

Interoperability Supported by Smart Contracts in the Hyperledger Framework

Purpose:

This paper explores the challenges and opportunities of interoperability, supported by smart contracts in the Hyperledger Framework, and offers a bicycle manufacturer use case as an example.

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Abstract

This paper explores supply chain challenges and opportunities among multiple vendors and, potentially, multiple blockchain systems utilizing open-source Hyperledger frameworks.

Initially, the document summarizes the terms interoperability, centralization, and decentralization in the context of smart contracts. An exploration of how those concepts inform commercial market architecture is intertwined throughout. A bicycle manufacturing industry supply chain use case proposes how implementation of a permissioned blockchain smart contract addresses interoperability challenges.

Keywords: Interoperability, Hyperledger Framework, smart contracts, Trust over IP

Interoperability and Smart Contracts with Hyperledger

Smart contracts offer immutable tracking of product components in a supply chain. The Hyperledger Framework includes smart contract projects, Burrow, Fabric, Indy, Iroha, and Sawtooth (The Hyperledger Architecture Working Group, 2018). The premise of these projects is that, given correct permissions, a consumer, producer, distributor, retailer, or manufacturer views each step in the supply chain for tracking, compliance, and validation purposes. Smart contracts on the Hyperledger blockchain support permissioned access for automating business logic, transparency and trust. Interoperability continues to challenge wide adoption due to complexity among parties, lack of data standards and Internet of Things (IoT) challenges.

This paper offers a bicycle manufacturer use case (Chiu & Okudan Kremer, 2014) to provide context, issues, options, and recommendations toward addressing smart contract interoperability in the Hyperledger Framework. Brief descriptions and Business Process Modeling & Notation (BPMN) set the context for the use case.

Supply Chain Use Case

The complicated architecture of commercial supply chain markets, throughout history, has often been resolved with innovations such as standardized shipping methods and global trade coordinating bodies. These innovations led to vast improvements in efficiency, cost reduction, and the integrity of processes (Allen, Berg, Davidson, Novak & Potts, 2018). Developing nations' increased roles in world trade (Ali & Stancil, 2009) accelerated the disbursement of parties communicating worldwide. This created requirements for new cutting edge ideas that support fault tolerance, scalability, and maintenance, transportation, and regulatory costs (Allen et al., 2018). Complexity in world trade creates a priority for trust, incorruptibility, data integrity, and information cost reduction (Allen et al., 2018). Interoperable blockchain technology forms a

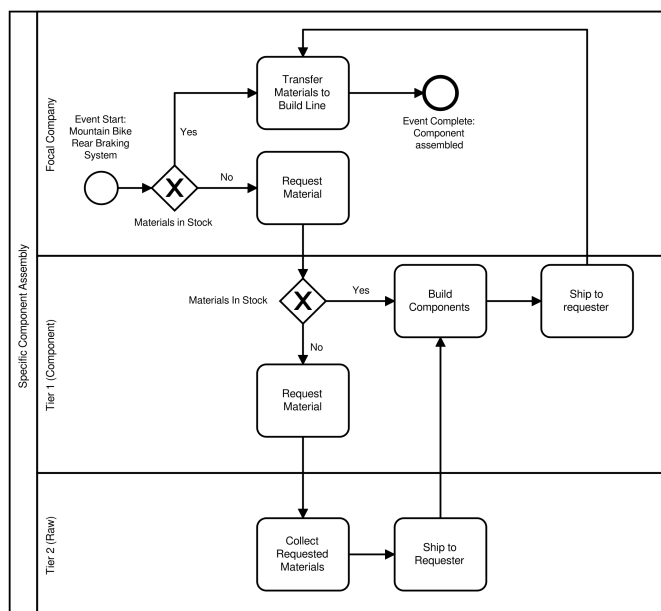
decentralized economic structure that improves upon, or possibly resolves, many of these complications (Allen et al., 2018).

Immutability and data integrity directly affect the widespread adoption of smart contract blockchain technology. A manufacturer must trust materials will arrive on time from designated suppliers (immutable) and follow contracted specifications, pricing, and provenance (data integrity). Likewise, if a supplier is unable to trust payment terms, contracted timetables, or change requirements to the order, they will cease to supply the business with the materials and goods ordered. Immutability and data integrity serve to alleviate these concerns, providing suppliers and manufacturers with a redundant system of checks and balances to ensure trust in smart contracts.

For example, in the bicycle supply chain use case, noted in Figure 1 below, a supplier of rear braking systems needs a guarantee that a predetermined number of seats requisitioned includes details, specifications, and delivery instructions.

