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Digital Contact Tracing During the SARS-CoV-2 Pandemic

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Abstract

Problem

Manual contact tracing (MCT) is considered an essential public health intervention for infectious disease control. During the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic, there was insufficient funding or personnel to reduce transmission effectively. Throughout the pandemic, Missouri remained below the recommended contact tracing response rate (CRR) of 50%. One method used globally to aid in pandemic control was digital contact tracing (DCT); however, Missouri was unable to implement digital contact tracing due to barriers faced, which were not unique.

Methods

DCT was selected as subject of a strategic plan (SP) to augment MCT efforts. Other locales' successes and failures evaluated possible outcomes for successful implementation of DCT. Using retrospective data, the SP details evidence-based goals, evaluation indicators and provides tools to assess execution and achievement of COVID-MO mobile application implementation.

Results

SP has thus far not received approval. However, some conjecture as to the outcome of its implementation is possible. A SP was designed for a local research university to provide a guide for successful COVID-MO implementation.

Implications for Practice

DCT has potential to strengthen contact tracing efforts, as well as conserve public funds. The use of technology allows immediate communication to individuals at risk for exposure to infectious diseases. SP thus can improve future efforts by providing a creative roadmap to address a complex issue.

At the height of the SARS-CoV-2 pandemic, in November 2020, Missouri reported 4,833 new daily cases with a positivity rate of 19%, which overwhelmed manual contract tracing (MCT) efforts (Covid Act Now, 2020). The state would have needed to employ an estimated 21,626 contact tracers and case investigators for adequate public health surveillance, but only 18% of staffing requirements were met at this critical juncture (Covid Act Now, 2020). Given the shortage of MCTs and rising number of average new daily cases, the number of contacts requiring exposure notification became unmanageable for the state (Clark et al., 2021). In this context, new contact tracing methods to contain the pandemic in the state of Missouri needed to be designed and implemented.

Contact tracing is an essential tool for containment of infectious diseases. WHO (2020, para 1) defines contact tracing as "the process of identifying, assessing, and managing people who have been exposed to a disease to prevent onward transmission." Due to rapid transmission of the SARS-CoV-2 virus, epidemiologists estimated both detection of cases in the community and successful outreach to exposed individuals by MCTs would need to exceed 50% to effectively reduce global transmission (Ferretti et al., 2020).

Exposure Notification System (ENS) is a digital contact tracing (DCT) tool created to allow public health authorities to notify smartphone users of SARS-CoV-2 exposure (Bradshaw et al., 2020). A notification is sent to mobile devices through Bluetooth technology using the Google/Apple application programming interface (API) (The National Academy for State Health Policy [NASHP], 2021). In order to use ENS, states must obtain a license, which then allows users to download the state-approved application (NASHP, 2021). In the United States, 24 states, and Washington D.C., have successfully used ENS technology to aid in control of SARS-CoV-2 (NASHP, 2021). Virginia was the first state to implement this form of DCT, releasing the application to the public in August 2020 (Virginia Department of Health [VADH], 2020). Following release, Virginia successfully reached a 10.6% application adoption rate (AAR) and a 24-hour CRR of 72.5% in less than four months (VADH, 2020). As of July 4, 2021, with approximately 8.5 million people, Virginia's total death count from SARS-CoV-2 was 11,431; Missouri, with approximately 6.16 million people, had a total death count of 10,114 (Centers for Disease Control and Prevention [CDC], 2020). Further, on July 4, 2021, average daily cases in Virginia were reported at 178, while Missouri reported 979 (CDC, 2020).

