Adoption of Blockchain in Critical Minerals Supply Chain Risk Management

Ivan Kudrenko, Independent Researcher, USA*
https://orcid.org/0009-0000-6295-457X

ABSTRACT

This study examines the impact of digital transformation, digital awareness, and supply chain risk management (SCRM) on the intention to employ blockchain technology in the US critical minerals industry. It examines the influence of digital transformation on supply chain resiliency and the adoption of blockchain by analyzing responses from 122 managers and professionals through structural equation modeling and partial least squares approaches. SCRM, perceived usefulness, and usability shape the intention to use blockchain, while digital transformation enhances supply chain resiliency. This research contributes to the existing literature by confirming the relevance of the technology acceptance model in blockchain adoption and by highlighting the importance of digital transformation in supply chain resiliency. Practically, it offers valuable insights for managers, emphasizing the role of SCRM in recognizing blockchain's benefits, the need for digital literacy and transformation to facilitate blockchain adoption, and the potential of blockchain to enhance supply chain operations.

KEYWORDS

Adaptability Capability, Digital Awareness, Digital Transformation, Green Supply Chain Management, Supply Chain Risk Management

INTRODUCTION

The expansion of the United States high-capacity battery market drives increasing demand for critical minerals such as lithium, cobalt, and nickel, especially for use in electric vehicles, stationary storage, and defense applications (Fleischmann et al., 2023). This growth offers the US opportunities in job creation, environmental progress, and national security. It also highlights challenges in the supply chain, however, mainly due to limited domestic processing capabilities and an underdeveloped recycling infrastructure (Meegoda et al., 2022). In selecting U.S. critical minerals companies as the focus of this study, we aim to address the unique challenges and strategic importance of this

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*Corresponding Author

sector in the context of national security, technological advancement, and sustainable development. The critical minerals industry is at the forefront of supply chain vulnerabilities, making it an ideal setting to explore the potential of blockchain technology in enhancing supply chain resilience. While resilience and agility are crucial in supply chain management, this study emphasizes resilience due to the increasing frequency of disruptions and their impact on the critical minerals supply chain. By concentrating on resilience, we seek to contribute to developing robust and adaptable supply chain strategies that can withstand and recover from unforeseen challenges.

Supply chain risk management (SCRM) aims to safeguard businesses from adverse events by managing the variability in supply chain outcomes, likelihoods, and impacts (Jüttner et al., 2003). SCRM is crucial in enabling firms to gain a competitive edge and enhance performance, primarily through innovative methods that augment supply chain efficiency, effectiveness, and resilience (Bag et al., 2021; Madhani, 2021). Key to this is the multifaceted understanding and addressing of risk involving culture, strategy, and team dynamics. The division of SCRM into culture, strategy, and team dynamics is grounded in a comprehensive approach to risk management that recognizes the multifaceted nature of supply chains.

Within SCRM culture (SCRMC), risks arise from resistance to change and innovation, which can hinder the adoption of technologies such as blockchain. An aversive culture can lead to missed opportunities, inefficiency, and competitive disadvantage (Dowty & Wallace, 2010). Conversely, a culture that encourages innovation, continuous learning, and adaptability can significantly mitigate these risks, leveraging technologies such as blockchain to enhance supply chain operations and maintain competitiveness. The SCRMC acknowledges that organizational culture is crucial in perceiving, managing, and mitigating risks. A culture resistant to change can significantly hinder the adoption of innovative technologies and processes, whereas a proactive, adaptable culture can facilitate quicker responses to disruptions and opportunities for growth (Altay et al., 2018).

Strategic planning in SCRM (SCRMS) involves aligning blockchain adoption with organizational goals and effectively mapping out the necessary procedures and resources for integration (Kadadevaramth et al., 2020; Narwane et al., 2021). SCRMS focuses on aligning risk management practices with organizational goals and objectives. This alignment ensures that the strategies for managing supply chain risks are integrated with the company's overall direction, thereby maximizing resource utilization and achieving strategic objectives efficiently. Risks in this domain are linked to misalignments in strategy and execution, leading to potential resource misallocation and ineffective implementation (Sofyalıoğlu & Karatal, 2012). A well-crafted strategy, however, can capitalize on blockchain's strengths, such as increased transparency and security, thereby improving supply chain resilience and operational efficiency (Rauniyar et al., 2023).

