Assessing Connections and Tradeoffs between Geospatial Data Ethics, Privacy, and the Effectiveness of Digital Contact Tracing Technologies

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Abstract

Contact tracing, a useful public health tool that aids in the identification of individuals who may have come into contact with a person known to be infected with a disease, has been identified as key to the mitigation and suppression of COVID-19. Effective contact tracing allows public health authorities to sever chains of transmission and shift policy to case-based interventions such as selective individual quarantines rather than population-wide interventions such as social distancing. While public health authorities have the ability to conduct manual contact tracing, many do not have the capacity to identify and trace infected individuals at the scale or speed needed to respond to the COVID-19 pandemic. To improve the reach and effectiveness of contact tracing, many are proposing to expand contact tracing capacity by introducing digital contact tracing technologies that use the geospatial tracking technologies (e.g., GPS, WiFi, Bluetooth) embedded in mobile devices to gather, store, transfer, and share the location and contact histories of individuals. This chapter examines contact tracing, its potential extension using geospatial technologies, and the tradeoffs between privacy and effectiveness that may arise as these systems are developed and deployed to address COVID-19. By identifying linkages between the potential capabilities of these technologies and ethical and privacy principles of geospatial data handling, we introduce a framework for assessing conflicts between privacy and effectiveness. This framework is needed if we are to hold an informed public discussion of two critical questions. First, how the potential spread of geospatial contact tracing technologies may impact the institutional structures of society. Second, how societal processes might change the form geospatial contact tracing technologies take and the role we intend for them to play.

Keywords: Contact tracing, COVID-19, Privacy, Geospatial Technologies, GIS and Society

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Introduction

Contact tracing is a set of activities employed by public health professionals to assist with the abatement of infectious diseases. A part of contact tracing, the identification of individuals who may have come into contact with a person known to be infected with a disease, has been identified as key to the mitigation and suppression of COVID-19 (CDC 2020, Kahn 2020). Effective contact tracing allows public health authorities to sever chains of transmission and shift policy to case-based interventions such as selective individual quarantines rather than population-wide interventions such as social distancing. While public health authorities have the ability to conduct manual contact tracing, many do not have the capacity to identify and trace infected individuals at the scale or speed needed to respond to the COVID-19 pandemic. To improve the reach and effectiveness of contact tracing, many academics and policymakers have proposed a shift to technology-assisted contact tracing (TACT) systems that use the geospatial technologies (e.g., GPS, WiFi, Bluetooth) embedded in mobile devices to gather, store, transfer, and share the location and contact histories of individuals (see Ferretti et al. 2020, Kahn 2020).

However, the movement to develop TACT and introduce digital contact tracing technologies (DCTT) into pandemic management has raised a number of practical, ethical, and privacy concerns. As a practical matter, the accuracy and reliability of DCTT are limited by both the geospatial technologies these systems are built upon and the ways in which the general public will, or will not, use them. As an ethical matter, differential access to key technologies and spatial variation in the efficacy of DCTT mean that some segments of society may not benefit from DCTT as much as others. At the same time, the large scale collection of detailed data about the location and social networks of individuals raises concerns about privacy and possible social stigmatization. Understanding and addressing each of these issues is fundamentally a geographic challenge because each issue is shaped by the capabilities of geospatial technologies and how those technologies are used to suppress COVID-19. Meeting these challenges requires identifying and evaluating the tradeoffs that exist between technology uses that may improve the efficacy of DCTT at the expense of selected groups or individual liberties.

This chapter presents a framework that can be used to gather the data needed to assess the potential tradeoffs between privacy and effectiveness that may arise as DCTT are developed and deployed to address COVID-19. How well DCTT support TACT efforts, and whether those efforts adhere to ethical principles presented in the public health and location privacy literatures depends largely on the purpose and boundaries of data collection, the entities responsible for data collection, the entities granted access to data, the definition of allowable data use, and how and when the data will be disposed of. To expand on each of these topics, the remainder of the chapter is organized as follows. First, we briefly introduce traditional forms of contact tracing and identify how the transmission characteristics of COVID-19 have strained this public system. We then present TACT systems and the DCTT they are built upon. We explain how these systems are intended to function and identify potential benefits and limitations of DCTT using selected examples from the COVID-19 pandemic. In the fourth section of the chapter, we present the ethical and privacy principles at the center of the DCTT debate. We develop an assessment framework around those central principles and the characteristics of TACT presented earlier in the chapter and discuss key data that will be needed to operationalize the framework. Finally, we conclude the chapter by identifying key contextualizing factors that have emerged during the first six months of the pandemic and reflect on potential contributions geospatial researchers can make going forward.

Contact Tracing, Digital Contact Tracing Technologies, and Technology Assisted Contact Tracing

In this chapter, we draw the following distinctions, which we emphasize here for clarity. When we use the term *contact tracing*, we are referring to the traditional process of using in-person or phone interviews to identify individuals that may have been exposed to a disease by coming into contact with an individual carrying that disease, and to the set of related activities (e.g., follow-up calls, connecting individuals to support resources) used to limit disease spread. In the United States, contact tracing is conducted by, or under the jurisdiction of, state or local public health departments that are bound by the Public Health Code of Ethics (APHA 2019) and related law (see Gostin and Wiley 2016). We use *digital contact tracing technologies* (DCTT) to refer to a specific set of technologies (e.g., GPS, Bluetooth, contact tracing apps) tied to mobile phones that can be used together to gather data about the location of individuals and/or their proximity to others. The related term *technology-assisted contact tracing* (TACT) refers to the use of DCTT to augment traditional contact tracing by recording the location histories of DCTT users, notifying users of potential exposure, or otherwise intervening in the interest of public health.

