REVIEW ARTICLE

The Role of Big Data Analytics in Digital Health for COVID-19 Prevention and Control in Asia

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ABSTRACT

Big data analytics (BDA) in digital health is critical for gaining the knowledge needed to make decisions, with Asia at the forefront of utilising this technology for the Coronavirus disease 2019 (COVID-19). This review aims to study how BDA was incorporated into digital health in managing the COVID-19 pandemic in six selected Asian countries, discuss its advantages and barriers and recommend measures to improve its adoption. A narrative review was conducted. Online databases were searched to identify all relevant literature on the roles of BDA in digital health for COVID-19 preventive and control measures. The findings showed that these countries had used BDA for contact tracing, quarantine compliance, outbreak prediction, supply rationing, movement control, information update, and symptom monitoring. Compared to conventional approaches, BDA in digital health plays a more efficient role in preventing and controlling COVID-19. It may inspire other countries to adopt this technology in managing the pandemic.
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INTRODUCTION

Big data is a large-scale dataset related to volume, variety, velocity, and/or variability that require a scalable architecture for efficient storage, manipulation, and analysis (1). It is complex and possesses specific characteristics, known as 5V's (volume, velocity, variety, variability, and veracity) (2). Volume represents the quantity of the datasets. A large amount of data processed will provide more valuable results from the analysis, known as the network effect. Velocity is a measure of data flow rate. Credit card transactions, for instance, require high data volume to be processed in a very short period of time. Variety refers to the wide arrange of data warehouses, repositories, domains, and types. The data can be structured or unstructured, characterised by the presence of the data model (1). Essentially, big data is a dataset of large quantity that requires a non-traditional storage system, high-speed data transfer, varies in all types of data format, variably changing from time to time and possess multiple quality of usages.

The healthcare system is a constellation of various specialties of different workplaces and healthcare workers. Every specialty generates its own data sources from structured data such as computerised laboratory test results, billings, vital statistical data and unstructured data such as clinical notes and imaging study reports. With the advancement of technology, especially the Internet of Things (IoT), and the increasing use of health information systems, healthcare data have grown massively in terms of its volume. With its complexity and high-speed requirement, the datasets cannot be handled efficiently with traditional methods. Hence, new sophisticated tools are used to analyse these datasets, known as big data analytics (BDA) (3). It provides various advantages to healthcare sectors, including decision-making and implementing disease prevention or control measures (4–7).

The process of big data analysis in healthcare management can be divided into five steps: data acquisition, data storage, data management, data analytics, and data visualisation and report. After data acquisition from any source such as Electronic Medical Record (EMR) or IoT, the datasets will be stored in a data warehouse such as clouds. Then the data management is about governing the data stored in its database, which includes data security, integrity, and availability to be used while maintaining the confidentiality of patient records. The next step, data analytics, is the process of transforming data into information. In healthcare, BDA can be grouped into descriptive, diagnostics, predictive and prescriptive. Descriptive analytics summarise performance based on historical data, whereas diagnostic analytics predict the root cause of a problem using historical data. This is different from predictive analytics, which forecasts the future based on historical and real-time data and prescriptive analytics that provide advice on various outcomes. Prescriptive analytics is superior among all because of its capability to provide the best outcome. Lastly, data visualisation is the presentation of the analytics data in various formats to convey information using visualisation tools (3). To put it in simpler words, BDA is the application of analytics techniques against any large and diverse data sets, including structured, semi-structured and unstructured data from various sources (8) to produce rapid and comprehensible information for decision-making.

The BDA use gives enormous benefits, which have been proven during the Coronavirus disease 2019 (COVID-19) emergence. Many countries in Asia leveraged this technology to manage the pandemic in their countries (9). The pandemic has been ongoing for almost two years since December 2019. More than 250 million COVID-19 cases and 5 million deaths are reported as of 17th November 2021 (10), and the statistics keep increasing despite global efforts to control the pandemic. Therefore, this review aims to identify what are the COVID-19 preventive and control measures that can be enhanced by incorporating BDA into digital health and how the six selected Asian countries implemented them. This review also aims to discuss the advantages and barriers in using this technology, as well as recommend improvements that can be made to facilitate its adoption. It is hoped that this review can assist other countries in their efforts in managing the pandemic.