The SCRM team's (SCRMT) role is pivotal in managing risks associated with the adoption of blockchain. This component recognizes that human capital is critical in navigating the complexities of supply chain risks and leveraging technologies for risk mitigation. A lack of expertise or understanding within the team can lead to inadequate implementation, loss of competitive edge, and underutilization of blockchain (Wang, 2023). On the other hand, teams equipped with technical knowledge of blockchain can better comprehend and leverage the opportunities it presents, thus facilitating more effective applications (Munir et al., 2022).

The theoretical foundation for integrating culture, strategy, and team dynamics within SCRM can be traced to the resource-based view (RBV) and the dynamic capabilities framework. RBV suggests that organizational resources and capabilities are pivotal for gaining competitive advantage, while the dynamic capabilities framework emphasizes the role of strategic management in adapting to changing environments. These theories support a holistic SCRM approach that leverages organizational culture, strategic planning, and team dynamics as critical resources and capabilities for enhancing resilience (Helfat & Peteraf, 2003).

Supply chain resilience is critical for organizational success. Key to this resilience is digital awareness and the capability for digital transformation, involving integrating advanced technologies such as the Internet of Things, artificial intelligence, and blockchain into supply chain processes (Rodríguez-Espíndola et al., 2022; Um & Han, 2021; Vanany et al., 2021). Blockchain technology significantly enhances the critical minerals industry by addressing transparency, efficiency, security, collaboration, and regulatory compliance challenges. It offers an immutable ledger for transactions and mineral movements, improving traceability from mine to market and ensuring the verification of sustainable and ethical sourcing practices. By automating transactions with smart contracts, blockchain reduces administrative burdens and mitigates fraud and error risks. Furthermore, it fosters a collaborative ecosystem among stakeholders through a shared, trustworthy platform, encouraging innovative solutions for industry challenges. Additionally, blockchain aids in adhering to national and international regulations by providing auditable records of compliance with environmental and labor standards, making it an invaluable tool for companies aiming to enhance supply chain resilience and operational efficiency. These capabilities are crucial for maintaining performance amidst disruptions, encompassing the development of adaptive capacity, risk management, and recovery strategies (Pettit et al., 2019; Scholten et al., 2014).

While studies have progressed in understanding supply chain management and blockchain's potential impact, gaps remain in the literature. The role of agility, resilience, and organizational culture in influencing blockchain's perceived usefulness and usability in supply chains is still underexplored (Altay et al., 2018). Moreover, the link between procurement strategies and blockchain adoption, critical for enhancing supply chain resilience and efficiency, requires further investigation (Madhani, 2021; Pereira et al., 2014). In this study, the impact of SCRM culture, team, and strategy on blockchain technology's recognized usefulness and usability in U.S. critical minerals companies were investigated.

To explore the role of digital awareness and digital transformation's degree in recognized usefulness, we developed the following research objectives:

1. To investigate the impact of SCRM culture, team, and strategy on blockchain technology's recognized usefulness and usability in U.S. critical minerals companies.
2. To explore the role of digital awareness and digital transformation's degree in recognized usefulness and blockchain's usability in U.S. critical minerals companies.
3. To examine the impact of digital transformation and adaptability capability to boost resiliency and intentions to use blockchain in the supply chain in U.S. critical minerals companies.

LITERATURE REVIEW

Blockchain in the Metal and Mining Industry

Blockchain technology has been identified as a transformative tool for the metal and mining industry, offering significant opportunities for enhancing sustainability and traceability. Notable applications include Australia's Everledger system, which tracks diamonds to reduce fraud (Mugurusi & Ahishakiye, 2022), and the United Kingdom's Provenance, which monitors environmental certification data (Calvão & Archer, 2021). These cases illustrate blockchain's potential in promoting responsible sourcing practices in the industry and effective risk management supported by high visibility and traceability. Additionally, blockchain's ability to bolster supply chain resilience, particularly under conditions of increased risk and uncertainty, is emphasized in systematic literature analyses (Mezzadra & Neilson, 2019). These findings suggest that while blockchain's adoption in the mining sector is growing, it remains an area with significant potential for innovation and development.

