

The applicability of blockchain technology in healthcare contexts to contain COVID-19 challenges

Mohammad Raihanul Hasan

School of Management, Huazhong University of Science and Technology, Wuhan, China and

Department of Business Studies, State University of Bangladesh, Dhaka, Bangladesh

Shiming Deng

Huazhong University of Science and Technology–Main Campus, Wuhan, China

Neegar Sultana

Department of Geography and Environment, Jagannath University, Dhaka, Bangladesh, and

Muhammed Zakir Hossain

Department of Business Studies, State University of Bangladesh, Dhaka, Bangladesh

Abstract

Purpose – Blockchain technology, a key feature of the fourth industrial revolution, is receiving widespread attention and exploration around the world. Taking the coronavirus pandemic as an example, the purpose of this study to examine the application of blockchain technology from the perspective of epidemic prevention and control.

Design/methodology/approach – Exploring multiple case studies in the Chinese context at various stages of deployment, this study documents a framework about how some of the major challenges associated with COVID-19 can be alleviated by leveraging blockchain technology.

Findings – The case studies and framework presented herein show that utilization of blockchain acts as an enabler to facilitate the containment of several COVID-19 challenges. These challenges include the following: complications associated with medical data sharing; breaches of patients' data privacy; absence of real-time monitoring tools; counterfeit medical products and non-credible suppliers; fallacious insurance claims; overly long insurance claim processes; misappropriations of funds; and misinformation, rumors and fake news.

Originality/value – Blockchain is ushering in a new era of innovation that will lay the foundation for a new paradigm in health care. As there are currently insufficient studies pertaining to real-life case studies of blockchain and COVID-19 interaction, this study adds to the literature on the role of blockchain technology in epidemic control and prevention.

Keywords Blockchain, China, COVID-19, Health care

Paper type Research paper

1. Introduction

On the morning of January 9, 2020, the expert group of the Chinese Academy of Engineering (CAE) revealed that a new form of coronavirus, known as Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), had been identified through laboratory testing at 21:00 on January 7, 2020 (Xinhua, 2020b). Since the evolutionary neighbors and outer groups of COVID-19 are found in various live animal species, including bats, snake, marmots and poultry, researchers posited that the natural host of COVID-19 may also be a live animal species

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(Lu *et al.*, 2020). Similar to the SARS coronavirus outbreak in 2002, COVID-19 is likely to have an unknown etiology during the transmission from animal species to humans (Sohrabi *et al.*, 2020). Wuhan, the capital city of Hubei province in China, is regarded as the epicenter of the outbreak. The Wuhan Novel Coronavirus has shown a strong human-to-human transmission ability because of its unprecedented natural epidemiology and transmission (Leung *et al.*, 2020).

The COVID-19 epidemic has been deemed a worldwide public health emergency, evolving at fast speed and on an unprecedented scale. The pandemic has not only battered people's lives, health and safety but also caused very substantive damages and changes to businesses, economies and society as a whole. As of February 16, 2021, over 108,246,992 confirmed cases and 2,386,717 confirmed deaths had been attributed to COVID 19; these span more than 180 countries or regions, and several countries have experienced local epidemics (WHO, 2021). The history of mankind is a history of fighting against diseases, such as variola virus in the distance, and poliovirus more recently. Embracing the latest advanced technology – artificial intelligence, big data, cloud computing, 5G and blockchain, which will usher in a new era of innovation – humans can certainly defeat this epidemic (Chamola *et al.*, 2020).

Blockchain technology as a revolutionary innovation has attracted significant mainstream interest worldwide due to its distributed architecture, irreversibility of records, transparency with pseudonymity, peer-to-peer transmission, robust computational logic, trust mechanism and particularly its ability to organize and govern transactions without any central authority (Nakamoto, 2008; Diffie, 1988; Schollmeier, 2001). Blockchain technology has been changing the landscape of many industries since its emergence. Its great success in various industries has also promoted demand for this technology in the medical industry (McGhin *et al.*, 2019). Blockchain technology lays a foundation for solving issues associated with data privacy, security and integrity in health care; thus, it is redesigning the DNA of the global medical system (Zhang *et al.*, 2018; Tanwar *et al.*, 2020).

In the field of health care, blockchain technology is actively influencing companies and stakeholders to optimize business processes, improve the effectiveness of medical treatment and patient data management, enhance compliance and reduce costs (Hylock and Zeng, 2019). Consequently, as an emerging technology, blockchain has been acknowledged as an enabler to aid the containment of various COVID-19 challenges. Challenges relevant to COVID-19 include complications associated with medical data sharing and breaches of patients' data privacy (Lenert and McSwain, 2020; Zeng *et al.*, 2020), absence of real-time monitoring tools (Leung *et al.*, 2020; Bi *et al.*, 2020), counterfeit medical products and non-credible suppliers (Newton *et al.*, 2020; Ranney *et al.*, 2020; Gereffi, 2020), fallacious insurance claims and overly long claim processes (Wang *et al.*, 2020; Xu *et al.*, 2020), misappropriations of funds (Bin-Nashwan *et al.*, 2020; Wu and Zhu, 2020), and misinformation, rumors, and fake news (Islam *et al.*, 2020; Barua *et al.*, 2020).

