The crisis of trust in COVID-19 pandemic: can blockchain technology help?

Anjum Khurshid

Submitted to: JMIR Medical Informatics
on: May 19, 2020

Table of Contents

The crisis of trust in COVID-19 pandemic: can blockchain technology help?

Anjum Khurshid[1] MD, PhD

[1]The University of Texas at Austin Austin US

Corresponding Author:
Anjum Khurshid MD, PhD
The University of Texas at Austin
1701 Trinity Street
Austin
US

Abstract

Background: The widespread death and disruption caused by COVID-19 pandemic has unraveled the failure of existing institutions to protect the health and well-being of humanity. Lack of accurate and timely data along with pervasive misinformation is causing even more devastation.

Objective: This paper describes how blockchain with its distributed trust networks may provide solutions to these informatics problems.

Methods: Blockchain is being applied in innovative ways that are relevant to the challenges of the COVID-19 crisis. We give examples of blockchain applications for supply chain, financial transactions, public health, credentialing, contact tracing, identity management, and data analysis.

Results: This review of existing and potential applications of blockchain technology in healthcare identifies a need to launch a national policy agenda to apply blockchain for addressing the failures of existing systems to fight COVID-19. It also suggests a not centralized governance structure in the form of blockchain consortia to avoid political and bureaucratic considerations adversely impacting future response. A partnership of academia, researchers, business, and industry is needed to expedite the adoption of blockchain in healthcare.

Conclusions: In summary, blockchain relies on a distributed, robust, secure, privacy-preserving, and immutable record keeping framework that can transform the nature of trust, value sharing, and transactions for the better. COVID-19 pandemic has provided a unique opportunity to use this remarkable technology for serving humanity.

(JMIR Preprints 19/05/2020:20477)
DOI: https://doi.org/10.2196/preprints.20477

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?
Please make my preprint PDF available to anyone at any time (recommended).
Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
Only make the preprint title and abstract visible.
✓ **No, I do not wish to publish my submitted manuscript as a preprint.**
2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?
✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**
Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v
Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http

Original Manuscript

Title: **The crisis of trust in COVID-19 pandemic: can blockchain technology help?**

Author: Anjum Khurshid, MD PhD[1]

Affiliation: [1]Assistant Professor and Director of Data Integration, Department of Population Health, Dell Medical School, The University of Texas at Austin.

Corresponding Author: Anjum Khurshid, 1701 Trinity Street, Austin, Texas 78712.

Email: anjum.khurshid@austin.utexas.edu

Abstract

Introduction: The widespread death and disruption caused by COVID-19 pandemic has revealed the failure of existing institutions to protect the health and well-being of humanity. Lack of accurate and timely data along with pervasive misinformation is causing even more harm and growing tension between data privacy and public health concerns.

Objective: This paper describes how blockchain, with its distributed trust networks and cryptography-based security, may provide solutions to some of these data-related trust problems.

Method: Blockchain is being applied in innovative ways that are relevant to the current COVID-19 crisis. We describe examples of the challenges in existing technologies to track medical supplies and infected patients and how blockchain technology applications may help in these situations.

Results: This review of existing and potential applications of blockchain technology for medical care show how its distributed governance structure and privacy preserving features may create a "trustless" system that helps resolve the tension between privacy and public health needs in the fight against COVID-19.

Conclusions:

Blockchain relies on a distributed, robust, secure, privacy-preserving, and immutable record framework that can transform the nature of trust, value sharing, and transactions for the better. A nationally coordinated effort to explore blockchain for addressing the failures of existing systems and a partnership of academia, researchers, business, and industry is suggested to expedite the adoption of blockchain in healthcare.

Keywords : Blockchain, Privacy, Trust, Contact tracing, COVID, coronavirus

Blockchain and COVID-19 Response

"In many ways, it is hard for modern people living in First World countries to conceive of a pandemic sweeping around the world and killing millions of people, and it is even harder to believe that something as common as influenza could cause such widespread illness and death." — Charles River Editors. *The 1918 Spanish Flu Pandemic: The History and Legacy of the World's Deadliest Influenza Outbreak* (2014)

1. Introduction

1.1. Facts about COVID-19 in US and the world

By the end of July 2020, COVID-19 had infected about 19 million people in the world with over 700,000 deaths. The United States, as the richest country in the world with a health expenditure of $3.5 trillion a year, topped the number of infected (~5 million) as well as the number of deaths (>150,000) [1]. Lack of reliable data, inability of healthcare and public health systems to perform active surveillance, inadequate management of needed medical equipment, conflicting information from multiple sources, and poor engagement technologies with patients have caused the pandemic to demonstrate quite clearly the failure of existing institutions to protect human health and to avoid widespread suffering.

1.2. COVID-19 is a crisis of trust

In the absence of reliable data and accurate information, the suffering from COVID-19 crisis was exacerbated by misinformation that ranged from news about imminent doom to conspiracy theories. The COVID crisis is an information crisis [2]. The crisis has been rightly described as an "infodemic", a term coined many years ago by Eysenbach [3]. However, the importance of this term is manifested in this crisis, more than ever before, due to the enormous influence of social media and

its role as a source of information for the public about the pandemic.[4] Several months into the biggest public health disaster in a century, with all our technology and information networks, there is still much confusion about actual prevalence, number of deaths, expected treatments, and best strategies to control the pandemic globally [5,6]. Due to this failure to provide timely, accurate, and reliable information about the infection, the pandemic has worsened the crisis of trust in government institutions and public health agencies [7].