Blockchain's success in mining is contingent upon overcoming technical, regulatory, and adoption barriers. Its adoption, however, is successful when aligned with clear regulatory frameworks, stakeholder collaboration, and integration with existing technological infrastructures. Blockchain's inherent features further facilitate this success—decentralization, transparency, and security—which directly contribute to resilience against supply chain disruptions (Calvão & Archer, 2021).

The US Supply Chain of Critical Minerals

Focusing on critical minerals instead of the mining industry at large allows for a targeted exploration of blockchain's impact. The U.S. critical minerals supply chain, vital for industries such as energy storage and electric vehicles, has been extensively studied. Schulz (2017) offered an overview of these resources in the US, focusing on their geology and future supply. Olivetti et al. (2017) analyzed the lithium-ion battery supply chain, highlighting bottlenecks in critical metals. Kim and Davis (2016) explored the sustainability and ethical aspects of the global supply chain for minerals such as cobalt. Hofmann et al. (2018) investigated the complexities in critical minerals' multi-tier supply chains, particularly in responsible sourcing and compliance. Gaustad et al. (2018) proposed circular economy strategies to address supply issues of critical materials. Hayes and McCullough (2018) emphasized the need to understand mineral criticality for effective supply chain management. Lastly, Golroudbary et al. (2019) assessed the environmental impacts of recycling critical minerals, focusing on lithium-ion batteries. By concentrating on these materials, research can provide deeper insights into how blockchain technology can specifically address the unique challenges faced by critical minerals supply chains such as traceability, ethical sourcing, and compliance with environmental standards.

SCRM in Critical Minerals Supply Chain

The segmentation of SCRM into culture, team, and strategy reflects the complex nature of supply chain risk management in the context of critical minerals (Bag et al., 2020). These components are interrelated, each playing a vital role in the broader framework of supply chain resilience. Blockchain technology can significantly enhance this resilience by providing a platform for secure, transparent transactions and records, facilitating better risk management and fostering stakeholder trust.

SCRM Culture in Critical Minerals Supply Chain

The studies by Chowdhury and Quaddus (2016), Altay et al. (2018), and others, highlight the pivotal role of organizational culture in supply chain risk management, particularly within the critical minerals supply chain. Chowdhury and Quaddus (2016) emphasized how a culture prioritizes risk management and continuous learning enhances supply chain resilience. Altay et al. (2018) focused on the impact of organizational culture on supply chain performance in humanitarian settings, identifying agility and stability as key determinants influenced by corporate culture.

This cultural emphasis within SCRM is crucial for managing the operations of the critical minerals supply chain. For instance, a culture valuing sustainability can lead to adopting circular economy principles in lithium-ion battery recycling, as Mossali et al. (2020) suggested. Similarly, a culture prioritizing transparency and traceability encourages the use of digital technologies such as blockchain, enhancing supply chain visibility (Calvão & Archer, 2021). These insights demonstrate that an organization's underlying values and priorities significantly influence its approach to managing risks and optimizing supply chain operations.

SCRM Team in Critical Minerals Supply Chain

SCRM teams also play a vital role in adopting resilience. Scholten et al. (2014) and Roberta Pereira et al. (2014) examined the mitigation processes and the role of procurement in achieving supply chain resilience. They demonstrated that teams with diverse skills and experiences are better prepared to manage supply chain disruptions and foster resilience and highlighted the significance of procurement teams in achieving supply chain resilience. Their findings emphasized the importance of strategic sourcing, supplier relationship management, and procurement team integration in enhancing supply chain resilience. The role of the SCRM team is also crucial in managing the critical minerals supply chain. A skilled and knowledgeable team can effectively navigate the complexities and risks associated with the sourcing and distribution of these minerals. For instance, the team's ability to understand and manage geopolitical risks due to total production in certain regions contributes to supply chain resilience (Shiquan and Deyi, 2023). The team's competence in digital technologies facilitates the adoption of tools such as blockchain for improved traceability and transparency (Mugurusi & Ahishakiye, 2022).

SCRM Strategy in Critical Minerals Supply Chain

The overarching strategy for supply chain management is another essential factor. Gunasekaran et al. (2015) discussed the role of complexities and strategies in supply chain resilience. Their findings suggested that a comprehensive, flexible strategy that addresses supply chain complexities enhances resilience. On the other hand, Mensah and Merkuryev (2014) provided a blueprint for developing a resilient supply chain, which includes strategic components such as network design, inventory management, and flexibility. Meanwhile, Pettit et al. (2019) traced the progression of resilience in supply chain management, emphasizing the importance of strategic measures that ensure resilience in response to the changing business environment.