An assessment of the current literature unveils the potential for applying new technology such as artificial intelligence, cloud computing, distributed ledger technology, big data analytics, the fifth generation mobile network and the Internet of things in the COVID-19 context (Chamola *et al.*, 2020). Indeed, some investigations have analyzed how blockchain technology is being used to help combat the COVID-19 crisis. For example, Ting *et al.* (2020) investigated the role of new-aged technologies, i.e. big data analytics, blockchain and artificial intelligence, to counter the COVID-19 pandemic. Mashamba-Thompson and Crayton (2020) examined artificial intelligence and blockchain-coupled electronic surveillance to help curb infectious diseases like COVID-19. Chang and Park (2020) explored different blockchain-based use cases, spanning disease reporting systems, monetary donations, spreading of false information and digital documentation to optimize responses to COVID-19. Recently, Dinh *et al.* (2020) used a survey method to explore the role of blockchain technology and artificial intelligence in containing the COVID-19 epidemic. Evidence shows that digital technology like blockchain is employed from the perspective of epidemic prevention and control but there are currently insufficient studies pertaining to real-life case studies in this domain.

Having considered the foregoing, the underlying aim of this study is to highlight blockchain's role against COVID-19. To address this, a framework is formulated exploring eight case studies in the Chinese context, where blockchain technology is leveraged to alleviate some of the major challenges associated with the COVID-19 epidemic.

The remainder of this paper is organized as follows. [Section 2](#) covers blockchain fundamentals, blockchain in health care, and some major challenges associated with COVID-19. Methodological details concerning data and case study selection are provided in [Section 3](#) followed by brief descriptions of the selected cases in [Section 4](#). In [Section 5](#), the role of blockchain in containing COVID-19 challenges is explored. Finally, [Section 6](#), [Section 7](#) and section 8 consecutively focus on challenges, future directions and conclusions.

2. Background

2.1 Blockchain fundamentals

A variety of underlying ideas behind the workings of blockchain technologies have been put forward by numerous scholars, demonstrating that blockchains are essentially a distributed storage network ([Diffie, 1988](#); [Schollmeier, 2001](#); [Nakamoto, 2008](#); [Drescher, 2017](#); [Iansiti and Lakhani, 2017](#)). The characteristics of this technology are delineated in what follows.

2.1.1 Distributed database. The blockchain is decentrally configured. The database is therefore distributed and the participants are able to share copies of all data with no single entity dominating in terms of information control and access. All blockchain participants can access the entire database and its full history.

2.1.2 Immutability and irreversibility of data. One of the most significant aspects of blockchain architecture is cryptography. Although a transaction is authenticated and registered, cryptographic technology is necessary to prevent manipulation of a block for digital signatures and data integrity. Thus, it is not possible to modify the records since they are linked to the recording of each preceding transaction.

2.1.3 No centralized authority. There are two characteristics of a typical business transaction: a public transaction ledger and private messages between the parties with identities, transaction security keys, as well as location. Combining these two characteristics and decentralizing the system (accessible to anyone validating) would eliminate the necessity of an external third party.

2.1.4 Transparency with innominate identity. Any transaction and its value are available to everyone with network connectivity, which ensures that each node or user recognizes a particular 30-plus character address in alphanumeric form. Users may opt to remain anonymous or provide someone with evidence of their existence after transfers between the blockchain addresses have taken place.

2.1.5 Consensus-based and trustworthy. A transaction is verified by the participants autonomously. The participants must decide on the origins of the truth to validate the transaction because of the decentralized storage and the existence of more than one copy of the database. The framework for consensus prevents errors or deceitful acts from negatively affecting the integrity of the database.

2.1.6 Computational logic. Blockchain transactions are digitally connected to computer logic, which permits users to set algorithms and rules, contributing to triggering transactions between nodes automatically. Blockchain is governed by participants who agreed in advance on the types of transactions stored in the chain as a smart contract.

2.1.7 Peer-to-peer networking. Instead of utilizing a central hub, interaction takes place between partners without anyone or anything intervening. Each node preserves information and transmits this to all other nodes.

2.2 Blockchain in health care

Blockchain is spurring the emergence of a new paradigm in health care through its diffusion and use across health information exchange, medical supply chain, health insurance and donation management contexts.

The health information exchange (HIE) enabled by blockchain not only could unleash the practical value of interoperability (sharing and transferring data among different sources) but also could deliver a groundbreaking new digital platform for facilitating and promoting the integration of healthcare information systems across a wide range of stakeholders (Hylock and Zeng, 2019; Tanwar *et al.*, 2020). For example, there are many specialists in Integrated Practice Units that provide different services and treatments, such as nutritionists and obstetricians. It becomes difficult to access all information when needed. As blockchain technology promotes interoperability by sharing data across multiple sources, it could, for example, identify patients with similar diagnoses and symptoms, enabling doctors to determine treatment plans more efficiently and effectively.

A serious concern in the pharmaceutical industry is the proliferation of counterfeit medicines. In developing countries, between 10 and 30% of drug supplies are deemed as counterfeit, according to the Health Research Funding Organization (EHR, 2018). Blockchain embedded traceability and visibility can be harnessed to track medical supplies with transparency. The whole medical supply chain, comprising medical supplies producers, agents, retailers, dealers, distributors and regulatory authorities can easily and safely take part in information transmission processes (Chang *et al.*, 2019; Perboli *et al.*, 2018; Feng, 2017). When transactions among supply chain participants take place, new data will be added to the corresponding block which are time stamped and immutable. A hash value is appended to each block containing drug details; thus, it is straightforward to trace the movement of drugs along the supply chain among various entities.

In the entire life cycle of a health insurance policy, there are usually multiple levels of intermediaries: hospitals, doctors, pharmacists and insurance companies. Information is shared among these stakeholders in an endless loop. This process is full of inefficiencies and blockchain can help to solve this problem. Blockchain allows insurance companies real-time supervision and information acquisition of the medical system is guaranteed (Cohn *et al.*, 2017). The relevant health information required by insurers can be obtained directly in the distributed architecture of blockchain; thereby, reducing the physical examination procedures for the insured. Due to the immutability of the blockchain, there are no options to enter false information, which effectively avoids the possibility of a fraudulent insurance claim (Cohn *et al.*, 2017; Saleh *et al.*, 2019). Through the application of blockchain technology, it is easy and straightforward for actual and potential clients to avail of information concerning policies, liabilities and claims; following the initiation of a claims process, insurance companies can also immediately receive the relevant information to expedite the process.