METHODS

A narrative review of the role of BDA in digital health for COVID-19 prevention and control of COVID-19 in Asia was conducted. Online databases, namely Pubmed, ScienceDirect, Google Scholar, and Official Government Websites, were searched to identify all relevant literature on the role of BDA in digital health for COVID-19 preventive and control measures. Search terms used were as follows: "big data", "big data analytics", and "big data and COVID-19". Inclusion criteria for selection were articles written in English and published between 1st January 2020 and 31st December 2020. From the review, many Asian countries had adopted BDA for COVID-19 management. However, six countries were purposively selected based on the availability of numerous publications, which are Singapore, South Korea, Hong Kong, Taiwan, China, and Malaysia.

SINGAPORE

Singapore launched a contact tracing mobile application named TraceTogether in March 2020 (10). The aim is to activate an efficient, quick, and aggressive contact tracing with less recall bias in COVID-19 cases via a community empowered approach (11). It uses Bluetooth technology to track proximity between users and exchange signals to record face-to-face encounters. Individuals who had close contact with an infected person will be notified and recommended for testing (10). It helps track down possible suspect cases and implement strict quarantine measures to reduce community infections (11).

In Singapore, personal data disclosure is also subjected to Personal Data Protection Act (PDPA) 2012 (12). For security and privacy purposes, the information in the TraceTogether devices will be deleted after 21 days. The application does not store personal details such as the user's name, phone number, and geolocation data (13). A Bluetooth application is said to be safer regarding privacy and hackers' access because it is a decentralised system that requires a person to voluntarily give data to the public health authorities for further management and contact tracing (11). However, it may cause false tracking of individuals who are separated by a wall and not in contact together (14), causing overreporting of close contact. The initial uptake of TraceTogether was only 20% (13). To increase the adoption rate, a wearable TraceTogether Token was introduced to tackle the technical issues, incompatibility, and people without mobile phones or technology proficiency, such as the elderly (11).

GovTech also collaborated with the Ministry of Communication and Information and the Agency for Science, Technology, and Research to develop artificial intelligence (AI) tools to provide updated information in multilanguage through WhatsApp. Users can choose their preferred language, either English, Malay, Chinese, or Tamil. The data is end-to-end encoded and connected to the government cloud (15). In addition, Singapore had developed the Singapore COVID-19 Symptom Checker, which provides a COVID-19 symptoms checklist for monitoring and recommendations for users to take appropriate actions (16). Other than that, digital thermometers are used as a symptoms screening measure in public facilities such as schools, workplaces, public transport, and others. These thermometers are used to predict emerging hot spots, possible outbreaks, areas to initiate COVID-19 testing (17).

To ensure quarantine compliance, the Ministry of Manpower and Immigration and checkpoint agency send SMS in random timing to the individuals under quarantine. They are required to click the link provided to report their current location (15). Any quarantine violation will be fined up to SGD 10,000 (USD 7,168) and imprisonment up to six months (18).

SOUTH KOREA

South Korea's Centre for Disease Control (KCDC), Ministry of Land, Infrastructure, and Transport (MOLIT), and Ministry of Science and ICT developed COVID-19 Smart Management System, an automated contact tracing application for COVID-19. The system is adopted from the existing data hub platform for smart cities in which MOLIT cooperate with police, telecommunication companies, finance association, KCDC, and credit card companies. It uses credit card records, security camera footage, and GPS data from cars and mobile phones to trace people's movements (9,19). The KCDC also requests information on infected individuals from various authorities to identify their routes and map out trajectories (19). In addition, the Ministry of Interior and Safety uses a text alerting system, based on the existing system for disaster communication that sends emergency SMS with a 40-60db alarm which includes the latest COVID-19 information update, newly confirmed cases, and their trajectories (20).