The strategic approach taken in SCRM is another critical factor in the critical minerals supply chain. Comprehensive strategies that account for various supply chain risks enhance resilience. For example, diversification of supply sources, stockpiling, and risk-sharing agreements mitigate supply risks (Fan et al., 2017). A strategy that integrates end-of-life management of products, such as recycling lithium-ion batteries, promotes sustainability (Meegoda et al., 2022). The strategic incorporation of digital technologies for enhanced visibility and coordination also contributes to more efficient and resilient supply chains (Zhang et al., 2023).

SCRM and Adoption of Blockchain

The adoption of blockchain in the critical minerals sector can markedly improve supply chain resilience. Blockchain's ability to ensure transparency and traceability addresses key challenges in the mining industry, such as fraud, compliance with environmental and social governance criteria, and the management of complex, multi-tier supply chains. Moreover, blockchain streamlines processes, reduces inefficiencies, and enhances the security of sensitive data, contributing to a more resilient and adaptable supply chain structure. The role of SCRM in industries, especially concerning product lifecycle and sustainability, is critical. This is evident in sectors such as electric vehicles, where the supply chains of essential components such as lithium-ion batteries are crucial (Amarakoon et al., 2013; Li et al., 2013; Meegoda et al., 2022). The sustainability and resilience of supply chains for critical minerals used in these batteries are significant (Kaikkonen et al., 2022; Van den Brink et al., 2020). Supply chain resilience, the ability to adapt to disruptions, is extensively studied (see, e.g., Um & Han, 2021; Yang et al., 2021), with Duchek (2020) emphasizing organizational resilience for business success.

Blockchain's role in enhancing supply chain resilience is increasingly recognized. It offers a transparent and immutable transaction record, improving traceability and resilience (Calvão & Archer, 2021; Madhani, 2021; Mugurusi & Ahishakiye, 2022). Tapscott and Tapscott (2016) described blockchain's function in managing transactions across distributed ledgers, while Ozdemir et al. (2021) highlighted its efficiency and transparency in smart contracts and asset management. Blockchain's evolution and application in various industries, including steel manufacturing (Zhang, 2021) and IoT for optimized SCRM (Kadadevaramth et al., 2020; Narwane et al., 2021), demonstrate its versatility.

Despite its potential, the adoption of blockchain faces challenges such as technological compatibility and privacy concerns, necessitating regulatory frameworks (Narwane et al., 2021). The digitization of supply chains and Industry 4.0 will likely further its integration in SCRM (Zhang et al., 2023). Mathivathanan et al. (2021) identified awareness and understanding as major obstacles to blockchain implementation. Sadeghi et al. (2021) explored blockchain's role in the construction industry's supply chain, addressing delayed payments and inefficient communication. Their research employed a novel approach within the multi-attribute decision making (MADM) framework called the ordinal priority approach (OPA). OPA is designed to concurrently determine the weights and rankings of experts, attributes, and obstacles. The authors argued that the most significant barriers are taxation and reporting, the lack of incentive programs, and compliance requirements. Bag et al. (2020) suggested that cultural differences among stakeholders, workforce hesitation, collaboration challenges, and the lack of management visions have been identified as barriers to blockchain adoption in supply chain management; management should tackle such large-scale, foundational misalignments to contribute to the adoption of blockchain. In this study, we offer the following research hypotheses that are limited to the critical minerals supply chain:

H_1. Supply chain risk management (culture, team, strategy) considerably and positively influences the blockchain's recognized usefulness.
H_2. Supply chain risk management (culture, team, strategy) considerably and positively influences blockchain's recognized usability.
H_3. The blockchain's perceived usefulness considerably and positively influences the intention to adopt blockchain.
H_4. The perceived usability of blockchain considerably and positively influences intention to adopt blockchain.

Digital Awareness, Digital Transformation Level, and Blockchain's Adoption

The digital transformation of supply chains, notably in the critical minerals sector, is crucial for enhancing sustainability and sourcing transparency (Kaikkonen et al., 2022; Van den Brink et al., 2020). Digital awareness and the integration of technologies such as blockchain are key to this transformation. Blockchain, known for its transparency and immutable record-keeping, improves traceability and responsible sourcing in critical mineral supply chains. (Calvão & Archer, 2021; Mugurusi & Ahishakiye, 2022).