Blockchain technology will change the information transmission mode of traditional charitable donations. Due to lack of transparency, accountability and restricted ways of accepting donations, charitable organizations often encounter obstacles on their way to success. If blockchain technology is used in the information management system of these organizations, by virtue of its distributed characteristics, it can store data on each user, making it difficult for the information to be maliciously modified (Saleh *et al.*, 2019; Sirisha *et al.*, 2019). When the user's charity enters the blockchain system, it will be automatically recorded, which is open, transparent, queryable and non-tamperable. The time-stamp feature allows anyone to know the whereabouts and purpose of each donation at any time. It eliminates human operations, thereby improving the efficiency, accuracy and fairness of charitable donations.

2.3 Some major challenges associated with COVID-19

Considering that healthcare providers' platforms pertinent to telehealth, laboratory testing, follow-up of health status and hospitalization can be disjointed, a health information exchange (HIE) is required to ensure the quality of patients' treatment while maintaining health information flows across provider platforms in a specific region without hindrance (Esmailzadeh, 2020). COVID-19 introduces huge obstacles to the healthcare system, which calls for the emergence of a modern and innovative alternative with synchronized HIE architecture (Lenert and McSwain, 2020). Knowing the purpose of information disclosures concerning patients is crucial for effective HIE network implementation. Data privacy policies set guidelines describing the manner how healthcare institutions receive, maintain, use and disseminate patients' information and at the same time preserve confidentiality. To reap the efficiencies of rapid communication of patient-level healthcare data in response to the pandemic, anonymization of datasets is necessary while concurrently ensuring the privacy of individual health information (Lenert and McSwain, 2020).

Early-stage rigorous surveillance and tracking of epidemic data, if accurate contact tracing is available and origins of infection can be precisely inferred, are especially important for determining and predicting the evolution, transmission classification, pathogenicity, future host adaptation and natural history of the disease; thus, influencing mortality rates (Bi *et al.*, 2020; Sohrabi *et al.*, 2020). Leung *et al.* (2020) suggested that the real-time prevalence of COVID-19 should be monitored with massive-scale testing, to quickly identify and isolate infected cases and to trace and quarantine their contacts. In addition, they stressed the risk and occurrence of second wave transmission and the need to provide policymakers with accurate and timely data and information so that they can act accordingly to minimize deleterious impacts.

There is a drastic shortage of medical materials, including personal protective equipment (PPE), respirators, hand sanitizers, testing kits, drugs and vaccines necessary to guard against, diagnose, treat COVID-19 infections (Gereffi, 2020; Ranney *et al.*, 2020). Cost-cutting induces substandard drugs and falsified suppliers thrive on shortages in emergency situations. Through illegal websites and social media, many falsehoods proliferate. There needs to be action domestically and internationally to ensure that those people infected with COVID-19 can depend on high-quality and reliable medical products. In addition, in order to minimize substandard and falsified medical products, effective regulatory supervision, standard pre-qualification, robust authentication measures and curbing informal markets and illegal websites will be required, together with trusted public engagement campaigns (Newton *et al.*, 2020).

Owing to the constraint of traditional insurance distribution channels and a subduing of household insurance demand, COVID-19 has had a significant negative impact on the insurance industry in the short term. This negative impact could be alleviated in two ways: social security, which helps individuals to manage financially through various income support measures, and digital insurance, which helps to resolve limitations on physical insurance marketing against the COVID-19 scenario (Wang *et al.*, 2020). The outlook of long-term treatment, especially for elderly people, has changed because of COVID-19 as fatalities associated with the virus are overwhelmingly concentrated in the older community. The high post-cure treatment costs associated with COVID-19 and the large number of casualties would definitely drive people toward a different view of life insurance policies, and purchasing intentions will inevitably change (Xu *et al.*, 2020).

In an exceedingly difficult period in the wake of the COVID-19 pandemic, the lives of people around the world are being shaken, causing misery and risk to many, financial challenges, and drastic shifts in daily lives. Thus, it is important that people come out together as symbols of solidarity and compassion for those afflicted by this disease in their respective communities (Bin-Nashwan *et al.*, 2020). Several countries have reacted to the

threat by initiating fundraising efforts to battle the effects of COVID-19 by assisting both frontline staff and vulnerable communities. In addition, it is important that sponsors and supporters play their role in fundraising for COVID-19 relief and contributions to those impacted in a transparent way (Wu and Zhu, 2020). Finally, states, humanitarian organizations and donors should function collectively to rebound while preserving donation processes with proper authentication.

The proliferation of inaccurate and exaggerated misinformation online pertaining to COVID-19 brings forth severe adverse consequences for public health in terms of anxiety, stress and mental morbidity (Rajkumar, 2020; Xiao and Torok, 2020). In addition, misinformation leads to some people taking medication without consulting physicians, leading to death-and-life risks for people amid the pandemic (Barua *et al.*, 2020). In order to ensure a sound public health atmosphere, a transparent communication mechanism which reveals the true picture of the prevailing situation is necessary in this unprecedented period (Farooq *et al.*, 2020; Zarocostas, 2020). Being able to count on reliable online media has become increasingly important throughout the current pandemic, where the situation's complexity, rapid growth and unpredictability contribute to misinformation as well as poorly organized and interpreted facts (Islam *et al.*, 2020). Solving these challenges is vital.

