Blockchain-based Data Access Environment for Disaster Risk Reduction[1]

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***Abstract*— This paper outlines an opportunity to apply blockchain technology to enhance access to the universe of data needed to assess risk and guide allocation of resources for Disaster Risk Reduction (DRR). The project aims to develop and implement a blockchain-based governance model, a Blockchain Based Data Access Environment (BDAE) for conditional data access and curation. A two-layered architecture creates an incentivized mechanism for data sharing and data quality services.**

Keywords—data interoperability, blockchain, data governance, disaster risk modeling, disaster risk reduction, infrastructure vulnerability, data ecosystems, data governance, data quality, behavioral incentives

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I. Introduction
The Need for More and Better Data for DRR Risk Models

Recent events have revealed an acceleration in the emergence of risks related to health, infrastructure, climate, water, food, conflict, and other threats to the well-being of global populations. Strategies for responding to these risks have evolved in the last decade from an emphasis on rapid response to preparation that will mitigate risk and impact. The efficient allocation of limited resources depends on the scope and reliability of disaster risk models. These models critically depend on widely distributed structured and unstructured data under diverse regimes of ownership and control. This paper outlines a strategy for applying blockchain and related technologies to improving disaster risk models through more effective data access and governance.[1], [2] This poses a key question for research: can blockchain enable an enhanced governance regime that improves data access and effectiveness of DRR models and response programs?

The assessment of risk depends on the data that can be used to construct models of vulnerabilities and capabilities for preparedness and response[3]. While there have been great advances in tools for analysis of large data sets and the use of technologies like machine learning for predictive models, daunting impediments persist in terms of data access. These include the diversity of data resources, ownership, data security, need for permissioned access, inconsistency in data definitions (ontologies), as well as the sheer volume of data relevant to DRR derived from public and private sources.

What is needed in this complex environment is both access and trust. Blockchain is already being used to address issues of interoperability for health data among other domains[4]. Nevertheless, in most domains data resources are scattered and often difficult to access. There is no consistent governance regime for access to DRR-related data. This initiative would use blockchain to implement a governance structure for data access and, in so doing, enable the use of an integrated data resource for DRR modeling and policy development.

II. Satellite Data as a Model for Blockchain-enabled Data Acquisition and Interoperability

One model for managing data as an input to risk modeling is provided by an initiative on the use of blockchain to gather satellite orbital data for collision avoidance. The design is described in an IEEE publication , "Blockchain Network for Space Object Location Gathering."[5] This model, developed by Mason Molesky and his team, was perhaps the most innovative use case to emerge from the author's Blockchain Fundamentals class at George Washington University.

There are several ways in which the model used for satellite tracking and collision avoidance may be relevant to other risk-modeling situations. This type of system is representative of what may be called a Slowly Changing Fragile System. Such systems stable over time, while being subject to perturbing events that may have cascading destabilizing impact. In the case of satellites, the system of orbiting objects is stable and predictable over time, except

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when the system is perturbed by a rare event, such as the launch of a new object that may cause a collision and perhaps a consequent chain of subsequent collisions. Other environments share similar characteristics. For example, the physical infrastructure for building, bridges, and roads may remain stable until there is a rare event such as a flood or emerging structural defect. A storm or earthquake may impact multiple systems that are normally stable over time – housing, transportation, food, communications, energy supply, education, and health. Communicable diseases are controlled through existing immune systems until an infectious agent emerges to create cascading impact on individuals and populations. Disasters are typically caused by rare events that are nevertheless inevitable on a certain timescale. While the timing of the disturbance cannot easily be predicted, vulnerabilities in the system can be anticipated, with the right data and capable models.