The initial purpose of this project was to collect data following implementation of a mobile application (COVID-MO), which utilizes the ENS API to conduct DCT. Due to implementation barriers, including delayed government approval from the state's governor and chief information officer, leadership changes, difficulties securing financing, and data collection concerns, COVID-MO was not released during the expected timeframe. This project was thus refocused on development of a strategic plan (SP) to provide evidence-based goals and performance measures supporting future application implementation. According to a meta-analysis study conducted by George et al. (2019), SPs can substantially influence organizational performance as they identify effective procedures, tools, and practices to inform dissemination and implementation activities. SPs have demonstrated correlations with performance outcomes, and their evidence base can provide insight into information processing (George et al., 2019; Meyfroodt & Desmidt, 2020; Vermillion, 2019).

Current research suggests bidirectional contact tracing (MCT & DCT) to be most effective in transmission control (Bradshaw et al., 2021). Even if efforts to implement COVID-MO fail to come to fruition in the current pandemic, processes described in the SP may prove beneficial during future public health crises. The project centers on the following research question: What constitutes an effective strategy for implementing digital contact tracing in the largest metropolitan area in a Midwestern state?

Review of the Literature

This literature search aimed to identify current, effective contact tracing methodology for disease containment during the SARS-CoV-2 pandemic. A comprehensive computer-assisted database search was implemented over an 18-month period utilizing Scopus, Medline, and CINAHL search engines. Formalized search strategy, including Boolean operators, consisted of the following:

1. (*COVID-19* OR *SARS-CoV-2* OR *SARS-CoV) AND*
2. (*Digital contact tracing* OR *exposure notification* OR *technology*) OR
3. (*Contact tracing* OR *case investigation* OR *contact investigation*)

Inclusion criteria:

1. Peer-reviewed studies with supporting quantitative data concerning project aim(s). Due to recent emergence of SARS-CoV-2, preprints with supporting quantitative data were also included in the search and retained if substantive quantitative data were reported.

2. Studies published in any language were included in the search strategy. If a particular article was unavailable in English, Google Translate function was applied to examine content and determine whether the study should be included or excluded.
3. The following study designs were included: systematic reviews, cohort studies, cross-sectional studies, and epidemiological modeling studies.

Exclusion criteria:

1. Studies published before December 2019 were excluded as DCT was a novel intervention during the SARS-CoV-2 pandemic.
2. Articles not including quantitative data were excluded.

Of eighty-nine studies identified from the initial database search, 44 were eliminated because they did not meet inclusion criteria and/or were unrelated to the project's goals. Forty-five were reviewed, and two articles were retained for further analysis. Ancestry approach/reference scanning method was used to identify nine additional studies, and 12 total studies were included in this literature review.

Studies reviewed demonstrate mobile applications used for DCT are effective at contact notification, resulting in an overall decrease in cases. Global responses varied in approaches to pandemic control. For example, Taiwan, South Korea, and Japan initiated fast and efficient control measures, including sophisticated DCT technology interventions, mandated lockdowns, and rapid testing (Jung et al., 2020). In contrast, pandemic control measures were delayed in Germany, France, and Italy, which led to exponential growth in recorded cases of SARS-CoV-2 (Jung et al., 2020).

Reproduction number (R_0) of SARS-CoV-2 is dependent on mode of transmission, which is categorized as presymptomatic (46%), symptomatic (38%), asymptomatic (6%), and environmentally mediated due to contamination (10%) (Ferretti et al., 2020; Moghadas et al., 2020). Abueg et al. (2020) found a direct correlation between modes of transmission and several key variables, including timeline of infection (initiated at the first positive test), susceptibility (age, race, history), and location (indoor vs. outdoor, and distance between infected and exposed). Both presymptomatic and asymptomatic modes of transmission are further classified as forms of "silent transmission" and have potential to prolong SARS-CoV-2 outbreak even if all symptomatic cases were to isolate immediately (Moghadas et al., 2020). It is further notable timing between initial exposure to case confirmation, notification, and quarantine can significantly impact R_0 (Ferretti et al., 2020).