Interestingly, it was a similar failure of governmental response that led to the 2008 financial crisis and precipitated the low trust in government and centralized institutions ever since. Banks, governments, and financial institutions had failed the common man and left many exposed and dejected during the financial crisis [8]. This motivated Satoshi Nakamoto, still an unidentified person or group, to write a paper that proposed a new system of establishing trust in the financial markets without intermediaries, like the government or banks. It relied on a distributed ledger technology of peer to peer networks which was called blockchain [9]. In 2009, bitcoin was launched as a decentralized cryptocurrency that bypassed intermediaries like banks, governments, and large financial institutions and allowed people to transact directly in a secure trust framework [10]. The COVID-19 pandemic promises to cause even greater hurt and misery to the public than the 2008 crisis, because it is not only an economic disaster but also a health calamity which has already caused the loss of precious lives all over the world. The role of intermediary organizations has not been satisfactory in this case either [11].

1.3. Issues of trust with existing institutions

The proponents of the decentralized and distributed system of blockchain technology point to the disadvantages of centralized institutions because these “intermediaries of trust” are slow to respond to changes in environment, add cost and time to transactions, and adversely affect

productivity [12]. Centralized institutions also store data centrally and not only restrict access to such data thus preventing coordination and efficient sharing of information, but also are a single point of failure for privacy and security of the information[13]. In 2017, more than 143 million customers' personal data were exposed through a single breach [14]. According to one source, in the last 10 years more than 1.4 billion records have been exposed due to government database breaches in the world [15].

Intermediary institutions are supposed to provide the much needed trust and reliable services to the society [16], however, the COVID-19 crisis exposed the limitations of these institutions in healthcare [17]. In this time of crisis, whether it was availability of timely data for projections of the cases [18], identification of high risk populations [19], tracing contacts of persons with COVID-19 [20], supply of protective equipment or inventories of life-saving drugs [21], both public and private institutions failed to overcome these problems that traditional information systems also have mostly failed to solve for routine healthcare delivery[22]. In fact, some would argue that the loss of life due to COVID-19 could have been reduced with better access to reliable data [23].

1.4. Blockchain and the "trustless" system

Blockchain has been described as a foundational technology [24] that can dramatically change the paradigm in which social and economic transactions take place. If one reviews the key characteristics that form the fundamental aspects of blockchain technology, it will not be hard to understand why such a technology can be invaluable in helping to address some of the issues of mistrust described above. Blockchain technology is based on this "trustless" system, where transactions can take place among people who do not have any prior relationship, yet can validate the objectivity and principles of the medium on which transactions occur. This allows for transparency of contracts, immutability of data, and accountability of transactions among strangers [25]. Public blockchain networks allow every individual to share their information with complete privacy while

keeping full control of their information. They also maintain an audit record of each transaction, make it easily available when needed, validate information sources to avoid misinformation, allow tracking of assets as part of the architecture of the network, and provide global connectedness without barriers to flow of information [26,27]. The rules of consensus and validation are transparent, mathematically proven, unbiased, distributed, and objective in nature – characteristics that cannot be ascribed to government or to most key institutions that will handle private information related to the pandemic [28]. The growth of the cryptocurrency market is a proof of the trustless system being a workable solution at a global stage, something the COVID pandemic has highlighted the need for [29].

2. Blockchain in COVID-19 pandemic

As a foundational technology that promises to provide new solutions to old problems, blockchain technology is increasingly being applied in innovative ways that are quite relevant to the challenges created by the COVID-19 pandemic. The failure of existing systems to provide reliable and effective solutions to problems created by this global crisis highlight even more the potential of blockchain applications [30]. The crisis has created a unique opportunity to test and develop blockchain-based solutions. While it is hard for healthcare organizations to implement blockchain technology and leapfrog into the more open, transparent, patient-focused, and robust systems of transactions and information management without more evidence of its effectiveness, it is worth testing this technology to develop robust systems that current information systems have struggled with. Fortunately, there are already some use cases of blockchain technology that may significantly contribute to the fight against the pandemic and infodemic more effectively in the short run and build capacity to respond to similar health emergencies in the future. We discuss two key examples that relate to medical care directly and where blockchain technology is being applied today but needs to be adopted even more widely if proven effective.

2.1. Supply chain and blockchain

COVID-19 crisis saw a major failure of supply chain for not only household items like toilet rolls and hand washing soaps [31], but more importantly personal protective equipment and life-saving ventilators in hospitals and clinics [32]. Blockchain technology's immutable and distributed ledgers with auditable records are ideal for tracking each asset in a supply chain as every actor in the supply chain shares the same information [34]. It is therefore easy to calculate the inventory, the exact stage where assets are in the chain, and create instant reconciliation without any additional audit or negotiation among the various suppliers and end users. A joint Walmart-IBM project has demonstrated how a task that took months in tracking sources of contamination in green vegetables could be tracked within seconds by using blockchain [20]. Some of the learnings of that system are now being applied at the Federal Drug Agency for counterfeit pharmaceuticals [35]. IBM has also designed *Rapid Supplier Connect* to help with medical supply chain during COVID-19 and offered it to health systems and government agencies to help find vendors for medical supplies and personal protective equipment [36].

Even during this global crisis there have been reports of counterfeit medications and poor quality equipment being sent to organizations and people who are in desperate need of these items [37]. This leads to trust issues in the supply chain [38]. In fact, an OECD report cautions about increased global trade in fake pharmaceuticals during the COVID-19 pandemic [39]. Blockchain provides not only an efficient way to manage supply chain but also a means to validate quality products from counterfeit ones [40]. This is particularly true when items have to move across international borders where the level of information about sources of production and the rules under which the quality checks occur vary greatly. Validation of the quality through peer-to-peer networks like blockchain can improve the trust and decrease unnecessary litigation and disputes [41,42]. An example of such a system is IBM's *Trust Your Supplier* where blockchain enables trusted sources of

supplier information and digital identity management to reduce the risk of counterfeits while allowing for relatively easy onboarding of suppliers and communications between buyers and sellers or suppliers and distributors [43]. As shown in Figure 1, it is a permissioned network which limits who has access to the information on the blockchain and it allows for transparency among nodes on the supply chain. Cryptographic security ensures confidentiality of data on the chain and the immutability of records guarantees that no one party can make changes unilaterally without a consensus.

