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REVIEW ARTICLE

Pandemic Analytics: How Countries are Leveraging Big Data Analytics and Artificial Intelligence to Fight COVID-19?

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Abstract
Emergence of coronavirus in December 2019 and its spread across the world in the following months has made it a global health concern. The uncertainty about its evolution, transmission and effect of SARS-CoV-2, has left the countries and their governments in a worrisome state. Ambiguity about the strategies that would work towards mitigating the impact of virus has prompted them to use data-driven methods. Several countries started applying big data and advanced analytics technology for management of the crisis. This study aims to understand how different nations have employed analytics to deal with COVID-19. This paper reviews various strategies employed by different governments and organizations across nations that use advanced analytics to tackle pandemic. In the current emergency of corona virus, there have been several measures that organizations have taken to mitigate its impact, thanks to the evolution of computing technology. Big data and analytical tools provide various solutions like detection of existing COVID-19 cases, prediction of future outbreak, anticipation of potential preventive and therapeutic agents, and assistance in informed decision-making. This review discusses the big data analytics and artificial intelligence approaches that policy makers, researchers, epidemiologists and private organizations have adopted. By examining the different ways and areas where data analytics has been utilized, this study provides the other nations with the progressive scheme to address the pandemic.

Keywords Pandemic analytics · Big data · Advanced analytics · Artificial intelligence · COVID-19 · Coronavirus

Introduction

The first 2 decades of twenty-first century have shown how infectious diseases are spreading globally—faster and more widely—mostly by way of increased intercontinental air travels. After SARS, H1N1, MERS, Ebola and Zika Virus, it is the Coronavirus disease 2019 (COVID-19) which is a global health threat today. Poor understanding of the incubation period and duration of infectious period for COVID-19 [1]; higher rate of its spread; and mortality 3,947,630 (at the time of writing of paper), heightens the concern even more. One way the epidemics of this scale can be managed is by a collaborative approach—be it academicians coming together for research on preventive or curative measures; or industries joining forces to provide adequate and timely resources; not-for-profit organizations coming to the rescue of vulnerable population; or even the governments ensuring proactive information dissemination, transparency of its actions and resource-sharing to better tackle the current situation.

Increased access to information, that is obtained either through streams of real-time spatial data depicting travel patterns of individuals or through cooperative governmental efforts or maybe the partnership activities of research communities, provide varied opportunities to address the current crisis. Vast amounts of data so generated, termed as *big data*, are the rich source of information for monitoring the spread of disease. Identification of patterns through analysis of these data streams can help to comprehend shifts in disease hotspots and support surveillance actions. Scaling the use of analytical tools on such large volumes of data, for examining the proliferation of disease and understanding

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the global state of pandemic can be referred to as *Pandemic analytics* [2].

There are a bunch of unknowns with COVID-19—how does the virus strain differ from previous known strains, what is the virus' behavior and its ability to infect, what is the disease incubation period, what are the true number of infections, whether the patients once infected and recovered will be protected against a repeat infection, how long does the virus live in the environment, can surface contact lead to transmission and many more [3]. Amidst this ambiguity, the centralization of all relevant data, be it unstructured or disorganized, and its analysis provides certain ability to derive insights on the transmission of disease. Hopeful about its potential, worldwide different nations and organizations are looking forward to using big data analytics and artificial intelligence (AI) for better management of the crisis. This study reviews the early steps of governments and private firms in using these digital technologies to slow down the spread of the disease. Figure 1 depicts the map of COVID-19-confirmed cases reported to WHO and highlights the early adopters of AI and other cognitive tools as identified through review.

Applications of Big Data Analytics and AI in COVID-19

First Warnings by Canada-Based Company

Days before the World Health Organization (WHO) released its statement on COVID-19, BlueDot, a Toronto-based infectious disease surveillance company, had alerted its clients of a cluster of unusual pneumonia cases in Wuhan. With the expertise in infectious diseases, big data analytics and digital technologies, this company found patterns across news reports that indicated the possible outbreak of infectious disease [4].

China Tracks COVID-19 with the Use of Big Data Analytics

Initial efforts by technology firms in China were in utilizing movement data to track the flow of population and understand the spread of disease. Telecom firm, Unicom, primarily provided reports on the public flow across 31 provincial traffic and health departments [5]. On the other hand, GeTui, a smart data provider, created a heat map of the outbreak in China by monitoring the movement of passengers from the worst-hit city of Wuhan [5]. Following that, a big data analytics platform which pooled data from National Health Commission, Ministry of Transport, China Railway and Civil Aviation Administration of China, was launched to help authorities identify the close contacts of COVID-19

Fig. 1 Application of big data analytics and AI; and total reported COVID-19 cases by countries [8]

patients or suspects [6]. Baidu, another technology company, created a map to provide real-time updates on the information of road closure and crowded areas to guide people in avoiding such places [7].

The Chinese government in collaboration with Alipay, a private online payment platform, has also created a smartphone app which gives color codes to the citizens based on the contagion risk, to help authorities track the people's movement [9]. Moreover, the government is also using big data analytics in decision-making—for instance, Beijing municipal government used analytics to evaluate the merits and demerits and made a decision on suspending inter-provincial road transport while not restricting the civil aviation and high-speed railways [7].