Many countries, including the United States, use symptom-based surveillance methods as the primary non-pharmacologic intervention for pandemic control (Moghadas et al., 2020). However, epidemiological modeling studies conducted by Moghadas et al. (2020) demonstrated rapid contact-based surveillance methods, which incorporate DCT interventions, correspond to depression of R_0 (average number of secondary cases produced) to a value of 1 or lower ($R_0 <1$). Through DCT, ENS technology provides immediate reporting of potential exposure, improving current symptom-based approach to surveillance, and removing timeliness of exposure notification as a barrier to infection control. DCT identifies exposure through a centralized or decentralized model (Hernández-Orallo et al., 2020). Decentralized models are maintained through a network of encrypted keys delivered via Bluetooth technology. This technology ensures privacy by maintaining user anonymity (Hernández-Orallo et al., 2020). Centralized models utilize GPS-location services to upload mobile user information and send extracted data to a centralized server (Hernández-Orallo et al., 2020). After data are sent to a centralized server, health authorities can obtain this information and contact exposed individuals (Hernández-Orallo et al., 2020). It is unlikely a centralized approach would ever be implemented in the United States due to privacy concerns; however, the decentralized system has demonstrated efficacy, even at low AAR (Hernández-Orallo et al., 2020; Hinch et al., 2020; Clark et al., 2021).

Drawing from experience with the SARS pandemic in 2003 and the Middle East respiratory syndrome coronavirus (MERS-CoV) outbreak in 2015, South Korea immediately implemented a centralized DCT model (Jung et al., 2020). This intervention was proven highly influential in response to SARS-CoV-2 (Jung et al., 2020; Clark et al., 2021). Immediate release of DCT, rapid testing, hand hygiene guidelines, social distancing guidelines, and mandated personal protective equipment (PPE) allowed South Korea to achieve fastest containment of viral transmission, with few cases reported after plateauing in March 2020 (Jung et al., 2020; Clark et al., 2021).

Within the United States, DCT using the decentralized model is the current method of implementation. A critical indicator for successful implementation of this intervention is AAR within the community; however, DCT may significantly decrease infections, hospitalizations, and mortality rates even with low adoption rates (Abueg et al., 2020; Hinch et al., 2020). Before release of decentralized DCT in May 2020, The Isle of Wight reported to have the third-highest R_0 of SARS-CoV-2 out of 150-Upper-Tier Local Authorities in England (Kendall et al., 2020). Following release of DCT, the region reported a 38% AAR, with R_0 decreasing rapidly from 1.0 to 0.25 over a one-month period.

As the pandemic progressed, manual contract tracers were limited in their ability to notify contacts of SARS-CoV-2 exposure (Flood et al., 2021). Strategic delivery of DCT directly addresses this issue by providing a more accurate list of contacts and increased exposure awareness, resulting in a shortened interval from time of exposure to quarantine (Hinch et al., 2020; Lopez et al., 2021). A modeling study conducted by Hinch et al. (2020) further suggests decentralized DCT has potential to reduce R_0 to pandemic goal of $R_0 < 1$, even if delivered as the sole intervention for containment. These projections are dependent on implementation of DCT with either 80% of all smartphone users or 56% of the overall population (Hinch et al., 2020). An additional modeling study conducted by López et al. (2021) reported DCT could decrease transmission by as much as 57% with a 32% AAR and a 50% CRR. Many countries faced issues implementing DCT, with a common source of error tied to privacy design, whether real or perceived (Flood et al., 2021). Successful implementation of any mobile application designed for DCT is reliant on robust privacy design.

SP is essential to guide implementation plans and publicize benefits to the target state residents to increase AAR and community understanding. A survey conducted by Pew Research Center (2021) reports a breakdown of the age of smartphone users in the target state for application implementation as 18-29 (96%), 30-49 (95%), 50-64 (83%), and 65 and older (61%). Future interventions utilizing DCT technology must prioritize privacy design and community education regarding the benefits of its use.