Figure 1

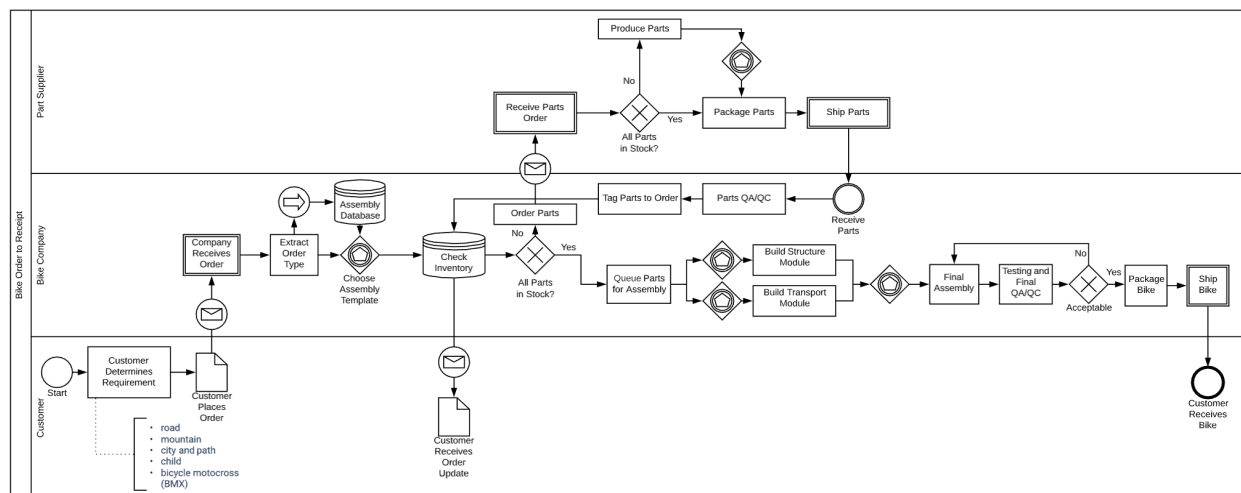
Detailed BPMN of bicycle use case parts supply chain



It is important to note that if data are corrupted, changed, or tampered with, valuable time and resources are wasted correcting the issue. Costly delays, due to multiple transnational suppliers and numerous bicycle parts in the supply chain, as shown in Figure 2, can lead to a potential loss of contract. In addition, confidentiality is important in smart contracts that should consumer minimally shareable information to produce a new state, particularly used in enterprise and commercial applications; however, “it also requires cryptographic integrity to enable participants to be confident the smart contract is the one they agreed to use and hasn’t been tampered with” (<https://www.ibm.com/blogs/blockchain/2020/02/confidentiality-and-integrity-for-blockchain-smart-contracts/>).

Figure 2

Bicycle manufacturing supply chain use case shown in BPMN



Note. <https://wiki.hyperledger.org/display/SCWG/BPMN+-+Bicycle+Use+Case>

Bicycle Manufacturing

The bicycle manufacturer’s use case posits vendor and customer gaps and issues with smart contract interoperability. In manufacturing, it is essential to design the supply chain during the early stages of new product design (Chiu & Okudan Kremer, 2014) rather than after the

product is completed with detailed design. A critical decision in the paper's use case is how to address the platform architecture. Digital Asset, developers of the Digital Asset Marketing Language (DAML) programming language, present three options: fully centralized; distributed ledger with untrusting participants; or distributed ledger with untrusting operators (Digital Asset, 2016). To better understand the choices that serve as a foundation for a supply chain framework, it is vital to understand the differences between centralized and decentralized systems.