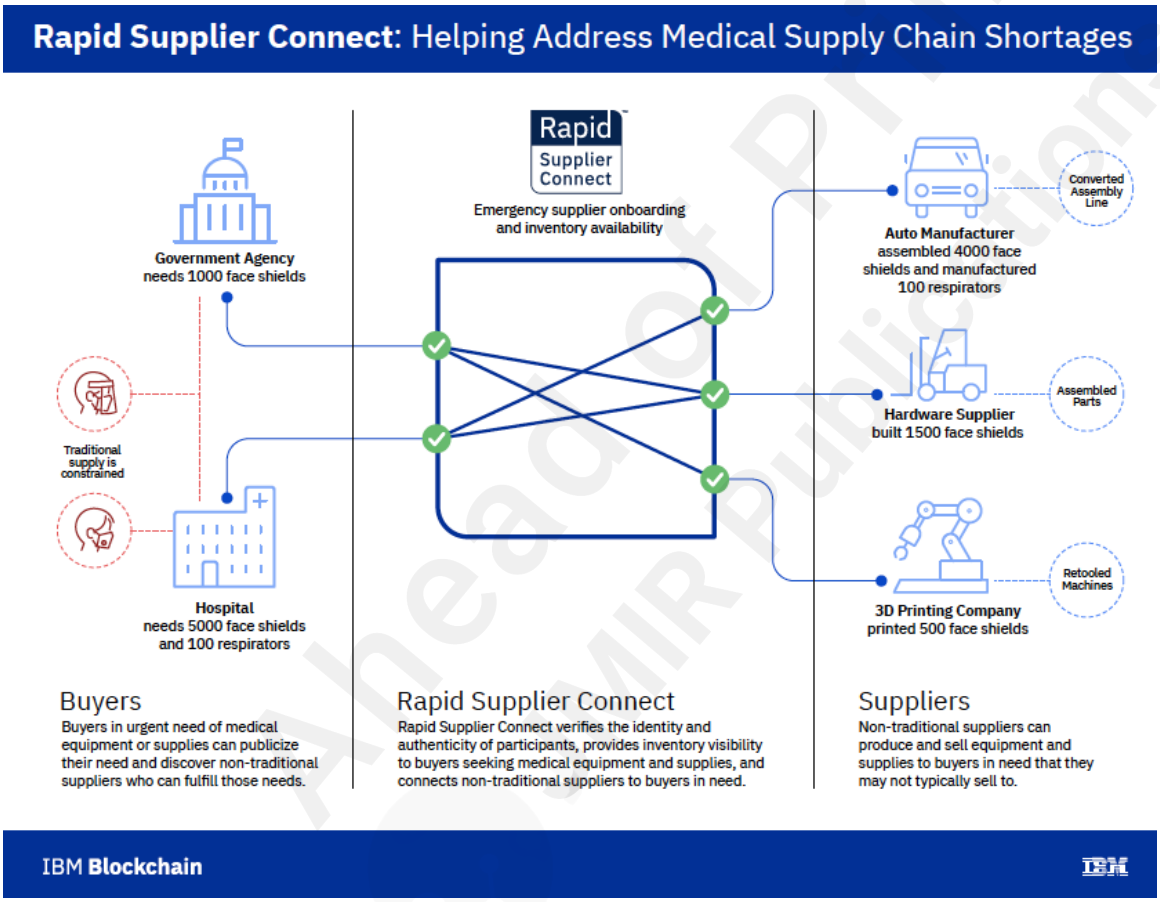


Figure 1: Rapid Supplier Connect (https://www.trustyoursupplier.com/)

Another example of the use of blockchain to address the issue of counterfeit drugs is Gcoin (Figure 2) [44].

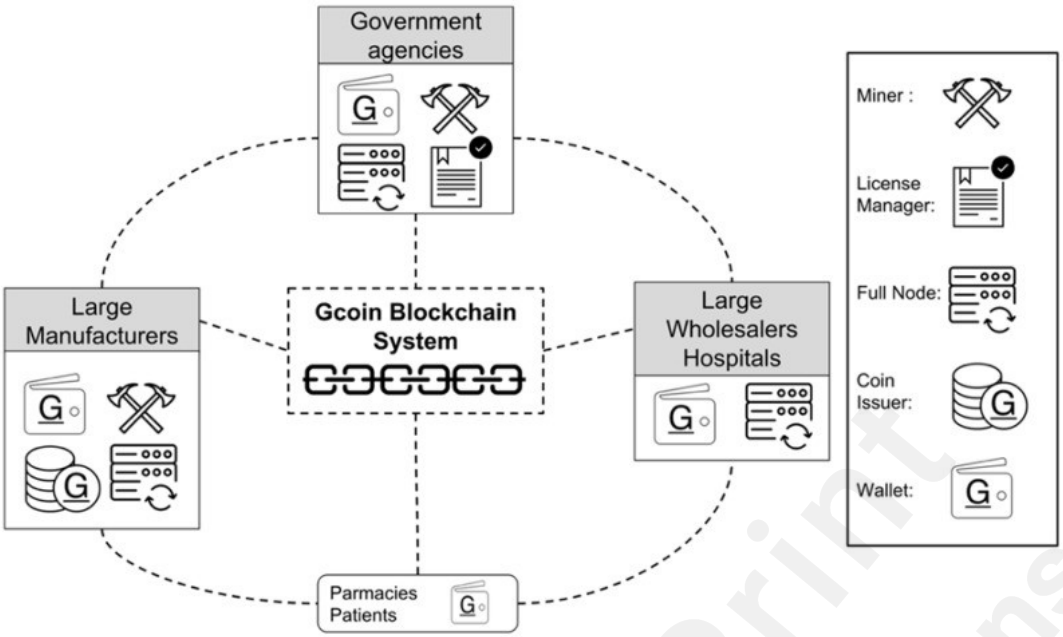


Figure 2: Gcoin. [44]