In this context, a SP was developed to plan, implement, and identify critical areas for improvement in the target state's implementation of COVID-MO. This project was guided by the Plan-Do-Study-Act (PDSA) model. This model is used by healthcare systems worldwide as an effective method for quality improvement (QI) and was selected due to its validated ability to identify, implement, and assess improvement methods (Vermillion, 2019).

Methods

Design

SP designed for COVID-MO implementation followed a basic SP (BSP) model while also integrating Deming's total quality management (TQM) concept of Plan-Do-Study-Act (PSDA) (Vermillion, 2019). BSP and TQM focus on identifying a purpose, creating a strategy process, and ongoing performance evaluation (Vermillion, 2019). Deming's TQM concept is integrated into the SP by focusing on a quality improvement approach using Deming's PDSA cycle to continuously assess for areas of improvement (Vermillion, 2019). Other locales' successes and failures were used as a starting point to evaluate areas for improvement and possible outcomes for successful implementation in the target state.

Information was also collected through discussions with key stakeholders responsible for application's release, including local research universities and public health officials seeking to implement similar interventions in other regions. Performance measures to evaluate efficacy of SP include time it takes to implement COVID-MO, AAR, pandemic trends, staffing requirements of MCT, and MCT-related costs. Performance measures are based on SP goals following Virginia's DCT success of 10%

AAR (VADH, 2020) (see Figure 1 for performance measures). Next steps to implement SP include approval and adoption by stakeholders from the local research university and publicizing COVID-MO SP as a resource for residents of the target state.

Setting

The entity for whom SP was developed is a research university located in the largest metropolitan area in this Midwestern state. Therefore, initial efforts would likely begin in the county where the university maintains its physical presence, home to approximately one million residents (CDC, 2020). After pilot implementation of COVID-MO at the research university, the SP will be expanded across the target state, covering an estimated current population of 6.16 million people (CDC, 2020).

Sample

Participants will include all mobile users who "opt-in" to use the COVID-MO application and are not limited to rural or urban populations. SP's exclusion criteria are individuals who do not have a smartphone device, as they cannot use the COVID-MO application. Initial SP sample is a research university in a large midwestern metropolitan area whose students choose to use COVID-MO. Using Tableau, public health data from the Contact Workforce Estimator Tool (CWET) provided a convenience sample for return on investment (ROI) analysis (Healthcare Workforce Institute, 2021).

Data Collection/Analysis

Retrospective analysis was conducted to assess other states' attempts to implement DCT. An ROI was completed using the CWET tool to illustrate public savings with bidirectional contact tracing (see Table 1 for ROI). For ROI, CWET provided numerical data for the following variables: average MCT salary, average new daily case rate per month, average recommended MCTs staffed to reach a 50% case CRR, reduced average daily cases, reduced requirements for recommended MCTs staffed, and average public savings with use of DCT. Data were obtained from November 2020 through May 2021.

Approval Processes

Approval processes necessary for completion of this project included: (1) A research university in a large midwestern metropolitan area, (2) the Department of Health (DPH) of a large metropolitan area in a Midwestern state and target state's government approval of the COVID-MO mobile application, and (3) the Graduate School of the University of Missouri-St. Louis. Since SP was developed using publicly available data, no Institutional Review Board (IRB) approval was necessary. Implementation of COVID-MO would pose no risk to participants, as all personal data will be anonymized, and participants will have the choice to opt in or out of the application at any time. Benefits of this project included potential for a decreased overall positivity rate for SARS-CoV-2.

Procedures

PDSA cycle started with assessment of critical areas for improvement in the target metropolitan area, using proprietary contact tracing methodology. Graduate students from the University of Missouri-St. Louis and DPH officials collaborated to identify pressing healthcare needs related to the pandemic. After discussion and review of current contract tracing methods, DCT was advanced as an effective and expedient target method for pandemic control.