On the healthcare front, railway stations and subways in China have deployed AI-based temperature scanners by Megvii Technology, that use body and facial detection to identify people with elevated body temperatures [10]. Chinese multinational company Alibaba is providing a CT Image Analytics Solution to the clinicians involved in COVID-19 disease management for faster and accurate testing [11]. A similar system was developed by Nankai University and Inference Technology, which assists physicians in diagnosis by rapidly screening and analyzing large number of high-resolution CAT scans [12].

Early Intervention by Taiwan

As soon as the word of outbreak of unknown pneumonia in China was out in the world, Taiwan had an immediate response to the upcoming crisis. Owing to its proximity and frequent travel to China, the state had been at the highest risk. Despite that, with its lessons from 2003 SARS outbreak, Taiwan adopted technology-driven strategies for prompt action. By centralizing the data with integration of the national health insurance database and immigration and customs database, the government was able to create a detailed map of 14-day travel histories and symptoms of its citizens and travelers [13]. The use of big data analytics on this pooled data enabled real-time alerts for hospitals and clinics assisting them in diagnoses and treatment and also allowed early identification of potential cases [14].

Moreover, the combination of big data analysis and mobile-phone location tracking in the form of "electronic fence" provided Taiwanese government an opportunity to ensure quarantine compliance [15]. Predictive analytics was also used to provide real-time updates on high-risk zones alerting public to avoid those locations [14]. Besides, data-driven insights helped track the availability of critical medical supplies. The government followed up on an interactive real-time map of the stock of supplies created by one of the software engineers. The locals could use this online map to obtain the information about availability of masks, including details of pharmacies providing them and their distance from the seeker [16].

NHS England Allocates 'Big Data Platform' to Defeat Coronavirus

With the purpose of providing up-to-date information to the decision-makers, UK's National Health Service (NHS) partnered with Microsoft, Amazon Web Services, Google, Faculty and Palantir to build a digital platform based on big data, AI and cloud computing technology [17]. The platform sourced COVID-19-related data from NHS and Public Health England, analyzed it and presented the authorities with real-time insights and recommendations in the form of a dashboard [18]. ZOE, a UK-based health science company, in collaboration with researchers from King's College London and Massachusetts General Hospital Boston, designed an AI model to predict COVID-19 infections [19]. Based on the data obtained from ZOE's "COVID Symptom Study app", the outcomes of this model aid public when access to traditional testing is limited. In collaboration with researchers from University of Cambridge, COVID-19 Capacity Planning and System (CPAS) was launched by NHS, to anticipate the need for hospital resources like equipments including ICU beds and ventilators in coronavirus patient management [20].

BenevolentAI, a London-based firm, utilized its drug discovery platform to spot drugs which had the potential to treat COVID-19 patients, driving its clinical trials [21]. Oxford-based Exscientia formed an alliance with Diamond Light Source and Scripps Research's Calibr to use AI and screen 15,000 drugs in search for a potent existing anti-viral drug that could be repurposed for treatment of COVID-19 [22]. Pharmacology-AI firm based in Cambridge, AI VIVO, with the help of its predictive engine identified Dexamethasone as one of the highly potential drugs which could treat COVID-19 patients [23, 24]. Later, based on the results of clinical trials, the drug was found to save lives of critically ill COVID patients and recommended by WHO for treatment of severe cases [25]. Another AI-biotech company, Healx, utilized its platform "Healnet" to consolidate biomedical data from varied sources and analyze it to predict effective drug combination therapies for severely ill COVID-19 patients with associated co-morbidities [26]. English company, behold.ai designed a cognitive computing platform "Red Dot" that analyzed chest X-rays to identify abnormalities and in association with Wellbeing Software, offered NHS Hospitals with the technology that enables quick diagnosis and triage of COVID-19 patients [27].

United States Applies Analytics and AI as a Defence Against Pandemic

As an additional line of defence against COVID-19, scientists in the worst-hit country of United States took assistance from big data, predictive analytics and cognitive computing technology. John Hopkins Center for Systems Science and Engineering (CSSE) developed an interactive dashboard displaying data through a GitHub repository to provide scientific community and general public with real-time up-to-date information on reported COVID-19 cases [28]. Institute for Health Metrics and Evaluation at the University of Washington created another dashboard with dataset enabling calculation of key statistics including incubation period, reproduction rate, etc. [29]. Google's Kaggle in collaboration with Microsoft built a platform in response to The White House Office of Science and Technology Policy's request for a data mining solution that provides an overview of scientific literature available on COVID-19 for researchers to interpret and analyze data [30, 31]. A New York-based company Tellic utilized Neo4j database to build a graph analytics platform "C19" that facilitates researchers to identify relationships and connections across scientific publications [32, 33]. Adaptive Biotechnologies and Microsoft launched "ImmuneCODE", an open database demonstrating the population-level immune response to COVID-19 [34]. The system utilized immune medicine platform and machine learning to interpret the response of T cells to SARS-CoV-2, and generate insights to support researchers for accurate diagnosis and development of drugs.

The U.S. "HealthWeather" map, a visualization tool by Kinsa Health, produced with the analysis of data generated through its internet-connected thermometers, offered the government information about the impact of lockdown and social distancing restrictions [35]. Unacast, using its Real World Graph Data Engine, created a "Social Distancing Scoreboard" that guided authorities and public health experts about the resident behavior and mobility pattern to understand the future trend for spread of disease [36]. A similar website was developed by HealthMap at Boston Children's Hospital. COVID Near You" which encouraged public to share the information about their health status and location [37]. Mayo Clinic, along with the Minnesota Health Department created an AI tool to assess the rate of positives to negatives for a number of tests done and thereby distinguish the zones with higher transmission [38]. These initiatives enabled public health officials and even general public get a better understanding of the evolution and spread of coronavirus.