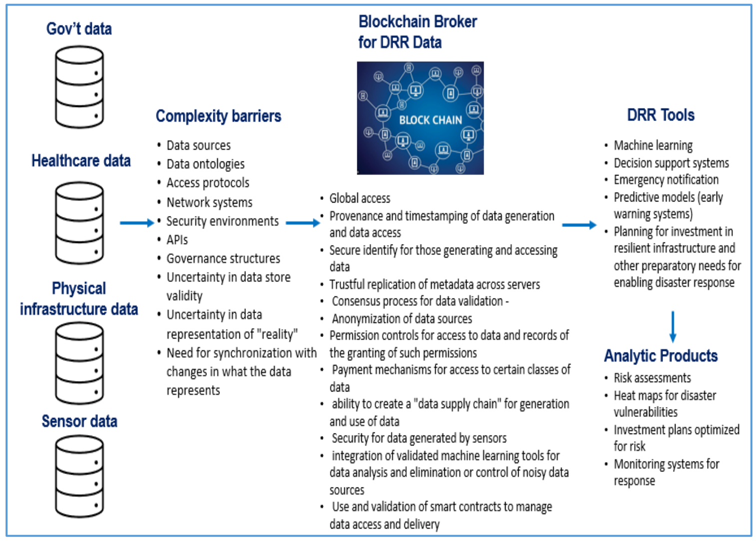

FIG. 1 DDR DATA FLOW IN THE SHARED ENVIRONMENT

III. CHALLENGES FOR ACCESS TO ESSENTIAL DRR DATA

A. Impementation Impediments

Whatever the potential value of a Blockchain-based Data Access Environment (BDAE) for mitigating disaster risk, an implementation will have to contend with obstacles that have often stood in the way of widespread use of other peer-to-peer applications.

- Legacy inertia – investment in existing systems and the additional investment that may be required for participation in the BDAE.
- Lack of standards for data exchange, security.
- Incentives to restrict access to data – Existing monetized data is a disincentive to data sharing.
- Need for governance processes that enable data access under appropriate conditions.

The transition to a more open environment will require demonstration of significant value for participants and possibly incentives and regulations such as those that motivated the adoption of electronic health data. Nevertheless, even modest increases in data access would be of significant value.[6] Some of these possible innovations are discussed in the next sections.

B. Balance between Data Transparency and Data Utility

The implementation of an integrated data access environment for DRR will potentially result in an avalanche of data made available for analysis. While blockchain consensus processes may reduce the entropy associated with data directly contained in the blockchain system, expanded data access can produce increases in data entropy that will overwhelm prospects for deriving actionable conclusions.

There are many models for managing large sets of data that show pathways to reducing entropy and providing value from a potential flood of data. Large investments by Facebook and Google, for example, have transformed huge networks of data sources into pathways of data value. The analytical tools that make use of data provided by the BDAE, and data filtering mechanisms embedded within the BDAE (or services built on the BDAE), will need to find a way through this universe of large, diverse datasets.

A helpful factor is that increased access to data for DRR analysis is likely to result in growth of available data in small steps with predictable growth. This would facilitate the parallel development of capabilities within and external to the BDAE to manage data environments and increase trust in the validity of the data produced.

IV. SOLUTION COMPONENTS FOR IMPROVED DATA ACCESS

A. Development of an initial governance model

The BDAE is at its core a governance model for controlling and facilitating access to data. There are many uncertainties in the governance structure that pose issues for design and research. What will be the process that determines rules (embedded in smart contracts and other representations of accepted behaviors) for access and data use? Who controls that process and how is it to evolve over time? To what extent will the governance model be decentralized? Can consensus processes that are used in existing blockchain implementations be a foundation for community agreement on rules of the road for data interchange? How should governance rules embedded in the blockchain environment interact with standards and regulations? How are exceptions adjudicated?

What is anticipated is the evolution of an ecosystem of data resources, access services, analytic tools, and DRR risk models that serve multiple needs of the community of data owners, generators, and modelers. Rules for data access are created by data owners, standards organizations, government regulators, and business that use, generate, and transform data. While a smart contract in a blockchain environment can incorporate and apply a defined governance regime, there are current limits to transparency and predictability of smart contract outcomes. This provides an opportunity for innovation in smart contract implementation tools and testing processes.