Contact Tracing

The goal of contact tracing is to identify every individual a person with an infectious disease has come into contact with, so those individuals who were exposed and potentially infected with the disease can be quarantined away from the general population, thus breaking the chain of disease transmission. While we primarily focus on the identification and notification of contacts in this chapter, contact tracing involves a wider set of activities that includes connecting infected individuals and their contacts with needed services, conducting follow-up activities to encourage and ensure that infected individuals take appropriate disease mitigating actions, and generally providing the support services needed to limit disease transmission.

Contact tracing is a cornerstone of infectious disease control. The eradication of smallpox relied on extensive contact tracing and subsequent patient isolation and community immunization (Eames and Keeling 2003). Public health professionals have also used contact tracing to control diseases that spread through sexual networks, such as syphilis and HIV (Cates, Rothenberg and Blount 1996, Judson and Vernon 1988). Most recently, contact tracing and subsequent control measures such as quarantine were critical in limiting outbreaks of SARS in 2003 and Ebola in 2014 (Riley et al. 2003, Saurabh and Prateek 2017).

For COVID-19, contact tracing begins with contact identification and notification, but also includes the immediate quarantining of individuals exposed to the virus or isolating of individuals infected with the virus. To reduce the burden these actions place on individuals and improve their compliance, contact tracers also share information about essential services such as child care and elder care and conduct regular follow-ups with affected individuals. Follow-up contact is another key component of contact tracing efforts as it helps individuals gain and maintain access to the resources they need to sustain isolation or quarantine until the risk of transmission has ended.

Given the wide set of activities involved, numerous factors can impact the effectiveness of contact tracing. First, contact tracing is most effective when testing is widespread, accessible, and has produced rapid results. Abundant testing speeds identification of disease transmission, which facilitates and improves the response of public health departments. Second, individuals must be willing to be tested for a disease, respond to contact tracers, and disclose infection for contact tracing to have the desired effect. Third, even when individuals are tested and respond to contact tracers, contact tracing will only impact disease transmission if those affected by the disease have access to the resources they need to successfully isolate or quarantine. Accessing resources begins with knowing that support services such as testing, therapeutics, mental health support, childcare, and grocery delivery exist and how to access them. Contact tracers provide this knowledge during interviews. Moreover, effective use of these services depends on repeated contact to ensure individuals isolating or quarantining have continued access to resources that meet their needs. As such, the number of contact tracers relative to the size of the infected population can severely limit the effectiveness of contact tracing - because contact tracers cannot notify and follow-up sufficiently with those infected or exposed, and because service providers may be overwhelmed. Finally, contact tracing is shaped by the dynamics of disease transmission. Contact tracing is most effective when a disease spreads through prolonged direct physical contact with an infected person (direct transmission) after the onset of symptoms (symptomatic transmission) and when infected.

As described, contact tracing that relies on voluntary interviews with infected individuals that can be both time consuming and costly. Using contact tracing to mitigate and control COVID-19 has been challenging because the underlying virus (SARS-CoV-2) can be spread directly through physical contact or the exchange of respiratory droplets (Stadnytskyi et al. 2020) and indirectly through contact with contaminated surfaces[1] (Kampf et al. 2020). At the same time, SARS-CoV-2 can be spread during the incubation period of the virus before the onset of symptoms (pre-symptomatic transmission) or in cases where an infected individual never develops symptoms (asymptomatic transmission) (Bai et al. 2020, Mizumoto et al. 2020). Pre-symptomatic and Asymptomatic transmission disrupts contract tracing efforts for at least two reasons. First, infected individuals who are unaware that they are carrying and spreading the disease cannot identify themselves to contact tracers. Second, even in cases where individuals do develop symptoms and then volunteer for contact tracing, those same individuals may have already spread the disease preceding the onset of symptoms while they were still pre-symptomatic[2]. Moreover, contact tracing is most effective when conducted soon after an infected individual is identified. For SARS-CoV-2, local health departments seek to initiate contact tracing within 24 hours of a confirmed positive test. In situations where transmission is widespread, departments may simply lack the resources to complete contract tracing in a timely manner. Due to this combination of factors, identifying personal contacts and delineating social networks may not alone be able to capture the underlying transmission mechanisms of SARS-CoV-2.

Contact tracing must also reconstruct the location history of individuals carrying SARS-CoV-2 to capture possible indirect, asymptomatic transmission. Examining the analogous case of the 2003 outbreak of SARS in Taiwan, Chen et al. (2007) demonstrate that introducing geographic contacts (when people share a location but not a direct interaction) into the construction of the disease contact network dramatically expands the size and connectivity of the network and by extension the number of possible chains of transmission. Studying tuberculosis, Klovdahl et al. (2001) and McElroy et al. (2003) similarly found that adding places as nodes in their social network analyses led to the identification of otherwise unrecognized contacts between patients and improved understanding of disease transmission. These findings collectively imply that a failure to account for geographic contacts and location in diseases with indirect, pre-symptomatic or asymptomatic spread is likely to dramatically misrepresent disease transmission.

