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Context-Aware Blockchain-Based Sustainable Supply Chain Visibility Management

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Abstract

Supply chain visibility allows a state of being able to see end to end in a supply chain. Sustainable supply chain visibility is premised on sharing of mutually benefiting information, to achieve associated sustainability objectives including those related to economic, environmental and social goals. Sustainable supply chains strive for distinctive visibility with its attendant benefits that include improving and strengthening the supply chain for competitive advantage. Advances in technology such as blockchain technology can help facilitate effective management of sustainable supply chain visibility and in delivering associated benefits. The relational characteristics of blockchain and sustainable supply chain visibility has recently been reported in the literature with some emphasis on the capacity, capability and context of sustainable supply chain visibility. This paper explores a notion of context-awareness and blockchain in relation to sustainable supply chain visibility. A landscape for an architecture of a blockchain-based sustainable supply chain visibility management platform centred on context-awareness is suggested. The main thrust of the considerations is provisioning of secure, auditable and mutually benefiting sustainable supply chain information sharing, for distinctive visibility, in heterogeneous context-aware scenarios whilst recognising the underlying characteristics of sustainable supply chain visibility.

Keywords: Supply chain; visibility; sustainability; blockchain; context awareness

1. Introduction

A sustainable supply chain is a system of stakeholders, information, and resources involved in flow of goods and/or services from suppliers to customers, with the added responsibility of avoiding the depletion of natural resources to maintain ecological balance. Hence the objectives of sustainable supply chain include those associated with sustain-

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ability such as economic, social and environment goals. Central to sustainable supply chain is quality information, visibility, and good decision making.

In a supply chain, visibility is the extent to which actors within the supply chain have access to timely and accurate information that is considered key or useful to the chain's operations [1, 2]. There are several advantages for supply chains in having good visibility. The advantages include a) ability to achieve higher level of market responsiveness, b) mitigate the risk of disruptions to flow of materials and products, and c) derive competitive advantage [1, 3, 4]. Without an appropriate level of visibility, a sustainable supply chain will find meeting its sustainability objectives challenging. Hence the need for sustainable supply chains to better manage visibility.

This paper focuses on an approach to managing sustainable supply chain visibility (SSCV) based on advances in digital technologies. The technology emphasis in this paper is on blockchain. Simply, a blockchain is a chain of blocks in which the blocks are digital pieces of information and the chain refers to its storage in a database. Blockchain provides a decentralized and distributed public ledger for all participating parties. The blockchain has come to be recognized as a driver of digital economy with applications in a wide variety of domains including in supply chains e.g. [5, 6]. The inherent characteristics of blockchain technology such as privacy, security, and smart contracts [7] can provide much needed support for managing visibility in sustainable supply chains. In this paper, a landscape for an architecture of a blockchain-based sustainable supply chain visibility management system is presented with an emphasis on context awareness.

The remainder of this paper is structured into four sections. Section 2 contains a background on sustainable supply chain visibility, its characterisations and the need for visibility management. An overview of blockchain in sustainable supply chain visibility is contained in Section 3. The landscape of the architecture for a context-aware blockchain based sustainable supply chain visibility management platform is motivated in Section 4. The paper ends in Section 5 with concluding remarks and recommendations for future work.

2. Sustainable Supply Chain Visibility Management

In 'traditional' supply chains, visibility is defined by [2] as 'the extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit'. Central to this definition is the envisioning of informational linkages of mutual benefit to actors in the supply chain. The concept of linkages in supply chain expresses the 'explicit and/or implicit connections that a firm creates with critical entities of its supply chain in order to manage the flow and/or quality of inputs from suppliers into the firm and of outputs from the firm to customers.' [8]. External and Internal informational linkages both contribute to supply chain visibility [1].