New York-based Dataminr, a company which predicts high-impact events and emerging risks, with its AI platform, published a study that predicted spikes in coronavirus cases in 14 states of the US, which later were badly affected by pandemic [39]. Apple, in association with the White House Coronavirus Task Force, the Centers for Disease Control and Prevention (CDC), and the U.S. Department of Health and Human Services (HHS) released "COVID-19 app" which utilized the information obtained from citizens, about their health and exposure, to advise the authorities of further measures on limiting the spread, screening of patients and their treatment [40]. Rimidi, an Atlanta-based digital health company, introduced an EHR-integrated app to identify potential COVID-19 patients [41].

Google DeepMind applied "AlphaFold", a system that predicted protein structure using huge genomic datasets, to anticipate the structure of SARS-CoV-2 proteins and support the researchers better understand the virus [42]. Scientists from New York University and Columbia University in collaboration with two hospitals in China created an AI tool to predict patients who would develop into severe respiratory disease and discovered the role of liver enzyme, myalgia, and hemoglobin levels in worsening of patient health [43]. Partnering with Amazon Web Services, UC San Diego Health designed and applied an AI solution to process lung X-ray images and identify patients with likelihood of developing pneumonia [44]. Moreover, researchers at Case Western Reserve University lab developed a computational tool to identify the patients with chances of developing complications and consequently in need of extensive care, to aid triage [45]. New York-based Mount Sinai Health System analyzed chest CT images with AI algorithms for rapid diagnosis of COVID-19 patients [46, 47]. Kentucky-based Baptist Health and Mayo Clinic applied remote-patient-monitoring solution by Current Health Ltd., to monitor COVID-19 patients distantly [48, 49]. Likewise, Providence Health & Services in Washington utilized tools from Twistle to track COVID-19 patients in their homes [48]. These systems enabled the hospitals to reserve beds for critical coronavirus patients, hence curtailing some pressure.

European Union Nations Use Data Analytics for Fighting COVID-19

Telecom operators in Europe came forward to aid the national authorities in their fight against COVID-19. Vodafone, a telecom service provider, created a heat map for Lombardy region in Italy, enabling the government authorities to better track population flow [50]. Vodafone Analytics Platform which utilizes big data and AI techniques, has also been in use in Spain, Greece and Portugal [51]. The company supported administrative authorities in anticipating the impact of policy decisions on the spread of virus and burdening effects on healthcare infrastructure.

EU countries also implemented different software for rapid testing of COVID-19 patients. AI-based chest X-ray analysis solution, INSIGHT CXR by Lunit, was deployed in Italy, France and Portugal to help healthcare providers in triaging and management of symptomatic patients [52]. San Raffaele Hospital in Italy used a similar tool by Qure.ai called qXR which analyzed chest X-ray scan to assess the severity of virus impact on lungs [53]. Another CT image screening system, InferRead by Infervision Europe was implemented by The Campus Bio-Medico University Hospital (UCBM) to detect potential COVID-19 cases [54]. Spanish Society of Anaesthesiology and Critical Care (SEDAR) approved a project by Ubikare, a bioengineering group, and scientists from 80 centers across Spain [55]. The company created "Reg Covid-19" statistical tool to provide healthcare professionals, access to datasets of coronavirus infected patients and insights on disease progression, anticipated mortality, thus enabling them take proactive decisions [56]. Spanish Government, in cooperation with Sngular, a Madrid-based tech firm, built "Hispabot-COVID19", a whatsapp-integrated chatbot to enable automated and accurate official information transmission to Spanish citizens [57].

Italian Ministry of Innovation, in cooperation with University of Pavia, used big data analytics to track lockdown compliance [58]. Anonymous datasets on users' movement were obtained from Facebook and Italian telecom companies, to aid contact tracing. Enel X, a global energy service company along with Here Technologies, a location mapping firm, developed City Analytics Mobility Map, which was used by Italian transportation agencies to evaluate mobility flows and plan containment measures [59]. Expert System, a global AI company, designed a big data solution that analyzed data from social media posts, hospital data, emergency call logs etc. to alert Italian authorities in case of alarming trends [60]. The company's Clinical Research Navigator (CRN) tool has been implemented by Inserm (France), to provide researchers with insights into latent connection between different pieces of research, by analyzing research content based on concepts [61].

France developed "StopCovid" contact tracing app which relied on Bluetooth Low Energy to track people who interacted for more than few minutes [62]. As the infected person updates a QR code on app provided by testing facility, the app notifies past two weeks of contacts about their exposure to virus. Latvia, a north European country, launched "Apturi Covid", a contact tracing app based on the toolkit provided by Apple–Google [63]. French government has also deployed DatakaLab's AI-powered video analytics tool which notifies the local transport authorities with the number of people not wearing face masks [64]. Based on the surveillance data, government can take measures like imposing fines upon violation of mandate to prevent future outbreak [65]. Researchers at the University of Barcelona produced an analogous solution. LogMask" to be used by the Spanish Government to identify if a person is wearing a mask or not [66].