3. Methodology

This study documents a framework concerning how some of the major challenges associated with COVID-19 can be alleviated leveraging blockchain technology. For this purpose, eight case studies are selected, which is thus above the recommended threshold of seven cases (Eisenhardt and Graebner, 2007). To instrument from multiple case studies, the approaches put forward by Whyte (1984) and Van *et al.* (1982) – widely used in qualitative social science research – were followed. Kshetri (2018) also constructed a framework from multiple case studies in the context of blockchain's role in attaining supply chain objectives. We believe that his framework can be adapted in the COVID-19 context. Eisenhardt and Graebner (2007) suggested that data, theory and framework should be “pattern matched” in case study research. Following this recommendation, arguments justifying how the cases are matched with theory are put forward to demonstrate how the framework, which entails a set of conceptions specifying core facets and stating general claims, can be used to discern the impact of blockchain in alleviating the challenges caused by COVID-19 (See Table 1).

3.1 Data

This research principally relies on archival databases, which are a widely accepted data source for case studies (Eisenhardt and Graebner, 2007). We endeavored to assess data consistency and internal coherence (HIQA, 2011) by equating identical data items with the same time span and the same data items for different periods. A successful mapping of the real-world phenomenon has also been contemplated pertaining to each case (Price and Shanks, 2005). In addition, we corroborated information from multiple sources in order to ensure the trustworthiness and unbiasedness of the data (Wang and Strong, 1996). Instead of simply collecting information directly from the selected organizations' websites, we relied more on published information from credible third parties. In addition, we ensured that the information for the selected cases is contemporary and not out of date (Eppler, 2006).

3.2 Case selection criteria

Case selection is based on two methods: the extreme case method, which is a unidimensional concept representing the rareness of the study of interest, and the diverse case method, which seeks to infer numerous casual directions for reaching the optimal variance in the

COVID-19 challenges	Health care contexts	Blockchain roles	Mechanisms deployed	Cases
Complications associated with medical data sharing; breaches of patients' data privacy	Health information exchange	Integrating the healthcare information management system	Through interoperability (sharing and transferring data among different sources), encryption of data, and decentralized ledgers, the health system pulls together information from multiple sources and stakeholders	Donghua Tencent
Absence of real-time monitoring tools	Epidemic tracking and monitoring	Depicting a true picture of the epidemic situation, e.g. suspected and confirmed cases, number of recoveries and fatalities	Deploying data on-chain operations corresponding to unique hashes recorded on the certificate storage platform, which ensures accurate disease knowledge pertaining to COVID-19, epidemic tracking and monitoring	Lianfei Tencent
Counterfeit medical products and non-credible suppliers	Medical supply chain	Mitigating the risk of counterfeit and sub-optimal products	Medical supply processes are guaranteed by means of visibility, traceability, and credibility tracking; thus, epidemic prevention materials can be easily audited and tracked	Alibaba Baidu VeChain
Fallacious insurance claims; overly long insurance claim processes	Health insurance	Streamlining insurance claims reviews	Secure storage of digitally signed documents certifies the insured's identification and the insurer validates claims based on immutable digital proof	Alibaba Tencent VeChain
Misappropriations of funds	Donation management	Ascertaining the transparency and accountability of charitable donations	By establishing provenance, auditability, and time-stamping of donations, robust management of COVID-19-related donation disbursement can be ensured	Xiong'an ICBC
Misinformation, rumors and fake news	Authentic information	Dispelling misinformation, rumors and fake news	Non-tampered and non-repudiated information improves the trustworthiness and credibility of COVID-related news circulated in the media	Lianfei

Table 1.
Framework:
Blockchain roles in
containing COVID-19
challenges

corresponding parameters (Seawright and Gerring, 2008). For example, the cases selected in this study are considered extreme as they are premier to demonstrating the applicability of blockchain technology in health care to contain COVID-19 challenges. A few years ago, it was unknown that blockchain would or could rewrite healthcare architecture. On the other hand, the selected cases are diverse due to their multi-faceted dimensions. For example, two types of firms are considered in our cases: specialist blockchain firms (e.g. VeChain and XuperChain), which deploy their blockchain expertise in healthcare contexts to counter contagious epidemics like COVID-19, and diversified business firms (e.g. Alibaba and Xiong'an), which intermingle blockchain with their other business expertise (e.g. insurance and supply chains).

4. Case descriptions

In recent years, Chinese healthcare firms have sought to enhance the efficacy of the public health system through blockchain-based applications while safeguarding patients' health information. Here we highlight some of those firms which are trying to contain the country's COVID-19 crisis by leveraging blockchain technology.

4.1 Case 1: Alibaba

Alibaba, China's e-commerce giant, launched Alibaba Health Information Technology Ltd in 2017 to seamlessly and cost-efficiently conduct health-oriented operations leveraging blockchain technology (Suberg, 2017). Ant Financial Services, an affiliated company of the Alibaba Group, operates a blockchain-based collective claim-sharing platform known as Xiang Hu Bao with over 104 million users. Considering the current COVID-19 crisis, they have handled over 25,000 insurance claims, contributing to eliminating paperwork and providing hospitals that are treating people infected with the coronavirus with back-and-forth document delivery. "Claim applicants can submit their supporting documents as evidence while investigation firms can get immediate access to them on the blockchain.. all parties involved can see the entire process," according to a report in the South China Morning Post (Lee, 2020). In collaboration with the Health Commission and ICT Department in Zhejiang, they also track the demand and supply for relevant medical materials, such as PPE, ventilators, test kits and sanitizers. During the epidemic period, around 15.2 million face masks have been produced every day, compared to an expected demand of 50–60 million masks as estimated by the National Development and Reform Commission, China. This drastic supply-demand gap contributed to a steep increase in counterfeit products. As a result, the Chinese authorities arrested 1,560 people and seized 31 million masks as of March 2020 (Cointelegraph, 2020). There is thus a clear need for blockchain solutions for the medical supply chain.