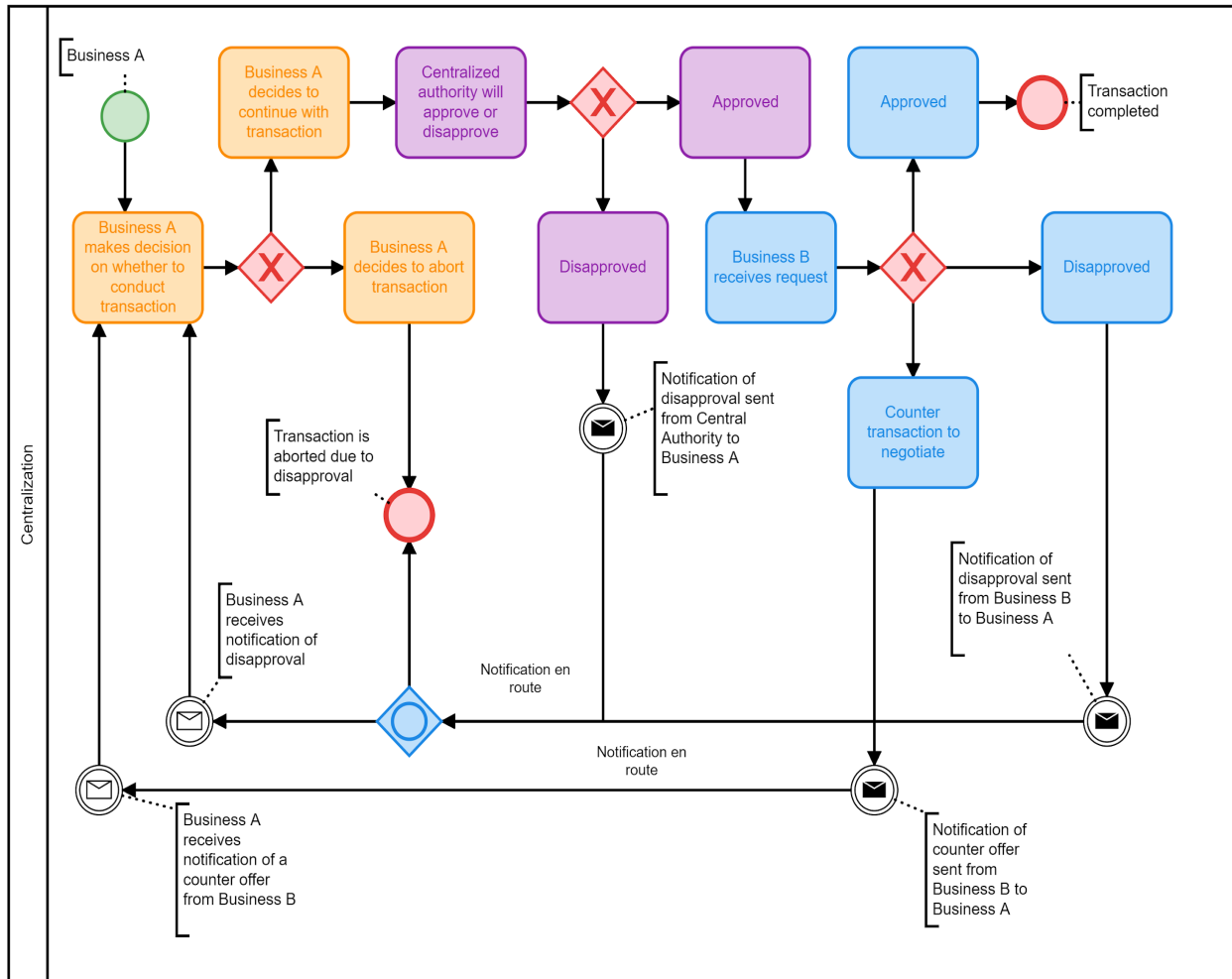
The framework selection decision regarding centralization or decentralization hinges on speed versus cost performance. The agility and speed of manufacturing is achieved through decentralized supply chains, and improved cost performance are found in centralized systems. These improvements gained by each system trade-off against the advantage of the system not chosen.

Centralization

Centralization serves less dynamic, more homogeneous market requirements with a clear chain of command, focused vision, reduction of costs priority, quick implementations of decisions, and improved transactional quality (CFI Education, Inc., 2015-2020). The diagram shown in Figure 2, below, provides a visual example of how a centralized business transaction functions between Business A and Business B:

Figure 3

Centralized Business Transaction Process



Note. All operations shown in purple highlight are the centralized part of the business transaction process between Business A and Business B.

Centralization causes communicational disconnects due to its inherent and often excessive bureaucracy. This method may lead to nonessential processing steps, inaccuracies, and a decreased motivation to promote integrity within the operation that allows for the corruption of the resulting interaction. The main reason that centralization was chosen, in terms of the bicycle use case, is that a centralized supply chain produced a cost savings of 3%, on average, due to complete control (Chiu & Okudan Kremer, 2014). However, with centralization, productivity is negatively affected because of unnecessary accumulated processing times, financial burdens, and

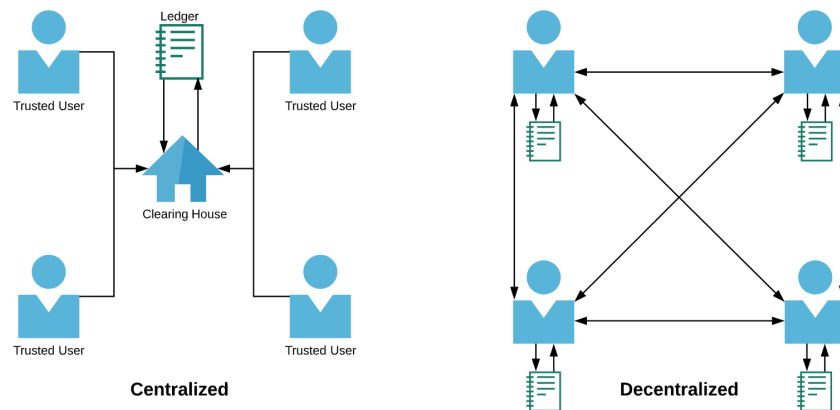
redundant workforce requirements (CFI Education, Inc., 2015-2020). Such is the reason that the technology sector asserts that the decentralized structure inherent to blockchain, combined with interoperability, addresses contradictions in the historic business transactional schema.

