Essay

Black Swan Events: Mitigating Disruption to a Supply Chain Using Blockchain and Artificial Intelligence

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Black Swan Events: Mitigating Disruption to a Supply Chain Using Blockchain and Artificial Intelligence

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Abstract: Geopolitical situations, such as the Ukraine–Russia war, the Israel–Hamas war, and pandemics, can disrupt supply chains, such as the rerouting of oil tankers via South Africa to avoid the impact of the Israel–Hamas conflict. These events will probably occur again, but they are black swan events and difficult to predict. How can firms manage these events to minimise disruption to their supply chains? Disaster events are treated as singular paradigms (holistically, vulnerability and hazard) and an inter-paradigm perspective is required i.e., holistically and vulnerability. However, in black swan events the inter-paradigm perspective is necessary. This paper proposes that a blockchain architecture has the potential to build resilience in supply chains and give them the flexibility to withstand the challenges of black swan events. The decentralisation ability of blockchain technology enables separation of the discrete elements of a sustainable supply chain so contagion does not impact the overall sustainable supply chain. To achieve flexibility in a sustainable supply chain ecosystem requires governance, leadership, and management. Also, artificial intelligence (AI), in conjunction with blockchain, is a technology that can enhance the flexibility and resilience of the supply chain. Thus, AI can act as a controller, co-ordinator, and an integrator in sustainable supply chain systems. The paper contends that black swan events require research on how the technologies (AI and blockchain) can be used to reduce the trade-off between resilience and sustainability, using an inter-disciplinary paradigm (strategic, political, economic, and social).

Keywords: artificial intelligence; blockchain; sustainable supply chain systems; black swan events

1. Introduction

Geopolitical events ranging from the COVID-19 pandemic to the war in Ukraine have impacted supply chain activities and economics [1,2]. Geopolitical tensions in 2023 have made collaboration between nations less certain. The attitude to supply chains is cautiousness. Governments and firms are exploring domestic self-efficiency and building "friendshoring" relationships; friendshoring refers to governments encouraging businesses to restructure their supply chains and move production of critical imports from geopolitical rivals to allies and like-minded countries. Thus, there are moves afoot to replace global supply chains with nearshoring (i.e., supply chain relationships are with countries that are geographically close). The geopolitical events identified above could be classified as black swan events because they are difficult to predict and how long the events will last is uncertain. KPMG [1] suggested that the effects of current geopolitical tensions on supply chains could be minimised by taking the following actions:

- Model different scenarios to be aware of the impact that geopolitical tensions could have on supply chains.
- Consider nearshoring or friendshoring to help build a secure supply chain network.
- Clearly identify actions that will be needed if access is denied to key components or material. Will product reformulation be required? How will it impact customer satisfaction and product specification? Will it have an impact on the regulatory environment of the product? Will additional costs be incurred if new suppliers or new markets are used?

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- Recognise the impact friendshoring and nearshoring will have on lead times and time to market. Can you become more agile, responsive, and reduce working capital?

It is evident that black swan events require considerable intervention by a firm and its many stakeholders (suppliers, customers, and potential suppliers). Government intervention is also likely, which will impact how firms respond to black swan events. Intervention by governments can lead to unexpected outcomes (due to poor government performance or a lack of urgency and behaving proactively). The application of technologies such as blockchain and artificial intelligence (AI) has a role in minimising black swan events in the supply chain: AI would facilitate the identification of likely events of a geopolitical nature that could influence supply chain performance, and blockchain architecture would help to isolate impacted parts of the supply chain, because of its decentralised governance structure, and reconfigure elements of the supply chain. Thus, AI and blockchain working simultaneously could keep the supply chain ecosystem working and establish reliability and resilience; this would give firms leadership and management of the supply chain in the event of its breakdown in a black swan event.

Disaster management is viewed from three perspectives these are hazard, vulnerability, and holistic view (Berg & De Majo, 2017). The objective of the paper is to take a holistic and a vulnerability view of disaster management in the context of unpredictable situations (Black swan event). Thus, the objective is not to decide on the constructs of resilience and sustainability but to view the problem holistically. The paper sits between vulnerability and holistically. Vulnerability paradigm is the consequence of political upheavals and has social consequences (Perry, 1998). The holistic paradigm is about taking a strategic perspective of disaster management. Supply chain disaster situations need to be discussed in an inter-paradigm approach and not review it from one perspective.

