to become digital in nature through contact tracing applications installed on these devices. Various countries, and even various regional units within those countries, developed contact tracing applications. Such applications relied on location and short-range communication technologies associated with wireless devices and found varying degrees of success. This work reviews research conducted by universities, governmental organizations, and other entities with respect to the adoption, use, and ultimate success of, digital contact tracing applications across various countries and points to their rather limited success in fighting the spread of the disease. The authors also briefly discuss some implications regarding privacy and security that affected their use in certain countries.

### KEYWORDS

COVID-19, Digital Contact Tracing, Wireless Application

### INTRODUCTION AND THEORETICAL FRAMEWORK

In this work, we reviewed a wide range of scholarly, governmental, and mass media sources with respect to the development and implementation of contact tracing applications for use in the COVID-19 pandemic. Such applications seek to identify individuals who have had contact with an infected, or suspected infected, person in order to notify them and presumably have them quarantine to prevent further spread of the virus. These applications began to appear across the globe in the Spring of 2020

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as the pandemic spread from country to country. These applications rely on location-based and short-range communication technologies in order to pinpoint such "contacts" between an infected individual and others. As will be seen in this work, many countries, and even states or provinces, rolled out their own versions of contact tracing applications along with guidelines or laws on their usage. Populations in these countries and other regional units adopted and utilized them in a rather haphazard fashion overall with some countries having much more adoption and success than others. Often the success was a result of the culture in the countries or policies/laws enacted by the government there.

This work first briefly describes the origins of digital contact tracing. It follows with a discussion of some of the technologies involved. It is important to realize that these applications took advantage of technologies already present in cellular phones and related wireless devices and were not the result of new technological innovations. We then describe the variations in digital contact tracing applications/approaches and levels of success in reducing the spread of COVID-19 across various countries spanning the globe through reviews of the literature. Additionally, we explore some factors that affected the success of digital contact tracing such as mobile device use and privacy and data security concerns.

The main goal, and implied theoretical methodology for this work, is to show the diversity of digital contact tracing applications across the globe and gain some insight with respect to the issues that affected their success or failure through the examination of the literature. Also, one can learn about the differences between countries and regions in terms of how easily they accept the use of technology to assist in a crisis and how committed their governments were in utilizing such technologies.

## LITERATURE REVIEW OF DIGITAL CONTACT TRACING TECHNOLOGIES

Early applications of digital contact tracing began in an area of the world where tuberculosis is more much of an issue for the population than the developed industrial world in the early 2010's. The use of a digital contact tracing application for tuberculosis was successfully tested in Botswana and later utilized in other African countries. Unlike most of the industrialized world, the limiting factor in its implementation was the availability of 3G bandwidth at the time. This lack of bandwidth hindered the ability of the application to complete its centralized reporting mechanism thus defeating its main purpose. Digital contact tracing was also tested in Africa in Sierra Leone from 2014 to 2016 (Danquah, et al., 2019). Unfortunately, the central collection of data was inefficient or nonexistent in some cases due to technical and human issues. Overall, the application of the digital contact tracing was not considered a success for its application to the Ebola outbreak in West Africa in this case.

As the COVID-19 pandemic began in 2020 health departments and governments across the globe raced to find a technological approach to augmenting the traditional person-to-person method of contact tracing. Considering the near ubiquitous use of smartphones in virtually every country, tapping into this technological resource seemed to be the smartest move. The technology that developers have utilized for digital contact tracing is Bluetooth since it is included in every smartphone.

Smartphones equipped with Bluetooth could be used to track COVID-19 in the following manner:

1. Smartphones would generate complex strings of characters and exchange them, providing a way to know what people have been near each other without the need for exchanging personal identifiable information (PII).
2. An app developed for contact tracing generates anonymous codes that change every few minutes.
3. If people with the app are within range (for Bluetooth approximately 32 feet) for several minutes (a time determined by the health department to allow for exposure to the virus), their phones trade codes via Bluetooth and create an encrypted record on their phones.
4. If someone is diagnosed with COVID-19, they can volunteer to work with a health agency to enter the test result in the app.

5. The app sends that person's anonymous report with their codes only to cloud-based computer servers.
6. The cloud servers then sends those codes to other phones, which search for matches. Anyone who was within range of the diagnosed person in the past 14 days receives an alert notification from the app with advice on quarantining, though their identity is protected (Ingram, 2020).