Sustainable supply chain visibility extends traditional supply chain visibility to encompass economic, environmental, and social objectives of the supply chain. Extending the definition of [2] and incorporating sustainability dimensions, sustainable supply chain visibility in this paper is defined as the extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit in achieving sustainability objectives. It is a state of being able to see end to end in a supply chain premised on the chain's actors sharing mutually benefiting information to achieve associated economic, environmental, social and cultural objectives. Four visibility impact areas and emerging themes regarding sustainable supply chain visibility were identified by [3], namely a) realisation of quality information in supply chain ecosystems, b) advances in technology, tools, and the critical role of industry 4.0, c) reference models, architectures and frameworks, and d) creating integral value for stakeholders. Central to the identified areas is the effective management of sustainable supply chain visibility, using appropriate technology.

Adopting the three bottom line notion of sustainability, [9] defined sustainable supply chain management as 'the management of all activities within interdependent supply networks through the strategic development of relational capabilities, driven by extrinsic and intrinsic drivers, with the goal of continuously improving the performance of all members of the networks in all three dimensions of sustainability over an extended period of time'. The definition underscores the importance of cooperation among partners. It also draws upon relational practices as well as antecedent of sustainability efforts including morality-based drivers and need to meet the requirements of customers and stakeholders. In the case of sustainable supply chain visibility management, there is the added focus on information sharing and its antecedents as a backbone of visibility in sustainable supply chains.

An understanding of the characteristics of supply chain visibility is important for effective sustainable supply chain visibility management. [10] categorises the main characteristics of supply chain visibility as automational, informational, and transformational. The automational characteristics expresses timely use of information and communications technology in capturing and transferring of necessary information. The informational characteristics captures managerial capability deployed to improve the quality of the exchanged information, and/or for channelling information flow. Whilst the transformational characteristics is about aligning accessed information with the business processes to create business value through improvements in operational efficiency and strategic competencies.

Following the idea put forward in [11] regarding incorporating green absorptive capacity as a variable in the framework for sustainable supply chain visibility, [12] identified green absorptive capacity, dynamic capability, and context as three important distinguishing characteristics of sustainable supply chain visibility. Absorptive capacity refers to an organisation's ability to recognise the value of new external information, absorb it, and apply it to commercial ends [13] and it is commonly described to consist of four processes of acquisition, assimilation, transformation and exploitation [14]. Dynamic capability is the ability to integrate, build, and reconfigure internal competences to address and/or make happen changes in the business environment[15].

This paper extends related work on blockchain-based sustainable supply chain visibility management to incorporate context-awareness. In this paper, context refers to the circumstances that form the setting for sustainable supply chain visibility, in terms of which it can be fully understood and managed. Context is important in sustainable supply chain management and it has been argued that the information shared in supply chains should not only be complete, objective and accurate, it should also be in the right context for it to be effectively used [16]. Visibility in supply chain contexts can be a complex issue to manage. For example, [17] noted that in the context of humanitarian organisation there is the added challenge of the temporary status of relief operations. Overall, conceptualisation of visibility in supply chains should include alignment of viewpoints, context, purpose and actions through information sharing and collective learning to arrive at a shared goal [17].

3. Blockchain in Sustainable Supply Chain Visibility

A blockchain consists of a growing list of digital records (blocks) and storage in a distributed database linked (chain) using cryptography for security. Each block contains a cryptographic hash of the previous block. It stores timestamped transaction information. Blockchain provides an electronically decentralized and distributed public ledger for all participating actors. A distributed ledger is a consensus of replicated, shared, and synchronized digital data distributed and without central administrator. Nodes in blockchain groups transactions into blocks. The nodes have responsibility for determining whether a transaction is valid and whether transactions should be kept in the blockchain.

Blockchain requires peer-to-peer network and associated algorithms such as consensus algorithms for ensuring replication across nodes, verifying transactions, and ensuring immutability of the chain [18]. The consensus protocol is central to blockchains as the protocols are used for reaching consensus regarding information sharing, replicating state, and broadcasting transactions, among participating actors. The responsibility for monitoring, executing and enforcing a contractual agreement in blockchains is vested in the concept of smart contract [7]. In blockchain systems, smart contract codes automatically execute when predetermined terms and conditions are met.

