Governance Attributes of Consortium Blockchain Applications

Completed Research

Kwok-Bun Yue
University of Houston-Clear Lake
yue@uhcl.edu

Pavani Kallempudi
University of Houston-Clear Lake
kallempudip8667@uhcl.edu

Kewei Sha
University of Houston-Clear Lake
sha@uhcl.edu

Wei Wei
University of Houston-Clear Lake
wei@uhcl.edu

Xinying Liu
University of Houston-Clear Lake
liux@uhcl.edu

Abstract

As a foundational and disruptive technology with unique features, blockchains can provide distinct technology pushes for novel business models, strategies, processes, and applications. Revised or new business models can be iteratively refined and transformed to increasingly more detailed design and implementation models to be realized by applications supported by blockchains. Governance concerns with how decisions are made, implemented, and controlled. It is an important focal point of any model and process. Blockchain enables new governance opportunities that are trusted, decentralized, automated, accountable, secured, and privacy-protected. These opportunities can be used to analyze governance issues in constructing models, processes, and blockchain applications. Based on our prototyping experience in two permissioned blockchain platforms, we propose a framework of six governance attributes for constructing consortium blockchain applications: decision process, accountability and verifiability, trust, incentive, security and privacy, and effectiveness. The framework aids in exploring blockchain-created governance opportunities and driving future research.

Keywords

Blockchain, Consortium, Governance, Business Process, Business Model, Software Development

Introduction

As a highly tamper-resistant Distributed Ledger Technology (DLT), blockchains store all transactions immutably and identically in nodes of a peer-to-peer network (Beck & Müller-Bloch 2017, Xu et al. 2017, Zheng et al. 2018). Blockchain Technology (BCT) is considered as a cornerstone of the fifth and current disruptive computing paradigm: decentralized inter-connection of the world (Swan 2015). BCT has been characterized as emerging, radical (Beck & Müller-Bloch 2017), disruptive (Frizzo-Barker et al. 2020), foundational, and general-purpose (Filippova 2019). With many unique foundational features, blockchains can provide distinct technology pushes for novel business models, strategies, processes, and applications. Revised or new business models can be iteratively refined and transformed to increasingly more detailed design and implementation models to be realized by applications supported by blockchains.

Blockchains can also be viewed as an institutional technology that enables new kinds of organizations (Yue 2020), governance (Beck, Müller-Bloch & King 2018), and contracts (Davidson, De Filippi & Potts 2016). In particular, governance concerns with how decisions are made, implemented, and controlled. It is an important focal point of any model, process, and application. Blockchain enables new business governance opportunities that are trusted, decentralized, automated, accountable, verifiable, secured, and privacy-protected. These opportunities can be used to analyze governance issues in constructing models, processes, and blockchain applications.

Based on our experience in developing proof-of-concept prototypes for a Model-Based Systems Engineering (MBSE) model repository (Yue et al. 2021) in two permissioned blockchain platforms, Hyperledger's Fabric (Androulaki et al. 2018) and Hyperledger's Sawtooth (Hyperledger 2021), we propose a framework of six governance attributes for constructing consortium blockchain applications: decision process, accountability and verifiability, trust, incentive, security and privacy, and effectiveness.

The remaining of the paper is organized in the following manner. The next section provides background on consortium blockchains, technology push, blockchain application development processes, and governance. The next section elaborates the framework of six governance attributes and how they may be used in modeling and software development processes. It describes the opportunities and challenges of blockchain on these governance attributes. We draw our conclusions in the last section.

Blockchain Technology and Governance

Blockchains store transaction records in every node of a distributed network to enhance decentralization, trust, and immutability. In the original Nakamoto blockchain used to support Bitcoin (Nakamoto 2019), a block contains the hash of the previous block and a timestamp, and thus blocks are cryptographically linked in a chain, resulting in strong tamper-resistance. Blockchain governance is supported by decentralized consensus algorithms, which dictate how transactions are executed, endorsed, confirmed, and then grouped to form blocks. For example, to incentivize participation in maintaining the Bitcoin network, Nakamoto blockchain uses the Proof of Work algorithm for miners to compete to earn the right to create a new block, and collect the associated newly minted Bitcoin and the transaction fees. Thus, distributed transaction and block governance decisions are known by all parties, precisely defined, and accurately executed by programming code to enhance trust, automation, and decentralization.