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[1] Although the risk of transmission of SARS-CoV-2 by contaminated surfaces is likely less than initially believed (Goldman 2020, Kanamori 2020)

[2] At the time of writing it remains unclear how prevalent pre-symptomatic transmission is and over what time period it extends. Research indicates that while infectiousness can start 12 days before the onset of symptoms, only a small percentage of transmission occurs before three days prior to symptom onset (a model-based estimate by He et al. (2020) suggests 9 percent). Epidemiological studies conducted in a variety of transmission contexts suggest actual rates may be lower than those predicted by transmission models (see Slifka and Gao 2020 for a summary). If presymptomatic transmission rates are low they become less of a barrier to traditional contact tracing.

Six months into the COVID-19 pandemic, contact tracing efforts have had mixed success - constrained by the dynamics of the virus, the lack of testing availability and the rapid return of test results, the ability of individuals to recall their location and contact history, and the magnitude of the COVID-19 pandemic overwhelming the number of available contact tracers (Steinhauer and Goodnough 2020). To improve this aspect of pandemic response, many have proposed a shift to TACT systems that use DCTT to record the location and contact history of users and notify them of potential exposures to SARS-CoV-2.

Digital Contact Tracing Technologies Used in Technology-Assisted Contact Tracing

Through the use of TACT, public health departments seek to improve the response to COVID-19 by using a digital record of the absolute location (where someone is in space) and/or relative location (where someone is in relation to someone or something else) of an individual to accelerate the contact tracing process. TACT may take several forms. One approach is to use DCTT to continuously record the location history of an individual that has downloaded a contact tracing application onto their mobile device. In the event that the individual tests positive for COVID-19, this information would then be used by contact tracers to retrace where that person had been, and to help identify who they came in contact with using the location history to prompt the individual's memory during an interview.

Individual location histories and the population level mobility patterns that can be constructed from those histories have been shown to be valuable resources during the management of Ebola (Wesolowski et al. 2014a, 2014b), influenza (Farrahi et al. 2015, Dong et al. 2019), Cholera (Finger et al. 2016). In some countries (e.g., South Korea), a user's location data is combined with other forms of personal data (e.g., purchasing histories) to add depth to the location histories. However, this approach is not common in the United States, although some systems do allow users to link personal data (e.g., age, sex) to their location histories and give those users the opportunity to release the information to health departments if they wish.

An alternative approach is to focus on the relative location of individuals In this approach, anonymized identification codes are exchanged through Bluetooth low energy (BLE) signals between the mobile devices of users that have downloaded an application to create a contact list for each individual (Ferretti et al. 2020). If an individual tests positive for COVID-19, the system would then send a notification to that user's contacts signaling that they should be tested for the virus or take other preventative actions (e.g., quarantine). To preserve privacy, the location or contact histories of the individual can be stored on a user individual mobile device and contacts could be anonymized to reduce the risk of identification. This decentralized, proximity-centered approach to recording potential contacts is the foundation of a collaborative Apple-Google exposure notification system (Apple-Google 2020), which several states have adopted as the framework for their own digital contact tracing efforts.

Irrespective of approach, to be effective at mitigating the spread of SARS-CoV-2, the DCTT used in a TACT system must be capable of identifying epidemiologically meaningful contacts. At a minimum, this requirement means that DCTT must be accurate enough to detect when one individual comes into close contact (within 2m) with another individual or identify when an individual enters an area (e.g., a restaurant) with a risk of virus transmission. Clinical evidence (Bourouiba 2020) and retrospective studies of the secondary attack rate of COVID-19 in different environmental settings (see Cheng et al. 2020, Rosenberg et al. 2020) suggest transmission risks rise with time of exposure, which has led public health agencies to use temporal thresholds around 15 minutes when evaluating transmission risk. For this reason, DCTT should also be able to provide an accurate measure of either absolute or relative location for a similar period of time. If location data and/or proximity data are accurately recorded, securely stored, and accessible to public health officials, these agencies could use individual or aggregated data to improve contact tracing, model the course of the pandemic, and coordinate testing and response resources. To adhere to the ethical guidelines for public health data (see Lee and Gostin 2009), it is critical that these TACT have a clearly stated purpose, that that data use is limited to the that purpose, and that data access is limited to public health personnel. For example, if the purpose of a TACT system is only to identify contact and facilitate tracer interviews limiting data collection to an individual's location and proximity history may be sufficient. However, if a TACT system is to send automated follow-up, notify individuals of changes in support services, or monitor the use of those services the system may need a broader set of data and may need to be accessible by a wider set of public health personnel.

Technological, Operational, and Environmental Constraints on Technology Assisted Contact Tracing

Whether a TACT system is able to identify epidemiologically meaningful contacts while also remaining aligned with public values, such as privacy, depends on at least three factors - 1) what *technologies* the system uses, 2) how the system is *designed* to use those technologies, and 3) the *environment* the system is used in. It is useful to distinguish between these factors because each plays a different role in determining the impacts and effectiveness of a particular TACT system.