The level of digital transformation within an organization significantly influences the adoption of blockchain. When integrated with Industry 4.0 innovations, this technology contributes to sustainable, transparent supply chain management and aligns with circular economy principles (Nandi et al., 2021; Wamba & Queiroz, 2020). Organizations advanced in digital transformation are more adept at incorporating blockchain, enhancing resilience and efficiency, especially in the face of disruptions like the COVID-19 pandemic (Faruquee et al., 2021; Li et al., 2022; Vanany et al., 2021).

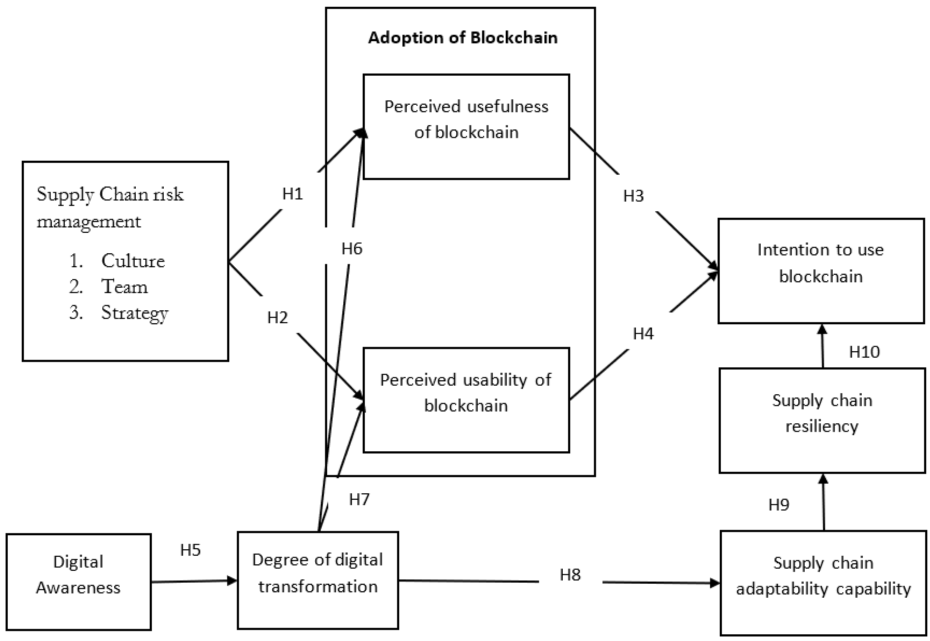
In this study, the term "adoption of blockchain" is conceptualized as the degree to which an organization is inclined towards integrating blockchain technology into its supply chain operations based on its perceived usefulness and usability. This inclination is measured by the intention to adopt blockchain, acknowledging that actual implementation may follow as a separate, subsequent stage influenced by this intention. Despite its potential, blockchain adoption faces challenges such as technical issues, privacy concerns, regulatory needs, and varying levels of digital readiness across supply chain segments (Narwane et al., 2021). Overcoming these challenges to fully leverage blockchain's benefits in critical mineral supply chains requires collective efforts and continuous innovation. Thus, we offer the following research hypotheses:

H_5. Digital awareness considerably and positively influences the degree of digital transformation.
H_6. The degree of digital transformation considerably and positively influences the perceived usefulness of blockchain.
H_7. The degree of digital transformation considerably and positively influences the perceived usability of blockchain.

Digital Awareness, Level of Digital Transformation, Adaptability Capability, and Resilience

Digital awareness, the understanding of digital technologies' benefits and risks, is essential for enhancing supply chain resilience, particularly in critical mineral sectors (Li et al.,

Figure 1. Conceptual framework



2022). High digital awareness promotes innovation and adaptability, key resilience factors, while its absence hinders the adoption of beneficial technologies, creating vulnerabilities (Narwane et al., 2021).

Digital transformation integrates digital technologies into all business aspects, changes in organizational operations, and value delivery. This process enhances supply chain resilience by enabling real-time visibility, better stakeholder coordination, and streamlined processes. It also facilitates early disruption detection and effective mitigation strategies (Kadadevaramth et al., 2020; Rodríguez-Espíndola et al., 2022).