After Bitcoin, Ethereum introduced and popularized Smart Contracts (SC) in blockchains by providing a more general-purpose scripting language called Solidity, which can be used to implement complicated transactions (Wood 2014). It becomes a popular platform for developing blockchain applications for many domains. The full automation of decentralized governance rules and transactions enabled Decentralized Autonomous Organizations (DAO), and their associated Decentralized Applications (DApp) (Beck & Müller-Bloch 2017). Bitcoin and Ethereum are examples of public, permissionless blockchains in which the public can participate in transactions and can read transaction records without any permission. To provide the needed privacy required by many business cases, permissioned blockchain platforms, such as Fabric and Sawtooth started to appear. These platforms provide membership services to define organizations, users, roles, privileges, and governance rules in some manners. This ability to fulfill privacy requirements is crucial for many applications in which consortia of organizations and users of diverse interests are common. As a result, consortium blockchains are emerging in many domains, such as energy trading (Li et al. 2017) and healthcare (Zhang & Lin 2018).

BCT and Technology Push

There are four current general characteristics of BCT that represent exciting opportunities and arduous challenges. First, it is a radical and disruptive innovation that provides new functionalities for disrupting and replacing current ways of operations (Beck & Müller-Bloch 2017, Frizzo-Barker et al. 2020). It challenges our habitual way of thinking about problems, and opens up numerous opportunities, many waiting to be explored. Second, BCT is considered to be a foundational technology that enables progresses and applications in a wide range of problem domains. More specifically, it is also considered as a general-purpose technology (GPT) (Filippova 2019). To qualify as a GPT, a technology must have high pervasiveness and strong innovation spawning effect, and must provide a wide scope of both benefits and applicability on different stages (Filippova 2019). As a GPT, blockchain can thus provide ample opportunities, including integration across domains and development stages. Third, BCT is still generally considered to be an emerging technology that has already attracted, and is continuing to attract very large investment, interest, and research.

In this respect, the demand-pull and technology-push theory can be used to illuminate BCT effects on innovation and application development. Although the classical debate between whether organizational innovation is more driven by pull of market demand or push by technology advancement are long-standing (Chidamber & Kon 1994, Di Stefano, Gambardella & Verona 2012), both are recognized as powerful forces for application development. Demand-pull and technology-push policies can be developed to induce innovation and the push-pull model can be used to guide successful application development (Peters, et al. 2012). A comparable emerging, disruptive, and general-purpose technology is Web technology in the 1990's. As shown in Figure 2(a), Web technology is the core component in the third and fourth disruptive technologies in the computing paradigms: Internet and mobile/social media (Swan 2015). It has spawned huge application development.

Despite the similarity with Web technology, BCT is different in its fourth general characteristic. Unlike Web technology, BCT is a complicated, diverse, and rapidly evolving technology, with very few standards, and many innovation directions. Blockchain platforms, such as B1, B2 and B3 in Figure 1 (b), have features distinct from each other. Furthermore, there are fewer commonalities between blockchain applications. The applications spawned by BCT do not fall into a single kind of applications in a way that we can generally call applications spawned by Web technology as Web applications. Indeed, based on their natures, domains, and purposes, there are multiple kinds of blockchain applications (depicted as A1, A2 and A3 in Figure 1 (b)). The technology push model is thus more complicated as both the technology and the kinds of applications are more diverse. Cautious BCT platform selection is both necessary and very consequential (e.g., applications A1, A2 and A3 are depicted to be implemented by blockchain platforms B1, B2 and B3 respectively in Figure 1 (b)). Application development methods and best practices do not necessarily port from one blockchain platform to another platform easily.

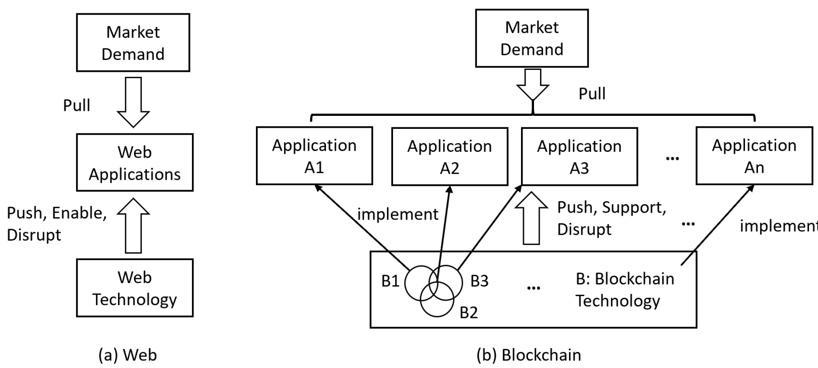

Figure 1 Demand Pull and Technology Push Models for Web Technology and BCT

Consequentially, blockchain application development is more difficult than many other general-purpose technologies. It calls for advancements in blockchain-specific modeling and software development techniques. As shown in Figure 2, consortium and business goals, strategies, and requirements can be captured by business models (Box 1 in Figure 2).