In attempting to assuage users' concerns over privacy and data misuse for these applications, Apple and Google created an Exposure Notification Bluetooth Specification which they freely made available to all interested parties. According to Apple, the Apple Google Bluetooth protocol utilized maintains privacy by the following means (Apple.com, 2022):

1. The Exposure Notification Bluetooth Specification does not use location for proximity detection. It strictly uses Bluetooth beaconing to detect proximity.
2. A user's Rolling Proximity Identifier changes on average every 15 minutes, and needs the Temporary Exposure Key to be correlated to a contact. This behavior reduces the risk of privacy loss from broadcasting the identifiers.
3. Proximity identifiers obtained from other devices are processed exclusively on device.
4. Users decide whether to contribute to exposure notification.
5. If diagnosed with COVID-19, users must provide their consent to share Diagnosis Keys with the server.
6. Users have transparency into their participation in exposure notification.

Despite these safeguards that the applications using this protocol would not be collecting personal identifiable information (PII), widespread usage of digital contact tracing apps still lagged behind a level that most health department officials cite as a minimum metric for useful usage (i.e., 60%) (Kreps, et al., 2020).

The Apple-Google Bluetooth protocol is an example of a decentralized architecture in that only the data of an identified COVID infected person gets uploaded to the centralized server. Contact tracing is performed locally on the user's smartphone. This is a major part of the architecture that helps protect the user's privacy. In contrast, a truly centralized architecture would require user data to be sent for processing and handled by centralized servers; thus, posing a greater risk to privacy and security overall.

Using Bluetooth (including the Apple-Google Bluetooth protocol) instead of Global Positioning System (GPS) tracking also appears to be a factor in persuading users that concerns over privacy are being addressed. While using GPS seems to raise concerns among users of a greater possible invasion of privacy largely because of the increased distances where tracking can occur, there are more practical reasons why contact tracing app developers have avoided using GPS. GPS is mostly unusable indoors and in most underground locations such as subways and rail transit systems. A study conducted at the University of Georgia found other serious issues which could affect the accuracy of GPS contact tracing purposes. Small errors in distances between people of 7 to 13 meters in GPS terms amounted to large errors for contact tracing purposes (UGA Today, 2020; Merry & Bettinger, 2019).

## LITERATURE REVIEW OF THE EUROPEAN USE OF DIGITAL CONTACT TRACING APPLICATIONS

Some of the first reports of the impact of COVID-19 came from Europe. Northern Italy became a "hotspot" for COVID-19 infections and resultant deaths during the initial phase of the pandemic in 2020. Even as China began to control the spread of the virus, Italy suffered through some unimaginable initial months of the pandemic. This section reviews various studies in specific European countries and across their borders with respect to the implementation of digital contact tracing. Unfortunately, it was with very mixed results that such applications were first implemented in Europe in 2020 seeking to curb the spread of COVID-19. A summary of the digital contact tracing sentiment, as reviewed in this section, is provided in Table 1.

An important study (Zimmer, et al., 2021) with respect to contact tracing applications and their acceptance in Western Europe focuses on Germany, Austria, and the German-speaking portion of Switzerland. All of these countries implemented contact tracing applications during 2020. The authors of this study conducted qualitative interviews with 110 people across the three countries and also reviewed survey articles regarding contact tracing apps from 12 German-language newspapers from the three countries. The individuals interviewed for this research in April 2020 (Zimmerman, et al., 2021) were participants in the larger-scope SolPan (Solidarity in Times of a Pandemic) study that included people from 9 European countries. The SolPan study sought to collect people's experiences with respect to policies and controls implemented by the various governments in the study to prevent the spread of the disease such as restrictions on movement, closures of workplaces and schools, and other such measures.

The focus of this work, beyond the newspaper review activity, was a subset of people who participated in the larger SolPan study across the three countries. Interviews ranging from 25 to 80 minutes related to their opinions on contact tracing applications and the nature of usage. The results of the work found that both newspaper coverage and the people interviewed regarding contact tracing applications as a form of government "surveillance". This term actually had different meanings to different people including: a way to manage the spread of COVID-19 and a way to track people's movements in a clandestine fashion. The fact that the term surveillance was used so often by study participants, even if it was meant in a positive fashion, gave the impression that a general lack of distrust and control was associated with the contact tracing apps. Ultimately, the applications in these three countries saw a relatively low usage rate by the populations.

A survey of the general population of 730 individuals in Belgium sought to ascertain the acceptance of digital contact tracing applications (Walrave, et al., 2020). The results point to a rather high intent to try digital contact tracing (about 49% of respondents), but not for reasons one would suspect. Both the perceived severity associated with contracting COVID-19 and personal susceptibility to COVID-19 (in terms of having comorbidities such as diabetes or heart disease) were determined to have no influence on the decision to use a digital contact tracing application. Surprisingly, the most influential factor in this decision was the perceived benefit of being made aware of contacts with those who had contracted COVID-19. In other words, respondents wanted information on their possible exposure and this desire drove their need for the digital contact tracing application. A secondary reason, but still rather important and related reason for trying such an application, included the need to adjust one's behavior if they had contact with an infected person. One might view this reason as directly related to their desire not to infect others such as family and friends by quarantining or social distancing.