By having the suppliers and buyers on a shared ledger, i.e. blockchain, and all transactions being recorded on the chain as immutable records, it becomes much easier to quickly see the origination of the products and also to search for the total supplies of an item without creating a centralized database. Not only is it difficult to keep centralized databases up to date in such crises but it may also present an easy target for hacks and breaches to occur. The trustless system of blockchain can significantly help with reducing supply chain failures, particularly as the pandemic enters the stage where vaccines and life-saving drugs will need to move across international borders to save lives.

2.2. Contact Tracing and blockchain

For a highly infectious disease like COVID-19, the ability to trace individuals who have been exposed to another infected person promptly is a likely public health strategy that can limit the continuing spread of the infection. As the COVID-19 infected cases keep rising and surges are happening across the world, there is increased realization that social distancing and lockdowns

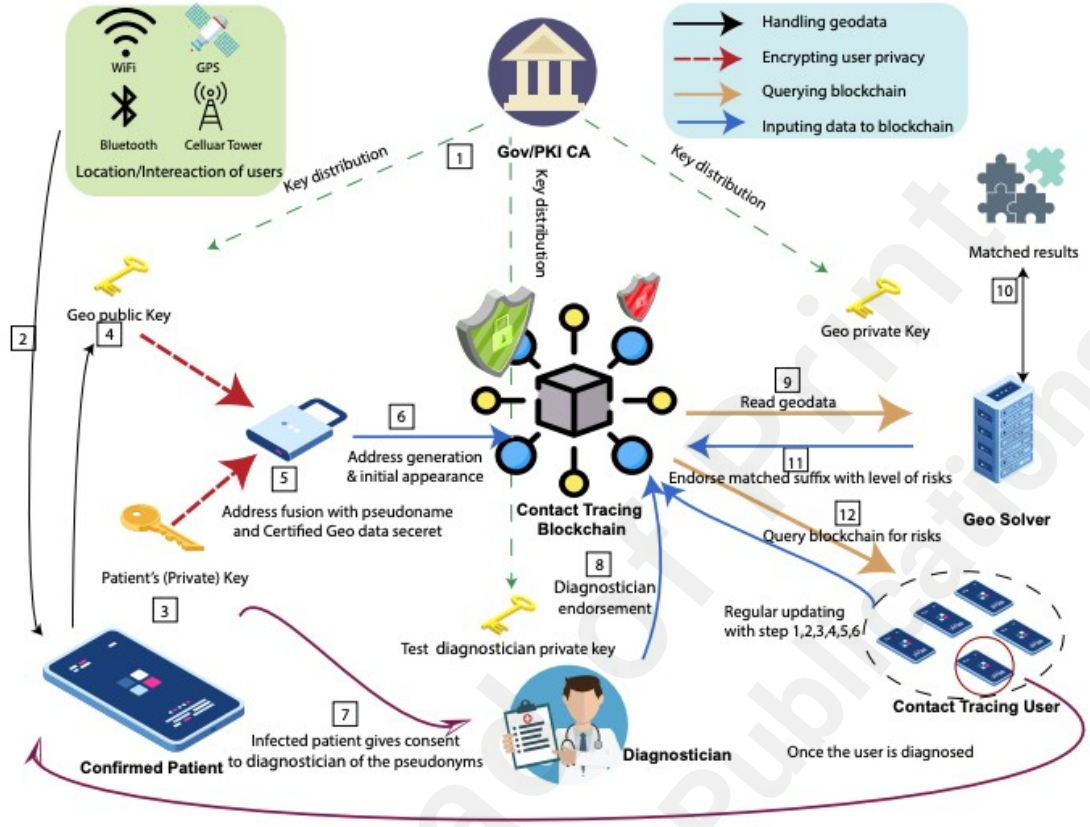
cannot be indefinitely extended. In many cases, even compliance of lockdowns has been hard to enforce, and if enforced, needed coercion and significant resource allocation [45]. Scenes of police, army, and other government agencies roaming streets to enforce closure of businesses and lockdowns were all over the internet with many examples of use of violence and threats against citizens [46]. With no other remedy to control the spread of the infection, widespread social distancing and lockdowns are blunt policy levers that are being used by most governments. However, the devastating consequences of such policy on economic activity, social interactions, mental health, and health seeking behaviors are already visible with the realization that this cannot be a sustainable strategy. Managing infections at an individual level and taking precautions in the close circles that are at risk of being infected will be needed to allow some level of normalcy to return. Contact tracing is an important tool in this regard [47].

Many states in the United States and countries across the world have quickly developed and adopted contact tracing applications since the beginning of the pandemic with mixed success [48]. As healthcare delivery systems were overwhelmed with testing and treatment needs, symptom-tracking apps were used to help individuals assess their risk for COVID-19 and their need to get tested. Most of these applications require notifications or data sharing with public health or healthcare organizations to coordinate testing and treatment. With limited supplies of testing, only those with symptoms are asked to be tested. If tested positive, the next steps are the tedious public health investigations that identify who else is at risk of being infected from this source. Traditionally, public health agencies have used contact tracers who would call or mail this information to potential contacts and ask them to be tested. This works when the numbers are not of the magnitude seen in COVID-19 pandemic. Also, these strategies were developed in the pre-mobile phone era. With mobile applications being relatively easy to develop and access to phones quite ubiquitous, contact tracing apps for COVID-19 are an obvious public health solution.