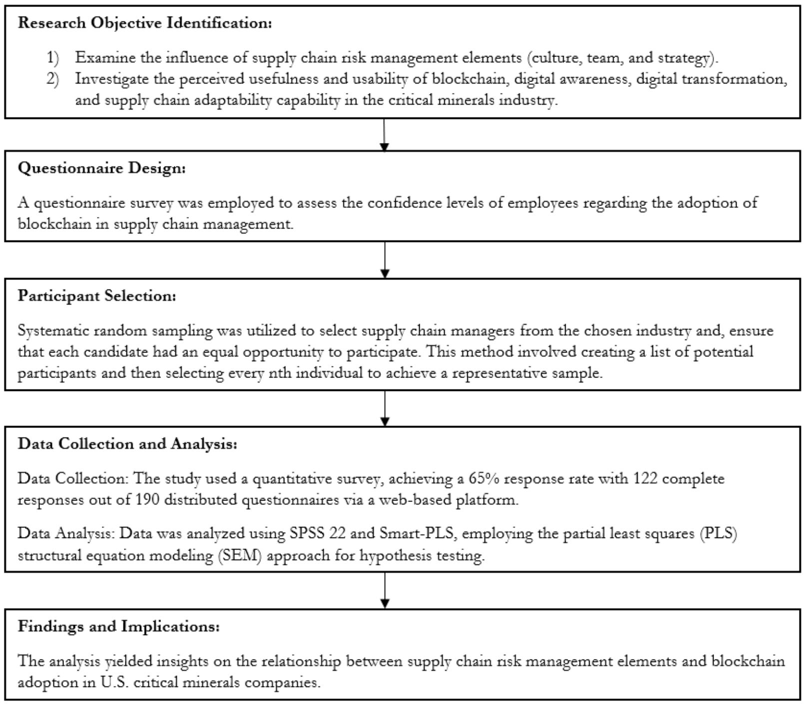
Digitally advanced supply chains benefit from improved decision-making, risk prediction, and rapid alternative strategy implementation during disruptions (Vanany et al., 2021). Blockchain, in particular, offers transparent, immutable transaction records, improving traceability and resilience (Mugurusi & Ahishakiye, 2022).

Digital transformation, however, faces challenges such as data security, privacy concerns, the need for digital skills and infrastructure, and regulatory issues, which can impede the effective implementation of digital technologies (Narwane et al., 2021). Consequently, we offer the following research hypotheses:

H_8. The degree of digital transformation considerably and positively influences supply chain adaptability capability.
H_9. Supply chain adaptability capability considerably and positively influences resiliency.
H_{10}. Adaptability considerably and positively influences the plan to adopt blockchain.

Finally, we developed the conceptual framework after reviewing the literature. The conceptual framework was developed to evaluate the research hypotheses and is illustrated in Figure 1.

Figure 2. Steps taken for research methodology



RESEARCH METHODOLOGY

Research Method

In this study, we employed a quantitative research methodology to investigate the impact of SCRM elements such as culture, team, and strategy on blockchain technology's integration and effectiveness in supply chain risk management. We used a structured questionnaire to capture data on key variables including SCRM elements, blockchain's perceived usefulness and usability, digital awareness, digital transformation, and supply chain adaptability capability. We collected data through systematic random sampling among supply chain managers and U.S. critical minerals sector professionals.

For data analysis, we applied descriptive statistics, correlation analysis, and regression analysis, utilizing SPSS (IBM Corp. [IBM], 2021) for preliminary analyses and Smart-PLS for partial least squares structural equation modeling (PLS-SEM) to explore complex model relationships. This dual-software approach was chosen for its complementary capabilities: SPSS for foundational statistical analysis and Smart-PLS for in-depth exploration of structural relationships between variables, which are crucial for the research objectives. The combination facilitated a comprehensive examination of data, focusing on understanding the interplay between SCRM, digital transformation, and blockchain technology's perceived value in enhancing supply chain management. The flow chart in Figure 2 below represents the methodology. In the context of formative measurement models, multicollinearity is a concern as it can affect the estimation of the weights of the indicators. In our study, however, the emphasis was on the overall construct validity and the prediction of the dependent variables rather than the individual contributions of the indicators. Therefore, while multicollinearity was not explicitly examined, the validation of the model through path coefficients and explanatory power ensures the reliability and relevance of the findings in the context of our research objectives.