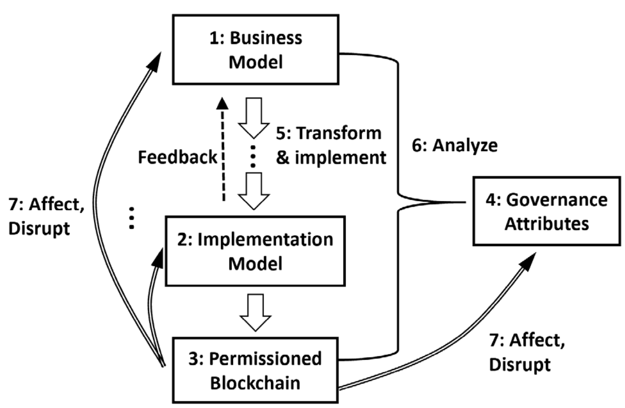

Figure 2 Governance Attributes for Consortium Blockchain Application Development

Business models can then be iteratively refined and transformed (Link 5 of Figure 2) to increasingly more detailed design and implementation models (Box 2). In consortium blockchain applications, implementation models are likely implemented using permissioned blockchains (Box 3). Well-constructed governance attributes (Box 4) can provide an important perspective to analyze (Link 6) and help constructing and transforming the various models and the blockchain application. Model transformations and implementations are difficult because each model has its own goals, constraints, languages, patterns, and best practices (Cuadrado, Guerra & de Lara 2014). Having a common set of governance attributes for analysis eases this process substantially. In reciprocal, the features supported by the selected permissioned blockchain platform affect and disrupt (Link 7) the model construction and the analysis of the governance attributes.

Governance Considerations

Governance research related to blockchains includes two major areas: (1) Blockchain governance (Pelt, Jansen, doBaars & Overbeek 2021, Bach, Mihaljevic & Zagar 2018, Smit et al. 2020) focuses on how blockchain platforms themselves are governed to support decisions and transactions. Important topics include what decentralized consensus algorithms (Mingxiao et al. 2017) and membership services (Androulaki et al. 2018) are supported, how SC can be updated, and what rules and processes are governing blockchain platform evolution. (2) Blockchain-*based* governance is concerned with governance issues and implications enabled by applying BCT and constructing blockchain applications. This area includes diverse efforts on investigating blockchain-enabled governance opportunities, such as constructing blockchain consortium (Zavolokina et al. 2020), and blockchain transformative potentials on self-governance of communities in the problem of the tragedy of the common (Rozas et al. 2018). It encompasses investigation on how blockchain-based organizations and governance interact with traditional organizations and governance mechanisms (Yue 2020, Lumineau, Wang & Schilke 2020). It also includes efforts on identifying potential blockchain-based governance issues. For example, 14 blockchain systems in four domains were investigated with semi-structured interviews to identify potential governance problems (Ziolkowski, Miscione & Schwabe 2020). Likewise, a framework of multiple layers and stages has been proposed to identify potential governance challenges, especially for DAO and permissionless blockchain, pointing to further research directions (Rikken, Janssen & Kwee 2019). This paper also aims to contribute to this still nascent blockchain-based governance area. However, our focus is on blockchain application development methodologies, especially on consortium blockchains using permissioned blockchain platforms. The paper provides a framework of six governance attributes that are influenced by blockchain (Link 7 of Figure 2). The framework can be used as a common and consistent lens to examine and aid the model transformation and implementation of blockchain applications (Links 5 and 6 of Figure 2), as well as pointing to future research directions.

Governance Attributes

Corporate governance is concerned with how power is exercised over corporate entities to make and implement decisions to accomplish business goals (Tricker & Tricker 2015). In this paper, we adopt a broad interpretation of governance to include decisions made in all levels of an organization or a consortium of organizations, from the board level, the managerial level, down to the business transaction level. Governance policies and processes on how decisions are made, implemented, and controlled can be scattered and only partially explicit-coded. Their successful implementations are accomplished in a mix of two ways: (1) software applications, and (2) organizational mechanisms and human actions. In blockchains, governance rules can be specified and executed autonomously by SC. It enables a blockchain economy epitomized by DAO in which little or no physical organizational mechanism and human management are needed (Beck, Müller-Bloch & King 2018). Even when DAO is not suitable, and a blockchain-assisted solution is instead preferable, blockchains can be used to devise more effective, innovative, and autonomous governance rules, tipping the scale for proper governance away from expensive organizational and human actions (Yue 2020). Accordingly, two questions can be asked:

(1) How do the unique governance features of blockchains alter our thinking and modeling of governance rules and processes?