German health authorities teamed up with Thryve, healthcare technology company, to design "Corona-Datenspende", an app that relied on vital signs data available from fitness trackers, to identify symptoms [67]. DZD (Deutsches Zentrum für Diabetesforschung)—German Centre for Diabetes Research—has been using graph database technology to connect different types of data, from extremely heterogeneous sources in their diabetes research [68]. To tackle the current crisis of pandemic, research center extended its graph database to apply it to coronavirus research. In collaboration with database software organizations Neo4j, YWorks and Linkurious; the diabetes center has prepared a COVID-19 graph database [69]. The availability of centralized database and analytical techniques provides opportunity to scientists, to generate hypotheses and query data for better understanding correlations between diabetes and COVID-19 disease [69, 70].

Thorough and Prompt Measures by Singapore

The earliest attempts by government of Singapore included launch of an app called TraceTogether to identify links between COVID-19 infected individuals and their contacts. By making use of location and proximity data with Bluetooth, the app-enabled community-driven tracing and alerted high-risk individuals [71]. Contact map was generated using different tracers with the help of digital signatures of activities like ATM card or credit card transactions to aid the assessment of nature and extent of contact between infected and others [72].

To monitor social distancing, a tech-company AI Hub Singapore designed an app SafeDistancer which combines AI and computer vision to monitor the distance between people by making use of phone's camera [73]. Images are processed using data analytics and an alarm rings as soon as someone comes closer, thus alerting people and helping businesses keep track of social distancing [74].

South Korea's Swift Response

As soon as South Korea identified its superspreader COVID-19 patient, the government started using cellphone location data for smart contact tracing [75]. The location information was shared publicly, providing a comprehensive map of infected patient's movement and enabling people to determine the exposure and potential danger. Thereby, the system assisted authorities in reducing reaction time to identify and isolate infected patients and helped hospitals to be well prepared for future healthcare eventualities [76].

Big data analytics was also leveraged for estimating the supply and demand of coronavirus testing kits and bridging the gaps [77]. Artificial intelligence (AI) enabled Seoul-based molecular biotech company, Seegene to develop coronavirus test kits at accelerated rate [76, 78].

To assist healthcare personnel in accurate and rapid screening of patients, a medical technology company Lunit designed AI-based big data solution that analyzes large-scale chest X-ray data to classify coronavirus patients into four different categories based on the severity [76, 78]. This solution is used in South Korean coronavirus centers, where it has helped the healthcare professionals in early discovery and mainly patient triage [79]. In the coronavirus situation when hospitals are overcrowded with patients, identification of patients in critical state has been vital for the mitigating the impact of pandemic.

Israel Develops Model to Predict COVID-19 Patients' Health Status

Israeli Defence Ministry launched a study to remotely diagnose and monitor COVID-19 patients [80]. In this study, an app developed by Vocalis Health was utilized to analyze "voice fingerprints", allowing hospitals to diagnose infected patients remotely without exposing and risking healthcare workers. Rambam Hospital in Haifa utilized Cordio Medical's app based on the same principle of speech analysis to identify patients having bilateral pneumonia with edema and thereby diagnose COVID-19 [81]. Sheba Medical Center and the Ichilov Hospital at Tel Aviv Sourasky Medical Center deployed a TeleICU solution based on predictive analytics to identify severity of disease and enable healthcare providers to proactively manage the patients and hospital resources [82]. Maccabi Healthcare Service in partnership with Medial EarlySign developed a system that identifies at-risk COVID-19 patients and determines the level of treatment required [83]. Scientists from Israel Aerospace Industries (IAI) designed an AI-based model that predicted the progression of disease [84]. By alerting the medical workers of possible deterioration, the system allowed better patient care and improved patient outcomes.

Australia's Use of Big Data for Decision-making

With a focus on dealing with the COVID-19 crisis, Australian government tapped into big data analytics. The government increased its external spending on COVID-19 data analytics from Quantium Health Pty Ltd., a data science consultancy firm in March 2020 [85]. By employing analytical tools, models were designed to explore the impact of social distancing, quarantine and self-isolation, on spread of infection and eventually on overloading of healthcare systems. Economic models were applied to determine measures for reducing the detrimental effect of pandemic on businesses. Analysis of COVID-19 big data, thus, fuelled the strategic planning by aiding decision-making on different levels, from augmenting the healthcare infrastructure capacity to closure of industries and services, and sealing of borders for limiting the effect of coronavirus [86].

United Arab Emirates (UAE) Deploys Technology to Curb Spread

Responding to coronavirus situation, UAE has been using AI, big data and internet-connected devices at different levels for tracking, testing and monitoring compliance to lockdown rules [87]. Internet-connected devices have helped government keep check if citizens are abiding by 'social distancing' rules. Dubai Police has been using a platform called 'Oyoon' which analyzes data from facial, voice and license plate recognition to monitor if a citizen holds a valid permit and, thus, regulates the movement of residents [88]. Abu Dhabi Health Services Company (SEHA) collaborated with Draper & Dash, a Britain based firm, to analyze data for predicting the spread of coronavirus, anticipating the demand for medical facilities, gauging their clinical capacity and planning the actions accordingly [89].