Technology: The specific hardware and software a TACT system uses determine the capabilities of that system by setting limits on the collection, storage, and transfer of location and contact data. At present, TACT uses four geospatial technologies to automate the collection of user location data: Cellular, GNSS, WiFi, and BLE. Each of these technologies offered a different level of spatial accuracy and temporal resolution. Generally, location information derived from cellular towers that has a spatial accuracy between 1km and 5km is not precise enough to identify meaningful contacts, particularly in rural areas with few tower locations. Locations derived using the global navigation satellite systems (GNSS), such as GPS, are typically accurate to 5-20m (Lee et al. 2016), which means that those systems can potentially be used to identify co-located contacts. However, GNSS alone is likely not accurate enough to identify all high-risk interactions between individuals. WiFi network access points and BLE signals can be used to infer individual locations both indoors and outdoors from device scans (Kwet 2019). BLE signals extend approximately 10-100m around a device depending on the hardware being used (Bluetooth 2020). By combining WiFi and BLE information with location data from a GNSS, a TACT system could improve location accuracy to <1m, but the exact level of accuracy will depend on obstructions (e.g., walls in buildings) and network density.

How accurately each of these technologies record the location and proximity histories of users depends on the hardware (e.g., antenna, chipset) and software (e.g., operating system, application) of each individual user's mobile device. For proximity tracking systems that rely on BLE exchange, the Bluetooth chipset of a device determines the strength of the signals sent by the device and how a device interprets incoming signals. Antenna position also affects how well signals are received. Chipsets and antenna orientation are customized by manufacturers (Bluetooth 2020), which makes it possible that the same signal will be interpreted differently by different devices. Software configurations can similarly impact the spatial accuracy of BLE by altering the transmission power, broadcasting interval, and duration of signals. In a review of 20 contact tracing applications, Zhao et al. (2020) show that these factors vary considerably across applications and that the minimal device-specific tuning that has been completed to date for these applications raises questions about their effectiveness. Positional accuracy similarly varies based on the model and configuration of each individual mobile device using GNSS or WiFi (see Menard et al. 2011). In addition users may disable location services, which restricts signal use and lowers positional accuracy.

Operational Design: While the technologies used in TACT set limits on how a system might function, how location and contact data are actually gathered, stored, transferred, and shared in practice are choices made by the system developers. Design decisions should be made by the public health agencies that commission or are responsible for the development of the central application and are ultimately responsible for the contact tracing effort. These agencies have the knowledge, experience, and responsibility to weigh the need for the type and quantity of information about an individual need to respond to COVID-19 against the ethical responsibilities of the public health agency and the privacy tolerance of the public. When location and proximity data are gathered it may be useful to also collect and link related user data (e.g., activities) that can later be used to prompt user memory during contact tracing interviews. At the same time, public health officials must collaborate with developers to make decisions about the frequency at which DCTT will gather location data. For example, a developer creating a BLE-based application can modulate not only how often a mobile device emits signals but how strong those signals are.

Once gathered, another key design decision public health agencies must make is how and where user data will be stored. TACT can be centralized or decentralized. Centralized systems store user location and contact data on servers. When a user tests positive and notifies the server, the system will analyze its overall database to determine exposure risk and notify those potentially exposed. While there are privacy-preserving protocols for this type of system (e.g., Inria 2020), decisions remain as to how potential exposure will be determined and if/when notification will be given and by whom, or whether key notification functions will be automated. Decentralized systems attempt to avoid the privacy concerns associated with a central server by hosting user data on their local devices and only occasionally synchronizing that data with a larger database. Nonetheless, decisions must be made about how long to store data, how frequently to synchronize, and how to provide notifications.

As data is stored and shared in either type of system, public health agencies must make policies related to the circumstances under which data will be released to with third parties (e.g., government agencies, employers), even in aggregated from, and whether data will be combined with other available data (e.g., purchasing histories). Public health agencies under ethical and legal obligations to collect the least amount of data possible, store and use the data safely, and dispose of the data once the public health effort is complete would not share data unless compelled to do so. However, agencies but could face circumstances, such as subpoenas, where other seek to compel that information from the agency. Similarly, agencies must balance the potential benefits of linking location or proximity data with other forms of data that could benefit contact tracing efforts and analysis of COVID-19 etiology, but will also likely raise risks of user identification or loss of public trust. Public trust in TACT systems and the public health departments operating them is essential for public use of the system and therefore their ability to gather needed information and support mitigation efforts.

Environment: The performance of DCTT can vary dramatically with the environment in which they are used. In an open field with an unobstructed view of the sky, a GNSS receiver can produce location data accurate to within a meter. In obstructed environments (e.g., canopy cover, buildings) the accuracy of GNSS can be in the tens of meters, limiting their usefulness in certain forms of contact tracing. To assess the potential effectiveness of TACT, we need to also consider the environments in which location and contact data will be collected.

For example, location data collected using a GNSS receiver will typically have greater spatial accuracy than location data collected using a cellular receiver. However, this relationship may be reversed in dense urban environments. Signal interference and multipath errors produced by tall buildings can lower the accuracy of location data gathered using a GNSS receiver (Lachapell et al. 2018), but the greater number of cellular towers in urban areas can raise the accuracy of location data collected using a cellular receiver. GNSS accuracy in multipath urban environments can be improved if combined with WiFi, as demonstrated by Merry and Bettinger (2019). However, the horizontal position accuracy of GNSS and WiFi-enabled mobile devices is between 5-15m in multipath urban environments and can vary with time of day and configuration of the surrounding urban environment (Zandbergen 2009, Menard et al. 2011, Garnett and Stewart 2015). Szot et al. (2019) suggest that static vertical position accuracy for devices using a combination of location technologies is in the 3-4m range. With this level of accuracy, we can use DCTT to create location histories for individuals but may find it difficult to pinpoint their location to the level of a room in a building. Vertical accuracy may be particularly problematic in this regard as an error of 4m could place an individual on two to three different floors of a building.