Countries like Norway, South Korea, China, Singapore, Germany, Qatar, and others

developed, encouraged, or enforced the use of contact tracing apps as a public health strategy. Different technologies have been used to provide contact tracing, which use various features built into mobile phone platforms such as global positioning systems, bluetooth, wi-fi, QR codes, or other such features. Very soon, however, individuals and advocacy groups raised concerns of data privacy, confidentiality and security [49]. Simultaneously, reports of hacks, bugs, and misuse of such data started pouring in. Some of these apps have been banned or discontinued. This lack of trust is not only reserved for governments but was also the reason that the Google-Apple contact tracing features were frowned upon in England and other countries [50]. However, the need for contact tracing and controlling infections by identifying people at risk has not reduced. This is a situation where the trustless system of blockchain technology can provide potential answers on how to balance public health needs with privacy concerns [51].

Blockchain allows information to be collected without identifying the individuals using a system of public and private keys [52]. For example, an application, BeepTrace, uses blockchain to



provide encrypted and anonymized personal identification while allowing regulators and healthcare providers to contact those at risk of the infection due to contact with an infected person. The application uses two chains and a public key generated by the government or a public entity for generating the location data but also generates a diagnostician key to verify test results. The infected person gives consent to the diagnosing entity, which participates in the blockchain to verify results, but the government cannot identify the individual. Notifications can be sent to the individual using a separate chain (see Figure 3) [53].

Figure 3: BeepTrace's privacy preserving contact tracing scheme [53]

Previously, the same privacy and data sharing has also been proposed in other blockchain-

based applications[54]. The key is that by anonymizing and cryptography, a blockchain-based contact tracing app ensures individual privacy while allowing public health departments to contact those who might have been exposed to the virus through an infected person. These features of security, privacy, trust, transparency and efficiency are built into the architecture of blockchain and have been hard to replicate or develop reliably in other applications.

Countries like Taiwan and South Korea have shown that a robust system of contact tracing can control the spread of the infection while allowing normal life to continue for healthy people at low risk for the infection [55]. However, concerns about privacy and security may limit the implementation of such strategies in different parts of the world, particularly in the United States, which has the highest number of cases and deaths [56]. Blockchain technologies that allow individuals to share their personal information in a secure manner with public health agencies without revealing their identity or contributing all that information into some centralized database with the government or corporations, may help identify those who come into contact with a COVID-positive patient. This can be done through public health agencies or through peer-to-peer notifications where only the positive status needs to be shared without sharing more medical or personal data [57] Being able to track COVID-19 positive individuals and to be able to check a seropositive status for the infection may be used as key tools to allow opening up the economy in a more responsible manner without causing a surge in cases. As we develop vaccinations or develop herd immunity for the infection, blockchain technology may also be used to issue health certifications that can be verified easily by employers and public health agencies to validate the status of an individual [58].

There are many other aspects related to the long-term fight against COVID-19 pandemic where blockchain technology may be applied, such as approval of insurance status within seconds rather than the multiple contacts needed today to verify insurance [59], patient identification at the point of care that does not require multiple form filling and carrying documents to doctor’s

appointments [60], or conducting research without increasing the risk to privacy of individuals [61]. Artificial intelligence [62], Internet-of-Things (IoT) [63] and 3D printing [64] using immutable and verified instructions through blockchain are other technologies that might be greatly helpful in fighting pandemics like COVID-19 in the future.

3. Future considerations

The devastation and suffering caused by the COVID-19 crisis should trigger a resolve to build better systems of data, trust, and transactions to track, respond, and control such pandemics in the future. While blockchain technology holds great promise and early demonstrations of solving systemic failures of our current healthcare, public health, and policy institutions are being developed, its widespread adoption requires planning and execution. A national policy agenda to immediately consider how blockchain applications may help with COVID-19 pandemic response safely and effectively, will help expedite the acceptance, adoption, and implementation of this technology for the improvement of our broken systems of healthcare data and health-related transactions.

Major blockchain and software companies are already in the process of creating a decentralized governance system to come up with international standards like W3C and internet protocols. Hyperledger, Ethereum, BankChain, and R3 are all examples of such consortium-building efforts [65]. Consensus on protocols and rules of business agreed by competitors and collaborators leads to more effective, egalitarian, and implementable rules which have helped in the interoperability and scalability of wireless and internet technologies. If governments and large private corporations actively participate and encourage such collaborative global governance rather than considering them a threat to their own hegemonic authority, the health systems of the world will be much better prepared for a future health crisis like COVID-19.

Finally, research and development to build and test robust use cases for blockchain applications are needed. University and research institutions should partner with industry and

business. Such collaborations are rare and need to be established widely to expedite the adoption of blockchain technologies in health. Development and funding of blockchain implementation labs in universities and medical schools will help promote such industry-academia partnerships and provide stronger and more reliable evidence to evaluate the impact of blockchain technology in healthcare. Both healthcare and blockchain technology require interdisciplinary teams to work together to solve problems. Blockchain labs in academic medical centers and public universities can provide such a platform for cooperation and creative problem solving that helps in the fight against pandemics like Covid-19.

4. Conclusion

In summary, blockchain technology relies on a distributed, robust, secure, privacy-preserving, and immutable record keeping framework that can transform the nature of trust, value sharing, and transactions for the better. COVID-19 crisis has highlighted the failure of current systems of trust and data sharing. While it presents a clear and serious danger to our way of life, it also provides a unique opportunity to apply and test new technologies that may help transform our capabilities to fight this pandemic and, in the process, establish a more efficient, democratic, and secure system to respond to future pandemics.