Healthcare startup—Nabta Health—has been utilizing AI solutions to identify symptoms and evaluate risks on the basis of underlying health conditions [89]. Nybl, a Dubai-based tech company, provided AI and big data technologies to the government to facilitate management of health supplies. These solutions enabled the matching of supply to demand by identifying the available resources and hospital needs and procuring stocks as per the necessity [87]. Another Abu Dhabi-based AI company, Group 42 (G42), in cooperation with various organizations has been employing technology for testing and research [89]. A COVID-19 detection lab was developed by the company in association with a global genome sequencing organization, BGI, to scale RT-PCR testing and diagnosis to the population level [90]. The company also provides other tools for rapid *virus genome analysis*, *CT scan evaluation* for COVID-19 and pneumonia, and in silico *drug discovery* to reduce drug testing duration [91].

India Initiates COVID-19 'National Supermodel' to Support Decision-making

The early response of Indian government towards pandemic was a country-wide lockdown, followed by the use of 'Aarogya Setu', a coronavirus tracking app, which used location and Bluetooth data to determine if the person has been in vicinity of an infected person [92]. Thereafter, Larsen & Toubro, an engineering company, harnessed AI and analytics to aid 20 Indian cities for crowd monitoring and alerting the authorities to disperse the crowd when needed [93]. The organization also offered automated number plate recognition system to assist Hyderabad police in ensuring compliance to administrative order of restricted movement [94].

Some of the states leveraged analytical technology for detection and surveillance. Where Kerala employed AI-enabled thermal scanner for screening; Karnataka applied these tools to keep a check on patients under quarantine; Uttar Pradesh took assistance from Staqu [95], an AI company, to analyze videos for monitoring social distancing protocol compliance; Bihar, through its Norway India Partnership Initiative (NIPI), utilized cough sound analysis tool to identify potential patients; and Tamil Nadu made use of analytical solutions for hospital inventory management, implementation of quarantine orders and call center operations [93]. In Maharashtra, Municipal Corporation of Greater Mumbai (MCGM) partnered with Qure.ai to deploy COVID-19 bus equipped with AI tools and medical testing facilities, for extensive screening based on X-ray analysis, in high-risk areas [96].

Apollo Hospitals Group, collaborated with Behold.ai, a UK-based AI radiology company, to identify suspected COVID-19 patients [97]. The 'instant triage' solution offered by the company differentiated abnormal chest X-ray images from normal in 30 s, thus assisting the medical professionals in prioritizing care delivery. A similar solution available free on the internet was developed by Researchers at the Defence Institute of Advanced Technology (DIAT) in Pune, where upon uploading chest X-ray images, the system promptly confirmed if there is any abnormality because of COVID-19 or other respiratory diseases [98]. Researchers at Indian Institute of Technology (IIT)—Hyderabad, developed a low-cost AI-powered test kit that instead of RT-PCR, utilized genome sequencing technique, to identify conserved region of COVID-19 genome and deliver test results in 20 min [99].

On the other side, the Department of Science and Technology (DST) launched COVID-19 'National Supermodel', a forecasting model based on predictive analytics, for disease surveillance and anticipating the spread of coronavirus [100]. With cooperative efforts of DST, Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) and IISc-Bangalore, the developed model would predict the rate of spread of the infection and its burdening effect on healthcare system, thus facilitating better-informed policy decision-making.

Findings and Discussion

Big Data Analytics and AI Application Initiatives

To address the prodigious impact of COVID-19 on health, economics and everyday life, governments and various organizations in different nations took aid of diverse advanced analytical tools (Fig. 2). Contact tracing applications have been widely used by them to understand the virus transmission and spread. Most of the countries, globally, have also utilized analytical tools for diagnosis and monitoring of COVID-19 infected patients. In some nations, organizations employed big data analytics for clinical research and accelerating drug discovery and development. Cognitive analytics was also put to use by countries for shaping healthcare governance and better decision support. This included applications such as ensuring flow of accurate and up-to-date information; identification of areas with need for medical resources and ensuring adequate distribution; determination of need for quarantine; and formulating resilience strategies for COVID-19. These big data analytics and AI application initiatives by various countries are summarized in Table 1.

Challenges and Perils of Data-Driven Measures to Combat the Pandemic

Besides bringing varied possibilities to deal with the universal crisis, big data and predictive analytics technology also

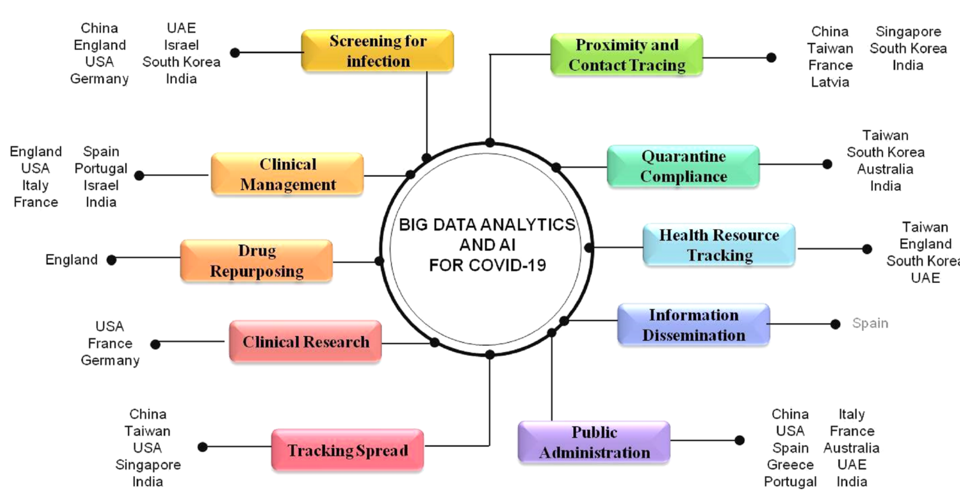

Fig. 2 Big data analytics and AI initiatives used by nations for pandemic preparedness and response