Many real-time exposures digital maps had been developed to visualise the trajectories of confirmed cases together with the time and transport they had used. Several websites such as "coronamap.live" and "coronamap.site" and a mobile application called "corona 100m" use these concepts. The "corona 100m" reached one million downloads as of 28th February 2020. It uses phone GPS history, government information system, credit card transactions, and surveillance footage to track the users. This application shows easy-to-understand trajectories and helps individuals know their risk, avoid hot-spot, track their history, and decide for testing and self-quarantine (21,22). In South Korea, digital contact tracing is only used if there is a lack of information from traditional contact tracing and more detailed information is needed on the individual's movement, especially when they cannot recall their commuting or travel history and too many close contacts to be traced manually. Their travel time and location data will be published on the government website for contact tracing and prevention purposes (19).

Digital contact tracing improves the speed of information collection and gives a more accurate location. It helps enormously for contact tracing in large cluster outbreaks. For example, with the help of telecommunication companies, the public health authority was able to do contact tracing immediately and tested 45,000 people in the large outbreak in Itaewon District (19). The digital contact tracing must be complemented with sufficient testing kits, timely sample analysis, and enough resources to act upon this information. In South Korea, more testing booths and drive-through testing are provided, with the results issued within a few hours. South Korea contained the spread of COVID-19 and successfully conducted parliamentary elections without resorting to total lockdowns (19).

The Ministry of Health and Welfare had developed the Self-Quarantine Safety Protection application for self-quarantine and digital diagnosis (21). Every traveller or foreigner entering South Korea is obligated to install this mobile application together with a GPS tracking function and report their health condition and symptoms for 14 days since arrival. If there are any symptoms like fever or respiratory discomfort, the users must report health status to KCDC for COVID-19 testing. The compliance to self-quarantine is actively monitored by GPS tracking, and the travellers must ensure that they are contactable by the government. Korean who leave the quarantine area will be fined KRW 10 million (USD 8,257) or one year imprisonment, and foreigners who refuse to install the application or leave the quarantine area will be immediately deported (18,21).

The Personal Information Protection Act in South Korea prohibits the personal data collection of individuals without their informed consent. It was modified after the Middle East Respiratory Syndrome (MERS) outbreak in 2015 to allow authorities to collect personal information during disease outbreaks (19). Most South Koreans prefer the protection of public good rather than individual rights (22), with roughly 80% of them would accept some privacy interference to fight the COVID-19 pandemic (21).

HONG KONG

Hong Kong put extra focus on isolating imported cases effectively. Upon arriving at Hong Kong airport, travellers are required to wear electronic wristband devices and install the StayHomeSafe mobile application. The wristband is scanned and integrated into the StayHomeSafe application. During the 14 days quarantine period, the travellers must always wear the wristband and turn on their mobile phone's Bluetooth, Wi-Fi, and geolocation (23). The wristband and mobile application detect the environment signals and do not collect personal data. If there is any discrepancy in the signals, the application will alert the Department of Health and police. The individuals under quarantine may receive surprise visits or video calls by the Hong Kong authority to check their location to ensure compliance. The public is encouraged to report to the government via an online e-report centre if they have seen or suspected any violation. Individuals who leave their quarantine premises without permission are subjected to criminal charges with a maximum penalty of HKD 5,000 (USD 641) and six months imprisonment (23).

Since November 2020, Hong Kong has utilised a new contact tracing application called LeaveHomeSafe. The application allows users to record the accurate date and time of their visit to shops or venues and taxi rides. Users need to scan QR codes before entering any facilities as well as before and after riding a taxi. As a privacy precaution, the data are saved in the users' devices and deleted after 31 days (24). The application also does not use geofencing technology or any GPS tracking. In addition, personal health data collection and usage in Hong Kong is subjected to Personal Data Privacy Ordinance 2012 (25).

TAIWAN

One of the main factors contributing to Taiwan's COVID-19 pandemic management is the BDA technology (26–28). Their success in handling the COVID-19 pandemic has been reflected by its low prevalence and mortality rate (29). The National Health Insurance (NHI) is a compulsory single-payer system for all citizens and legal residents, which is run by the Taiwanese government. As a method of organisation of all the individuals' data under NHI, the NHI Administration under the Ministry of Health and Welfare uses a centralised health information system which comprises of integrated data from NHI MediCloud (keyed in by healthcare workers) and My Health Bank (keyed in by patients) (30,31). The country uses the existing NHI database and integrates it with the immigration and customs database, which enables real-time alerts to help identify a probable case based on the individual's clinical symptoms and travel history, especially for healthcare providers (9,18,27,28). Individuals with no or mild symptoms are allowed to self-quarantine at home, while the rest will be referred to a hospital (28). If an individual is noted to be diagnosed with pneumonia in the NHI database, the treating facilities will be informed to consider for COVID-19 testing (32), especially if they have severe respiratory symptoms with a negative influenza test (18,28). Suspected cases in Taiwan were screened for various viruses, including Severe Acute Respiratory Syndrome (SARS) and MERS (28).