The aim of this conceptual paper is to demonstrate how emerging technologies such as blockchain and AI can work complementarily to reestablish a supply chain ecosystem, after a black swan event beyond the control of the firm and stakeholders, with minimal disruption. Thus, disaster management in the context of sustainable supply chain in paradigms of holistic and vulnerability paradigms. In a black swan events resilience and sustainability might both be expected from stakeholders although a trade-off will be required which could be achieved with blockchain and AI technologies. The paper discusses supply chain governance and disaster management, blockchain in the supply chain, leadership and management in the supply chain, redundancy in supply chains, and the application of AI technology to oversee the discrete elements of the supply chain and manage overall control to supplement supply chain management. The paper closes with a methodology, discussion of the implications followed by a brief conclusion.

Literature review

2. Supply Chain Governance and Disaster Management

Many organisations recognise that they can be held responsible for the environmental, social, and economic impacts of their internal activities and their suppliers' activities [3]. Thus, supply chain management is based on social, economic, and environmental sustainability and their integration in the supply chain [4]. However, the implementation of supply chain management utilising social, economic, and environmental parameters over geographical distances is challenging [5]. Barriers to the implementation of sustainable supply chain management (SSCM) are related to sustainable parameters (economic, social, and environmental), which are influenced by different expectations that arise from cultural differences [6]. There is also the issue of transparency between suppliers and sub-suppliers and between developing countries that have environmental regulations and developing countries where regulations are not always enforced [7].

Sustainable supply chains incorporate the management of materials, information, and capital flows and co-operation between companies in the supply chain, while meeting the environmental, economic, and social obligations that are linked to customer and stakeholder requirements [8]. The implementation of sustainable parameters will enable a sustainable competitive advantage [9]. However, a sustainable supply chain is about co-ordination of supply change management based on economic, environmental, and social parameters, which leads to voluntary integration of the

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parameters [10]. It is necessary to achieve this efficient management of materials, information, and capital flows, which are linked to the procurement and distribution of products and services, to meet the requirements of stakeholders to improve profitability and competitiveness. "The role of SCM [supply chain management] is to ensure competitive advantage for the supply chain members through close collaboration, which includes trust, open communication and real-time data sharing, joint planning, and managing supplier relationships" [11] (p. 74).

Simply creating a pro-environmental and pro-social environment in the supply chain does not necessarily lead to long-term profitability. There needs to be a balance between the pressures of social factors and the pressures of environmental factors. Thus, implementation of the social and environmental factors should support them (social and environmental) and avoid harming these parameters. Creating the "right" environmental and social conditions requires long-term decision making to give rise to long-term economic improvement [4]. The challenge is that sustainability in the supply chain is not just linked to the elements of the supply chain but also to overall supply chain management.

According to Carter and Easton [12] (p. 49), SSCM requires the following logic:

"Strategy – holistically and purposefully identifying individual SSCM initiatives which align with and support the organization's overall sustainability strategy.

(2) risk management, including contingency planning for both the upstream and the downstream supply chain.

(3) an organizational culture which is deeply ingrained and encompasses organizational citizenship, and which includes high ethical standards and expectations (a building block for SSCM) along with a respect for society (both within and outside of the organization) and the natural environment; and

(4) transparency in terms of proactively engaging and communicating with key stakeholders and having traceability and visibility into upstream and downstream supply chain operations."