Table 1 Country-wise big data analytics and AI application initiatives for COVID-19 pandemic response

Country	Application area	Application/advantage	Solution	Technique/technology used	Organization and partners	References
Canada	Disease Surveillance	Registered a cluster of unusual pneumonia cases in Wuhan and alerted its clients of possible global spread through international air travel	BlueDot Insights—cloud platform for outbreak risk awareness	Artificial Intelligence	BlueDot	[101, 102]
China	Clinical Research	Secondary structure prediction for COVID-19 RNA sequence to accelerate and optimize vaccine design	Linearfold Algorithm	Artificial Intelligence	Baidu Research Institute; Oregon State University; University of Rochester	[103–105]
	Disease Diagnosis and Clinical Research	AI model for pneumonia CT image analysis	PaddlePaddle (company's open-source deep-learning platform)	Artificial Intelligence	Baidu; LinkingMed	[105]
	Disease Diagnosis and Detection	Prediction of the probability of different pneumonia types including COVID-19	CT Image Analytics technology with deep-learning algorithm	Artificial Intelligence	Alibaba Cloud	[11, 106]–[108]
	Disease Surveillance	Contact tracing of people and alerting for potential infection risk prediction	Close Contact Detector App	Big Data	General Office of the State Council, the National Health Commission; China Electronics Technology Group Corporations (CETC); National Health Commission, the Ministry of Transport, China Railway; Civil Aviation Administration of China	[109, 110]
	Pandemic Prevention and Control	Visualized data for informing public of the risk-prone areas	Self-developed platforms for population flow, pandemic assessment, AI pandemic compliance monitoring	Big Data and Artificial Intelligence	Unicom	[111]
	Pandemic Prevention and Control	Modeling epidemic characteristics of COVID-19	Epidemic Prediction Solution based on machine learning	Artificial Intelligence	Alibaba DAMO Academy	[107, 108, 112]
	Strengthening Medical Infrastructure	Navigation map for COVID-19 designated hospitals	Baidu Map	Big Data	Baidu; National Commission of Health, China	[113]
Taiwan	Pandemic Prevention and Control	Real-time alert on high-risk zones, tracking availability of critical medical supplies, and quarantine compliance measure	Predictive analytics	Big Data Analytics	Taiwanese government	[12–15]

Table 1 (continued)

Country	Application area	Application/advantage	Solution	Technique/technology used	Organization and partners	References
England	Disease Diagnosis and Detection	Real-time tracking of disease progression for identification of COVID-19 symptoms	Predictive model	Artificial Intelligence	ZOE Global Ltd.; UK Government Department of Health and Social Care; NHS Wales; NHS Scotland; King's College London; Massachusetts General Hospital Boston	[114–116]
	Disease Diagnosis and Detection	Identify abnormal chest X-rays in COVID-19 patients	Red Dot AI algorithm	Artificial Intelligence	behold.ai	[117]
	Drug Discovery	Identify highly potential compound for COVID-19 treatment	Prediction Engine	Artificial Intelligence	AI VIVO	[24, 118]
	Drug Discovery	Predict drug combinations that would succeed against coronavirus and improve immune response	Healnet	Artificial Intelligence	Healx	[26]
	Drug Repurposing and Clinical Research	Search for pre-approved drugs with anti-viral properties	Knowledge Graph	Artificial Intelligence	Benevolent AI	[21, 119, 120]
	Drug Repurposing and Clinical Research	Screening pre-approved drugs to search for rapid treatments against COVID-19	Drug Discovery Platform	Artificial Intelligence	Exscientia; Diamond Light Source; Scripps Research	[22, 121]
	Pandemic Prevention and Control	Insights through analysis of consolidated information about COVID-19, for key government decision-makers	Data platform for tracking the spread	Big Data, Cloud Data Processing and Artificial Intelligence	National Health Service, UK; Microsoft; Amazon Web Service; Google; Faculty; Palantir	[122, 123]

Table 1 (continued)