Data Collection Procedure

In this study, following methodologies of previous research (see, Hanus & Fox, 2015; Martin-Consuegra et al., 2019), we employed a quantitative approach using a survey questionnaire to assess employees' confidence in adopting blockchain in supply chain management within U.S. critical minerals companies. Participants were selected from 22 companies familiar with blockchain capabilities (see Appendix C), using a convenient sampling method with a minimum of four respondents per company. This approach yielded 122 complete responses from 190 distributed questionnaires, a participation rate of about 65%, and a margin of error of +/- 9%.

The survey was conducted March 1-25, 2023, and collected demographic data (age, gender, qualification level, years of experience) and insights on employees' perspectives and intentions regarding blockchain use. The validity and reliability of survey items were verified post-data collection. The questionnaire, distributed via a web-based platform and promoted through email and social media, aimed to educate employees about the study and ensure their anonymity, ultimately achieving a substantial response rate. Appendix A provides more details regarding the obtained results.

Measurement Scales

We focused this research on SCRM culture, team, and strategy concerning blockchain implementation, which is guided by the technology acceptance model (TAM) principles. TAM provides a framework to understand technology acceptance, emphasizing perceived usefulness and ease of use. We examined the influence SCRM culture, team dynamics, and strategy, have on blockchain adoption in supply chain management. We specifically investigated these elements due to their critical role in accepting and effectively implementing blockchain technology. This approach delves into how organizational factors within SCRM shape the adoption of innovations such blockchain.

During the research process, we treated digital awareness from a strategic and organizational angle, recognizing that successful digital transformation in blockchain adoption extends beyond technical know-how. The questionnaire encompasses broader digital awareness aspects including leadership, vision, employee engagement, and stakeholder relationships, which are vital for comprehensive digital technology adoption. It evaluates organizational readiness and openness to integrate digital technologies into their operations and strategies, thereby adopting a holistic view of digital awareness that transcends technical proficiency. We have adapted reliable and accurate measurement scales from previous studies, ensuring a comprehensive evaluation of the relevant factors. Each scale and its associated items are tailored to assess specific aspects of SCRM, digital transformation, and blockchain adoption, emphasizing how these factors interact with and impact risk management within the U.S. critical minerals industry. Respondents were asked to indicate the extent of their agreement with the statements listed in Appendix B, using a scale from 1 to 5, where one means "completely disagree" and five signifies "absolutely agree." The following details each scale.

1. SCRM culture (SCRMC). This scale, adapted from Fan et al. (2017), comprises items that evaluate how an organization's culture supports risk management practices. It measures the extent to which a company considers risk management requirements, fosters an organizational-wide understanding of supply chain risks, and promotes a culture emphasizing risk management to employees. This scale is crucial for assessing how internal culture facilitates the management of risks inherent in the supply chain.
2. SCRM team (SCRMT). This scale assesses the involvement and capability of teams in developing and executing SCRM practices. It includes items that measure the presence of specialized risk management groups, the involvement of top management in SCRM, and the provision of risk-related training. This scale is vital for understanding the role of team dynamics in managing risks, particularly as blockchain implementation success relies on individual and collective efforts.

3. SCRM strategy (SCRMS). Adapted from Fan et al. (2017), this scale evaluates how well SCRM practices are integrated into companies' long-term strategies. It assesses the alignment of SCRM strategy with the overall business and supply chain strategies, which is essential for managing risks effectively.
4. Perceived usefulness of blockchain (PUB). This scale aims to gauge respondents' perceptions of blockchain technology in the context of risk management. It includes items adapted from Rodríguez-Espíndola et al. (2022) that assess the ease of use, integration, and effectiveness of blockchain for managing risks, reflecting the technology's potential impact on SCRM.
5. Perceived usability of blockchain (PU). This scale measures how blockchain technology facilitates various risk management functions such as secure transactions, communication with stakeholders, and enhancing information quality for managing risks effectively.
6. Supply chain resiliency and adaptability capability (SCRC). These scales, adapted from Um & Han (2021), assess the ability of companies to anticipate, react to, and recover from supply chain disruptions. They are pivotal in understanding how companies manage operational risks and enhance their resiliency in facing challenges.
7. Digital awareness (DA) and level of digital transformation (LDT). These scales measure organizations' strategic leadership, vision, and implementation of digital transformation initiatives. They provide insights into how digital awareness and transformation efforts can mitigate risks and enhance organizational adaptability.
8. Intention to use blockchain (ITUBC). This scale evaluates the future plans and expectations regarding adopting blockchain technology for risk management, highlighting its perceived role in digitally transforming risk management operations.