In September 2020, global applications of DCT were identified and evaluated, and the Chief Commercial Offer (CCO) of a large technology company in Ireland was contacted as a resource for discussions related to ENS technology concerns. To gain more insight into DCT, a 15-person “round table” meeting was conducted by the Irish Consul on November 12, 2020. This meeting was attended by leading state and federal officials fighting the SARS-CoV-2 virus at the national level. The large metropolitan area and target state’s DHP were provided information concerning the importance of DCT and research supporting ENS use for transmission control.

Meetings between two local universities took place to collaborate to implement DCT as a tool in the target metropolitan area. Despite promising beginnings, approval required by the target state’s DPH to enable ENS interface could not be secured. Nevertheless, work on a SP for application implementation continued in order to support current and future DCT efforts for the pilot work in the targeted metropolitan area.

Strategic Plan

Subject of SP is COVID-MO, envisioned as an application created to aid in infectious disease control by promptly notifying users of exposure to an individual confirmed positive for SARS-CoV-2. The mission statement for COVID-MO is to create a secure mobile application using Bluetooth technology compatible with Google/Apple API. Finally, benefits of the application include prompt notification of infectious disease exposure, increased public safety, and user anonymity. Strategic goals for implementation of DCT with the COVID-MO application include: (1) Improving time of notification to an individual exposed to an infectious disease after a confirmed positive case is identified, (2) Shortened interval from exposure to quarantine, (3) Decrease infectious disease transmission, (4) Improve current contact tracing method, and staffing restrictions, (5) Anonymity of application users, and (6) Utilization of technology in the future for infectious disease control.

Pulling from the strategic goals in SP, a strategy process was created to focus on methods to achieve goals selected for COVID-MO implementation (see Figure 1 for strategy process). Performance measures were created for assessment of COVID-MO implementation, including: (1) Total time to implement COVID-MO, (2) AAR (%), (3) R0, (4) CRR, (5) Average time of notification of exposure, (6) Average time of notification to quarantine, (7) Privacy of application users, (8) Required MCT staffed with the use of DCT to reach 50% CRR, and (9) Cost to staff MCT. Further, to aid public health officials, George Washington University Milken Institute School of Public Health (Milken Institute SPH) created CWET, a tool to estimate the number of MCT needed to contain viral transmission (CWET, 2021). The CWET tool estimated the target state's savings of approximately $20,301,801 at a 50% CRR and reduced infections by approximately 50,400 individuals (see Table 1 for ROI).

Discussion

Rapid transmission rate of SARS-CoV-2 surpassed ability of public health organizations to achieve infection control through case investigation and MCT. Unfortunately, like many other states, the target state could not adequately hire and train sufficient contact tracers. An alternative strategy to explore is DCT, which can substantially improve contact tracing rates even at low AAR in the community. DCT and SP implementation rely on AAR; however, Virginia exceeded CRR requirements with only 10% AAR. This project explored use of DCT via a mobile phone application, whose development and implementation were laid out as a SP. Had SP been followed, savings to the target state are estimated at $20,301,801.00, freeing these resources to be used for other purposes.

Additionally, the target state would have gained ability to notify exposed individuals immediately, decrease time from exposure to quarantine, and ultimately decrease transmission of SARS-CoV-2. Barriers to implementing this project as proposed included privacy concerns, approval by the state's governor and chief information officer, funding for the application, and ability to assess impact due to utilizing the decentralized approach of DCT for user's anonymity. A strategic plan creates a roadmap to address these concerns and barriers, adding credibility and a guide to project implementation.

Conclusion

Although potential benefits of digital contact tracing are clear in the state of Virginia, this practice has yet to be fully realized in the target state for SARS-CoV-2 control. Based on the background work in application development and planning for implementation by the local academic research team, DCT remains relevant as a strategy for future infectious disease control. Implementation barriers immobilized implementation of COVID-MO; however, potential for future containment of infectious disease using technology still stands. Furthermore, the SP has proven to be a comprehensive, practical guide to project implementation. Future considerations are immediate design of a SP for guidance and credibility to aid project implementation. It is recommended leaders in the community continue to advocate, educate, and implement use of technology for public health interventions, as a comprehensive understanding of the past will strengthen ability to anticipate and respond to infection in the future.