B. *Use of complementary technologies*

The BDAE will both use and generate innovative services that facilitate data access under conditions specified by data owners. Blockchain provides capabilities for instantiating such conditions in smart contracts as well as capabilities for monitoring and documenting release and use of data from particular sources. The blockchain services will need to be complemented by other service capabilities derived from AI, cloud technologies, distributed data management systems, cybersecurity, and other technology services. Innovation often emerges at the interface between disciplines. At the very least, the BDAE will depend on innovation at the intersection of technologies involving blockchain distributed ledgers, data access and validation techniques, and DRR modeling.

C. *An Ecosystem Based on Decentralized Governance*

What is anticipated is the evolution of an ecosystem of data resources, access services, analytic tools, and DRR risk models that serve multiple needs of the community of data owners, generators, and modelers. Rules for data access are created by data owners, standards organizations, government regulators, and business that use, generate, and transform data. While a smart contract in a blockchain environment can incorporate and apply a defined governance regime, there are current limits to transparency and predictability of smart contract outcomes. This provides an opportunity for innovation in smart contract implementation tools and testing processes.

D. *Ecosystem Data Services*

The implementation of a governance model will enable an ecosystem to support the exchange of data resources, tools for analysis and modeling, data gathering and observation and other services.

Possible areas of service innovation include:

- Cloud-based storage and data management services integrated with blockchain facilities.
- Anonymized Access – Certain data in areas such as healthcare and infrastructure may be sensitive for reasons of privacy or security. Blockchain, in conjunction with anonymization services, can provide data that contains data of value, but which is stripped of personal identifying information.
- Multi-Party Computation (MPC) – One step beyond anonymization is MPC, techniques that can enable computation on data without exposing data content.
- AI based tools for data search, filtering, and validation.
- Improved design and standards for data storage, validation, exchange, and documentation of transactions.
- Automated tools for managing the interface between the human understanding of data permissions and the incorporation of corresponding conditions in smart contracts in the blockchain exchange environment.

The BDAE will evolve into a market for data and data services supporting DRR customers. This will realize returns for data owners and service providers in the data-sharing ecosystem.

E. *Incentives for Data Interchange*

In the marketplace for DRR data and services, data products have value. Blockchain offers well-tested mechanisms for tokenization of virtual products and market mechanisms for exchange and incentivization of behaviors that benefit the community. Such incentives can encourage fluid access to data and compensation for owners of data and for skills and services that are of demonstrable value to the DRR community.

F. *Crowdsourcing of expertise in DRR-related data*

The development of the data exchange ecosystem described in the previous section is challenged by the decentralization of data sources and the numerous ontologies that characterize data content and organization. That challenge may be usefully addressed by crowdsourcing data expertise in a decentralized network of experts. With proper incentives, individual experts can take responsibility for a particular class of data and become the curator and advocate for that data set in the community of data users. The users and producers of data relevant to DRR form a community of experts that can facilitate use of diverse data to make DRR models and actions for preparation and response to disaster events more effective. Like processes using experts to review academic papers, evaluate clinical trials, and qualify other intellectual property, the proper use of experts, i.e., data stewards, for specific data domains can engender wider use and greater trust in data, whatever its origin. Transaction records in the blockchain can then document data flows and validation procedures.