(2) How can these business governance models be effectively transformed to more nuanced design and implementation models, and eventually implemented by a specific blockchain platform?

We propose a framework of six governance attributes that aids in answering these two questions: decision process, accountability and verifiability, trust, incentive, security and privacy, and effectiveness. Building blockchain applications are highly complicated, and design compromises on conflicting and mutually interacting goals and desirable attributes must be carefully investigated, weighted, and made. By explicitly stating and analyzing governance attributes, the proposed framework aims to help in exploring new blockchain-enabled governance opportunities and making effective compromised solutions.

Among the six attributes, three are based on the three dimensions of a framework for understanding the characteristics of governance in blockchain economy: (1) decision control becomes more decentralized, (2) accountability becomes more technically encoded, and (3) incentives are more aligned (Beck, Müller-Bloch & King 2018). Likewise, Lumineau, Wang & Schilke (2020) argue that BCT promotes contractual governance mechanisms (legally enforceable agreements as supported by SC) as opposed to relational governance mechanisms (such as relying on social and corporate relationships). This consideration of governance mechanism is also assimilated into the decision process attribute in our framework.

Overall, governance concerns with making, implementing, and controlling decisions. It is realized by processes and actions (referred to as business transactions in this paper). Traditional databases are effective storage technology. However, they are data-based, and not transaction-based. Low-level physical transaction models can be added, such as ACID transactions to ensure data consistency, and BASE transactions to enhance performance and scalability (Tai, Eberhardt & Klems 2017). However, they are low-level additions. As a result, many desirable business governance and transaction attributes are not directly supported, and the semantic gap is large (Yue 2021). As a result, traditional databases are lacking in supporting many desirable prerequisites of the six governance attributes, especially in the attributes decision process, incentive, and trust. On the other hand, blockchains are transaction-based, and they are designed that way from the ground up. Many desirable business transaction attributes are natively or better supported by the underlying blockchain transaction models.

The six governance attributes and their sub-attributes are stated with explanations of their relevance in Table 1. Although these governance attributes are especially applicable to consortium applications, they are also mostly appropriate for applications within a single organization. The opportunities provided by blockchains and the challenges they presented are described in Table 2. Because of space restriction, this paper cannot provide detailed elaborations and examples. However, most entries on the tables are self-explanatory. The few ones that necessitate further explanations are discussed after Tables 1 and 2.

Attributes	Sub-Attributes	Explanation
Decision Process (Beck & Müller-Bloch 2017,)	Clear specification of the natures of decisions, the process of decision making, and their implementations are central to effective governance.	
	Decision control routine	A precise algorithm that guides and implements the decision-making process (Mintzberg, Raisinghani & Theoret 1976) ensures correctness and enables contractual governance mechanism, but decreases flexibility.
	Decision right and consensus algorithm	Explicit specifications of rights in decision making and the decision consensus algorithm clarify the decision process and build trust (Bach, Mihaljevic & Zagar 2018, Mingxiao et al. 2017).
	Degree of centralization	A decision has a desired degree of centralization. Some decisions should be made centrally by an authority. Others can better be made in a distributed manner to enhance concurrency, reliability, transparency, security, and privacy (Rikken, Janssen & Kwee 2019, Zavolokina et al. 2020).
	Decision data	Decision data, such as the What, Who, Where, When, Why, and How (5W1H) information of a decision, are different to regular application data. They have different governance attribute values, such as different accountability and privacy requirements. They should be designed separately for proper and effective handling and storage.
	Granularity	The internal sub-decisions of a coarse-grained decision can be converted to clearly-specified standalone decisions, resulting in finer-grained governance with better control and automation, but less flexibility.
	Contractual degree (Lumineau, Wang &	A decision may range from fully and legally contractual (thus rigorously defined and open to automation) to relational (more flexible, but relying on