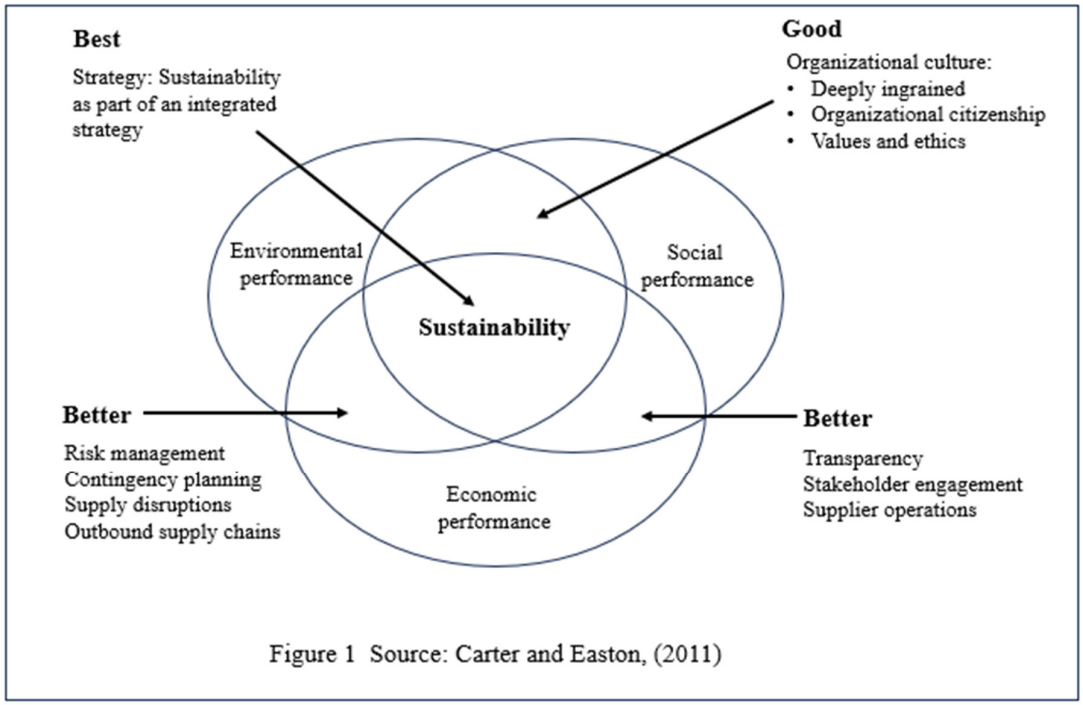

Figure 1. [12] expands SSCM logic.

Researchers that review of the literature in supply chain management tend to focus on environmental and sustainability issues of the supply chain. However, the interchangeability of

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environmental and sustainability have become less common. Thus, researchers are distinguishing the meaning of the terms environmental and sustaianability [12].

According to Carter and Easton [12], the theoretical lenses applied to supply chain management include stakeholder theory [13], which is the most widely applied, the resource-based view (RBV), which is the next most widely applied, and natural RBV. RBV incorporates the strategic capability and natural RBV links to competitive advantage such as pollution prevention leading to lower costs, product stewardship leading to pre-empting competitors and sustainable development leading to future position [14]. Other theoretical models applied include dynamic capabilities in achieving competitive advantage in sustainable global supply chain management [15]. Furthermore, the application of brand equity theory to achieve competitive advantage derived from sustainability [16,17] employs efficacy theory to predict safe employee behaviour.

A review of the literature on disaster management (DM) in emerging technologies in the context of AI and blockchain. Table 1 (adapted) below reviews the literature in disaster performance management context with reference to emerging technologies in AI and blockchain. Performance management is preparing the context for performance (Lebas, 1995). Performance management is the whole process starting with defining the process, application targets and outcome of the results (Lebas, 1995).

Table 1. Source: Noto et.al. (2021) – adapted.

Technology	Process description	Application	DM outcome
AI	Machines that can learn from past experiences. AI systems can assist with human decision making (Duan, Edwards & Dwivedi 2019)	Process and task automation; machine learning algorithms to aid cognitive understanding patterns and trends; Cognitive engagement Language processing	Mitigation or prevention
Blockchain	Blockchain is a ledger system that uses peer-peer architecture (Felin & Lakhani, 2018)	BC is used in financial sector, supply chain, logistics, food safety, health care, food care art market and agriculture	Relief and disaster management

3. Blockchain in the Supply Chain

In the past, focus on the supply chain was economic, but with environmental damage created by supply chain activities there is a shift towards SSCM (environmental, social, and economic) [18]. Thus, the main benefits of supply chain activities were economic, but how can the balance be struck between these competing parameters? According to de Oliveira et al. [19] and Manupati et al. [20], pressure from governments and other stakeholders, such as regulatory organisations and customers, is forcing firms to redesign their supply chain architecture internally and externally due to environmental and social concerns.

Supply chain innovation faces many challenges; according to Chowdury et al. [21], these include the following:

Permission for access and control,
Legal and regulatory compliance,
computing power,
data management,
efficiency and performance,
knowledge, skills and expertise,
standard platform,
operational costs,

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resistance to organisational change (inside the organisation)
resistance to organisational (between firms)
privacy,
scalability,
security,
strategy,
suitability,
trust in automated software.

In a black swan event, which challenges are of the greatest significance? This will be addressed in Section 6 (Implications).

Chowdury et al. [21] reviewed five pilot cases in which blockchain technology was applied. These all have relevance to a black swan event. The main findings of each pilot case are discussed in Sub-Sections 3.1–3.5.