Country	Application area	Application/advantage	Solution	Technique/technology used	Organization and partners	References
United States	Clinical Research	Visualize connections across millions of unique research documents and publications to expedite research	Tellic graph.C19	Artificial Intelligence	Tellic LLC	[124, 125]
	Clinical Research	Real-time tracking of COVID-19 specific T-cell response for Vaccine development	ImmuneCODE based on machine learning	Artificial Intelligence	Adaptive Biotechnologies; Microsoft	[34, 126, 127]
	Clinical Research	Prediction of protein structure to understand SARS-CoV-2 virus structure	AlphaFold	Artificial Intelligence	Google's DeepMind	[42, 128]
	Clinical Research Pandemic Prevention and Control	Identification of effective treatments and policies for managing COVID-19	CORD-19: COVID-19 Open Research Dataset	Artificial Intelligence	Allen Institute for AI (AI2); The White House Office of Science and Technology Policy (OSTP); National Library of Medicine (NLM); Chan Zuckerburg Initiative (CZI); Microsoft Research; Kaggle (Google); Georgetown University's Center for Security and Emerging Technology (CSET)	[129, 130]
	Disease Diagnosis and Detection	Early detection of pneumonia associated with COVID-19 infection	AI algorithm	Artificial Intelligence	UC San Diego Health; Amazon Web Service	[44]
	Disease Monitoring and Management	Remote health care delivery for COVID-19 patients	Remote-monitoring system	Artificial Intelligence	Baptist Health; Mayo Clinic; Current Health Ltd	[131]
	Pandemic Prevention and Control	Visualize and track COVID-19 reported cases	Web-based interactive dashboard	Artificial Intelligence	Center for Systems Science and Engineering (CSSE), John Hopkins University	[28, 132]
	Pandemic Prevention and Control	COVID-19 projections and state-wise data	COVID-19 case tracking dashboard	Artificial Intelligence	Institute for Health Metrics and Evaluation, University of Washington	[133, 134]

Table 1 (continued)

Country	Application area	Application/advantage	Solution	Technique/technology used	Organization and partners	References
European Union Nations	Clinical Research	Mining and analysis of research content from publications, clinical trials, patents etc. for helping researchers accelerate their research activities	Clinical Research Navigator (CRN) tool	Artificial Intelligence	Expert System; French national institute for Health and Medical Research (Inserm)	[135]
	Clinical Research	Provides insights to researchers about cause and progression of diabetes and helps understand impact of SARS-CoV-2 infection on diabetes patients	Neo4j Graph Software	Artificial Intelligence	DZD (Deutsches Zentrum für Diabetesforschung)—German Centre for Diabetes Research; German Society of Infectious Diseases (DGI); German Center for Infection Research (DZIF)	[136–138]
	Disease Diagnosis and Detection	Identify COVID-19 patients with chest X-ray analysis	Lunit INSIGHT CXR	Artificial Intelligence	Lunit	[52]
	Disease Surveillance	Heat map visualizing the spread of coronavirus infections	Vodafone Analytics Platform	Big Data and Artificial Intelligence	Vodafone	[50, 51]
	Pandemic Prevention and Control	Automated information dissemination for pandemic awareness	Hispabot-COVID19	Artificial Intelligence	Sngular; Spanish Government	[57]
	Pandemic Prevention and Control	Map mobility flows to facilitate containment of COVID-19 pandemic	City Analytics—Mobility Map	Big Data	Enel X; HERE Technologies	[139]
Singapore	Pandemic Prevention and Control	Real-time monitoring of compliance with social distancing norms	SafeDistancer	Artificial Intelligence	AI Hub Singapore	[74]
South Korea	Disease Diagnosis and Detection	Quick identification of COVID-19 suspected patients by analyzing chest X-rays	Lunit INSIGHT CXR	Cloud technology and Artificial Intelligence	Lunit	[140, 141]
	Disease Surveillance	Automated epidemiological investigation by contact tracing	Smart Management System	Big Data	Government of South Korea	[142]
	Strengthening Medical Infrastructure	Quick development and distribution of COVID-19 test kits	Artificial intelligence-based big data system	Big data and Artificial Intelligence	Seegene Inc	[76, 77, 143]

Table 1 (continued)

Country	Application area	Application/advantage	Solution	Technique/technology used	Organization and partners	References
Israel	Disease Diagnosis and Detection	Monitoring disease progression and recovery through analysis of patient voice samples	VocalisCheck	Artificial Intelligence	Vocalis Health; Israeli Ministry of Defense	[144]
	Disease Monitoring and Management	Prediction of surge in ICU admission and proactive management of disease severity and resources	CLEW-ICU predictive analytics platform	Artificial Intelligence	Sheba Medical Center; Ichilov Hospital; CLEW	[82]
Australia	Pandemic Prevention and Control	Developing epidemiological models to understand the impact of COVID-19 and assist decision-makers	Data Modeling	Big Data	Australian Government; Quantium Group Pty Ltd	[85, 86, 145]
United Arab Emirates	Disease Diagnosis and Detection	Detection of risk and exposure to COVID-19	Aya, virtual personal assistant	Artificial Intelligence	Nabta Health	[146]
	Disease Diagnosis and Detection	Rapid detection of SARS-CoV-2 infection	LamPORE assay	Cloud technology and Artificial Intelligence	Group 42; Oxford Nanopore Technologies	[147]
	Pandemic Prevention and Control	Predict the infection rate and plan response against COVID-19	Impact Assessment Tool (IAT)	Artificial Intelligence	Abu Dhabi Health Services Company (Seha); Draper and Dash	[148]
	Strengthening Medical Infrastructure	Tracking and management of health supplies during COVID-19	asset.ai	Artificial Intelligence	Dubai Health Authority; Nybl	[87, 149]

Table 1 (continued)