Attributes	Sub-Attributes	Explanation
	Schilke 2020)	exogenous mechanisms for realization, thus more difficult to automate).
	'Metaness' and decision level (Wang 2000)	Explicit investigation of meta-decisions and meta-meta-decisions (Boureau, Sokil-Hessner & Daw 2015) can effectively improve decision making in the higher levels (e.g., the board level and management level). More elaborations follow after Table 2.
Accountability and Verifiability	Accountability and verifiability are crucial to build trust in governance, which are especially expected by consortium applications (Beck & Müller-Bloch 2017).	
	Traceability	Various degrees of a secure and trusted audit trail of decisions, their decision data, and their accesses are required to be implemented in effective software solutions.
	Compliance and legal concerns	Better automation of complicated compliance and legality requirements (O'Shields 2017) reduce cost and enhance concurrence, but increase complexity.
Privacy and Security	Privacy and security are central in any consortium application.	
	Privacy	Nuanced privacy models satisfying the privacy and intellectual property requirements of both the consortium and the individual organizations must be realized to ensure organizational participation (Bernabe et al. 2019. (Zhang & Lin 2018). Privacy needs to be balanced with effectiveness.
	Security	The processing and storage of decisions and transactions, not just application data, must be secure.
Trust (Miraz & Ali 2018)	Effective governance is based on participants trusting that decisions are fair, properly executed, privacy-protected, and highly tamper-resistant, with decision policies transparent and accessible.	
Incentive	Proper alignments of incentives for organizations and users are crucial for successful consortium governance (Ba, Stallaert & Whinston 2001, Beck & Müller-Bloch 2017).	
Effectiveness	Software solutions with the needed governance support must be effectively developed, and their executions need to meet performance requirements.	
	Semantic gap	Large semantic gaps between business transactions and the implementation's transaction model increase software complexity and cost.
	Performance	Effective solutions must meet scalability and business transaction throughput requirements (Dinh et al. 2017).

Table 1. Governance Attributes and Sub-Attributes

Attributes	Sub-Attr.	Blockchain Opportunities	Blockchain Challenges
Decision Process	Overall	A decision can be implemented as one or more blockchain transactions. BCT provides strong transactional support, with SC for automating complicated decision processes.	Semantic gaps between business decisions and blockchain transactions can still be large. Desirable supporting features may be missing.
	Decision control routine	SC is a natural tool in BCT for realizing decision control algorithms.	SC languages may have restrictions (e.g., only deterministic operations). Blockchain can add its own complexity. Desirable functions may be missing.
	Decision right and consensus algorithm	Permissioned blockchain platforms support definitions of users, rights, and transaction consensus algorithms.	The transformation of decision rights and consensus algorithms to a specific blockchain platform can be nuanced and not straightforward.
	Degree of centralization	Decentralized in nature, blockchains are nevertheless designed to support	Some decisions, such as meta-decisions, are more centralized in

Attributes	Sub-Attr.	Blockchain Opportunities	Blockchain Challenges
		transactions and decisions of various degrees of centralization.	nature, and supporting features may not be mature. Tradeoffs are needed.
	Decision data	Some decision data, such as timestamps and endorsing parties, are stored automatically. Others can be effectively stored as metadata.	Effective decision data need to be identified and mapped to blockchain assets' metadata.
	Granularity	Decisions of any grain can be supported by SC.	Right-grained decision models and their effects on blockchain performance need to be investigated.
	Contractual degree	SC implements contractual governance decisions well.	When and how to implement more relational-oriented decisions in blockchains are nascent questions.
	'Metaness' and decision level	Comparing to many other technologies, BCT provides better support of higher-level decisions, such as meta-decisions.	The support is still far from mature, standardized, or thorough.
Accountability and Verifiability	Overall	As an immutable DLT, blockchain is built to support accountability and verifiability.	Compliance, legal, and regulation issues still need to be better addressed before wider SC adoption (O'Shields 2017).
	Traceability	Transactions and their data are automatically stored immutably.	Additional decision data still need to be modeled. Read queries are usually not native blockchain transactions and additional arrangements are necessary.
	Compliance and legal concerns	Strong blockchain transaction models support compliance and legal requirements better.	Inflexibility introduced by SC and laws regulating blockchains are obstacles for using blockchains as legal tools (Sklaroff 2017)
Privacy and Security	Overall	Blockchain is highly secure and permissioned blockchain platforms provide privacy supports.	Nuanced support of organizational privacy and intellectual properties is difficult in many domains.
	Privacy	Membership services support many privacy models. Features like private data collections in Fabric can further enhance privacy. Metadata can be used to ensure proper privacy (Faisal, Courtois & Serguieva 2018).	Privacy solutions need to be carefully designed (Bernabe et al. 2019). Privacy features of a specific blockchain platform may not match requirements well. Blockchain networks need to be designed to preserve needed privacy.
	Security	Blockchains are generally very secure.	Networks and SC needs to be securely designed. Platform-specific attacks need to be analyzed and prevented.
Trust		Blockchains are sometimes known as trust or confidence machines (Miraz & Ali 2018) with strong support for building trust.	Fairness in decision algorithms and other trust-enhancing governance policies must be designed and implemented.
Incentive		Cryptocurrency and digital tokens are directly or easily supported by many blockchains to represent valuable assets for incentive management.	Proper business incentive alignments by a mix of incentives from blockchain and other exogenous sources require careful planning, design and studies.
Effectiveness	Overall	Blockchains are effective in satisfying many governance attributes.	Performance is a serious issue for blockchains. It attracts much research.
	Semantic gap	As a transaction-based technology, the semantic gap is likely to be smaller	The semantic gap is still very significant.