Proximity detecting technologies face similar challenges. BLE signals can penetrate some forms of building materials such as glass and wood (Estimote 2020). This feature creates the possibility that individuals located in different rooms or different floors within a building may be identified as being in contact when in reality, they were never in a situation in which SAR-CoV-2 could be transmitted. False-positive or false-negative contacts may also be generated if surrounding WiFi signals use channels that overlap with BLE signals. This overlap can also create interference between signals, which can impact the accuracy of distance measurements (Wen et al. 2020).

Assessing the Ethical and Privacy Implications of Technology-Assisted Contact Tracing

The ethical and privacy implications location tracking technologies raise are well-documented in the literature (Armstrong and Ruggles 2005, Curtis et al. 2006, Krumm 2009, Johnson and Sieber 2013), and the related study of the ethical and privacy implications of DCTT and TACT is now beginning (see Chan et al. 2020, Hekmati et al. 2020, Kishore 2020, Wen et al 2020). The literature on the ethics and privacy of location tracking technologies revolves around issues of (i) notice-and-consent to location data collection and (ii) the risk of revealing the identity of an individual through their location history.

While the application of location tracking technologies to contact tracing is relatively new, public health agencies have long grappled with the implications of collecting, storing, handling and using confidential information (Fairchild et al. 2007, Lee and Gostin 2009). Public health ethical practices enforce the principal that all confidential information that could bring harm to either community or the individual must be protected by public health institutions (Thomas et al. 2002). Further, any framework for designing public health programs must consider threats to privacy, particularly disease surveillance or contact tracing, prior to implementation (Kass 2001). Even in extreme public health situations, such as global HIV/AIDS epidemic, personal information is guarded by a structure of administrative and regulatory protections within the public health administration (Bayer and Fairchild 2002).

Providing notice to an individual that their location data will be collected and receiving their affirmative consent to do so are at the center of U.S. protections of location privacy (Boshell 2019, Rothenberg 2020). As early as 1994, Onsrud et al. (1994) introduced eight principles related to privacy and the handling of geospatial data, including - (1) limiting the collection of personal information, (2) only collecting relevant, accurate, and up-to-date data, (3) clearly stating the purpose of the data being collected and limiting use to those purposes, (4) not allowing secondary uses of personal information without individual consent or authorized by law, (5) protecting personal data, (6) open policies surrounding the use of personal data, (7) individual ability to inspect and correct their personal data files, and (8) data controllers should be held accountable for complying with the guidelines. These principles are similarly reflected in both the Public Health Code of Ethics (American Public Health Association 2019) and the GIS Code of Ethics (GIS Certification Institute 2003). The Public Health Code of Ethics establishes that for policies and practices to be ethical, special attention must be given to “protecting the privacy and confidentiality of individuals when gather data” and stresses the removal of “personal identifying information from the data set as soon as it is no longer needed.” Further, the data collected on individuals or communities should be limited to “only data elements and specimens necessary for disease control or protection.”

The GIS Code of Ethics states that it is a GIS professional's duty to "allow individuals to withhold consent from being added to a database, correct information about themselves in a database, and remove themselves from a database." More recently, these principles can be seen in rights-based approaches to privacy like the signal code of Greenwood et al. (2015), which focuses on crisis situations and argues that data privacy and security, data agency, and regress and rectification are fundamental rights that also facilitate crisis response. Empirical evidence suggests these principles are not often being applied to much of the location data being regularly collected from many mobile devices. See for example the cases of LocationSmart (Krebs 2018, Oremus 2018), or the illegal sale of augmented GPS data (Brodkin 2019).

Even in situations where the majority of the principles related to notice and consent to collect location data are maintained, the risk of identifying individuals remains. To preserve privacy, location data are de-identified and are often aggregated in time and space. However, location data is difficult to fully anonymize. If individual identifying information (e.g., name, age) is removed from the data, but spatial information is unaltered, it is often easy to identify an individual. Research suggests that a small number of spatial-temporal locations is needed to identify a large portion of the U.S. population (De Montjoye et al. 2013). Even when data are spatially aggregated, it is often possible to identify individuals. Golle and Partridge (2009) suggest that when location data are aggregated to census tracts, but work and home locations can be inferred, half of the population can be identified as one of ten individuals. Incorporating demographic information can narrow this set to one.

Ethical and Privacy Principles Linked to Digital Contact Tracing Technologies

As DCTT emerge as a tool for pandemic response, an accompanying literature is developing around how these technologies can and should be used to mitigate and suppress COVID-19 and quell future outbreaks of communicable disease. To address this cross-cutting issue, contributing scholars are drawing central ideas from the public health literature (CDC 2020, Kahn 2020), privacy law (Gilmor 2020), digital data governance (Raskar et al 2020), human rights frameworks (Morley et al. 2020), and moral philosophy (Morley et al. 2020, Gasser et al. 2020, Hart et al. 2020). While terminology varies slightly across authors, this emerging body of literature has coalesced around a set of five principles that address the potential privacy, ethical, and social impacts of these technologies. Here, we briefly present each principle along with an accompanying set of characteristics that define the principle, and a short description.