Country	Application area	Application/advantage	Solution	Technique/technology used	Organization and partners	References
India	Disease Diagnosis and Detection	Rapid self-use test for COVID-19 detection	CoviSelf	Artificial Intelligence	Mylab Discovery Solutions	[150]
	Disease Monitoring and Management	Rapid detection of COVID-19 by analyzing chest X-ray and instant triage	Red Dot AI algorithm	Artificial Intelligence	Apollo Radiology International, Apollo Hospitals Group; Behold.ai	[97, 151]
	Disease Surveillance	Monitoring crowd and providing real-time alerts to authorities for ensuring compliance to social distancing and lockdown rules	Smart Technology Solution	Artificial Intelligence	Larsen & Toubro's Smart World & Communication; Municipal Authorities across 20 cities	[152, 153]
	Pandemic Prevention and Control	Real-time alerts on digital proximity with a COVID-19 infected patient	Aarogya Setu App	Big Data Analytics	National Informatics Centre (NIC), Ministry of Electronics and Information Technology, Government of India	[154–156]
	Pandemic Prevention and Control	Assistance to authorities in contact tracing, diagnosis, patient triage and remote monitoring of COVID-19 patients	qXR and qScout	Artificial Intelligence	Qure.ai	[157–159]

brings certain challenges in its application. Some of these challenges are discussed below:

Lack of Historical Data

Due to the novelty of SARS-CoV-2 virus, there has been limited evidence about its transmission, incubation period, associated pathophysiology and duration of infection [1, 160]. There is also a paucity of data on the extent of protection, duration of immunity and chances of re-infection after contracting COVID-19 [161]. Moreover, the genetic evolution of virus and development of different mutant variants over time makes predicting COVID-19 incidence and outcomes, further difficult because of lack of availability of historical data [162, 163].

Interoperability and Access to Real-Time Data

Since pre-COVID, one of the major barriers in effective use of data in healthcare has been the lack of cross-system interoperability and this has further amplified during the pandemic. The siloed nature of ubiquitous technologies in healthcare has restricted real-time access to COVID-19 treatment and clinical trials data [164–166]. Capturing, documentation, distribution and sharing of healthcare data across different hospitals and government bodies, therefore, would also require a manual compilation in spreadsheets for better monitoring and management of the crisis [167]. In the current state of pandemic, spending more time and resources on recording and exchanging data, would delay the response and cost hundreds of lives.

Data Sharing

Given the urgency to accelerate effective response to COVID-19, there was a need for governments, public health agencies and private organizations to promote data sharing initiatives [168]. Most of the nations encountered issues with inadequate data exchange. The primary challenge these organizations faced was consolidation of the data that differed in its characteristic and extent [163]. Other problems that hampered effective data exchange include legal issues, limited financial support and international communication [169]. On the other hand, some of the organizations and research communities created integrated platform models and open-source structures to enable frictionless data sharing resulting in extensive amount of research and therapeutic data [169].

Data Quality

When it comes to the healthcare data, quality of data is of utmost importance. Growing amount of data added with the demand for prompt response to the pandemic, makes it difficult to guarantee high quality data that can be relied on to for safe medical care [170, 171]. Incomplete and poor-quality data aggregated from different sources in varied formats, results in development of inaccurate predictive models and hinders its use for effective policy decision-making [163, 170]. For instance, detection of COVID-19 through chest X-ray or CT image analysis is also not completely dependable, because in some infected patients, the results yield normal chest image; while in other cases, the abnormalities are connected with separate pathological conditions [172].

Privacy and Security of Data

With the increasing amount of COVID-19 data being continuously created, some newer challenges arise [164]. One such challenge was encountered by the countries that relied on the geographical location data to track the spread of virus. Implementation of contact tracing applications to understand and predict the spread of COVID-19 has raised the concern about exposing the sensitive personal health information and jeopardizing privacy [173, 174]. Moreover, exchange and aggregation of medical data from different sources pose threat to security of healthcare data [175]. There have been instances where cybercriminals were identified phishing the organizations involved in COVID-19 vaccine research, development and distribution [176, 177]. In this time of pandemic, when there is a need for rapid response, regulatory authorities are required to define policies that allow reaping the rewards of technology at the same time ensuring the privacy and security of data.

Limitations of the Study

The field of big data and advanced analytics is rapidly evolving since the time world is facing the coronavirus pandemic. First, owing to the recentness of these applications in dealing with the global emergency, this study derives information majorly from news articles. Such information does not enable differentiating the proposals from those solutions which have been put into practice, making it a limitation in understanding the real use of data analytics. Second, this review provides an overview of country-specific measures taken by those nations which are either gravely affected or those which have addressed the crisis at its onset and avoided the larger damage. Given the focus on such countries, the study might have missed instances where other governments and organizations would have exploited big data technologies in their COVID-19 combat.

Conclusion

Emergence of SARS-CoV-2, no prior knowledge about its structure and behavior, and its higher rate of transmission have all led to the governments and organizations turning towards technology for prompt management of the crisis. Several measures are being utilized by governments and other organizations for application of big data and advanced analytics: be it for prediction of outbreak, detection and diagnosis of infected patients, anticipation of critical cases; or decision support in what treatment would work well for which kind of patients; what measures would curb the spread; and planning the future action. Big data and AI have also augmented the research activities by simulating the viral morphology and its evolution; and providing quicker identification of potential drug candidates for treatment of COVID-19 patients. Furthermore, these technologies have proven useful for hospitals in predicting the demand for healthcare resources and planning the allocation in advance. In these unprecedented times, big data and AI empower countries and the governing authorities with solutions that can reduce the impact of virus and be instrumental in effective planning to address immediate public health challenges.

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