Decentralization

Blockchain decentralization accommodates a global supply chain because all parties can transact, independently with each other, and all have equal rights on the network (Rutland, 2007). A representation of centralization and decentralization concepts is featured below in

Figure 4

Centralized vs. Decentralized and Distributed Transactions representation



The decentralized network shown demonstrates an end-to-end principle where a distributed, trustless environment operates with no single point of failure. With the help of a decentralized network, the transactions are faster among users without the need to trust other users. The use of cryptography ensures that information and transactions are secure. In contrast to a centralized network, there is no need for a central server as an acting agent for communications in a decentralized network. Encryption of data among peer-to-peer (P2P) connections allows users to perform device encryption without the need for administrator rights

to ensure data integrity and confidentiality. Industries that adapt supply chain models from centralized to decentralized, and implement smart contracts, enhance transparency and efficiency. The bicycle use case benefits most from a decentralized supply chain in the agility decentralization provides. On average, a decentralized supply chain realizes 11% (2-component) and 21% (3-component) lead time improvement for assembly modules, respectively (Chiu & Okudan Kremer, 2014).

Smart Contracts and Permissioned Blockchains

An essential feature of blockchain is transparency; all nodes in the chain can view all data. In permissioned blockchains, there is a trust boundary between nodes inside and outside of the system. Data access control determines blockchain membership and the ability to read or write data within protected nodes. Write access from outside the system is restricted to maintain data integrity. Read access from outside the system is restricted or not allowed to maintain data privacy. An underlying platform/framework ensures data integrity through means of verification and provides mechanisms to read and protect data. Hyperledger Fabric provides a membership service that uses an access control list to determine who is allowed to read or write to the ledger or event streams. The architecture of a permissioned blockchain utilizes supportive policies, arranged to lay the groundwork for access control. These policies are data-dependent, time-dependent, provenance-dependent, and aggregate (Dinh, Datta & Ooi, 2019). Validation of data checks dispute conditions and verifies whether claims in the chain prove as legitimate or invalidated. Predicates are predetermined external contracts used to implement this functionality (Ethereum Optimism, 2019). Data Dependent policies confirm the accuracy of these predicates and govern user access based on the result of this analysis. Provenance-dependent policies work conjointly with data-dependent policies to review the integrity of predicate realization and

traceability. Upon fulfillment of these built-in audits are appropriate users established and granted access within the smart contract.

Blockchains require an eventual conclusion set. The cessation of a smart contract is set using a time-dependent policy that ends after a certain number of blocks within a blockchain execute. Within a multi-party transactional setting, involved individuals receive contractual information, prearranged as appropriate and allowable to obtain. Aggregate policies are included within these agreements to partition specific summaries of data to individuals preassigned to receive that distinct set of information. These business logic policies enable smart contracts to process transaction requests accurately and determine their validity within a distributed, multi-party setting. As in the bicycle use case example, smart contracts allow two parties to transact without a centralized, trusted third party. The importance of smart contracts in enterprise solutions regarding supply-chain can be derived by the fact that the pioneering real-world applications were about this crucial industry. A case study titled, “How Walmart brought unprecedented transparency to the food supply chain with Hyperledger Fabric” can be found at the Hyperledger official website. The study describes how Walmart and IBM implemented blockchain technology to achieve the required decentralization and transparency needed by the food supply ecosystem (<https://www.hyperledger.org/>). Hyperledger Grid, a platform for building supply chain solutions that include distributed ledger components, was adopted as an open project under the umbrella of Hyperledger. Grid provides a set of modular components for developing smart contracts and client interfaces, including domain-specific data models (such as GS1 product definitions), smart-contract business logic, libraries, and SDKs for supply-chain-centric data types based on industry best practices (https://grid.hyperledger.org/docs/grid/nightly/master/about_grid.html).

Interoperability

Interoperability, within the parameters of computer science, is defined as “the ability to exchange and use information, usually in a large heterogeneous network made up of several local area networks” (The Trustees of Princeton University, 2020). Within the supply chain manufacturing setting it is not enough to support multi-party contracts. There is a need “...for today’s supply chains to become 43% more global in the next decade to stay competitive...” (Hult, Closs & Frayer, 2014, p. 4). Interoperability effectively supports contract design in a dynamic framework across international regulations, programming languages, and technologies that vary from legacy to emerging. These demands inevitably lead to challenges during planning stages for smart contract composition.

Interoperability Challenges and Opportunities

Obstacles faced while attempting to implement interoperability within the supply manufacturing environment are often about hindrances concerning disparity between corporate systems. When organizational operating environments are individualistic in this way, barriers become apparent quickly upon attempts to actualize interoperability with another company’s schema. Issues that hamper interoperability often fall under the category of either: 1) business, or 2) technology.