4.2 Case 2: Tencent

Tencent is the pioneer in China vis-à-vis innovations in medical billing systems. In 2019, the Internet giant launched blockchain-based medical and insurance solutions in conjunction with Waterdrop, a crowdfunded health insurance firm with over 80 million members, to securely access auditable medical bills, relieving medical institutions and insurance firms from the burden of fallacious claims through clone invoices (Suberg, 2019). Recently this Tencent-backed mutual aid platform rolled out COVID-19 coverage, allowing members to enroll in health plans for all required medicines and medical services. The payout for these unprecedented medical expenses could reach RMB 60,000 (around USD 8,500) (Jao, 2020). In another effort, WeChat – the social media and mobile payment app owned by Tencent, with over 1 billion active users – allied with VastChain, a Chinese IT firm that supports trusted data infrastructure based on blockchain technology. VastChain developed a WeChat-based

mobile app dubbed Access Pass, which was designed to generate Q.R. codes, enabling citizens to enter restricted communities. The company reports that all personal information stored in blockchain-based cloud repositories is encrypted, i.e. original data are restricted from the perspective of public retrieval (Xinhua, 2020a). Furthermore, WeBank, a Tencent-backed online lender, has joined with Cross Border – a financial blockchain service platform launched by the foreign exchange regulator of China – to help small- and medium-sized enterprises struggling to survive the effects of COVID-19 disruptions (Cheng, 2020). This platform improves the efficiency and convenience of finance, overcoming the obstacles of traditional systems.

4.3 Case 3: Lianfei Technology

Lianfei Technology was established in 2010 with the spirit of being responsible to society, customers and enterprises, creating and providing value to society. The first Chinese blockchain application dubbed WingChain, Lianfei's epidemic monitoring platform based on blockchain, was launched on 5 February 2020 to track COVID-19 cases in different provinces and cities around the country in real time. The data in this platform are integrated with national health and health committees, provincial health and health committees and authoritative media reports to count the number of confirmed cases, suspected cases, number of recoveries and deaths from COVID-19 cases at home and abroad (Xiaoxia 2020). WingChain has two major functional sections: "Dispelling Rumors" and "Disease Knowledge". The "Dispelling Rumors" section includes rumors related to the epidemic and alleviates people's concerns; the "Disease Knowledge" section provides officially verified pathological information. All data and information are stored in the WingChain blockchain platform through data on-chain operations, corresponding to unique transaction hashes, which users can view at any time on the chain. At the same time, the traceable data constructed through the blockchain also provides closed-loop evidence chains for follow-up rumor content, dissemination and accountability. The epidemic database composed of epidemic data and disease knowledge also provides a necessary reference for to reduce difficulties associated with epidemic prevention and control (China.com, 2020).

4.4 Case 4: Baidu

An open-source blockchain-based medical platform named XuperChain was unveiled in September 2019 by Baidu, China's largest search engine firm. It is supported by hyperledger fabric and strives to preserve patients' health information, including diagnoses, medications and prescriptions (Ledgerinsights, 2019). In the past, there were informational barriers between various health stakeholders which made it difficult to integrate and analyze relevant data. Baidu's blockchain-based medical network improves the efficiency of coordinated responses among various health stakeholders during the current epidemic period. XuperChain records information about people infected with COVID-19 to solve problems associated with patients' data security whilst concomitantly offering real-time functionality and rapid sharing (Jingli, 2020). PPE shortages have led to many unscrupulous merchants capitalizing on this by making substandard, non-protective variants, causing many people to be deceived. In the domain of product traceability, Baidu's XuperChain combines artificial intelligence and the Internet of things to launch mature solutions: the PPE manufacturer's production process is chained from the source and a smart chip is implanted in the imported product to ensure that the information in each operation process can be checked so that users are assured of quality (Zhejiang, 2020).

4.5 Case 5: Xiong'an group

China Xiong'an Group Co. Ltd. is a wholly state-owned enterprise which was established on July 18, 2017. Since the end of 2017, this company's major foci – investment management, infrastructure construction, urban development, and public service management – have all depended on a blockchain system, the Xiong'an Blockchain Platform (Chinaxiong'an, 2017). In the fight against the COVID-19 epidemic, Xiong'an Group and Hyperchain, a Chinese start-up firm, set up a donation tracking platform that works on a blockchain platform called Shanzong. It aimed to improve the transparency and credibility of donation information and optimize the entire process from issuing donation needs to receiving donations. As of March 2020, this platform has attracted USD 2 million in donations (Cointelegraph, 2020). There have been a number of scandals in China over the management and delivery of charitable donations and aid that have undermined the trust of citizens in some state-supported charitable organizations. Recently, several hospitals documented a shortage of PPE for frontline medical workers to protect themselves while they are treating patients and this caused uproar on social media. A statement was released by Hubei's Red Cross Society on February 1, 2020, stating that they were "deeply distressed, blamed themselves and felt guilty about problems with the distribution of donated materials" (Zhang, 2020). Through the tracing and provenance embedded in the blockchain system, donors can identify the recipients who require funds as a matter of priority and then follow up on donations until they obtain proof of appropriate utilization.