Research on digital contact tracing in the Netherlands sought to predict the usage of these applications (Jonker, et al., 2020). Using a sample of 900 people from the Dutch population, attitudes towards different potential contact tracing application attributes were surveyed. Some interesting results regarding potential usage of such applications showed that would-be users preferred functionalities or benefits beyond merely being used to track their proximity to COVID-19 infections. Small payments for using the application is an example of a popular desired attribute that came from the study. Respondents also showed a desire to stay in control of their data (or at least as best they could be given the nature of the application). An interesting result of the survey was that over half of the total respondents preferred using an app with some minimal contact tracing functionality over not using an app at all. Another result of the survey that is not that surprising is that the predicted adoption rate for people under the age of 35 was rather higher than that for older people and especially those 75 years and older.

A digital contact tracing research paper that was part of the overall SolPan study previously described dealt with the UK (Samuel, et al., 2022). A total of 35 people in the UK were interviewed for this work which was under the umbrella of the previously mentioned SolPan project. Considering that the UK has had one of the highest numbers of COVID-19 cases and fatalities in Europe, this number seems quite low. One does have to remember that these interviews were conducted relatively early in the pandemic. Much like the results with respect to the surveys conducted in the German-speaking countries, issues such as data security, privacy, and governmental control important to the people interviewed in the UK about contact tracing applications. Specific mention in this work of interviewees mentioning the need to balance invasions of privacy by such applications with the benefits to society of the actual contact tracing procedure is also noteworthy.

A survey (O'Callaghan, et al., 2020) was conducted in May 2020 with 8088 responses from people across all counties in Ireland regarding their attitudes towards digital contact tracing applications. The survey asked whether people would download a contact tracing application with over 50% (54%) stating that they would definitely download such an application. Another 30% percent indicated they probably would download such an application. The survey also probed their reasons for doing such. Responses included the potential to help family and friends and a sense of responsibility to the wider community. Such percentages and responses indicate a generally wider acceptance of contact tracing applications than in other European countries and beyond. The survey also asked for reasons for not downloading such an application; fear of how companies or the government might utilize the data from the application was the popular reason.

An interesting piece of research dealt with the attitudes and practices of health science students in France with respect to the StopCovid application utilized in that country (Montagni, et al., 2020). Several hundred students taking health science-related classes in Bordeaux were surveyed with respect to their usage and attitudes towards the digital contact tracing application. It seems logical that health science university students would be more likely to possess mobile phones capable of utilizing the StopCovid application and also more likely to at least try it, but we note that this is a very specific population, and this work certainly would not apply to the more general public. Even with the perceived tendency to be more favorable to the use of the application, the researchers found that only about 11% of the surveyed students actually downloaded it and that only about 5% were actually using it at the time of the survey. The survey was part of a larger effort to survey the French student population with regard to health and related matters and it shows a trend seen throughout most of the world. This trend of lesser concern about the COVID-19 virus and its health affects with respect to the younger sector of a given country's population has been seen both in world news and other research.

A multi-country survey (France, Germany, Italy, UK, and the US) sought to gauge support for the use of contact tracing applications to aid in the COVID-19 mitigation effect (Altmann, et al., 2020). In total, 5995 responses across these countries were gathered and analyzed in March and April of 2020. A result that correlates with a similar study in Ireland was that 4484 respondents (74.8%) stated they would definitely or probably download a contact tracing application utilized in their respective country. An expected result of this study found that people who carry their mobile phones with them most of the day tended to be more willing to install the application on it. One might extend this result to postulate that working professionals and younger people would tend to carry their phones with them rather than the elderly.

Another more useful result for public health officials found that people with comorbidities with respect to COVID-19 were 3.7% more in favor of the use of contact tracing applications. This result in particular points out a flaw in the rollout of contact tracing applications in general during the pandemic. It possibly would have been a more effective strategy had such applications initially been targeted to people with comorbidities before using a broader approach aimed at the general population of a country or state. Another result of this study that correlates with other research we reviewed was that people in the US and in Germany in particular were much more likely to have concerns about the app being used for government surveillance. An additional result of this study that correlated with a study in Ireland was that one of the biggest reasons for having a favorable opinion of contact tracing apps was to seek the protection of family and friends.