Business

The bicycle manufacturing use case demonstrates components passed among multi-party supply and manufacturing businesses. A clean interoperability plan to transfer data utilizing a blockchain smart contract among chains mitigates complicated information tracking challenges.

Blockchain smart contracts address a multitude of supply chain interoperability issues. Prearranged agreements, meticulously constructed, give all involved parties due consideration.

Some of the essential layers of interaction that transactional participants examine include Governance policies and standards, Semantics concerning trust protocols, Syntactic as layer supporting messaging format, and Technical, pertaining to the wire protocol (Abebe et al., 2019). For global industries to collaborate utilizing blockchain smart contracts to resolve these layers, commonalities of value are needed to support international governance. These standards are flexible enough for diverse international regions to adopt. Developing credential formats in an Intellectual Property Rights (IPR) protected place is not sufficient. For interoperability, a credential from system A can be consumed in system B, and identities of system B can issue credentials in System A. This distributed aspect of administrative planning is similar to the technical elements; blockchain smart contract frameworks are portable and support global supply chain ecosystem adaptability (Meszaros et al., 2020).

Resolutions to these challenges are explored and applied through various means. For example, the non-profit GS1 tackles common language and global standard differentiation issues within supply chain governance and supports international trade efficiency (GS1, 2020). The GS1 Global Data Synchronisation Network (GDSN) lays the groundwork for product information sharing to mechanisms such as:

- Globally unique identification keys
- Location information - Global Location Number (GLN)
- Automatic data capture through barcodes, and Electronic Product Code (EPC) / Radio-Frequency Identification (RFID)
- Data networks that support the exchange of business-critical information

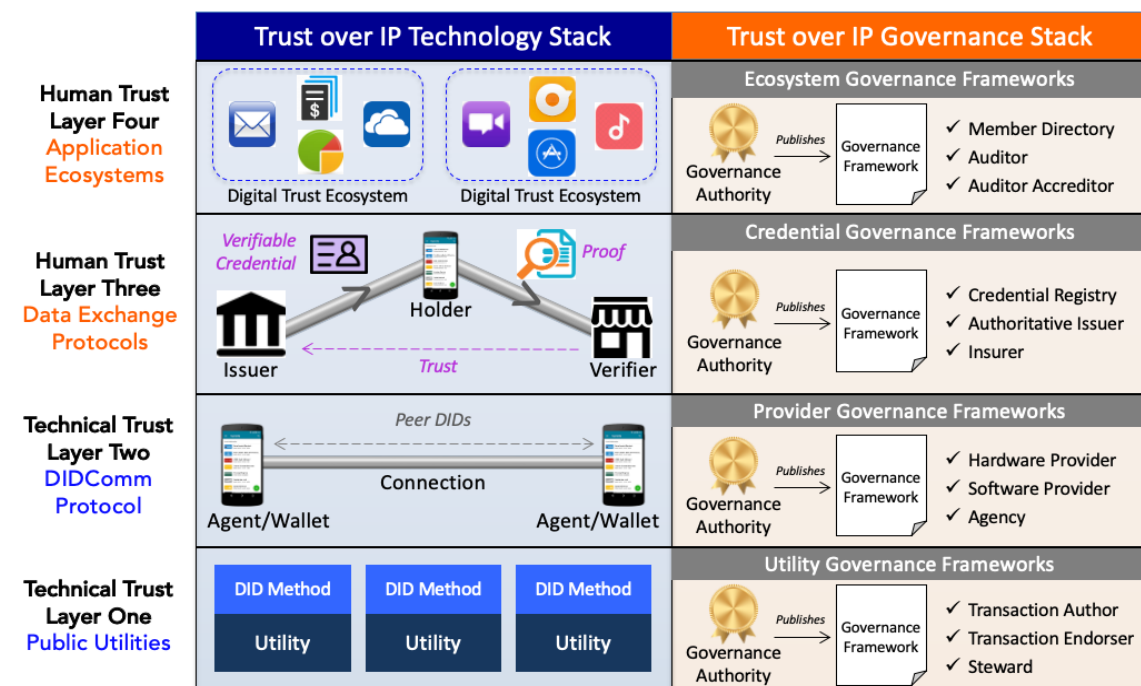
GS1 standards address language commonality issues by providing a global, adaptable framework, implemented in 114 countries, and supporting supply chain traceability and

interoperability (GS1, 2020). This structure provides a schema that discourages illicit trade and increases data integrity throughout international industrial communications, to include physical or legal location information critical for supply chain logistics. A more granular ability to define product data elements is often required. Further research will explore Hyperledger Grid and Sawtooth, to test and review implementation with the bicycle use case.