When Diamond Princess cruise ship disembarked at Keelung harbour in Taiwan on 31st January 2020, Taiwan used smart mobile contact tracing with geopositioning to identify 627,386 people who were in contact with the ship's passengers. Each potential contact was given an alert notice using an SMS to self-quarantine and seek treatment if symptomatic (9,32). Individuals undergoing self-quarantine are monitored through their mobile phones (geofencing) to ensure compliance (9,17,28). Anyone who violated their quarantine will be fined up to NTD 1 million (USD 36,147). Individuals who were found giving false information also will be fined (9,17,18,33,34). Data collection, process, and usage for public health are also addressed in the PDPA (35).

The community in Taiwan fully supports the government's decision to access an individual's personal information during a health crisis for public health purposes (36). Their experience with SARS infection in 2003 and MERS infection in 2015 proved the importance of contact tracing and strict quarantine enforcement, which upholds well-being over social freedom or privacy concern (9,37). BDA also helped COVID-19 management in Taiwan through other angles, which are not confined to an epidemiological investigation. For example, face mask supply monitoring and rationing system using NHI Card, which is linked to NHI database (18,26,27,33,37,38). Taiwan has gained substantial public health benefits through BDA, as proven by not needing a lockdown and its resilient economy (18,26,33,39).

CHINA

Despite being the first country hit by this novel/newly discovered virus, China has shown tremendous success in controlling COVID-19 even with its large population and country size (40). China was able to come up with strategies for fast response (40), in which one of them is through the application of BDA (9,41). China uses the Health Code application, which is mandatory centralised mass surveillance (9,42). This three colour-coded application is developed through a public-private partnership and used by almost 900 million people in China (9,43). The Health Code application mandated all individuals to register with facial recognition on top of their personal information. The application will utilise the individual's daily self-reported health assessment and mobile phone GPS to map out their travel history to calculate the probability risk (9,41,43,44). The result is updated daily at midnight and shown as one of three colours – green, yellow, or red – to denote their exposure risks and level of mobility. Green indicates that the individual has low exposure risk and is allowed to travel or work, yellow indicates that the individual has medium exposure risk and needs to self-quarantine for seven days, while red indicates that the individual has high exposure risk and need to self-quarantine for 14 days. The colour status will be updated daily at midnight (9,17,42,43). Individuals with yellow or red codes are not allowed to bypass a checkpoint (9,44). The Health Code also enables users to book appointment and order medication which help them seek early treatment for their health condition (44). To increase the accuracy of the analytics generated in the Health Code, the information keyed-in by the individuals are also cross-checked with other sources, such as the COVID-19 database, various transportation systems, financial transaction records, AI-powered surveillance cameras with facial recognition ability, and social media (9,17,41–46).

Other than that, China is able to control movement to prevent overcrowding or congestion of certain areas, such as checkpoints, subway stations, or bus stations, thus reducing the risk of disease spread (9,44). Locations determined to be high-risk will be broadcasted to the public, and individuals who have COVID-19 exposure risk will be informed to undergo testing and self-quarantine. The COVID-19 cases rise in proximity areas will trigger an early outbreak alert mechanism prompting disease control measures. Beyond that, China also utilises BDA to monitor possible outbreaks by monitoring pharmacies' purchase of anti-pyrexia or online keyword searches related to COVID-19 symptoms and to predict the peak and end of an outbreak to determine the appropriate time to allow resumption of operations in the area (44). Based on experience with SARS infection in 2003, China had accentuated the importance of rapid disease notification. Consequently, hospitals' EMR systems are integrated with the country's Centre for Disease Control and Prevention monitoring and early warning system. The integration enables AI to be deployed to monitor the accuracy and completeness of EMRs of a suspected COVID-19 patient, accelerate disease reporting, allocate limited health resources, and explore possible treatments for COVID-19 patients (44,47).