**Table 1. Sample of European sentiment towards digital contact tracing applications**

| Country | Sentiment Towards Using Digital Contact Tracing Applications |
|---|---|
| Germany | Unfavorable |
| Austria | Unfavorable |
| German-speaking Switzerland | Unfavorable |
| Belgium | Favorable |
| Ireland | Favorable |
| Netherlands | Favorable |
| Italy | Somewhat Favorable |
| UK | Somewhat Favorable |
| France | Somewhat Favorable |

## LITERATURE REVIEW OF THE NORTH AMERICAN USE OF DIGITAL CONTACT TRACING APPLICATIONS

The use of mobile health applications is not a new concept in the U.S. or North America in general. The advent of the smart phone in the early 2000s brought about various applications related to maintain physical and mental health. One only has to watch television in the U.S. today to see devices that can be integrated with smart phone applications for tracking exercise and activity, determining heart function, and monitoring caloric intake in one's diet. A 2013 study conducted by researchers in Pennsylvania examined the use of digital contact tracing applications for monitoring the spread of another contagious disease that long predated COVID-19: tuberculosis (Ha, et al. 2013). A summary of the issues of concern for potential users and the usage of digital contact tracing applications in this section is provided in Table 2.

Even with these mixed reviews for such technology use prior to COVID-19, one would think that such a "head start" on digital contact tracing of over half a decade would help its implementation in the U.S. for COVID-19 to be somewhat successful. Unfortunately, this is not the case for the most part due to political, privacy and data security, and technological issues. Relative to Europe and other parts of the globe, there is a dearth of research on the success of digital contact tracing applications in the United States. This could be due to the factors just mentioned that affect the acceptance of these applications and also due to the fact that these applications were implemented on a state-by-state basis with little national coordination.

The United States, with its federal government in Washington, D.C. creating policies regarding mask wearing, social distancing, and vaccine requirements, saw a mixed approach by individual states with respect to digital contact tracing. One of the three approaches for states involved the in-house (by the state) directing the development and implementation of a digital contact tracing mobile application (National Academy for State Health Policy, 2022). A second approach involved partnering with one or more other states to direct and develop such an application as a consortium. Finally, the third, and least-used approach, was to contract with an outside entity to direct the development and rollout of an application in the state.

The most popular approach to creating and implementing a digital contact tracing mobile application was the partnering one which is not surprising given the urgent desire to combat the spread of COVID-19 in the spring and summer of 2020. Twenty-seven U.S. states chose this path to digital contact tracing (National Academy for State Health Policy, 2022). An additional sixteen states chose in-house development of the application with eight states contacting with outside companies to obtain such a mobile application. The funding amounts and sources for each state's efforts varied dramatically as did the implementation speed and nature of the application rolled out to the state's populace. Although each state had to decide its method for implementing digital contact tracing, interoperability existed between applications for most states. For example, COVID Alert, the mobile application for the state of Pennsylvania, is compatible with applications from twenty-seven other states even though it chose to use an outside contractor to direct and implement its digital contact tracing application (Pennsylvania Department of Health, 2022). The ability to interface with other such applications would provide a measure of effectiveness for the applications as users traveled between states if a critical mass of people in those states were actively using the applications.

Although a brief discussion of a digital contact tracing application utilized in Mexico is included in the South America and Latin America section of this work, we felt obligated to detail one particular application that was undertaken by a state in the country. The Mexican state of Nuevo Leon launched the digital contact tracing application entitled COVID Radar in 2020 (ITSRIO, 2022). The application was developed by a private company in consultation with a biotechnology research center in Chile. Unfortunately, by June of 2020, it only had 10,000 downloads within a Mexican state population of over 5 million residents. This represents about a .2% potential usage; far short of an effective percentage for preventing the spread of COVID-19 through this method of contact tracing.

With respect to the overall United States and the use of digital contact tracing applications, the potential existed for it to be useful in the controlling the spread of a contagion such as COVID-19; but many obstacles exist which limit success. MIT researched the use of digital contact tracing and published the percentages of the population for each state that downloaded such applications. The percentages, as of May 2021, varied widely from 1.2% in Arizona to 45.7% in Hawaii (MIT Technology Review, 2022). This certainly represents a very mixed set of results for such applications in the U.S. as percentages of use reached 70 or more percent in some countries.