Governance is notoriously diversified across the globe. This diversification causes a lack of congruence within standards among communicating institutions and contrasting opinions concerning transforming cross-corporate regulations into a unified format. The inherent decentralization of a blockchain smart contract structure requires governance in the initial planning and composition of the framework, as opposed to the decisions of a centralized third-party. For example, the Sovrin Foundation Trust over IP (ToIP) stack notes the need for governance at every layer of the stack.

Figure 5

Sovrin Foundation Trust over IP stack representation



A clear, usable governance framework serves as a guide to be adopted by countries and organizations. Interoperability is improved when governance frameworks are clear and adapt to local laws and regulations. Conflicts ranging from General Data Protection Regulation (GDPR) misinterpretation to proprietary datasets slow development and implementation. The information must be shared for a smart contract to function. In the bicycle use case, if a bicycle manufacturer commits significant resources into redesigning its braking system, applies new materials to gears to increase product lifespan, or redesigns the flow of the drive mechanism, resources placed into the research and development are significant. Legal, regulatory, compliance, and logistics rules interact to protect this valuable information from global competition.

Resolving interoperability barriers encourages global smart contract adoption and improves the functionality, consistency, performance, and scalability of blockchain smart contract processes. Smart contracts enable parties to be free of centralized restraints, support data integrity, and immutability in multi-party agreements and create a foundation that supports free trade. The inability to alter smart contract blockchain data underpins an incorruptible foundation for corroborating interoperability within transnational business exchange settings. In countries where free trade is limited, heavily regulated, or entirely under the control of a centralized authority, the need for smart contracts becomes essential. Maintaining the integrity of original agreements ensures that trust is immutable and transparent between parties. In the bicycle use case, blockchain and smart contracts add the ability to record all parts' origination and logistics. Smart contracts data support legal remediation among conflicted parties.

Technical

Technical interoperability challenges include the various industrial tools, applications, and mechanisms utilized across organizations. The distribution of modern networking systems

requires business communication architectures to maintain dynamic organizational structures, products, hardware, and software that cannot be easily substituted (Blair et al., 2011). These challenges introduce conflict into interoperability decisions, while chain specialization contributes to rigid structures and functions. Variability in company application configurations and programming languages creates compatibility obstacles. For example, if three bicycle parts suppliers communicate in an interoperable transaction with one specific framework, the contract only takes place if all companies involved access and utilize applications that interact with the chosen framework. Blockchain frameworks perform particular functions and support proprietorship goals. Another technical challenge is different unique identifiers for identical items. If incompatible bicycle parts identification mechanisms interact across platforms for transactional logistics purposes, barriers to interoperability ensue. If a bicycle part uses different identifiers among companies, complicated interactions in the smart contracts reduce the capacity to identify products and complete transactions accurately. The time for the bicycle manufacturer to complete contractual functions increases due to resulting additional information checks; inefficiencies create business risk versus benefit issues and may halt attempts at interoperable communication altogether.

Privacy and information sharing are challenges with interoperability. When changes are made to any data, all parties benefit by knowing who, when, why, and what data changed. Smart contracts support transparent and timely data tracking challenges. For example, Known Traveler Digital Identity (KDTI) shares selected data with specific sources. KDTI applies to the bicycle use case smart contracts by providing appropriate information to relevant authorities. Denying a full release of data keeps proprietary information confidential and safe from competitors. “Verified Credentials are shared by the Traveler only after informed consent to Verifiers using

private, secure communication channels.” (Bachenheimer, 2020) KDTI potentially allows more businesses to take risks in smaller, untapped markets otherwise ignored due to inherent risk.

Current methods of database management often include a back-end programming that allows users, with specific permissions, to make untracked modifications using SQL or similar coding methods. Flagship ERP vendor implementers often build an external ETL-EDI-ETL data integration layer to bridge different systems. More so now that SQL is locked down by cloud ERP vendors. A greater impetus for federated smart contracts and distributed ledger technology (DLT) support the development of smart contract tracking methods that do not allow back-end modifications and keep data intact. All parties involved with the transactions remain confident data provided are untampered (George, 2020). One option to address these challenges includes Hyperledger Fabric’s Pluggable ordering service (consensus) or Hyperledger Sawtooth’s Dynamic Consensus which isolates the agreement among the participants from the transaction semantics. The transition to execute-order-validate architecture and flexible endorsement policies, have, over the past couple of years, eliminated some of the potential bottlenecks for smart contracts such as, “...current blockchain platforms, especially the recent permissioned systems, have architectural limitations: smart contracts run sequentially, all node executes all smart contracts, consensus protocols are hard-coded, the trust model is static and not flexible, and non-determinism in smart-contract execution poses serious problems” (Lokam, 2017). Portability, in technical interoperability for blockchain smart contract implementation, can be promoted with the pluggable framework Hyperledger Transact (Meszaros et al., 2020). Universal adoption barriers supported with an open-source, interpretable programming language create multi-party smart contract applications versatile enough for use in diverse industries, with varying levels of technical skill (Digital Asset Holdings, LLC., 2020; Lambert, 2019). Due to the

diverse nature of the blockchain frameworks currently used, significant challenges for interoperability are the support of cross-chain transactions, efficient read-transactions, and transaction concurrency (Tien Tuan Anh Dinh et al., 2019). All the above are inherent limitations because of the blockchain smart contracts security features that prohibit these functions from communicating with the outside world. A proposed solution is the “oracles,” which are capable of feeding the blockchain’s smart contracts with real-world data and messaging between external messages.