1. Efficacy (necessary, proportionate, scientifically valid, impactful): The best available scientific evidence should show that TACT will improve pandemic response efforts and that the positive effects DCTT create will outweigh the negative effects of these technologies. Those responsible for these systems should also monitor their performance and provide some measures of their ongoing positive and negative impacts. Compatibility, across-platform functionality, and backward compatibility are also key to effectiveness. It should also be recognized that effectiveness may be difficult to quantify and assign to different parts of the larger contact tracing effort, as contact tracing may also involve the use of auxiliary data collected during tracing interviews, outside data sources, or user inputs when at the time of application download.

2. Privacy (voluntary, consent, limited, anonymous, editable, secure, temporary): Participation in TACT should be voluntary and non-participation should not incur any punitive measures. Any data collected from users should be limited to the purposes of COVID-19 prevention, be securely stored, and destroyed when no longer relevant for this purpose. Users should be given clear notice about the types of data that will be collected and how that data will be stored and transferred. User data collected for COVID-19 prevention should not be share with third parties. Users should also have the ability to opt out of participation at any time and have as much control over their data as possible.

3. Equity (equally available, equally accessible): DCTT should be free and available to any user that wishes to use them. These technologies should also be accessible to people of different backgrounds, levels of experience, incomes, and other differentiating characteristics. Some form of oversight should be designed to identify if DCTT are creating inequitable public health outcomes.

4. Transparency (open source, accessible, customizable): As an extension of the privacy and equity discussions above, the rules governing the collection and management of user data should be understandable and publicly accessible. Ideally, TACT systems would use open architectures and standards, so others can audit and amend the systems. Evaluating and monitoring TACT for data misuse, privacy, and other concerns is far easier if the underlying platform of the system is openly available.

5. Accountability (auditable, amendable): Assessing and ensuring the efficacy, equity, and privacy of DCTT and the TACT systems they are used in pandemic response relies on the auditability and amendability of these systems. TACT systems should undergo regular, independent assessments organized around the above principles. Those assessments should also be publicly accessible.

Connecting Ethical and Privacy Principles to Technological, Operational, and Environmental Constraints

Each of the five principles presented above must be linked with measurable characteristics of TACT and the DCTT that support their operation to be useful as assessment criteria. Table 1 contains a listing of key data about a TACT that can be collected and used to assess the ethical standing of the system. While we link each piece of data to the principle we believe it is most directly related to, we recognize that much of this data can be linked to multiple principles. For example, the spatial accuracy of the DCTT will clearly impact the efficacy of the contact tracing system. However, spatial accuracy also has clear and direct implications for privacy and equity. Higher spatial accuracy makes it easier to identify individuals, which can by extension lead to the differential treatment of individuals.

Table 1. Key data needed to assess the ethical and privacy implications of technology-assisted contact tracing

Efficacy ● How is contact defined as proximity in space and duration in time ● How frequently is location and/or proximity data collected? ● What technologies are used in location and/or proximity data collection? ● What is the locational accuracy and precision of these technologies? ● What is the consistency of accuracy and precision of the location/proximity data across mobile devices? ● What is the consistency of accuracy and precision of the location/proximity data across environments?
Privacy ● Is the technology optional to install and use? ● Is there an articulated plan for the collection, storage, and use of data that is consistent with public health ethics principles and guidance for best practices (e.g., public health code of ethics)?

● Is there a mechanism for providing notice of private data collection, storage, and transfer? ● Is there a mechanism for gathering consent to collect and use private data ● What is the timing of consent (e.g., is consent gathered prior to data collection, data release)? ● What are the limitations on the use of data collected (e.g., limited to contact tracing effort) ● What measures are taken to preserve anonymity (e.g., will data be stored on user devices)? ● How will the data be protected from unauthorized use (e.g., security protocols)? ● What are the third party sharing and data transfer policies (e.g., shared with other government agencies)? ● Are there any exceptional situations in which the data will be shared for non-public-health purposes (e.g., subpoena)? ● What are the user rights/abilities to edit or delete their data? ● What is the plan for data deletion (e.g., will data be deleted when it is no longer useful for contact tracing?)? ● Has a privacy officer been appointed to ensure effective privacy/ethical standards?
Equity ● What mobile devices support the contact tracing system? ● Is there a cost to users? If so, what is it? ● Are there features for users with disabilities (e.g., design for visually or hearing impaired) ● Are interfaces designed for all users? ● What are the options for individuals without access to the preferred TACT platform?
Transparency ● Is the underlying data collection code available and editable? ● Is data storage plan available? ● Is the privacy officer available to relate how ethical standards were upheld? ● Was the public included in the development and implementation of the TACT?
Accountability ● What criteria are used to assess the impact and efficacy of the TACT? ● Is there an independent third party auditor of the system? ● Will impact assessments and efficacy audits be made public? ● Is there a stated process to update the TACT as new information becomes available? ● Is there a plan to phase out the system as the pandemic recedes?

To explore the connections between each principle and the data that can be used by that principle, we frame the following discussion around the technical, operational, and environmental characteristics that may shape adherence to each principle in practice.

Efficacy: To monitor the efficacy of DCTT, it will be critical to gather data on the accuracy and precision of the proximity and location information these technologies collect. Understanding when and where accuracy and precision degrade will be key to adjusting or augmenting these systems to increase effectiveness. As presented above, variations in the environment and the spatial distribution of key infrastructures can alter the effectiveness of these technologies. However,

DCTT should also be examined for device-specific performance variations. Early research in this area by Wen et al. (2020) suggests that different devices receiving the same signal may not produce the same proximity measurements. Adjusting and correcting for how different devices process BLE of GNSS signals to ensure accuracy will be critical to improving overall system efficacy. Linking those adjustments to our evolving understanding of the dynamics of SAR-CoV-2 transmission will also be a key to maintaining efficacy. To do so we will need to know how contact is defined by different systems and whether that definition is updating as our knowledge progresses.