A very interesting piece of research on digital contact tracing was conducted by researchers from Google Research, the Stanford University School of Medicine, and the Nuffield Department of Medicine at Oxford in the United Kingdom (Abueg, 2020). This research modeled both the effect of digital contact tracing (termed digital exposure notification by the researchers) and non-pharmaceutical interventions such as manual contact tracing and social distancing in Washington State in the United States. The work used a representative household model for three counties in Washington State and simulated various exposure and mobility conditions to ascertain the effectiveness of a combined approach on preventing the spread of COVID-19. In contrast to many of the other published works on digital contact tracing that involved surveys of existing and potential users of the mobile applications, this work attempted to combine such with the ongoing use of manual contact tracing and social distancing to get a clearer picture of overall effectiveness against the spread of the virus. The ability to do a "what if" analysis with respect to various levels of participation percentage of the digital contact tracing application, percentage of people who contracted the virus, and other parameters, made this approach an especially useful tool for public health officials in that state. For example, a participation percentage of 15% in the digital contact tracing could reduce exposure to the virus by 8% and deaths by 6% when complementing the other manual procedures.

Published research from an author in Canada (McGrail, 2021) delved into a different aspect of digital contact tracing beyond mere acceptance by potential users or issues data security. It examined the broader issue of personal data collection from such applications and the security of such and how this process is classified. In fact, the work explored the issue of whether digital contact tracing might be considered to be "signals intelligence" or SIGINT. SIGINT would certainly have implications with respect to privacy; but the as the author explains, it goes beyond to even issues of equity in society. One might say that those that cannot afford smart phones are not able to take advantage of the benefits of digital contact tracing and could be considered more at risk for exposure and contraction of COVID-19. The work also discusses the impact on societal trust in technologies by such applications and the notion of surveillance that is implied in their use.

An additional Canadian published work examined the province of Alberta's rollout of a digital contact tracing application that was based on the protocol for the one used in Singapore (Kleinman, 2020). The article stressed the need for testing the application prior to actual rollout to the public. It also brought to light the inherent issues of privacy and security that are present for all digital contact tracing applications, regardless of the country or country subunit such as Alberta.

## LITERATURE REVIEW OF THE EAST ASIAN USE OF DIGITAL CONTACT TRACING APPLICATIONS

The first COVID-19 cases were reported in Wuhan City, Hubei Province of China, at the end of December 2019. With no evidence of significant human-to-human transmission, there were also no recommendations to limit or restrict travel or trade (WHO, 2020).

However, by February 2020, the risk of human transmission was apparent. In efforts to contain the spread, the Chinese Health Code centralized location tracking app was launched in Alibaba's Ant Financial wallet app, Alipay, in conjunction with the Hangzhou Communist Party (Zherjiang Province) and Chinese national government. Users are assigned a green, yellow, or red color code that indicates their health status and contagion risk, and whether to permit them into public spaces such as subways and malls. Enforcement on travel and shopping restrictions for citizens without a green color code led to quick adoption where almost 90 percent of the Zherjiang Province population, or 50 million people, signed up for the app.

This was followed by a second color code tracking app launched by Tencent, the Internet provider hosting WeChat. WeChat is a messaging app with over a billion monthly users. There is little information on the data mining algorithms used to assign colors, which at times seemed confusing to users. In addition, analysis indicates that personal data is shared with police, causing some to wonder whether these location and personal information tracking apps borne in COVID will continue beyond for other social control purposes (Mozer et al., 2020). A summary of the digital contact tracing applications mentioned in this section is provided in Table 3 below.

In April 2020, India launched the AarogayaSetu app which was mandated for use by citizens. By May 26, with almost 90,000 confirmed cases and over 5,000 deaths, 114 million users had subscribed to the contact tracing app (CTA) (Jalabneh et al., 2021). This number is currently reported to have grown to over 163 million, the largest of any other CTA. The app tracks the location, Bluetooth contact, and also assigns a color-coded badges indicating infection risk (O'Neil et al., 2020). Although India is the only democracy mandating the use of a CTA, the courts limit data sharing between government agencies and the length of time the data is stored (Plumber, 2021).

COVID cases in Malaysia began spiking in January 2020, leading to the creation of three CTAs by different agencies. MyTrace is a community-driven app exchanging proximity information between users detected by the app detects, and was developed by eight governmental agencies, the International Islamic University Malaysia, and Google. MySejahtera enables users to perform a self-assessment and monitor progress, while also permitting necessary interventions by the Ministry of Health. Gerak Malaysia raises the most concerns for data privacy by not only granting travel permissions to users during moving control orders, but also providing the Ministry of Health user movement data and contact information, as well as personal data such as name, ID number, and postcode (Jalabneh et al., 2021).

**Table 2. Usage and issues of concern for north america digital contact tracing applications**

| Country | Usage and Main Issue of Concern in Using Digital Contact Tracing Applications |
|---|---|
| United States | Low – Privacy/Security |
| Mexico (Nuevo Leon) | Low – N/A |
| Canada | N/A – Privacy/Security |

Singapore's TraceTogether community-driven app was launched by the government and Ministry of Health on 20 March 2020, becoming the first major Bluetooth CTA (O'Neil et al., 2020). Registration for the app only requires a phone number and no further data is collected. The data deletes every 21 days if the user did not come in contact with a positive case during this period (Jalabneh et al., 2021).