4.6 Case 6: ICBC bank

Industrial and Commercial Bank of China (ICBC) is a dominant global player in terms of assets and market value. Since 2016 it has been continuously researching and developing the application of blockchain technology in the financial field, and actively exploring the deep integration of blockchain with A.I., big data, 5G, Internet of Things and other emerging technologies. ICBC believes that blockchain technology can help drive tremendous changes in domains such as logistics, fund management, trade finance, payment management, virtual assets and payment settlement. It has successively developed various platforms in this respect (Liu, 2020). In support of epidemic mitigation and recovery work, the bank has developed an enterprise-level blockchain system and launched facilities for monitoring and tracking the flow of funds and their whereabouts. These functions have been embedded in the Guangxi Branch of the Chinese Red Cross and the Zhuhai Charity Federation to streamline relief efforts. In the future, other major charitable organizations will introduce similar functions. In early 2020, ICBC released a white paper on the application of blockchain technology in the financial sector. This publication carefully studied common barriers and opportunities to the deployment of blockchain in the financial industry, with a focus on international comparisons to contextualize the situation in China (Tran, 2020).

4.7 Case 7: VeChain

Shanghai VeChain Information Technology Co., Ltd. was founded in 2017. Being the first blockchain application connecting to the real business world, VeChain has been cooperating with multiple leading global commodity groups and logistics companies in various industries covering luxury goods, food and beverages, supply chains, transportation, agriculture and health care. Peoples Insurance Company of China (PICC) has been partnered with VeChain since September 2018. They have collaborated to establish digital automation and blockchain embedded secured storage of immutable digital records whilst minimizing processing time and avoiding fallacious claims. In this unprecedented period where people across the country are facing severe financial problems, PICC Health hopes to provide relief for families of critically ill patients by giving special care guarantees, i.e. compensation up to 100,000 Yuan

(Weiyang, 2020). VeChain's vaccine traceability solution is important to prevent public health crises. The product traceability platform of VeChain works with Bayer-China throughout the medical supply chain and eventually to the consumer to trace unsafe drugs and vaccines during the COVID-19 epidemic (Cream, 2020). VeChain's blockchain application utilizes a digital medical passport, which is an encrypted NFC Chip. Both patients and medical institutions can use the application through VeChain's Cloud repositories. When patients check in at the emergency room, a "DigitalHealthPassport" can identify the patient. The card also helps to organize inspection records, track patient demand and share health-related data with hospitals.

4.8 Case 8: Donghua Software

Donghua Software Co., Ltd., encompassing a wide range of businesses, including network security applications and information system integration applications, was established in 2009 to ensure diverse IT solutions with high-quality and reliable services for its clients. Donghua Software has developed more than 20 key blockchain embedded systems to support banking, insurance, manufacturing intelligence, smart cities, education, health and social welfare. It developed a hyperledger fabric blockchain engine based health solution dubbed hBlock, which aims to establish a mutual trust mechanism for data exchange and sharing applications among medical institutions, patients and regulators pursuant of forming a set of practical technical solutions for information interconnection; thereby promoting the development and utilization of medical data resources and ensuring the orderly and free flow of data according to prevailing laws. The blockchain smart contract mechanism is used to solidify transaction rules and profit distribution rules in advance to eliminate doubts among institutions (Donghua, 2018). In early 2020, a team from Beijing travelled to Wuhan to participate in the construction of an information management system for Vulcan Hill hospital, one of the newly built specialized centers in Wuhan to treat coronavirus patients. Similarly, Huoshen Mountain and Raytheon Mountain hospitals, both specialized facilities in Wuhan city focusing on the treatment of coronavirus patients, were also equipped with Donghua's information management system. Donghua's health file and health data-sharing platform based on blockchain technology solves problems of data comparison between patients with the same symptoms and allows horizontal information sharing of patients' treatment between hospitals and stakeholders (MIITRMS, 2020).

5. Findings

Seamless communication across the entire healthcare system – a transparent way to track patients' illnesses along with treatment history, equipment requirements, medical supply chains and so on – can improve the efficiency of the healthcare ecosystem. The illustrative examples in Table 1 demonstrate how blockchain contains some of the major challenges associated with the COVID-19 epidemic, spanning complications associated with medical data sharing and breaches of patients' data privacy (Lenert and McSwain, 2020; Zeng *et al.*, 2020), the absence of real-time monitoring tools (Leung *et al.*, 2020; Bi *et al.*, 2020), counterfeit medical products and non-credible suppliers (Newton *et al.*, 2020; Ranney *et al.*, 2020; Gereffi, 2020), fallacious insurance claims and overly long insurance claim processes (Wang *et al.*, 2020; Xu *et al.*, 2020), misappropriations of funds (Wu and Zhu, 2020; Bin-Nashwan *et al.*, 2020), and misinformation, rumors and fake news (Islam *et al.*, 2020; Barua *et al.*, 2020). The following discussion addresses each of the challenges in the light of the blockchain-based healthcare cases.

5.1 Health information exchange

In the prevention and control of epidemics, it is difficult to verify, save and synchronize medical data, and it is also challenging to share data among medical institutions.

The Donghua case study indicates that there is a lack of comparison between patients with the same symptoms, and horizontal information sharing has not been achieved. Interoperability embedded in blockchain information sharing systems can overcome this problem (MITRMS, 2020). The case of Baidu suggests that there are many stakeholders throughout the entire medical industry chain, which made it difficult to integrate and analyze the data. Via electronic prescriptions, doctors' diagnostic records, prescriptions, medication information and payment information will be "stamped" and recorded on Baidu's XuperChain, ultimately improving network efficiency and medical experience (Ledgerinsights, 2019). The features of blockchain technology, such as tamper resistance, distributed architecture and encryption of data, directly address fundamental problems and propose new solutions for data sharing and efficiency improvements in the medical industry. The introduction of blockchain technology in the medical industry can effectively protect sensitive information about patients; thus, it can improve the safety and reliability of medical data, even if the central data source is damaged, this would not affect other nodes.