In addition to these technical limitations, efficacy will also be determined by adoption. Hinch et al. (2020) suggest that TACT can begin to produce protective effects when adoption rates are as low as 10 percent of the population and that benefits rise with greater adoption. A finding reinforced by a systematic review by Brairwaite et al. (2020). However, adoption rates have varied by country. Countries that have mandated adoption, such as Qatar, have seen adoption rates over 90 percent, but most countries with official DCTT have adoption rates below 20 percent (Rivero 2020). To assess efficacy, the performance of any particular DCTT and related TACT needs to be placed in this social context. A perfectly accurate and highly precise DCTT is unlikely to be effective at producing population-level benefits if it has a small number of non-representative users. Plans to include users and affected communities in TACT development are one way to raise the chances of voluntary use of these systems. While community involvement may present practical challenges, increased use may offset such potential costs.

Privacy: DCTT adoption appears to be limited in large part by the privacy concerns of potential users. Academics and civil liberties groups (see Gilmor 2020) acknowledge the productive role DCTT can play in pandemic response, but also caution about the potential for misuse of user data or possible expanded use of user data beyond a system's initial intention. These concerns are grounded in the misuse and sale of user data observed in other forms of application-based data collection and the economic incentives to collect and sell information about users (Zuboff 2020).

Whether a TACT system violates privacy is largely a function of the operational decisions of those responsible for the system. To understand whether DCTT are being used by TACT developers in ways that challenge privacy, we therefore need to gather information about how data are managed during all phases of the contact tracing effort. The need for this information arises not because public health agencies are conducting contract tracing, but because new entities (e.g., private companies) are involved in the data collection effort. Public health agencies have a well-established record of performing contact tracing and a clear set of ethical principles and related policies and laws that guide their behavior (Thomas et al. 2002, Lee and Gostin 2009, American Public Health Association 2019, Gostin and Wiley 2016). To preserve privacy, data must be gathered with clear notice to and consent from the user and notice should be given in a way that is understandable by a non-specialist. Information about how user data is deidentified, transferred, and stored is also needed to ensure the system has adequate measures in place to preserve user anonymity. Decentralized systems focused on proximity measurement that do not collect location data have the advantage of reducing opportunities for later reidentification.

However, decentralized TACT systems still need to be evaluated for editability and the length of data storage. Editability can be assessed by gathering information about how and when systems prompt users to retain their data, share their data with contact tracers, and which specific aspects of their data users can change or remove. Systems may for instance, allow users to decide if their location and proximity data are shared with a central authority but not allow users to edit those same histories. Similarly, the Center for Disease Control and Prevention (2020) notes that TACT following privacy best practices will only retain user data as long as they are useful for disease prevention. The ACLU suggests that this condition means that the location and proximity histories of users should be deleted after 14 days as this is the typical length of the contagious period for COVID-19. This practice has the added benefit of removing incentives to aggregate and sell user data to third parties for unrelated purposes. Finally, TACT systems should share information about the editing and data deletion process in user agreements so users can make informed consent decisions.

Equity: Actions that preserve privacy may have the additional benefit of enhancing equity. In its simplest form, equity can be measured by access to DCTT. If a particular DCTT is not available to all users it is unlikely to achieve the broadest and most equitable outcomes. Access can be measured by cost of use. For example, does a user have to pay to use the system? However, cost of use can also be measured in effort and accessibility. For example, TACT systems should have intuitive user interfaces that can be used by all members of society (e.g., those with visual impairment). Access is also a function of the platforms a TACT supports. Most TACT work across mobile device platforms, but some socially underprivileged groups may not have access to these platforms further placing an undue burden on them. Additionally, socially privileged groups may be allowed to opt out of the program adding additional pressure to a groups that are already stressed. Lastly, these systems should also be assessed for their interoperability with the different contact tracing systems of different public health agencies. If health professionals cannot access data approved for release by users these systems may be less useful to mitigation efforts. The Association of Public Health Laboratories is now developing a national server and systems to facilitate state-to-state interoperability in the United States.

Transparency/Accountability: Ensuring the equity of TACT systems is closely related to maintaining their transparency and accountability. Understanding if a TACT is producing equitable outcomes will require systematic reviews of who the users of a system are, how those users are using the DCTT, and whether those technologies are underperforming expectations in particular environments. To date, we have limited evidence in this area. While some of the technical details for DCTT are generally available, the operational details of TACT are less accessible and often can only be gathered with some effort. At the same time, many of these systems do not have clear auditing plans or procedures outlining how amendments will be made and what triggers those amendments. This situation is somewhat understandable given that many of these systems are new. However, Clear operational rules and guidelines need to be created and matched with enforcement mechanisms to ensure these systems enact espoused principles.