Thailand implemented MorChana ("Doctor Wins") in April 2020, a Bluetooth, location-based CTA, and paired this with a proximity contact tracing app with a QR code check-in system called Thai Chana. Users self-assess risk levels based on travel and contact history. The app uses push notifications when users enter a high-risk area (Yuduang et al., 2022).

CTAs enabled governments and health agencies in centralized database cases, or users in decentralized cases, to monitor waves and clusters to control infection exposure and direct self-isolation when necessary. Going forward a caution remains concerning data anonymizing, privacy, usage, and rights (Jalabneh et al., 2021).

## LITERATURE REVIEW OF THE SOUTH AND LATIN AMERICAN USE OF DIGITAL CONTACT TRACING APPLICATIONS

Unfortunately, there is a scarcity of information on digital contact tracing applications implementation in South America and Latin America. We were able to glean some limited information, though, mostly from online sources. The first confirmed case of COVID-19 in Latin America was discovered in Brazil in February 2020. By mid-March, most Latin American countries had confirmed cases. By May 2020, the World Health Organization announced that Latin American to be the new epicenter for the pandemic. Implementing contact tracing apps in Latin America proved to be particularly challenging due to widespread lack of trust in the governments; low trust in fellow citizens; high data privacy concerns; and the concern by low-income individuals about overloading their data plans (Boruchowicz, et al., 2021) A summary of the digital contact tracing applications mentioned in this section is provided in Table 4 below.

By the end of 2020, at least 28 contact tracing COVID-19 apps were used across Latin America. The apps had provided many features including virus prevention guidelines, self-diagnose tools, quarantine compliance monitoring, and contact tracing. Argentina, Colombia, Costa Rica, Mexico, Peru and Uruguay were among the first to roll out a contact tracing app. (Ordonez & Ross, 2022)

In Brazil several contact tracing apps were introduced. The first was introduced by the Brazilian federal government (Coronavirus SUS); the second was developed by the private sector (DyCovid). The third was funded by a local municipal government (Fox, et al., 2021).

In March 2020, Argentina required visitors to download the country's COVID-19 app which among other things is used to ensure that travelers are complying with the quarantine rules. The app Detectar was also used to help the user self-diagnose the symptoms and to provide assistance to COVID-19 patients. The app was used by more than 10 million people (Privacy International, 2022; Ordonez & Ross, 2022).

**Table 3. Sample of East Asian digital contact tracing applications**

| Country | Name of Digital Contact Tracing Application |
|---|---|
| China | Centralized Health Tracking Application |
| India | AarogayaSetu |
| Thailand | MorChana |
| Singapore | TraceTogether |
| Malaysia | MyTrace |

Uruguay's CoronavirusUY app, which was the first in Latin America, was designed to distribute information, to enable self-assessment and symptom reporting, and to arrange testing. Similar apps were used in Mexico (COVID-19MX), Columbia (CoronaApp), Peru (PeruEnTusManos), and Costa Rica (EDUS) (Ordonez and Ross, 2022; Scrollini & Baliosian, 2022).

## FINDINGS REGARDING PRIVACY AND DATA SECURITY FOR DIGITAL CONTACT TRACING

As detailed in the previous section, digital contact tracing's use across the globe varied widely from country to country and region to region. Two of the main factors affecting its use by the populace of a given country or region were the privacy and data security aspects of the applications. The United States' Centers for Disease Control and Prevention (CDC) identify two types of digital contact tools for COVID-19: "case management" and "proximity tracing / exposure notification" (Centers for Disease Control and Prevention, 2022). In both cases, the use of technology in contact tracing allows for faster collection and analysis of date to provide timely communications regarding important health information. However, the use of technology also introduces a number of challenges regarding the security of the systems and the privacy of collected user data. Notably, the CDC identifies two key disadvantages to the use of digital contact tracing tools: (1) "Expansion of tool capabilities will require more consultation on the ethical and legal issues related to electronic tracking" and (2) "Hacking and other unauthorized access or use of data may compromise data security and confidentiality" (Centers for Disease Control and Prevention, 2020).