From a network management and permissions viewpoint, blockchain can be categorised as either public, private or federated [19]. Anyone can join as a new anonymous user in public blockchain and allowed to perform operations such as transactions or contracts, permission less. Public blockchains are secured using a mixture of cryptographic verification and economic incentives, referred to as crypto economics. Both private and federated blockchains are permissioned blockchains. Only a specific organisation has the authority to join a private blockchain network to carry out a new transaction and to contribute to the consensus mechanism. A federated blockchain is a mixture of public and private blockchains operated under a group of entities and allows for a partially decentralised design where leader nodes can grant permissions to other users.

Blockchain based supply chain applications are increasingly being reported in the literature. The applications include [5, 20, 21, 22, 23], covering a variety of operations and supply chain functions and practices. Blockchain has also been integrated with digital technologies such as Radio-frequency identification (RFID) and Internet of Things (IoT) to facilitate supply chain transparency and traceability [5, 20]. Blockchain is known to be beneficial to supply

chains and can facilitate informational security and accuracy, technological advantages, improvement of supply chain collaboration and trust, reducing economic loss and product waste, sustainability and transparency [5]. According to [24], blockchain critical success factors for sustainable supply chains are accessibility, customer satisfaction, data management, safety and decentralization, documentation, laws and policy, overall cost, overall performance, quality reliable system, smart system, and system robustness. Blockchain presents some challenges. The challenges include scalability, security and stability requirements, design constraints, system performance, transaction capacity, and data accessibility [25]. Some of the challenges can be contextual such as social, cultural and institutional including legal and regulations issues.

[12] highlighted relational characteristics of blockchain and sustainable supply chain visibility. The blockchain characteristics of accessibility, quality, transparency, traceability, smart contract, trust and decentralisation are reported to make the blockchain technology attractive for supply chain visibility particularly in support of the automational (the ability to access information) and informational (the quality of the information) characteristics of supply chain visibility. Blockchain technology makes information sharing easier, facilitates real-time analysis and enables two or more actors to work simultaneously on the same kind of information. Hence, resulting in a better prospect for the transformational (the utilization of information) characteristics of sustainable supply chain visibility. Blockchain can deter trust issues to come in the way of information sharing. Choice of public, private and federated blockchain can also be a significant decision as completely public or a completely private ledger architecture for information sharing may fail to address the requirements of supply chain visibility applications. Using a completely public or a completely private ledger architecture for information exchange may fail to address the requirements of various applications including supply chain visibility applications [26].

4. Landscape of an Architecture for Context Awareness in Blockchain-based SSCV Management

Context is a complex notion and has been expressed in a variety of ways across many different research disciplines. Primarily, context is the set of circumstances that form the setting for an entity and facilitates an understanding of the entity. An entity is a person, place, thing or object that is considered relevant to the interaction between a user and an application. The generally accepted definition of context, used widely in context-aware recommender systems, is adopted in this paper, expressed by [27] as 'any information that can be used to characterise the situation of an entity'. This is a representational view of context in which a main assumption is that context is a form of information [28], such as location, temporal, and social information. Context is made of several elements. According to [29], the elements consists of interacting entities or stakeholders, the objective of the interaction, and the time and place of the interaction. Data structures for context will typically include a unique name that identifies the context, set of relevant features associated with the context and range of values each of the feature can take [30]. Entities may depend on partially observable or unobservable contexts that can present in situations where some of the relevant contextual factors are unobservable or inaccessible. To leverage context, the system needs to be context aware.

Context-awareness is the capability of an entity to sense and adapt to the relevant part of its environment, using reasoning mechanisms. Context-awareness is relevant to blockchain based sustainable supply chain visibility management for several reasons, including that sustainable supply chains are characterised by contextual factors such as cultural-related factors [31] that can have significant impact on visibility. There is also a need to consider sensitive preferences of actors and informational linkages of supply chains, particularly in terms of willingness to share information. Characteristics of blockchains such as immutability also makes it necessary to ensure that there is appropriate awareness of the context in order to be able to sense events and react to stimuli accordingly. Contextual issues such as transparency, trust, and security have also been raised as potential concerns regarding blockchain development[32] The growing complexity and diversity of supply chains also presents another important reason for context-awareness in sustainable supply chain visibility management supported by the automation inherent in blockchain.