3.1. Food Supply Chain

An imperative for a food supply chain is freshness of food because of the health risks involved. Provenance (a food supply firm) [22] invested in blockchain architecture to improve transparency in the food supply chain. They suggested that transparency in the food supply chain is growing. Provenance also suggested that a centralised system is not supportive of transparency. Furthermore, Provenance uses blockchain to improve transparency and blockchain's data is driven by consensus and different elements of the blockchain will require certification to gain access to the different blocks [21]. Blockchain in the food supply chain has the potential to improve traceability, which reduces duplication and paperwork. It enables marketplace innovation by connecting customers and suppliers, which encourages data sharing among operators in the supply chain and can lead to increased access to capital investments and improving customer payments.

3.2. Energy

Implementation of a fully decentralised system is another potential application of blockchain. The transaction of the payments between customers in different roles (B2B or B2C roles). Electrify an energy company [23] has employed blockchain technology in their electricity network since 2018 to accelerate growth and enhance AI applications. Blockchain technology is especially pertinent to the Electrify network because of the energy market deregulation in Singapore. PwC [24] suggested that blockchain can be used for billing and the archiving of billing data, and that blockchain can be integrated with smart devices.

3.3. Relief and Disasters

Governments, non-governmental organisations, charities, and civil organisations need to collaborate and co-operate in relief or disaster situations. With so many stakeholders involved in these situations, co-ordination and control are required to prevent duplication of efforts. Blockchain has a role in improving traceability, transparency, immutability, and information sharing. The US government realised blockchain can be utilised to develop a decentralised system and enhance collaboration [25]. Blockchain can also facilitate donations and financial transactions in disaster situations [26].

3.4. Housing

An example of the application of blockchain technology to housing is the Kenyan National Housing Fund, which provides government funding for families in need. The Kenyan National Housing Fund has been open to corruption and fraudulent activities [27]. James Macharia, Cabinet Secretary for Transport and Housing, at a meeting at the World Bank in Nairobi said that the nascent technology would be used to distribute housing to deserving applicants in a bid to address past issues

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concerning "graft fears arising from beneficiaries and even legislators … Kenya will use blockchain technology to ensure the rightful owners live in government-funded housing projects" [27].

Sharma [28] on behalf of the Blockchain Council stated that blockchain technology enables transparency in the allocation of housing because blocks cannot be altered once added to the blockchain. The illegal adding or removing of information from the land registry housing database will be recorded using blockchain technology. The embezzlement of funds would be more challenging, and bribery would be considerably reduced.

3.5. Banking

Although blockchain is linked to cryptocurrency, it is an ideal way to improve financial transactions. Finextra [29] is a collaboration between 10 banks; HSBC is the lead bank on the We.Trade platform. HSBC has spearheaded the use of blockchain in financial banking. In 2018 HSBC [30] set up a transaction using R3's Corda scalable blockchain for a Cargill's shipment of soybeans from Argentina to Malaysia. The test was to reduce the transaction time (from days to less than 24 hours) and abandon the use of multiple systems and instead share one application. Ganesh et al. [31] demonstrated that trade can be digitalised and lead to a reduction in fraud in letters of credit and the introduction of streamlined procedures.

Chowdhury et al. [21] captured themes from a systematic review of the literature on the implementation of blockchain in supply chain scenarios; the themes they identified were: interoperability, platform dependency, trust in rule-based automation software, and consensus among supply chain actors. The technical requirements were interoperability and platform dependency, and the social requirements were trust in rule-based automation software and consensus among supply chain actors. The outcomes for the five pilot areas are summarised below.

Food supply chain: *Operability* – must operate in a wide range of industries from retail to fishing. *Platform dependency* – multiple platforms with differing stakeholder requirements. *Trust in rule-based automation software* – rule agreement and development can have significant influence on the supply chain. *Consensus among supply chain actors* – acceptance of technology innovation can be challenging.

Energy: *Operability* – decentralised technology requires similar requirements for users/producers for recording. *Platform dependency* – complex platform with many nodes, which is a single platform for users/producers. *Trust in rule-based automation software* –GDPR requirements and data sharing rules require designing. *Consensus among supply chain actors* – accessed rule rules are agreed upon and practice is consistent.