Attributes	Sub-Attr.	Blockchain Opportunities	Blockchain Challenges
		than that of databases.	
	Performance	Despite many rapid improvements, blockchain transaction performances are still far behind that of database transactions (Dinh et al. 2017).	The selection of a proper platform, good blockchain asset and transaction design, and performance tuning are crucially needed.

Table 2. BCT Opportunities and Challenges on Governance Attributes

Seven sub-attributes are identified for the decision process attribute: decision control routine, decision right and consensus algorithm, degree of centralization, decision data, granularity of decision, contractual degree, and 'metaness' and decision level. Overall, when comparing to traditional methodologies, blockchains support fine-grained, precisely defined, contract-oriented, decentralized, and low-level decision-making very well. These kinds of decisions can be automated in a consistent, distributed, and accurate way in blockchains. On the other hand, since the governance policy in blockchain is strictly encoded, the needed flexibility for some use cases may be lost. Among these seven sub-attributes, the metaness and decision level sub-attribute deserves more explanation. Meta-decisions (Wang 2000) can be regarded as decisions on the planning and realization of the decision-making process. A focus on meta-decisions encourages more carefully computed, goal-directed, deliberative, and controlled decisions, as opposed to defaulting, habitual, heuristic, and impulsive ones (Boureau, Sokil-Hessner & Daw 2015). A meta-meta-decision may be considered as a decision on the process on how to change the decision-making process. Thus, without a better term, we use the term 'metaness' to refer to how meta a decision is. A regular decision is usually a day-to-day, more decentralized business transaction decision. A decision with a high 'metaness' is usually more centrally decided in the higher board and managerial levels. Despite their importance, meta decisions are relatively understudied and in general not well supported by many IT technologies, such as databases. Unlike other traditional technologies, blockchains provide some support on meta-decision making, such as SC lifecycle, evolution and update, which represent changes in the decision-making processes. This opens up research opportunities in the study of meta-decisions.

For the privacy attribute, blockchains provide unique features for implementing nuanced privacy models required by a consortium. However, it also creates unique challenges. For example, in Nakamoto blockchain, an identical copy of the blockchain is stored in every full node. This is the nature of DLT. For performance and privacy reasons, some blockchains allow storing a subset of the blockchain in a specific node. It is important to design the blockchain and its network of nodes to ensure that private data should not be stored in nodes owned by organizations without the access right. This is because even if the private data is encoded, so long as it is stored in and thus physically accessible by an adversary or competing node, there is a chance the private data can eventually be decrypted. Future proofing in privacy concerns is thus uniquely challenging in blockchain development because of distributed data storage in blockchains.

For the incentive attribute, proper alignments also deserve further explanation. In traditional corporate governance, the popular agency model (Eisenhardt 1989) distinguishes between a principal who has ownership of a business (e.g., a stock holder), from an agency the principals relied on to handle the business (e.g., a manager). Proper incentive alignments of the agencies and principals are important and is deemed to be a third dimension in information systems design (Ba, Stallaert & Whinston 2001). This alignment includes disincentives for cheating the system and inserting distorting information (Ba, Stallaert & Whinston. 2001). The immutable, traceable, and verifiable DLT nature of blockchains can provide these disincentives well. Blockchains can also support positive incentives of good governance policies by SC. On the other hand, the agency model may need to be extended: (1) Consortium applications have principals and agencies across *multiple* organizations that can be both collaborators and competitors. (2) Agencies may no longer be persons, but SC, that execute the governance decisions. As a result, there is much room for innovation on effective uses of blockchain for incentive alignments.