Acknowledgement: The author wants to thank Dr. Robert John Bautista for his help in formatting for submission.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] Worldometer, COVID-19 Coronavirus Pandemic. (2020) (accessed April 27, 2020), https://www.worldometers.info/coronavirus/.

[2] B. Xie, D. He, T. Mercer, Y. Wang, D. Wu, K.R. Fleischmann, Y. Zhang, L.H. Yoder, K.K.

Stephens, M. Mackert, M.K. Lee, Global health crises are also information crises: A call to action, J. Assoc. Inf. Sci. Tech. (in press), https://doi.org/10.1002/asi.24357.

[3] G. Eysenbach. How to fight an infodemic: The four pillars of infodemic management. J Med Internet Res 2020;22(6):e21820

[4] J. Zarocostas, How to fight an infodemic, Lancet. 395 (2020) P676. https://doi.org/10.1016/S0140-6736(20)30461-X.

[5] A.C. Madrigal, R. Meyer. How could the CDC make that mistake? The Atlantic. (May 21, 2020) (accessed June 7, 2020), https://www.theatlantic.com/health/archive/2020/05/cdc-and-states-are-misreporting-covid-19-test-data-pennsylvania-georgia-texas/611935/.

[6] C. Shalby. Serious breakdown in California systems causes inaccurate coronavirus numbers. Los Angeles Times. (Aug 5, 2020) (accessed August 14, 2020) https://www.latimes.com/california/story/2020-08-05/coronavirus-test-results-collecting-hampering-pandemic-response

[7] E. Mystal. The lesson of the coronavirus? There's no one left to trust. The Nation. (Apr 14, 2020) (accessed July 31, 2020), https://www.thenation.com/article/society/coronavirus-reopen-trust/

[8] T.C. Earle. Trust, confidence, and the 2008 global financial crisis. Risk Analysis. 29 (2009) 785-792. doi: 10.1111/j.1539-6924.2009.01230.x

[9] S. Nakamoto. Bitcoin: A peer-to-peer electronic cash system. Bitcoin.org (2008) (accessed July 26, 2020), https://bitcoin. org/bitcoin.pdf

[10] R. Böhme, N. Christin, B. Edelman, T, Moore, Bitcoin: Economics, technology, and governance, J. Econ. Perspect. 19 (2015) 213-238. https://doi.org/10.1257/jep.29.2.213.

[11] Z. Tufekci, The WHO Shouldn't Be a Plaything for Great Powers, The Atlantic. (2020) (accessed May 11, 2020), https://www.theatlantic.com/health/archive/2020/04/why-world-health-organization-failed/610063/.

[12] J.L. Schenker, The distribution of trust, The Innovator. (2017) (accessed May 11, 2020), https://innovator.news/blockchain-the-distribution-of-trust-4d36b7bd2508.

[13] H.F. Atlam. A. Alenezi, M. Alassafi, G.Wills. Blockchain with Internet of Things: benefits, challenges, and future directions. *International Journal of Intelligent Systems and Applications*, 10 (6) (2018) 40-48. doi:10.5815/ijisa.2018.06.05.

[14] T.S. Bernard, T. Hsu, N. Perlroth, R. Lieber, Equifax says cyberattack may have affected 143 million in the U.S., The New York Times. (2017) (accessed May 11, 2020), https://www.nytimes.com/2017/09/07/business/equifax-cyberattack.html.

[15] D. Tapscott, A. Tapscott, April 7, 2020. Blockchain solutions in pandemics: A call for innovation and transformation in public health. Blockchain Research Institute.

[16] M. Freitag, M. Bühlmann, Crafting trust: The role of political institutions in a comparative perspective, Comp. Polit. Stud. 42 (2020) 1537-1566. https://doi.org/10.1177/0010414009332151.

[17] D. Blumenthal, E.J. Fowler, M. Abrams, S.R. Collins. Covid-19 - Implications for the Health Care System. N Engl J Med. 10 (2020)1056/NEJMsb2021088. doi:10.1056/NEJMsb2021088

[18] L. Wynants, C.B. Van, G.S. Collins, D.R. Riley, G. Heinze, E. Schuit et al. Prediction models for diagnosis and prognosis of covid-19: systematic review and critical appraisal BMJ. 369 (2020) m1328

[19] L. Holmes, M. Enwere, J. Williams, B. Ogundele, P. Chavan, T. Piccoli, C. Chinaka, Comeaux, C.; Pelaez, L.; Okundaye, O.; Stalnaker, L.; Kalle, F.; Deepika, K.; G. Philipcien, M. Poleon, G. Ogungbade, H. Elmi, V. John, K.W. Dabney. Black–White Risk Differentials in COVID-19 (SARS-COV2) Transmission, Mortality and Case Fatality in the United States: Translational Epidemiologic Perspective and Challenges. Int. J. Environ. Res. Public Health 17 (2020) 4322.

[20] A.B. Dar., A.H. Lone, S. Zahoor, A.A. Khan, R.N. Mir. Applicability of Mobile Contact Tracing in Fighting Pandemic (COVID-19): Issues, Challenges and Solutions. IACR Cryptol. 2020 (2020), 484.

[21] R.L. Megan, V. Griffeth, A.K. Jha. Critical Supply Shortages — The Need for Ventilators and Personal Protective Equipment during the Covid-19 Pandemic N Engl J Med 382 (2020) e4. DOI: 10.1056/NEJMp2006141

[22] E.W. Colglazier, Response to the COVID-19 Pandemic: Catastrophic Failures of the Science-Policy Interface, Science & Diplomacy. (2020) (accessed May 11, 2020), http://www.sciencediplomacy.org/editorial/2020/response-covid-19-pandemic-catastrophic-failures-science-policy-interface.