As illustrated in Fig. 2, the BDAE will address the needs of different participants—data owners, data stewards, data service providers, and data customers. There are other

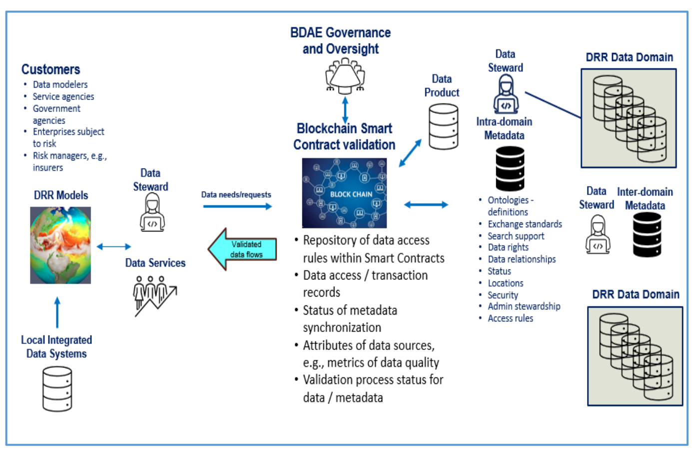

FIG. 2. DATA AND METADATA DTEWARDSHIP AND VALIDATION

interested parties such as government and NGO officials, researchers, and educators. Data stewards and data owners in this ecosystem will be incentivized to ensure that data provided to customers via the BDAE will be of a quality that meets the needs and standards of the community. Data for modeling of risk can derive from multiple domains related to subject areas like infrastructure, emergency response capabilities, risk analysis for climate, seismic, and health threats. This will require specialized expertise on the part of domain-specific data stewards. It is anticipated that blockchain functions for tracking data access can be handled separately from functions for incentivizing data quality and stewardship.

G. Two-Layer Architecture for Data Sharing

Like trade in other commodities, data sharing activity depends on mutual parties responding to incentives that overcome existing obstacles and disincentives to action. Reducing friction through standards and efficiencies can be encouraged with the design of smart contracts in the blockchain environment. To achieve both incentives for data production and reducing friction for data exchange, the BDAE will employ a two-tier architecture in the blockchain environment. The lower tier, embedded in the smart contract execution environment, will contain and apply conditions for data exchange imposed by parties to data governance, and also establish a transaction record of data access, which is traceable and stable over time. A second layer will contain token payment mechanisms to compensate data stewards and data owners for the services they provide to the environment. The currency exchange layer establishes a token under the ERC-20 protocol. This layer implements smart contracts for payments to and from participants in the data sharing ecosystem. The token capability may also facilitate investment in the BDAE, only partly motivated by the possibility of increases in token value. An important design goal is stability in token value and utility as a medium of exchange within the data-sharing environment.

V. Forward-Looking Requirements

One of the challenges in developing DRR models is reducing the complexity involved in the development of the pilot. Predicting the impact of a single event such as a hurricane may involve climate data, infrastructure data, topographic data related to flooding, emergency housing, medical supplies, nutrition, and other elements related to the well-being of the affected population. The initial development of a pilot, however, can be more narrowly focused.

Initial steps have been taken in using data in a circumscribed domain such as earthquake vulnerability[7] as an initial target of opportunity. The pilot will demonstrate how conditions for data access can be encoded in smart contracts. This would be a foundation for assessing how relationships between data providers and data consumers can be made more efficient and trustful. Such conditions can restrict, for example, unauthorized secondary distribution and monetization of data. The initial implementation will test the smart contact operation on the blockchain platform as well as an initial design for governance. The rules for governance involve reconciling the human world of ownership and negotiation with the automated representation of agreements on data use. The pilot implementation can test the process and instantiation of rules within these smart contracts.

VI. Conclusion

In the coming years, expenditures on disaster mitigation and response will rival spending on national defense. DRR models will be at the heart of enabling efficient allocation of such resources. Data interoperability and enhanced access to DRR-related data will in turn make essential DRR models more effective and useable. The goal is to test how blockchain and related technologies can enhance data flows to these models and create an ecosystem for shared data within a distributed governance structure. The shared data environment will also support other innovations such as the application of AI methods to DRR needs for data validation, supply-chain tracking, and identity management. Further research will help answer how innovations in data governance and architecture using blockchain and other technologies may be able to improve DRR capabilities and ultimately improve the well-being of affected populations.

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