Indeed, research demonstrates that there are security and privacy gaps in some of the most popular contact tracing application programming interfaces (APIs) developed by Google and Apple. Baumgärtner, et al. (2020) identify two key gaps in security and privacy of these APIs. First, the research team identified a security gap which would allow a bad actor with relatively simple technology (a mobile device or Raspberry Pi) to implement a wormhole attack that would link two geographic locations and allow for a COVID-19 exposure in one place to be reported falsely as a COVID-19 exposure in the linked location, resulting in undue concern for individuals who were not actually in proximity to a COVID-positive individual. Additionally, a data privacy concern was raised: Both APIs use of a 24-hour Temporary Exposure Key (TEK); however, some apps using the APIs ask for multiple days of TEKs (usually 14 days, based on the typical COVID-19 exposure to symptoms window). The larger collection of TEKs comes more data that can be attributed to one user, resulting in an increased risk of deanonymization of a user's data.

In May 2020, the MIT Technology Review began a running compilation of the various digital contact tracing apps being released around the globe. It also evaluated each for its privacy features

**Table 4. Sample of South/Latin American digital contact tracing applications**

| Country | Name of Digital Contact Tracing Application |
|---|---|
| Brazil | Coronavirus SUS |
| Brazil | DyCovid |
| Argentina | Detectar |
| Uruguay | CoronavirusUY |
| Mexico | COVID-19MX |
| Colombia | CoronaApp |
| Peru | PeruEnTusManos |
| Costa Rica | EDUS |

(O'Neill et al., 2020). They created a number of key criteria and, for each affirmative answer, added a star to the app's rating. The criteria are: (1) "Is it voluntary?", (2) "Are there limitations on how the data gets used?", (3), "Will data be destroyed after a period of time?", (4) "Is data collection minimized?", and (5) "Is the effort transparent?" (O'Neill et al., 2020). The database was last updated in March 2021, with 19 of 49 global apps receiving the full five stars (Ryan-Mosley, 2021).

There is quantitative research that supports the use of digital contact tracing applications in the control of the spread of COVID-19 (Feretti et al., 2020). Technology-based contact tracing can help public health officials and individuals more quickly respond to possible COVID exposure (thereby allowing individuals to take proactive precautionary steps to help stop possible further transmission of the virus). For that reason, continued use of these apps is prudent in the face of a global pandemic. However, it is also important to recognize and address the existing shortcomings of some of the most widely used APIs for these apps. All of this leads to asking the question, "What can be done to improve the security and privacy of digital contact tracing apps?" The solution may lie with both regulation and technology.

Recent research suggests that contact tracing apps should be treated – in terms of government regulation and oversight – as medical devices (Kamenjasevic and Biasin, 2020). Biasin, et al. (2022) demonstrates how contact tracing apps align with the criteria for European Union's medical device (MEDDEV) guidelines, considering key classification questions, including:

(1) "Is the product a software according to the definition of MEDDEV 2.1/6?"
(2) "Is the software a standalone software according to the definition of MEDDEV 2.1/6?"
(3) "Is the software performing an action on data different from storage, archival, communication, or a simple search?"
(4) "Is the action for the benefit of individual patients?"

With affirmative responses to each of these questions, Biasin, et al. (2022) recommended that digital contact tracing apps should be considered – and regulated as – medical devices. In addition to applying additional governmental oversight and regulation to the development and deployment of digital contact tracing apps, different technical solutions to the existing security and privacy gaps have been identified:

One proposal is a "perturbed location" approach to proximity-based digital contact tracing apps (Lohan et al., 2022). The model relies upon two things: the assumption that the users have full control of their location information and are able to get some floor-map information when entering a building of interest from a remote service provider (Lohan et al., 2022). The result is a digital contact tracing app that is less granular in terms of an individual's location, providing the individual with a greater level of privacy while still performing the key functions of a contact tracing app. While there will be developmental overhead to this solution (particularly, the mapping and collection of building floorplans), this proposed solution is applicable not only to digital contact tracing apps, but to future implementations of location-based mobile apps which are more privacy-focused that the current models.

Another approach that is being widely researched are blockchain-based digital contact tracing solutions. It is worth noting that there are already a number of blockchain-based digital vaccine certificate applications currently in development, and they are backed by various organizations and companies including well-known technology companies such as IBM (Mithani et al., 2022). Proponents for the use of blockchain to create a digital contact tracing app for COVID content that it would be more secure and private than current apps because the blockchain contact tracing solution enables user-centric data management, so each user holds the power of ownership of the data (Ciaburro, 2022). Additionally, the immutability of the data assures us that once a block has been inserted it can no longer be modified, thus ensuring reliability and transparency to all users (Ciaburro, 2022).