Future research plans include Proof of Concept (PoC) and prototype development of the full bicycle use case (see Appendix A) across Hyperledger Projects Sawtooth, Grid, and Burrow, to analyze potential smart contract implementation challenges and opportunities. Further analysis will include Grid evaluation in two parts, with Sawtooth as underlying blockchain and with Scabbard as underlying smart contract engine. Required time to design, challenges with interoperability, and performance metrics will be explored.

Conclusion

Blockchain smart contract applications introduce many constructive developments in the future of supply chain interoperability. In an IBM Corporation report of conversations with 2,965 C-suite executives, one Chief Marketing Officer stated, “Blockchain can bring transparency to the supply chain and make our image more trustworthy and reliable” (IBM Corporation, 2017, p. 10). In some cases, businesses may be compelled to adopt smart contract blockchain technology to address regulations that require the functionality of an interoperable blockchain smart contract. For example, the U.S. Drug Supply Chain Security Act (DSCSA) 2023 pushes the pharmaceutical industry to quickly improve upon supply chain traceability in an interoperable manner to address supply chain logistics in at least 17 countries (Colombo et al., 2019). Some

experts in the manufacturing industry surmise that the pharmaceutical industry will soon take the lead on blockchain smart contract usage (Meszaros et al., 2020).

Blockchain smart contracts, designed to support interoperability among global multi-party transactions, serve as a fundamental mechanism to meet transactional requirements of modern trade demands. Open-source smart contract projects, such as the Hyperledger frameworks, offer the flexibility required for businesses to select an architecture that prioritizes adaptation and inclusion of their organization's unique negotiation conditions into transactions. These technical options, combined with the governance of international supply chain regulations and traceability tools, such as those developed by GS1, construct a substantial foundation toward real-world, interoperable trade environments. As the global trade sector now has open-source access to the resources required to properly begin implementation of blockchain smart contracts, the valued principles of data decentralization, data protection and immunity, cost reduction, and fraud prevention can be satisfied for bicycle manufacturers and others in the supply chain ecosystem.

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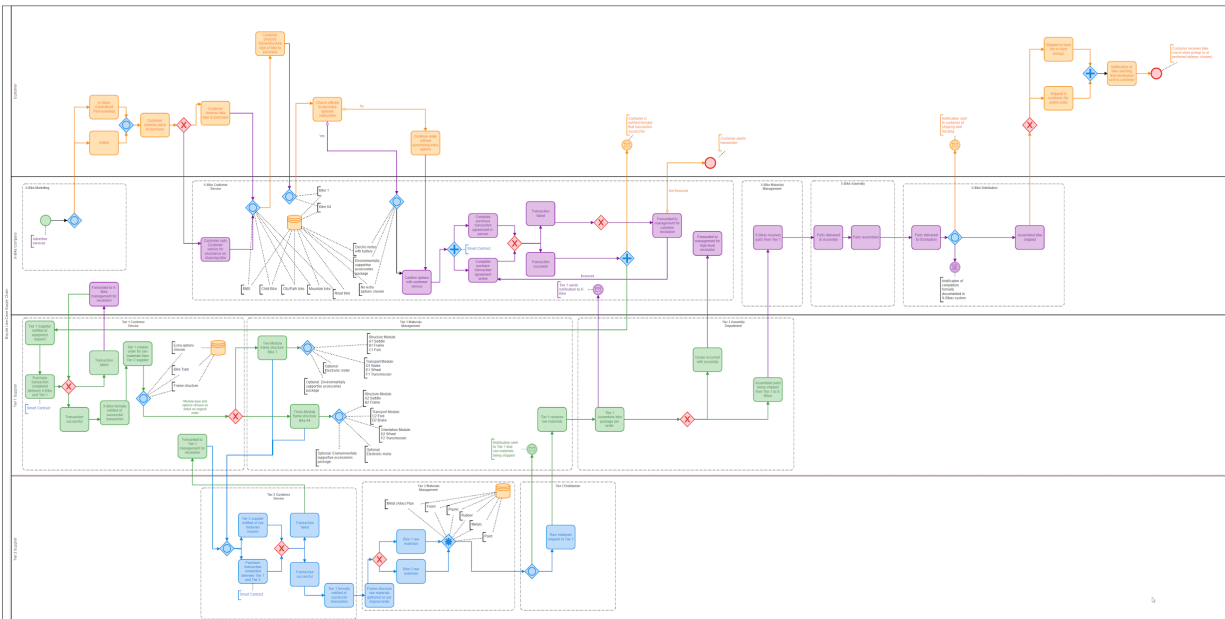
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Appendix A