Conclusion

When building consortium applications, governance issues such as accountability, privacy, incentive and trust need to be modeled from the beginning. Blockchains provide novel governance support that can disrupt our way of thinking about governance and its implementation. This paper presents a general framework of six governance attributes and 13 sub-attributes for modeling and implementing governance processes and models. Some of them are based on prior works, while others are newly proposed. The opportunities and challenges of blockchains listed in Table 2 represent possible future research directions and questions, especially in metaness, granularity, decision data, contractual degree of the decisions, and incentive alignments. The list of governance attributes are not exhaustive. The framework should be viewed as a starting point for exploring blockchain-created governance opportunities, and it needs to be field-tested, refined, and improved to achieve higher accuracy, relevance, and fidelity. Equally importantly, a more solid theoretical foundation, such as that based on design science, using a formal research method is currently missing, and it will need to be developed. Another goal of our group is to integrate governance into a proposed model-based process-driven blockchain application development methodology (Yue 2020), with the collection of best practices and design patterns for implementations in generic as well as in specific permissioned blockchain platforms. Our team has just started our work on a Phase II prototype grant of the MBSE model repository project, which will support expanding this work and remediating some of the mentioned limitations.

Acknowledgement

This work is partially supported by NASA's STTR program: 80NSSC19C0525 and 80NSSC21C0020. Kallempudi is partially supported also by National Science Foundation grant #1723596.

REFERENCES

Androulaki, E., Barger, A., Bortnikov, V., Cachin, C., Christidis, K., De Caro, A., Enyeart, D., et al., S. 2018. "Hyperledger Fabric: a distributed operating system for permissioned blockchains," *Proceedings of the Thirteenth EuroSys Conference, 2018*, pp. 1-15.

Ba, S., Stallaert, J., and Whinston, A. 2001. "Introducing a third dimension in information systems design: The case for incentive alignment," *Information Systems Research*, (12), pp.225–239

Bach, L. M., Mihaljevic, B., & Zagar, M. 2018. "Comparative analysis of blockchain consensus algorithms," *41st IEEE International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO),* pp. 1545-1550

Beck, R., & Müller-Bloch, C. 2017. "Blockchain as Radical Innovation: A Framework for Engaging with Distributed Ledgers as Incumbent Organization," in *50th Hawaii International Conference on System Sciences* (HICSS 2017). Waikoloa, Hawaii, USA.

Beck, R., Müller-Bloch, C., & King, J. L. 2018. "Governance in the blockchain economy: A framework and research agenda," *Journal of the Association for Information Systems,* (19:10), pp.1020-1034.

Bernabe, J. B., Canovas, J. L., Hernandez-Ramos, J. L., Moreno, R. T., & Skarmeta, A. 2019. "Privacy-preserving solutions for blockchain: Review and challenges," *IEEE Access,* (7), pp.164908-164940.

Boureau, Y., Sokol-Hessner, P. and Daw, N. 2015. "Deciding how to decide: Self-control and meta-decision making," *Trends in cognitive sciences,* (19:11), pp.700-710.

Chidamber, S. R., and Kon, H. B. 1994. "A research retrospective of innovation inception and success: the technology–push, demand–pull question," *International Journal of Technology Management,* (9:1), pp.94-112.

Cuadrado, J. S., Guerra, E., and de Lara, J. 2014. "A component model for model transformations," *IEEE Transactions on Software Engineering*, (40:11), pp.1042-1060.

Di Stefano, G., Gambardella, A., and Verona, G. 2012. "Technology push and demand pull perspectives in innovation studies: Current findings and future research directions," *Research policy*, (41:8), pp.1283-1295.

Dinh, T.T.A., Wang, J., Chen, G., Liu, R., Ooi, B.C. and Tan, K.L. 2017. "Blockbench: A framework for analyzing private blockchains," *Proceedings of the 2017 ACM International Conference on Management of Data*, pp. 1085-1100.

Eisenhardt, K.M. 1989. "Agency theory: An assessment and review," *Academy of management review*, (14:1), pp. 57-74.

Filippova, E. (2019, June). "Empirical Evidence and Economic Implications of Blockchain as a General Purpose Technology," in *2019 IEEE Technology & Engineering Management Conference (TEMSCON),* pp. 1-8. IEEE.

Frizzo-Barker, J., Chow-White, P. A., Adams, P. R., Mentanko, J., Ha, D., & Green, S. 2020. "Blockchain as a disruptive technology for business: A systematic review," *International Journal of Information Management*, (51), p.102029.

Hyperledger, 2021. "Hyperledger's Sawtooth," https://www.hyperledger.org/use/sawtooth, retrieved 1/5/2021.

Li, Z., Kang, J., Yu, R., Ye, D., Deng, Q., & Zhang, Y. 2017. Consortium blockchain for secure energy trading in industrial internet of things. IEEE transactions on industrial informatics, 14(8), 3690-3700.