Over the past two years, there was a rush to quickly develop and release digital contact tracing applications. As the pandemic wears on, there is a continued need for robust digital contact tracing apps. Research has identified both gaps in the existing technologies and regulations and have proposed possible solutions. Rather than remaining content with the existing solutions, governments and technology developers should integrate this information into the continued evolution of digital contact tracing, which can be useful not only in the current pandemic, but for future public health emergencies.

## CONCLUSION AND RECOMMENDATIONS

Although contact tracing applications were developed by various countries across the globe to fight the spread of COVID-19, their success varied from country to country. A general conclusion from the authors is that countries that relied more on their governments for health care and other services generally had more adoption, and therefore success, of the contact tracing applications. The review presented here, although not exhaustive by any means due to a restriction on the size of the work, nonetheless pointed out the fact that without a minimum threshold of adoption/use, such applications have limited value in curtailing the spread of an airborne pathogen such as COVID-19. Distrust of the government in general, fears regarding privacy and data security, and a lack of mobile device usage or technology skills all lead to a rather limited amount of success with such applications across the globe. Only governments that mandated their use had some success in using it to track infected persons and to notify others of exposure.

In reviewing the regions cited in this paper, western Europe focuses on Germany, Austria, and the German-speaking portion of Switzerland. All of these countries implemented contact tracing applications during 2020. In many western European countries, a general lack of distrust and control was associated with the contact tracing apps. Ultimately, the applications in these three was somewhat representative of western Europe as a whole and saw a relatively low usage rate by the populations. While some recognized the need to control the pandemic and avoid contact with an infected person, or prevent the spread to friends and family, others viewed contact tracing as a way to track people's movements in a clandestine fashion. The fact that the term surveillance was used so often by study participants, even if it was meant in a positive fashion, gave the impression that a general lack of distrust and control was associated with the contact tracing apps. Ultimately, the applications in these three countries and most of western Europe saw a relatively low usage rate by the populations.

Compared to Europe and other parts of the globe, there is not much research on the success of digital contact tracing applications in the United States. This could be due to the factors just mentioned that affect the acceptance of these applications, and also due to the fact that these applications were implemented on a state-by-state basis with little national coordination. The United States, with its federal government in Washington, D.C., including the location of the Centers for Disease Control (CDC) creating policies regarding mask wearing, social distancing, and vaccine requirements, saw a mixed approach by individual states with respect to digital contact tracing. As expected, the conservative leaning states viewed contact tracing as another form of government intrusion, while the more progressive states generally had higher usage rates. Reasons for reluctance generally involved concerns over what data were being collected, who would have access to the data, and how long it would be preserved.

South of the US border was no better. An application for Mexican residents was developed by a private company in consultation with a biotechnology research center in Chile. Unfortunately, by June of 2020, it only had 10,000 downloads within a Mexican state population of over 5 million residents. This represents about a .2% potential usage, far short of an effective percentage for preventing the spread of COVID-19 through this method of contact tracing.

East Asia saw much different results in their efforts of contact tracing. In efforts to contain the pandemic spread, the Chinese Health Code centralized location tracking using an app in Alibaba's Ant Financial wallet app, Alipay, in conjunction with the Hangzhou Communist Party (Zherjiang

Province) and Chinese national government. Users are assigned a green, yellow, or red color code that indicates their health status and contagion risk, and whether to permit them into public spaces such as subways and malls. Enforcement on travel and shopping restrictions for citizens without a green color code led to quick adoption where almost 90 percent of the Zherjiang Province population, or 50 million people, signed up for the app.

India also reported a much more favorable and widespread usage of contact tracing apps. In April 2020, India launched the AarogayaSetu app which was mandated for use by citizens. By May 26, with almost 90,000 confirmed cases and over 5,000 deaths, 114 million users had subscribed to the contact tracing app (Jalabneh et al., 2021). This number grew to over 163 million, the largest of any other contact tracing app. Malaysia, Singapore, and Thailand, also areas with high pandemic numbers likewise reported better than average contact tracing compliance and the use of contact tracing apps.

And finally, in Latin America where obtaining reliable data was difficult the implementation of contact tracing apps proved to be particularly challenging due to widespread lack of trust in the governments; low trust in fellow citizens; high data privacy concerns; and the concern by low-income individuals about overloading their cellular data plans and the associated costs.

The use of a centralized and standard contact tracing app has not been highly discussed, but such an app possibly created by the World Health Organization (WHO) might in some areas be more universally accepted. It would not have the stigma of gathering information for use by a perceived "prying" government, and likewise it would not have the stigma of gathering data for a private company seeking to somehow monetize the data for uses other than contact tracing. Unfortunately, in areas of the world consisting largely of developing countries it might be perceived as another form of European colonialism considering the location of the WHO headquarters in Geneva despite its connection to the United Nations.

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