A landscape of an architecture for a context-aware blockchain based sustainable supply chain visibility management (SSCVM) developed in this paper is illustrated in Figure 1. The landscape presents an overview of the main layers and services for the SSCVM platform. The bottom layer of the architecture consists of smart objects that covers the resources in the SSCVM. Internet of Things (IoT) and associated digital technologies can be used in this layer to capture and transform typical resources in the supply chain into smart objects. The primary task of the smart objects is to collect multisource quality data in real or near-real time. Next-up is the communication layer which

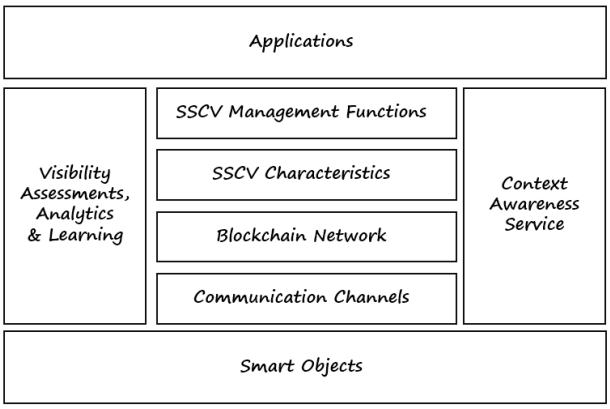

Fig. 1: Landscape of a Context-Aware Blockchain based Sustainable Supply Chain Visibility Management Architecture

is responsible for managing diversified communication channels incorporating suitable configuration properties and guarantees for data transmission reliability and stability. Data coming through these two layers are used for forming a chain of blocks in the blockchain layer. The data can be pre-processed, cleansed for ease of integration as necessary. Blockchain characteristics and algorithms such as the consensus mechanism comes to play in the blockchain network layer to guarantee the data quality and trust for applications and services.

The next two layers relate specifically to sustainable supply chain visibility. First is the SSCV characteristics layer whose responsibility is accounting for SSCV characteristics and informational linkages. This specifies the context, green absorptive capacity and other associated aspects of dynamic capabilities. This provides abilities for the processes of acquisition, assimilation, transformation and exploitation of information in sustainability environments and deploying appropriate competencies. The sustainable supply chain context captured in this layer presents a bedrock for the context awareness services of the architecture. Similarly, the visibility assessment, analytics, and learning services featured in the architecture will rely on the SSCV characteristics layer particularly regarding the capacity and capabilities incorporated. The services can leverage existing services, algorithm and mechanisms. For example, algorithms for assessing sustainable supply chains are now becoming increasingly available (e.g. [4, 33]).

The SSCV management functions layer has the responsibility for specific management processes of dealing with and/or controlling visibility to achieve the desired visibility levels and associated sustainability objectives. The application layer is at the top of the architecture and has the responsibility for supporting aspects of the supply chain that relies on the visibility concept including facilitating decision making and actions at all levels i.e. operational, tactical and strategic. The landscape presented has potential issues and challenges, particularly those associated with the blockchain technology, such as incentive mechanisms for its adoption, deployment and implementation concerns, government policy and regulations. These issues would be addressed in the advances of the technology.

5. Conclusions and Future Work

Quality information is key to sustainable supply chain and the sharing of the information is necessary for visibility. Achieving good visibility requires effective management and appropriate technology including blockchain. The context-aware landscape of an architecture presented in this paper would allow for effective management of blockchain-based sustainable supply chain visibility. The landscape consists of layers for smart object, necessary infrastructure, communication channels, sustainable supply chain characteristics, sustainable supply chain visibility management functions, and applications. The layers are complemented by visibility assessment, analysis and learning service, and context awareness service. The landscape would be implemented as part of future work and empirically validated using real world case studies.

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