5.2 Epidemic tracking and monitoring

During the coronavirus outbreak, blockchain became a key technology that helped in terms of tracking and monitoring. The Lianfei case makes it clear that the blockchain epidemic monitoring platform uses non-tamperable and traceable architecture, which enhances the credibility of the data, ensuring a closed-loop for the responsibility and accountability of information (China.com 2020). The Tencent example indicates that social security and control systems can be successfully developed harnessing blockchain technology. Local authorities in Wuhan and nearby provinces are using blockchain to ensure that data are archived and protected from any unauthorized access, whilst still keeping it available for the whole healthcare system (Xinhua, 2020a). As emerging information technology, blockchain has its own characteristics: data on-chain operations corresponding to unique hashes recorded on certificate storage. This reporting platform can further strengthen information reporting, becoming a strong point in building a prevention and control system which is accurate, efficient and intelligent.

5.3 Medical supply chains

Since its emergence, blockchain has been regarded as a key technical tool to improve supply chains, especially during the COVID-19 pandemic. In this unprecedented period, the shortage of epidemic prevention materials required by healthcare professionals poses a huge challenge to the healthcare system: counterfeit products diffused apace. The example of Alibaba suggests that its platform solves challenges by identifying credible suppliers, effectively recruiting them and evaluating their inventory availability in real time. After sorting this information, buyers such as hospitals and pharmacies can start acquiring items from suppliers on a large scale (Cointelegraph, 2020). Baidu's case also indicates that deployment of Xuperchain traceability for medical resources can effectively prevent inferior products from flowing to the market (Zhejiang, 2020). The case of Vechain makes it clear that their solution enables traceable, transparent and auditable product transactions among its suppliers, distributors, partners and end-users, creating and maintaining trust between all stakeholders through digital innovations (Cream, 2020). Blockchain can mitigate barriers and bottlenecks in the global medical supply chain and enhance trust between all parties.

5.4 Health insurance

Chinese insurance companies have been relying on blockchain technology to quickly track claims during the coronavirus outbreak. The example of Alibaba makes it clear that the

claims process is settled faster through Xiang Hu Bao, as decentralized, trustworthy and immutable features of blockchain enable applicants to submit their supporting documents as evidence while investigating insurance companies can access them immediately on the blockchain (Lee, 2020). Mutual aid platforms' coverage in response to COVID-19 ensures welfare as blockchain ensures transparency with pseudoanonymity. For example, the Tencent–Waterdrop mutual aid platform supports the sharing of treatment costs that are generally more affordable than traditional health insurance products (Jao, 2020). Insurance fraud causes the insurance industry to lose \$40 billion annually, resulting in higher premiums and inadequate consumer coverage. By transferring from paper contracts to a decentralized and immutable ledger, blockchain can eliminate fraud in the industry (CBINSIGHTS, 2020).

5.5 Donation management

Blockchain donation platforms facilitated by the technical characteristics of the blockchain network, such as provenance, auditability and time-stamping, render the data source transparent and traceable and enhance trust. Specifically, this application allows users to track the distribution and donation of relief supplies (Wu and Zhu, 2020). For instance, Xiong'an and ICBC aim to increase the transparency and efficiency of internal processes of charitable organizations (Liu, 2020; Cointelegraph, 2020). Their platform appears to be a shared network on which organizations can register, store and manage personal information. Donors and recipients can apply in their own names, and medical institutions can apply for authorization certificates through identity certification agencies (CA) to obtain signatures. The CA certificates contain information about the company or individual, including name, contact details, public key and the validity period of the certificate. Such certificates help verify identities and link them to encryption key pairs with digital certificates.

5.6 Authentic information

Another way blockchain contributes to the fight against COVID-19 is to contain misinformation and rumors. Since the nature and scale of this crisis is unprecedented, people have paid close attention to information about the outbreak. Rumors and misinformation can lead to confusion and harm. Blockchain technology achieves non-tampering, non-repudiation and information credibility objectives through a decentralized consensus mechanism (Dinh *et al.*, 2020). If a certificate storage platform is built based on blockchain technology, and then news is saved on it, the veracity and validity of that news is duly ensured. This certificate storage platform can significantly reduce the cost of tracing rumors and improve the efficiency of news management. For example, Lianfei's WingChain is a certificate storage platform comprising information reporting, information security and responsibility traceability. This makes the collection of epidemic-related information more efficient, more convenient and safe for transmission and reporting (China.com 2020).

5.7 Challenges of blockchain in the healthcare context

Challenges remain for the medical industry, for example, the transformation from paper to digital is still in progress, data interoperability is still nascent and there is scope for regulatory changes to optimize development (Zhang *et al.*, 2018). Despite the major enabling power of blockchain, there remain technical and organizational obstacles and bottlenecks that inhibit its implementation in health care in the context of COVID-19. First, the blockchain is used as a decentralized storage system, which facilitates faster access to medical data; but these data need to be checked for authenticity before they are on the chain (Azaria *et al.*, 2016). This has implications for institutional information authentication costs.

Second, decentralized consensus embedded in blockchain technology creates difficulties vis-à-vis adequate supervision of peer-to-peer transactions, especially in emergency situations. As a result, it can be challenging to locate the designated authority to settle conflicts and the resolution of disputes has often proved to be complex (Hasan and Salah, 2018). Third, legal and regulatory changes lag behind blockchain deployment (Dinh *et al.*, 2020). In the absence of sufficient regulatory assistance, the process of aligning the algorithms used in smart contract signing with the current legal framework has not been easy or smooth in the area of health care.