[23] J.P.A. Ioannidis, A fiasco in the making? As the coronavirus pandemic takes hold, we are making decisions without reliable data, STAT. (2020) (accessed May 11, 2020), https://www.statnews.com/2020/03/17/a-fiasco-in-the-making-as-the-coronavirus-pandemic-takes-hold-we-are-making-decisions-without-reliable-data/.

[24] M. Iansiti, K.R. Lakhani, The truth about blockchain, Harvard Business Review. (2017) (accessed May 11, 2020), https://hbr.org/2017/01/the-truth-about-blockchain.

[25] Q. Xia, E. B. Sifah, K. O. Asamoah, J. Gao, X. Du and M. Guizani, "MeDShare: Trust-Less Medical Data Sharing Among Cloud Service Providers via Blockchain," IEEE Access. 5 (2017) 14757-14767. doi: 10.1109/ACCESS.2017.2730843.

[26] T-T. Kuo, H-E Kim, L. Ohno-Machado, Blockchain distributed ledger technologies for biomedical and health care applications, JAMIA. 24 (2017) 1211–1220. https://doi.org/10.1093/jamia/ocx068.

[27] D. Tapscott, A. Tapscott, Blockchain revolution: How the technology behind bitcoin is changing money, business and the world. (2016) Portfolio/Penguin.

[28] J. Barrett, C. Jones, E. Reed, Mayors move to address racial disparity in Covid-19 deaths. April 8, 2020 (accessed April 11, 2020), https://www.wsj.com/articles/black-hispanic-new-yorkers-account-for-disproportionate-number-of-coronavirus-deaths-11586359447.

[29] P. Ferreira, E. Periera. Contagion Effect in Cryptocurrency market. J Risk Financial Manag. 12 (2019) 115. https://doi.org/10.3390/jrfm12030115

[30] I. Wladawsky-Berger, Blockchain May Offer Solutions to Fighting Covid-19, The Wall Street Journal. (2020) (accessed May 11, 2020), https://blogs.wsj.com/cio/2020/05/01/blockchain-

may-offer-solutions-to-fighting-covid-19/.

[31] L. Manderson, S. Levine, COVID-19, Risk, Fear, and Fall-out, Med Anthropol. (2020). https://doi.org/10.1080/01459740.2020.1746301.

[32] The Lancet, COVID-19: Protecting health-care workers, Lancet. 395 (2020) 922.

[33] H. Min, Blockchain technology for enhancing supply chain resilience, Bus. Horiz. 62 (2019) 35-45. https://doi.org/10.1016/j.bushor.2018.08.012.

[34] F. Yianis, A new era of food transparency powered by blockchain.(2018). (accessed May 7, 2020), https://www.mitpressjournals.org/doi/pdf/10.1162/inov_a_00266. Also, The Linux Foundation Projects, Case study: How Walmart brought unprecedented transparency to the food supply chain with Hyperledger Fabric. (accessed May 11, 2020), https://www.hyperledger.org/resources/publications/walmart-case-study.

[35] U.S. Food and Drug Administration. FDA takes new steps to adopt more modern technologies for improving the security of the drug supply chain through innovations that improve tracking and tracing of medicines. (Feb 6, 2019) 2019 (accessed July 6, 2020) https://www.fda.gov/news-events/press-announcements/fda-takes-new-steps-adopt-more-modern-technologies-improving-security-drug-supply-chain-through.

[36] M. Miliard, IBM launches blockchain network to bolster medical supply chain during COVID-19, Healthcare IT News. (2020) (accessed May 11, 2020), https://www.healthcareitnews.com/news/ibm-launches-blockchain-network-bolster-medical-supply-chain-during-covid-19.

[37] A. Su, Faulty masks. Flawed tests. China's quality control problem in leading global COVID-19 fight, Los Angeles Times. (2020) (accessed May 12, 2020), https://www.latimes.com/world-nation/story/2020-04-10/china-beijing-supply-world-coronavirus-fight-quality-control.

[38] G.J. Ackland, E. Chattoe-Brown, H. Hamill, K.R. Hampshire, S. Mariwah, G. Mshana. Role of Trust in a Self-Organizing Pharmaceutical Supply Chain Model with Variable Good Quality

and Imperfect Information. Journal of Artificial Societies and Social Simulation 22 (2019) 5 DOI: 10.18564/jasss.3984.

[39] OECD/EUIPO Trade in Counterfeit Pharmaceutical Products, Illicit Trade, OECD Publishing, Paris, (2020), https://doi.org/10.1787/a7c7e054-en.

[40] P. Sylim, F. Liu, A. Marcelo, P. Fontelo. Blockchain Technology for Detecting Falsified and Substandard Drugs in Distribution: Pharmaceutical Supply Chain Intervention. JMIR Res Protoc. 7(9) (2018) e10163. doi: 10.2196/10163.

[41] I. Haq, O.M. Esuka, Blockchain technology in pharmaceutical industry to prevent counterfeit drugs, Int. J. Comput. Appl.. 180 (2018) 8-12. https://doi.org/10.5120/ijca2018916579.

[42] R. Kumar, R. Tripathi, Traceability of counterfeit medicine supply chain through Blockchain, 2019 11th International Conference on Communication Systems & Networks (COMSNETS). (2019). https://doi.org/10.1109/COMSNETS.2019.8711418.

[43] IBM. Trust Your Supplier. (2020) (accessed on July 6, 2020) https://www.trustyoursupplier.com

[44] J-H. Tseng, Y-C. Liao, B. Chong, S-W. Liao, Governance on the Drug Supply Chain via Gcoin Blockchain, Int. J. Environ. Res. Public Health. 15 (2018) 1055. https://doi.org/10.3390/ijerph15061055.