Relief and disasters: *Operability* – varying levels of technological competence among actors, especially donors. *Platform dependency* – multiple platforms with software not consistent or easily integrable. *Trust in rule-based automation software* – different stakeholders will need to agree the rules and who will be making them and how to integrate the stakeholders. *Consensus among supply chain actors* – combination of private and public funding and the impact on the different stakeholders; decision making on how much information is shared and how it is shared.

Housing: *Operability* – technological competence in blockchain and data collection and recording specifications. *Platform dependency* – governmental organisations need access to the systems and integration with different parts of the system. *Trust in rule-based automation software* – GDPR requirements' complexity, the level of sharing of personal data and level of access. *Consensus among supply chain actors* – involvement of contractors/suppliers and government officials to identify type of data to be shared and the participants.

Banking: *Operability* – consistency in technology competence for all actors. *Platform dependency* – multiple platforms can become a single platform. *Trust in rule-based automation software* – agreement on how much data can be shared and who will define the rules and modification if required. *Consensus among supply chain actors* – banks and government officials need to agree on what data is useful for transactions and access level of access for the varying parties.

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4. Supply Chain Leadership and Management

Leadership in sustaining a blockchain-centric supply chain requires firms to reduce the negativity of environmental and social effects of their supply chain [32,33]. Sustainability in the supply chain is an opportunity for firms to redesign their supply chain. Incorporation of big data and AI can help firms achieve sustainability goals connected to traceability, security, environmental degradation, and social ethics [34]. There is limited knowledge of the circular economy, but developing countries are taking a prominent role in its adoption and application [35]. This has implications for supply chains that traverse developing countries. However, the concept of a circular economy is changing, and the current focus is on transforming products into new products after their usefulness [34].

Society is more focused on the environment and the social impact of supply chains [34]. The core components of blockchain that are supportive of the sustainability of the environmental and social aspects of a supply chain include decentralisation, secure transactions, information transparency, and smart contracts [36,37]. Firms are focusing on technical improvement of their supply chain without affecting the triple bottom line [38]. The success of blockchain in the sustainable supply chain is customer awareness. If manufacturing becomes green, then the environmentally aware and friendly customer will prefer purchasing the green product [34]. The drive to green the supply chain will increase as awareness of sustainability increases and spreads to firms and customers. Thus, it is a matter of when and not if.

It is expected that managers of a global supply chain will protect the rights of workers and ensure they have a safe working environment. However, violations of these rights, regulations, and rules can occur in reputable organisations and this is not unusual. Blockchain is committed to providing social sustainability [34]. Measures of the success of sustainable supply include "regional development, the welfare of workers, humanitarian supply chain, animals' health, transparency, fraud mitigation, trust development, and food security" [34] (p. 16). Leadership in a social sustainable supply chain includes humanitarian supply chain areas of research with the following objectives [34]:

1. Application and acceptance of blockchain in the traceability system in the meat supply chain [39].
2. Evaluation and assessment of blockchain on fraud mitigation, welfare, animal health, food security, and transparency [40].
3. Blockchain to facilitate social sharing dynamics [41].
4. Barriers (14) of blockchain for humanitarian supply chain management [42].
5. Social influence model on blockchain adoption and verified with Brazilian professionals [43].
6. Co-operation between stakeholders in disaster and relief situations. [44].
7. Barriers for blockchain adoption in the humanitarian supply chain [45].
8. The role of senior management participation, market pressure, market changes, and regulatory concerns on the use of blockchain [46].
9. Delphi method to gain knowledge from experts on economic, social, and technical influences of blockchain on supply chains [47].
10. Blockchain – social relationship between supplier and buyer [48].
11. Blockchain can improve clarity and trust in social media analytics [49].
12. Understanding the behaviour in blockchain adoption in India and United States [50].
13. Development of a verifiable framework on how blockchain can increase social sustainability [51].
14. Quality of data on the sustainability of supply chains [52].

Countries such as Japan and the United States are leading in the application of blockchain technology in sustainable supply chains. Blockchain supply architecture is gaining momentum in developed countries, but many African and Asian countries are also participating and implementing blockchain technology in their supply chain network. However, sustainable supply chain architecture is embryonic because green practices in procurement and regulatory requirements are not always adhered to [34].