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Table 1

Staffing Requirements for Manual Contact Tracing with and without Digital Contact Tracing

Month	MCT	Cost of MCT	MCT/ DCT	Cost of MCT/ DCT	Savings with DCT
November 2020	21,626	$84,060,262	19,898	$77,343,526	$6,716,736
December 2020	14,971	$58,192,277	13,783	$53,574,521	$4,617,756
January 2021	11,702	$45,485,674	10,324	$40,129,388	$5,356,286
February 2021	4,048	$15,734,576	3,733	$14,510,171	$1,224,405
March 2021	2,738	$10,642,606	2,526	$9,818,562	$824,044
April 2021	2,829	$10,996,323	2,603	$10,117,861	$878,462
May 2021	2,231	$8,671,897	2,055	$7,987,785	$684,112
Total	-	$233,783,615	-	$213,481,814	$20,301,801

Note. Data in this table obtained from the CWET tool developed by the Milliken Institute SPH at George Washington University (CWET, 2021). Functionality of CWET tool is described in detail on page 12. Contact Tracing Workforce Estimator (CWET), Manual Contact Tracing (MCT), Digital Contact Tracing (DCT).

Additional Note: Contact Tracing with and without Digital Contact Tracing

Using CWET, which provides information regarding how many manual contact tracers are required to reach a CRR goal. A Return on Investment showed conservation of public funds by approximately 20 million dollars.

Figure 1.

Strategy Process of COVID-MO

Strategic Plan "Plan"	Strategic Goal	Tactical Plan "Do"	Operational Plan "Study"/"Act"	Performance Measures
Implement the COVID-MO application in Missouri over two weeks	1,2,3,4,& 5	Publicize COVID-MO by utilizing a marketing team hired by the local research university	Monitor platform analytics to ensure that social media activity continues to increase.	Total time to implement COVID-MO application in Missouri Application adoption rate (%)
Preliminary report on effects of DCT 30 days after implementation	5	Ongoing analysis of COVID-MO application and pandemic trends	Weekly monitoring of: • Application adoption rates • R_0 • CRR	Application adoption rate (%) R_0 CRR of 50%
Improve the following pandemic trends • Time of exposure notification • Time of notification to quarantine • R_0 of SARS-CoV-2	1, 2, & 3	Implement the COVID-MO application using ENS for DCT	Analyze the number of notifications sent to mobile devices using ENS technology Analyze pandemic trends including: • R_0 • Average new daily cases	Average time of notification of exposure using DCT Average time of notification to quarantine R_0
Ensure anonymity to COVID-MO application users	4	Implement DCT through a decentralized approach using Bluetooth technology	Information Technology team from COVID-MO application creator continuously monitors for privacy breaches	Privacy of application users
Reach a 50% CRR with the use of bidirectional contact tracing (MCT & DCT)	1,2,3,& 4	Implement COVID-MO application for DCT to improve contact tracing efforts and CRR	Monitor required staffing of MCT with the use of DCT to ensure adequate staffing to reach 50% CRR	Required staffing of MCT with the use of DCT
Reduce required MCT staffed, further conserving public funds	1,2,3,4,& 5	Implement a bidirectional approach to reduce required MCT staffed	Monitor required MCT staffed to maintain a 50% CRR Analyze cost to staff MCT while using DCT as a tool	MCT staffed to reach 50% CRR Cost to staff MCT

Note: This figure represents strategy process to implement COVID-MO in Missouri. Performance measures are based off of Virginia's success of 72.5% contact response rate at 10% application adoption (Virginia Department of Health, 2020). Manual Contact Tracing (MCT), Contact Response Rate (CRR), Digital Contact Tracing (DCT), Exposure Notification System (ENS), Reproduction number (R_0).