[45] M. Bodas, K. Peleg, Self-isolation compliance in the COVID-19 era influenced by compensation: Findings from a recent survey in Israel, Health Aff. (2020). https://doi.org/10.1377/hlthaff.2020.00382.

[46] A. Mukhopadhyay, India: Police under fire for using violence to enforce coronavirus lockdown, Deutsche Welle. (2020) (accessed May 11, 2020), https://www.dw.com/en/india-police-under-fire-for-using-violence-to-enforce-coronavirus-lockdown/a-52946717.

[47] M.J. Keeling, T.D. Hollingsworth, J.M. Read. Efficacy of contact tracing for the containment of the 2019 novel coronavirus (COVID-19). J Epidemiol Community Health 0 (2020) 1-6. doi:10.1136/jech-2020-214051

[48] N. Singer. Virus-Tracing Apps Are Rife With Problems. Governments Are Rushing to Fix

Them. (July 8, 2020) New York Times. (accessed on July 26, 2020) https://www.nytimes.com/2020/07/08/technology/virus-tracing-apps-privacy.html.

[49] C. Timberg, D. Harwell. Government efforts to track virus through phone location data complicated by privacy concerns. (March 19, 2020). The Washington Post. https://www.washingtonpost.com/technology/2020/03/19/privacy-coronavirus-phone-data/

[50] L. Kelion. NHS rejects Apple-Google coronavirus app plan. (April 27, 2020) BBC.com. (accessed May 25, 2020) https://www.bbc.com/news/technology-52441428

[51] M. Jones, M. Johnson, M. Shervey, J.T. Dudley, N. Zimmerman. Privacy-Preserving Methods for Feature Engineering Using Blockchain: Review, Evaluation, and Proof of Concept. J Med Internet Res. 21 (2019) e13600. doi:10.2196/13600

[52] L. Xu, N. Shah, L. Chen, N. Diallo, Z. Gao, Y. Lu, W. Shi, Enabling the sharing economy: Privacy respecting contract based on public blockchain, BCC '17: Proceedings of the ACM Workshop on Blockchain, Cryptocurrencies and Contracts. (2017) 15-21. https://doi.org/10.1145/3055518.3055527.

[53] H. Xu, L. Zhang, O. Onireti, Y. Fang, W.B. Buchanan, M.A. Imran. BeepTrace: Blockchain-enabled Privacy-preserving Contact Tracing for COVID-19 Pandemic and Beyond. (accessed Aug 14, 2020) https://arxiv.org/abs/2005.10103v1

[54] Q. Xia, E. B. Sifah, K. O. Asamoah, J. Gao, X. Du and M. Guizani, "MeDShare: Trust-Less Medical Data Sharing Among Cloud Service Providers via Blockchain," IEEE Access 5, (2017). 14757-14767, doi: 10.1109/ACCESS.2017.2730843.

[55] M.S. Kim, Seoul’s radical experiment in digital contact tracing, The New Yorker. (2020) (accessed May 11, 2020), https://www.newyorker.com/news/news-desk/seouls-radical-experiment-in-digital-contact-tracing.

[56] J. Abeler, M. Bäcker, U. Buermeyer, H. Zillessen. COVID-19 Contact Tracing and Data Protection Can Go Together. JMIR Mhealth Uhealth 8 (2020) e19359. DOI: 10.2196/19359

[57] R.H. Hylock, X. Zeng, A blockchain framework for patient-centered health records and exchange (HealthChain): Evaluation and proof-of-concept study, J. Med. Internet. Res. 21

(2020) e13592. https://doi.org/10.2196/13592.

[58] B. Wistrom, How blockchain and immunization passports could help us re-open, Austin Inno. (2020) (accessed May 11, 2020), https://www.americaninno.com/austin/inno-insights/how-blockchain-and-immunization-passports-could-help-us-re-open/.

[59] S. Sinclair, Chinese insurers tap blockchain to speed coronavirus payouts, Coindesk. (2020) (accessed May 11, 2020), https://www.coindesk.com/chinese-insurers-tap-blockchain-to-speed-up-coronavirus-payouts.

[60] G. Morris, G. Farnum, S. Afzal, C. Robinson, J. Greene, C. Coughlin, Patient identification and matching final report, Office of the National Coordinator for Health Information Technology. (2014) (accessed May 11, 2020), https://www.healthit.gov/sites/default/files/patient_identification_matching_final_report.pdf.

[61] T-T. Kuo, L. Ohno-Machado, ModelChain: Decentralized privacy-preserving healthcare predictive modeling framework on private blockchain networks, arXiv.org. (2018) (accessed May 11, 2020), https://arxiv.org/abs/1802.01746.

[62] D. Nguyen, M. Ding, P.N. Pathirana, A. Seneviratne, Blockchain and AI-based solutions to combat coronavirus (COVID-19)-like epidemics: A survey, TechRxiv. (2020) (accessed May 11, 2020), https://www.techrxiv.org/articles/Blockchain_and_AI-based_Solutions_to_Combat_Coronavirus_COVID-19_-like_Epidemics_A_Survey/12121962/1.

[63] D.S.W. Ting, L. Carin, V, Dzau, T.Y. Wong, Digital technology and COVID-19, Nat. Med. 26 (2020) 459-461. https://doi.org/10.1038/s41591-020-0824-5.

[64] M. Diemer, Blockchain – Implications and use cases for additive manufacturing, Frankfurt School Blockchain Center. (2019) (accessed May 11, 2020), http://explore-ip.com/2019_Blockchain-Additive-Manufacturing.pdf.

[65] S. Karkeraa. Technological Tools. In: Unlocking Blockchain on Azure. (2020) Apress,

Berkeley, CA. https://doi.org/10.1007/978-1-4842-5043-3_7