China has strict quarantine monitoring and enforcement (42), along with good community support and participation, which allows usage of individuals' personal information and mobile location tracking for public health benefits (9,46). China enforced legal implications in the mishandling of collected data. Nevertheless, there is still some privacy concern brought up and needs to be addressed (42,44).

MALAYSIA

Malaysia had come up with a digital-forward approach in the COVID-19 response (48). Malaysia utilises several contact tracing applications, mainly the MySejahtera (49). MySejahtera is a compulsory QR code-based contact tracing mobile application, while MyTrace is Bluetooth-based. Other contact tracing mobile applications available in Malaysia are SELangkah, COVIDTrace, and Jejak Johor. Globally, the adoption of QR code-based is higher than Bluetooth-based. A similar situation is seen in Malaysia; thus, QR code-based is preferred as the higher the adoption, the higher the success in contact tracing coverage (50). MySejahtera is a collaboration between the Ministry of Health Malaysia (MOH), National Security Council (NSC), Malaysian Administration Modernization and Management Planning Unit (MAMPU), Ministry of Science, Technology, and Innovation (MOSTI), and Malaysian Communications and Multimedia Commission (MCMC) (51,52). MySejahtera application utilises the users' daily self-reported health assessment and the "Check-In" function to map out their travel history. MySejahtera also considers community empowerment as a step in combatting COVID-19 in which it provides a flowchart guide, health tips, daily COVID-19 cases update, hot-spot tracker, and virtual consultation function. There is also a traveller version for MySejahtera for individuals returning or visiting Malaysia. It has extra functions, including health declaration form completion reminder, digital Home Surveillance Order issuance, mandatory 14-days self-reporting health assessment during home-quarantine, and COVID-19 test reminder on day-13 (51). Positive COVID-19 cases and positive COVID-19 contacts can also be detected through MySejahtera (50,53). MySejahtera is planned to be integrated with Hospital and Clinic Information Systems in the future (50).

Any confirmed cases, including those detected by healthcare providers or through MySejahtera, will be registered in the COVID-19 disease reporting surveillance system called e-COVID19, which is the extension of a national disease reporting surveillance system called e-Notifikasi. e-COVID19 is another inter-agency project between MOH Malaysia, MCMC, and NSC. This web-based system is used by the National Public Health Laboratory and Crisis Preparedness and Response Centre (CPRC) at national, state, and district levels to ensure uniform, accurate, and real-time COVID-19 case reporting while avoiding overlapping and redundant information (54). Through e-COVID19, CPRC Hospital can plan and allocate the resources needed for COVID-19 management (48).

By using Malaysian Health Data Warehouse (MyHDW) which is integrated with the Geographic Information System (48,55,56), National CPRC implemented the MyCPRC Dashboard and Analytics. Using this dashboard, they are able to monitor/overview real-time COVID-19 cases in Malaysia (50). MyCPRC dashboard is also integrated with NSC Dashboard and CPRC Hospital Data Analytics & Visualisation at the state level (48). As of date, MySejahtera is not yet integrated with MyHDW or MyCPRC (50). Using the data collected from all the systems previously mentioned and leveraging the BDA capability, MOH produced daily case reports, wrote standard operating procedures, performed people's sentiment analysis, and forecasted future daily in-country COVID-19 cases (50).

Malaysia has not yet implemented any geofencing enforcement and surveillance systems such as facial recognition or financial transactions, presumably due to a lack of clear legislation, regulatory frameworks, policies, or guidelines (57–60). Currently, personal health data collection and usage in Malaysia is subjected to the PDPA 2010. However, this Act only applies to private sectors, not federal or state governments (56,61–63). For the development and implementation of MySejahtera, Malaysia uses Act 342 of Prevention and Control of Infectious Diseases Act 1988 to increase the community support/public uptake (50,52). Under Section 24 of the same Act, any individual who was found violating a home surveillance and monitoring order will be charged with either fine or imprisonment (64,65).