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5. AI Technology in the Supply Chain (Integrator/Controller)

The uncertainty of decision making in sustainable supply chain ecosystems is a significant problem [53]; this is compounded by black swan events. The characteristics of decision making in sustainable supply chain ecosystems include variety and complexity, and decisions are made based on asymmetric information. For example, estimating demand for the different elements of a sustainable supply chain with changing order volumes is a challenge [54]. Provost and Fawcett [55] suggested a data-driven decision-making approach that includes facts, metrics, and data to assist in the execution of business strategy so that a firm can achieve its objectives, which will influence policies, practices, and activities. [56] Sustainable supply chain management decision making will require sophisticated data and information with improved analytics; arguably, this will lead to a competitive advantage and drive data capture innovation.

Supply chain activities in which AI could play a role include demand forecasting, flow management, and optimising logistics performance, which would contribute to the overall customer experience [54]. Real-time data from social media and forums can supplement demand forecasting [57]. Improved forecasting will lead to better sales forecasts and stretch the product life cycle [58]. AI technology could improve flow management, which includes sales management, and optimise inventories; thus, leading to improved finances [54]. Amindoust et al. [59] proposed the application of fuzzy logic to identify sustainable suppliers due to uncertainty in the decision-making process. They identified several criteria and sub-criteria that sustainable suppliers employ in their decision-making processes; these include the following [59].

Criteria	*Sub-criteria*
Economic	Profitability
	Product quality
	Delivery performance
	Service quality
Environmental	Environmental management system
	Environmental competences
Social	Actors rights
	Health and safety – workplace and people

The application of AI in SSCM is in its infancy. However, what is the role of AI in the sustainable supply chain process: decision maker (controller) and/or technical (integrator)?

Methodology

Conceptual design is categorized into 4 types: Theory synthesis, Theory adaptation, Typology and Model (Jaakkola, 2020). The paper uses theory from different parts of the literature to link unconnected areas of the literature. Disaster management in supply chain management is viewed through a singular paradigm, typically the hazard paradigm. The novelty of the paper is that it is theorizing the in certain situations such as black swan events an interdisciplinary disaster management paradigm would aid to reduce the unpredictable nature of black swan events. Theory synthesis which is the research design philosophy that underpins this paper is not only about synthesis of the literature which is spotting gaps but requires narrative reasoning to give the 'big picture' patterns and connections and not to develop a mechanism (Delbridge & Fiss, 2013). In the development of the conceptual paper applying theory synthesis the literature is a supplementary tool and the choice of theory and concepts is left to the author that is considered to the best fit of the phenomenon (Jaakkola, 2020). The author is stating that there is a gap between disaster management in black swan events and the literature and that to address the topics requires a combination of disaster management paradigms.

When developing a conceptual paper of the type of theory synthesis is suitable for integration of several perspectives across different parts of the literature. Theory syntheses applicable when a new idea or phenomenon requires outlining. The problem (phenomenon), literature, choice of theory

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and the argument are characteristics of theory syntheses, and these are selected and decided by the researcher (Becker & Jaakkler, 2020; White, Habib, & Hardisty, 2019; Vargo & Lusch, 2004).

Whilst the extant literature provided the basis for the idea it needed to be deconstructed so that the integration of the idea and literature could develop a new theoretical perspective (Jaakkola, 2020).

6. Implications

Implementation of sustainable supply chains is challenging because of the balance required between social and environmental dimensions, which will impact economic success and consequently long-term profitability. Thus, sustainability in "normal" business environments is challenging. However, the implementation and management of sustainable supply chains in business environments that experience black swan events is even more challenging. This does not mean that preparation for such event should not occur, but the supply chain management must be proactive to such an event occurring. Supply chain management and governance requires flexibility that gives rise to agility. The dimensions of the supply chain culture should include proactiveness, agility, and openness to changes in the business environment, which will have a major impact on the operational ability of the supply chain to function and deliver the outcomes required by the stakeholders. Thus, the cultural dimensions necessary for supply chains to function and deliver the economic, social, and environmental dimensions for SSCM and governance require integration with the elements of the supply chain and across the whole supply chain. The complexity of integrating the cultural fit is compounded by black swan events. How to legitimise the cultural dimensions across geographical boundaries with different cultures and sub-cultures of different countries is truly a challenge. The above discussion links to the vulnerability paradigm which requires social, economic, and political environmental considerations (Buckle, 2005; Cutter, 1996). The traditional approach (hazard paradigm) is to consider disasters as hazards which is reactive and focuses on short-term solutions. Black swan events require strategic thinking and developing a strategic process to identify them (scenario planning).