The framework needed for a clear chain of responsibility and enforcement is already in place under the auspices of the state public health authority. To ensure efficacy, these systems should also be customized and amended as new evidence becomes available about disease transmission and system effectiveness. For example, there is increasing evidence that SAR-CoV-2 may be transmissible through the air and not just via respiratory droplets, which has prompted revision of CDC guidelines for the disease (CDC 2020). If this proves to be the case, TACT systems will need to be amended to reflect the science and remain effective at capturing transmission risk. For instance, if SAR-CoV-2 can remain suspended in the air for a period after an individual leaves a location, capturing movement by other into and out of that location increases in importance.

Technology-Assisted Contact Tracing in the Context of the COVID-19 Pandemic

At the time of writing, TACT has played different roles in the response to COVID-19 across the globe (see Kahn 2020, Lee et al. 2020, Lin et al. 2020). In the United States, DCTT and TACT are only beginning to emerge as part of the toolkit for pandemic response. However, even as these technologies emerge their effectiveness and impact is constrained by a number of factors. First, TACT is most effective in environments with widespread, easily accessible, and regularized testing for COVID-19. Recording location and proximity histories of users is only useful for disease prevention if users exchanging information are tested and then share that information with public health authorities or other users in privacy-preserving ways. Without knowledge of infection, chains of transmission cannot be identified and broken. Negative results are equally useful because they provide health professionals with a clearer picture of disease prevalence in the population and allow for more accurate estimation of key indicators like case fatality rates. Using the framework presented here in an environment without adequate testing resources may skew evaluation of DCTT, as the TACT they support may simply not be receiving enough information to be effective.

Second, the availability of DCTT does not necessarily mean that these technologies will be adopted and widely used. In the United States, it remains unclear whether DCTT will be widely adopted by the public. However, the benefits of these technologies are subject to strong network effects - the more people that adopt a DCTT the more benefit it produces. To facilitate adoption DCTT developers could focus their release and adoption efforts on sub-segments of the population (e.g., in a hotspot city) to ensure broad localized use. Farranato et al (2020) identify that this strategy is commonly used to successfully launch mobile applications of all types and has the virtues of building a critical mass of users, which allows for the gradual scaling of adoption. If this approach to adoption is used, the evaluation criteria outlined here will need to account for the localized nature of the deployment strategy. In the simplest case, efficacy would need to be measured in the adoption rate within the target sub-population and not as a raw count of users. Similarly, additional considerations for privacy may be needed. If the target population is small enough it may be more difficult to preserve anonymity. This selected release strategy could also run counter to the equality principles outlined here. Nonetheless, targeted release and widespread adoption within an urban center that is a hotspot of SAR-CoV-2 transmission could have clear benefits. Another approach to expanding adoption could be to focus effort during TACT development on gathering future user feedback and involving affected communities in meaningful ways in system development. Such an approach would not only match the ethical principles of the public health profession, it would likely raise adoption rates because it would increase community trust in TACT.

Third, to some extent, an undirected version of the targeted release strategy is becoming the default for the use of TACT in many locations. In the United States, for example, state governments have made different decisions about whether to use TACT in the response efforts. At the same time, DCTT are being deployed at schools, universities, and corporations. The use of these technologies in these settings raises a host of additional questions that extend the assessment criteria presented in this chapter beyond the technical, operational, and environmental considerations presented here. One key difference are the incentives of the parties responsible for the data collection and management. As Zuboff (2019) demonstrates, companies have clear incentives to collect large quantities of diverse data on users as this information creates economies of scale and scope in secondary data markets. These incentives therefore encourage behavior in direct opposition to the limited, purpose-specific, and collaborative forms of data collection outlined in the public health code of ethics. More directly, detailed location and proximity data could be used by companies to monitor behavior or map social interactions. For firms, this type of information could be used to increase the efficiency of production through the reorganization of labor, but at the expense of worker autonomy and self-determination. Another key difference is the responsibilities some non-governmental organizations have for their members. For example, nursing care facilities may carry a duty of care to all residents that the institution believes would be fulfilled by digital contact tracing but may simultaneously conflict with the wishes of individual residents. Primary and secondary schools may have similar in loco parentis responsibilities that might come into conflict with the rights or preferences of their individual students.

Fourth, how effective DCTT are rests on how they are integrated into the wider set of activities that make up a contact tracing effort. While this chapter, and much of the emerging literature on DCTT and TACT, focuses on whether and how well technologies can record location and proximity histories, it is as important to consider how these technologies may be used to ethically facilitate follow-up activities and service provision. For example, the location data gathered by a TACT system could be used to automatically identify which service providers are located closest to an individual isolating after potential exposure to COVID-19. This may be ethical and helpful if the individual volunteered their address information to the system, but becomes questionable if the address is inferred from the data in the system. As another example, in a situation where contact tracers are overwhelmed by the scale of the pandemic, data gathered by DCTT could be used to create prioritization schemes to identify individuals which individuals should be scheduled for interviews in what order. Simple summary statistics of the number of people an individual that has received a positive test has come into contact with, or the number and diversity of locations they have visited could be calculated from proximity and location histories to support such an effort. Creating such a scheme would force us to reengage the principles identified above and outlined in the GIS and public health codes of ethics.

The need to understand these and the many other questions that will arise as DCTT evolve during and after the COVID-19 pandemic is an opportunity for geographic research. Addressing these questions will provide a foundation for public health geographers, legal geographers, economic geographers, critical geographers, as well as others from the field's varied sub-disciplines to critically examine the implications of DCTT through their unique lens. Further, it demonstrates the importance of having spatial scientists and scholars involved in the evaluation and analysis of technologies that potentially have such far-reaching ethical implications.

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