Lumineau, F., Wang, W., & Schilke, O. 2020. "Blockchain Governance—A New Way of Organizing Collaborations?" *Organization Science*.

Miraz, M. H., & Ali, M. 2018. "Applications of blockchain technology beyond cryptocurrency," *arXiv preprint* arXiv:1801.03528.

Mingxiao, D., Xiaofeng, M., Zhe, Z., Xiangwei, W. and Qijun, C. 2017. "A review on consensus algorithm of blockchain," *IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, pp. 2567-2572).

O'Shields, R. 2017. "Smart contracts: Legal agreements for the blockchain," *NC Banking Inst.,* (21), p.177.

Pelt, R. V., Jansen, S., Baars, D., & Overbeek, S. 2021. "Defining blockchain governance: a framework for analysis and comparison," *Information Systems Management*, (38:1), pp.21-41.

Peters, M., Schneider, M., Griesshaber, T., and Hoffmann, V. H. 2012. "The impact of technology-push and demand-pull policies on technical change–Does the locus of policies matter?" *Research Policy*, (41:8), pp.1296-1308.

Rikken, O., Janssen, M., & Kwee, Z. 2019. "Governance challenges of blockchain and decentralized autonomous organizations," *Information Polity*, (24:4), 397-417.

Rozas, D., Tenorio-Fornés, A., Díaz-Molina, S. and Hassan, S. 2018. "When ostrom meets blockchain: Exploring the potentials of blockchain for commons governance." Available at *SSRN* 3272329.

Sklaroff, J.M. 2017. "Smart contracts and the cost of inflexibility," *U. Pa. L. Rev.,* No. 166.

Smit, K., el Mansouri, J., Saïd, S., van Meerten, J., & Leewis, S. 2020. "Decision Rights and Governance within the Blockchain Domain: a literature analysis," *PACIS*, p. 197.

Swan, M. 2015. *Blockchain : Blueprint for a New Economy*, O'Reilly Media, Sebastopol.

Tai, S., Eberhardt, J., and Klems, M. 2017. "Not acid, not base, but salt," *Proceedings of the 7th International Conference on Cloud Computing and Services Science,* SCITEPRESS-Science and Technology Publications, Lda, pp. 755-764.

Tricker, R. B., & Tricker, R. I. 2015. *Corporate governance: Principles, policies, and practices*, Oxford University Press, USA.

Wang, Z. 2000. "Meta-decision making: concepts and paradigm," *Systemic practice and action research,* (13: 1), pp.111-115.

Wood, G. 2014. "Ethereum: A secure decentralised generalised transaction ledger," *Ethereum project yellow paper*, No. 151, pp.1-32.

Xu, X., Weber, I., Staples, M., Zhu, L., Bosch, J., Bass, L., ... & Rimba, P. 2017. "A taxonomy of blockchain-based systems for architecture design," in *2017 IEEE International Conference on Software Architecture (ICSA)*, (3), pp. 243-252.

Yue, K. 2020. "Blockchain-Augmented Organizations, "*Proceedings of the 26th Americas Conference on Information Systems AMCIS*, 5.

Yue, K., Guerra, M., Wagner, H., Thamarai Selvan, J.S., Collector, K., Tang, V., Sikes, M., Sha, K., Kallempudi, P., Mardani, S. & Kasichainula, K. 2021. "Applying Blockchain Technology on Model-Based Systems Engineering," *AIAA Scitech 2021 Forum,* p. 0093.

Yue, K. 2021, "A Blockchain-Inspired, Multi-Layered Transaction Model for Business Process Modeling," to appear in *Proceedings of the 27th AMCIS*.

Zavolokina, L., Ziolkowski, R., Bauer, I. and Schwabe, G. 2020. "Management, Governance and Value Creation in a Blockchain Consortium," *MIS Quarterly Executive*, (19:1), pp.1-17.

Zhang, A., & Lin, X. 2018. "Towards secure and privacy-preserving data sharing in e-health systems via consortium blockchain," *Journal of medical systems,* (42:8), pp.1-18.

Zheng, Z., Xie, S., Dai, H. N., Chen, X., & Wang, H. 2018. "Blockchain challenges and opportunities: A survey," *International Journal of Web and Grid Services,* (14:4), pp.352-375.

Ziolkowski, R., Miscione, G. and Schwabe, G. 2020. "Decision problems in blockchain governance: Old wine in new bottles or walking in someone else's shoes?" *Journal of Management Information Systems*, (37:2), pp.316-348.