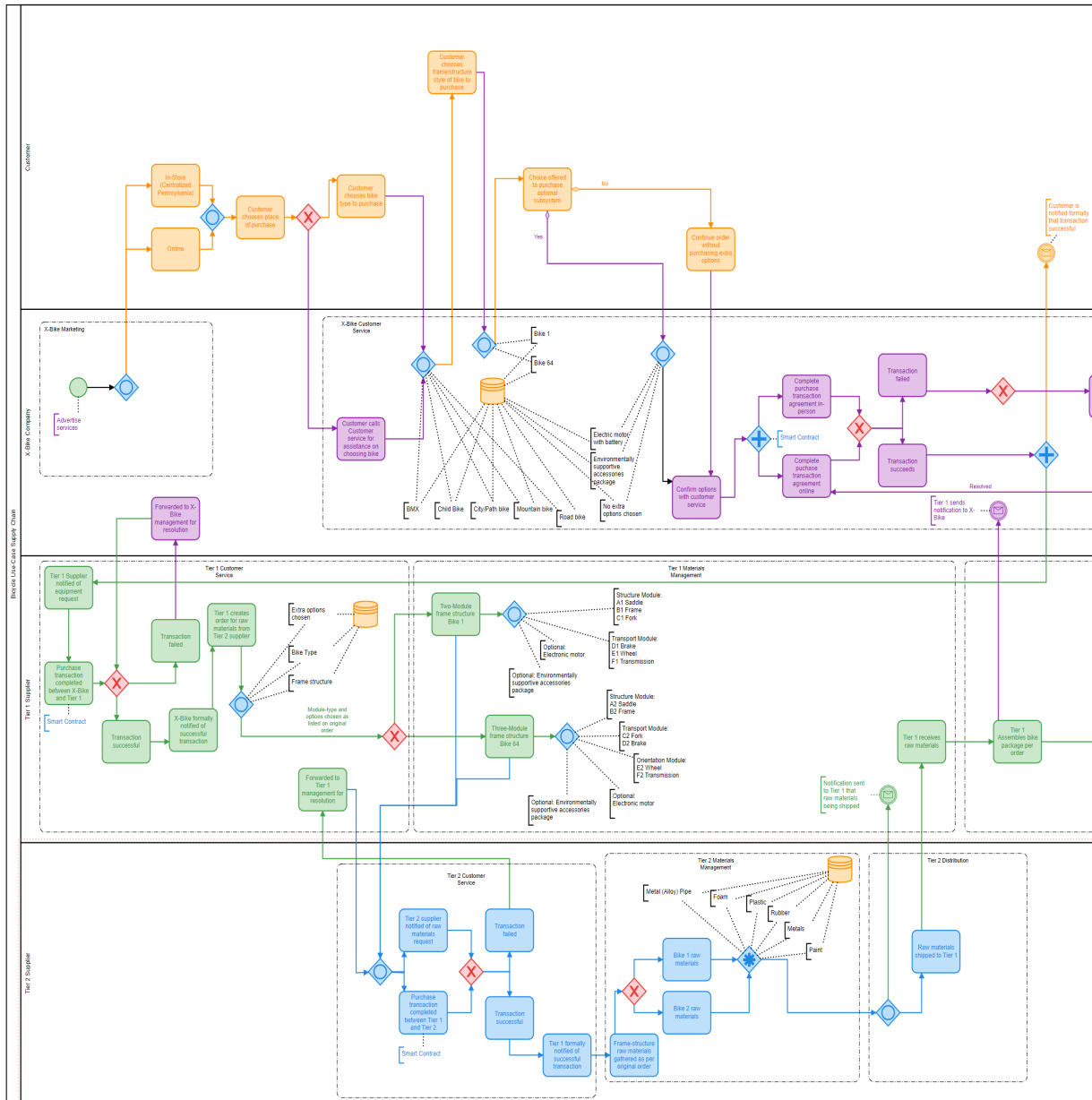
Appendix A1: Detailed BPMN of the bicycle manufacturing supply chain process.

<https://cawemo.com/share/d8d1ac46-3dc4-4561-8578-4997f69c7f39>

<https://wiki.hyperledger.org/display/SCWG/BPMN+-+Bicycle+Use+Case>



Appendix A2: Left detail BPMN of the bicycle manufacturing supply chain process.



Appendix A3: Right detail BPMN of the bicycle manufacturing supply chain process.