DISCUSSION AND RECOMMENDATIONS

Based on the literature review that has been done, several recommendations can be considered. Firstly, a public-private, inter-ministry, or inter-agency partnership should be forged to allow enhanced digital contact tracing (through a comprehensive database by integration), faster application development and roll-out, and accurate case reporting. Digital contact tracing is the way to go during this pandemic, as it is less time, energy, and cost-consuming than traditional contact tracing and case investigation methods (32).

Another recommendation is to use BDA as an opportunity to empower the community. These Asian countries increase the awareness and education through health information, which is widely disseminated by SMS broadcast and easily accessible by mobile applications, allowing them to take responsibility in protecting themselves, their family, and their communities from getting infected by COVID-19. Without the help and cooperation of communities, no country will be able to stop the spread of COVID-19. Community empowerment is essential for sustainable population health improvement (66).

The main concern with digital contact tracing is privacy violations and social stigmatisation towards confirmed and suspected COVID-19 cases. People hesitate to install position-tracking applications because they fear personal information breaches and hacking threats (19). Therefore, contact tracing with personal information must be conducted following data privacy guidelines (18). Every country must establish a clear policy and regulation of digital health to further strengthen and expand the utilities of BDA, especially in the public health context (57–60). Act(s) related to personal information sharing must be modified to include a special clause during epidemic management. The legal basis also needs to be accentuated to promote the private-public partnership to ensure any sensitive data is safe from breaches to third parties. Other than that, to ensure quarantine compliance, a country may consider utilising geofencing technology, which requires strong legal backup (9,17,23,28). This technology will alert the authority when an individual has breached their quarantine parameter. It should be enforced on all individuals who are undergoing quarantine through the contact tracing application. It is also applicable in controlling mass movement by reducing inter-state or inter-district travels without needing roadblocks. In addition, travelling can be monitored by road surveillance cameras and financial transactions records. BDA should be utilised to prevent mass crowds in large public areas such as malls and markets. This can be done in several ways, such as predicting crowd visits in peak hours using a real-time digital map.

Public support is a critical element in determining the success of digital contact tracing in the COVID-19 outbreak. The effectiveness of digital contact tracing will depend on user uptake. Uptake of 80% is recommended for the application to function effectively (67). In Singapore, the citizens are provided with TraceTogetherToken to increase its uptake after local research discovered concerns regarding high battery usage when using the TraceTogether application and the absence of mobile phones in the elderly (11). More research should be done on the level and factors related to usage uptake of contact tracing applications from the users' perspective in other countries.

Human resources in healthcare can be defined as clinical and non-clinical workers in the healthcare system (68). Proper management of human resources is vital in delivering quality healthcare services. Human resource capacity is greatly needed as the burden of COVID-19 increases day by day. Urgent mobilisation of healthcare workers through risk assessment is required to strengthen human resources at national, state, and district levels. The predictive capabilities of BDA are beneficial in predicting daily COVID-19 cases in an area together with the number of healthcare workers needed to control the disease. Through resource optimisation, better quality healthcare service can be delivered.

Through telemedicine, healthcare services can be provided to distant individuals or communities via IOTs (69). Community surveillance through remote health monitoring using real-time data helps identify COVID-19 related symptoms such as fever and cough in a community, predicting the risk of an outbreak in that area, and alerting health authorities. In addition, the BDA should be used in a multiracial country to translate and disseminate information in various languages (15) to improve the information preciseness and understanding. Other than that, BDA can also be used to cross-refer multiple databases (9).

CONCLUSION

The use of BDA in digital health is crucial during a crisis as it can process and analyse massive data in the least amount of time, enabling swift responses and prompt interventions. It has a significant and efficient role in preventing and controlling the COVID-19 compared to conventional approaches. From this review, this technology proves to be an effective measure in breaking the infection chain, contact tracing, and ensuring quarantine compliance. It is unarguably an invaluable tool for health, transcending epidemiological purposes to clinical curative and economic purposes. The use of BDA in these Asian countries may inspire other countries to use this technology in managing the pandemic. However, the barriers to using BDA should be addressed to ensure that each country can reap the full benefits of this technology.

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