Fourth, the massive amount of medical data with decentralized storage and computing is practically cumbersome, especially where outbreaks of fast spreading infectious diseases such as COVID-19 are concerned. In order to optimize algorithms, participants can use alliance chains, or even private chains, or increase efficiency by reducing nodes, but this is back to the trade-off between decentralization and efficiency. Blockchain needs to improve efficiency to meet timeliness requirements in medical scenarios (Roehrs *et al.*, 2017). Fifth, blockchain deployment is resisted in some quarters of the medical industry itself. Currently, a centralized medical system exists, which is quite different from the blockchain that emphasizes the spirit of decentralization. For example, in the case of pharmaceutical pricing, blockchain platforms are not widely accepted because transparency is antithetical to the vested interests of multiple parties (McGhin *et al.*, 2019).

6. Future directions

Although the application of blockchain in medical contexts is not without obstacles and hindrances, early participants have seen the major opportunities of this technology. The issues encountered today will eventually be overcome, and blockchain technology will lay the cornerstone and foundation for future medical innovations.

Distributed networks appear to be significantly slower than centralized structures in terms of transfers per second. A wide network of blockchains with several nodes can take more time to transfer and synchronize data compared to a centralized system. This is particularly relevant for massive datasets where information on millions of COVID-19 cases is eventually collected and monitored, and high resolution picture files such as computer graphical imagery or MRI scans are processed. New consensus mechanisms are required to accelerate this process. These new models are called “proof-of-stake” systems. The evolution of the consensus mechanism has significantly increased the speed of the blockchain, which is important for health care (Shae and Tsai, 2017).

Standardization and interconnection are other issues that need to be addressed. Standardization can help companies collaborate in application development and verify proof of concept (Øines *et al.*, 2017). As more and more healthcare stakeholders are committed to achieving cross-blockchain data transmission, standardization and interconnection has been accomplished to some extent, which improves their ability to overcome operational issues, e.g. Donghua software handles horizontal information sharing for COVID-19 cases.

Blockchain deployment is complex and costly. It is necessary to realize an easy-to-use and plug-and-play user interface, and at the same time, speed up the development of blockchain applications. New cloud computing products have entered the market at an accelerated rate, which has the potential to reduce barriers to developing and operating blockchain networks with minimum effort and cost (Shrestha and Vassileva, 2016). Cloud providers are publishing blockchain templates designed to automatically set up basic blockchain infrastructure, reducing application development times from months to days.

7. Conclusions

The case studies and framework presented herein show that utilization of blockchain acts as an enabler to facilitate the containment of several COVID-19 challenges. This study highlights how healthcare institutions can leverage blockchain technology to respond to major public health emergencies. Specifically, the challenges of epidemics – comprising complications associated with medical data sharing; breaches of patients' data privacy; absence of real-time monitoring tools; counterfeit medical products and non-credible suppliers; fallacious insurance claims; overly long insurance claim processes; misappropriations of funds; misinformation, rumors, and fake news – are addressed through technical architecture, incentive mechanisms, consensus frameworks, immutability, traceability, auditability, interoperability and other characteristics of blockchain technology. Blockchain embedded applications that promote robust, transparent and affordable decision-making contribute, therefore, to quicker and better responses in such emergencies.

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About the authors

Mohammad Raihanul Hasan is currently a Doctoral Research Student in the School of Management, majoring in Management Science and Engineering, Huazhong University of Science and Technology, People's Republic of China. He has been working as an assistant professor in the Department of Business Studies at State University of Bangladesh (SUB) since 2008. He completed postgraduate and undergraduate from the Department of Marketing, University of Dhaka, Bangladesh, in 2001 and 2000, respectively. During his teaching period, he published articles in different journal including Review of International Business and Strategy.

Dr. Shiming Deng is currently working as a Professor in School of Management, Huazhong University of Science and Technology, China. He is a Ph.D. from the University of California, Berkeley, USA. His research has been published in leading International Journals, including Management Science, Operations Research, M&SOM, POM, Naval Research Logistics, European Journal of Operational Research, Omega, International Journal of Production Economics, etc. He also has extensive industrial experience in leading domestic and international corporations such as Oracle, FedEx, Chengdu

Construction Group, KLA-Tencor, and ILOG and received research grants from the National Science Foundation of China and Foundation of Ministry of Education of China. Shiming Deng is the corresponding author and can be contacted at: deng.shiming@qq.com

Dr. Neegar Sultana is currently an associate professor in the Department of Geography and Environment, Jagannath University, Bangladesh. She received a Ph.D. *major* in Land Resource Management from the College of Public Administration, Huazhong University of Science and Technology, Wuhan, China. Prior to that, the author studied Geography and Environment at the University of Dhaka, Bangladesh, and during seven years of her working time, contributes eight articles in national and international journals with one conference proceedings about disaster management, environmental pollution, causal effects on early marriage, regional disparity, rural development and transport disadvantages.

Muhammed Zakir Hossain is currently working as an assistant professor in the Department of Business Studies, State University of Bangladesh, Dhaka, Bangladesh. He completed MSc in Business and Economics from Karlstad Business School at Karlstad University in 2012 and MBA in Accounting and Information System from the University of Dhaka in 2003. During his teaching period, his eight research article appeared in the Imperial Journal of Interdisciplinary Research (IJIR), Journal of Service Science and Management and Journal of Human Resource and Sustainability Studies. His research interest area in corporate governance and corporate social responsibility practices through audits of internal control systems.

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