The pressure to change the supply chain architecture due to environmental and social issues is an opportunity to apply emerging technologies to streamline and improve the design of supply chain activities to make them sustainable. However, there are many challenges in the implementation of blockchain technology in supply chains, such as access and control of data management, privacy, security, computing power, and trust in the automated software [21]. Although Chowdury et al. [21] did not identify all the challenges, the ones they did identify will be of great importance in black swan events. In a black swan situation control will require access being restricted to ensure peer-to-peer communications to make sabotage less likely to occur. Thus, the supply chain becomes a series of peer-to-peer connections with limited integration to minimise disruption. Although the supply chain will have improved security, because of the decentralised management system, it becomes more challenging to gain an overall picture of the supply chain's performance. Does blockchain architecture require an ability to integrate peer-to-peer activities so an overall analysis from a centralised command and data management can be achieved? This would only be a requirement in black swan events where threats to the supply chain will be heightened. The complexity of managing the application of blockchain would be less challenging where nearshoring and friendshoring can be accomplished. Reducing the complexity would be an overriding consideration in black swan events. However, should this not always be the goal to reduce the complexity of the supply chain? Supply chains require co-ordination, collaboration, and integration, but in black swan events these are not necessarily feasible or desirable. Thus, in black swan situations, the ability of the supply chain to operate in an optimal way is compromised. The application of the holistic paradigm is a necessary technique to resolving black swan events because they impact the economic, political, and social environment. The application of technology such as blockchain and AI are tools that could help to overcome the complexity of managing supply chains in black swan events. Taking a strategic perspective requires a trade-off between sustainability and resilience. Stakeholders will want both constructs to be operational in black swan events, so a choice needs to be made.

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The role of AI needs to be defined in sustainable supply chain systems. Previously, it was noted that the role could be an integrator of the elements that provide the sustainable supply chain system, so it holistically controls the overall sustainable supply chain. In black swan events this will not be necessarily desirable and individual control via the use of blockchain technology would be preferable. Even in black swan events blockchain as part of the decision-making process would be desirable. Nevertheless, actors allowing AI to be a decision maker depends on their confidence in the software and platform (technical considerations). Black swan events compound the challenges experienced by SSCM and these will need prioritising to enable functionality. Arguably, black swan events will hit developing countries the hardest because they do not have the training, knowledge, and experience to navigate the application of blockchain technology integrated with AI. The severity of the impact of black swan events will be dependent on the geographical location (developed or developing countries), the sectors and the type of black swan event.

In a black swan event will customers still expect sustainable supply chain conditions even if the cost of maintaining the quality of a product would lead to increases in price? Customers will likely expect sustainability and resilience in the supply chain in black swan events. Under normal conditions a green customer would be less forgiving if the social and environmental dimensions of a sustainable supply chain were compromised. However, in black swan events would green customers be more forgiving and empathetic. Decision makers in the sustainable supply chain system will also need to have an empathetic disposition because the accuracy of AI is questionable and could lead to false data/information, which would compromise the integrity of decision making. In black swan events, culture, people, and legal factors could play a more decisive role in the use of technologies. Confidence in research relating to AI and blockchain in the sustainable supply chain system could be limited due to limited research, especially of a longitudinal nature. One must also bear in mind that AI and blockchain technologies are in their infancy. More research into the technology from a standalone to an integrated approach would help to accelerate the implementation of these technologies in a sustainable supply chain environment. Also, firms need more exposure to the technologies, which require more training, and wider applications of the technologies in firms' sustainable supply chain systems and in other parts of the business.

The combination of blockchain and AI technologies have the potential to leverage the competitive advantage of a firm. However, the competitive advantage is based on statistical algorithms and probability (Bayesian statistics). Can one put trust and privacy of the data to one side and have confidence in the outcomes? Are blockchain and AI disruptive technologies for social innovation or just incremental technologies that have very low strategic significance in supply chain sustainability?

7. Conclusions

How to ensure social, environmental, and economic success in each element of the supply chain and transferring that success to the overall supply chain management is a pressing requirement. Black swan events will disrupt sustainable supply chain systems but with careful use of blockchain technology and AI the risks can be contained or minimised. However, the accuracy of AI is a barrier to wide-scale adoption and to decision making in sustainable supply chain. The combination of blockchain and AI is going to disrupt sustainable supply chain technology, but how widescale will the disruption be – niche or global? Black swan events viewed through a single paradigm is inappropriate because these events have strategic and social, political, and economic consequences and require an inter-paradigm approach.

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