The list of questions is presented in Appendix B.

Data Analysis

In this research, advanced software tools, specifically SPSS 22 and Smart-PLS (Ringle et al., 2022), have been employed to thoroughly analyze the data collected, focusing on examining the conceptual framework and testing the hypotheses. The initial phase involved descriptive statistics to establish a baseline understanding of the dataset, followed by linear regression analysis to evaluate the influence of SCRM elements (culture, team, strategy), digital transformation, and blockchain perceptions (usefulness and usability) on the adoption process. PLS-SEM was selected as the primary method for hypothesis testing in this research, following recommendations by Hair et al. (2021) and Henseler et al. (2015) for its suitability in expanding existing conceptual frameworks and early-stage theory development. This methodology provides a comprehensive understanding of these relationships, underscoring the appropriateness of PLS-SEM for testing theories in this research area, as Hair et al. (2021) supported.

FINDINGS OF THE STUDY

Demographic Information

The demographic data from the U.S. critical minerals industry in Table 1 reveals a predominantly mature male workforce, with 42.6% aged 46 and above and 75.4% aged 36 or older, indicating substantial industry experience. Additionally, the majority hold at least a master's degree. This profile suggests that the industry's current practices and decisions, including blockchain adoption, are largely driven by experienced professionals, many of whom may have transitioned from other sectors. Given this profile, it is reasonable to infer that the respondents are well-acquainted with their companies' practices and decisions, including adopting new technologies such as blockchain. This assumption

Table 1. Demographic information

Demographic Information		Frequency	Percent	Valid Percent	Cumulative Percent
Age	21-27 years	6	5.0	5.0	5.0
	28-35 years	24	19.6	19.6	24.6
	36-45 years	40	32.8	32.8	57.4
	46 years and more	52	42.6	42.6	100.0
	Total	*122*	*100.0*	*100.0*	
Gender	Male	108	88.5	88.5	88.5
	Female	14	11.5	11.5	100.0
	Total	*122*	*100.0*	*100.0*	
Qualification level	Bachelor's degrees	31	25.7	25.7	25.7
	Master's degrees	79	64.8	64.8	90.5
	Ph.D.	12	9.5	9.5	100.0
	Total	*122*	*100.0*	*100.0*	
Years of experience	2-3 years	13	10.3	10.3	10.3
	4-5 years	44	36.5	36.5	46.8
	6-7 years	35	28.8	28.8	75.7
	8 years and above	30	24.3	24.3	100.0
	Total	*122*	*100.0*	*100.0*	

is based on the fact that such experienced professionals occupy senior roles or positions that involve strategic planning and technology adoption decisions.

The study also notes a relative underrepresentation of younger demographics, particularly Generation Z, attributed to their newer presence in decision-making roles within the industry. The current demographic makeup, characterized by a gender imbalance and the dominance of older age groups, highlights the importance of addressing diversity and adapting to future demographic changes. This adaptation includes acknowledging the rising influence of younger professionals and implementing strategic initiatives to foster diversity such as mentorship programs, flexible work arrangements, and educational opportunities. These findings imply that U.S. critical minerals companies, while currently employing a highly educated and experienced workforce, need to consider strategies for enhancing gender diversity and attracting younger talent to prepare for future workforce evolution.

Descriptive Statistics Analysis

The analysis of the survey data utilized descriptive statistics to validate the consistency of responses and the reliability of the survey. The mean scores for various items ranged from 3.26 (indicating a moderate agreement for SCRMT3) to 4.28 (indicating a closer to a strong agreement for SCRMS3), most averaging above the neutral midpoint of the scale (3.0) around 4.0, suggesting a generally positive attitude of the respondents. The standard deviations were low (0.65 – 1.09), demonstrating a high level of agreement among the respondents. The range of responses for each item was confined to 3 to 4 points out of the possible 1 to 5, indicating that while there was some variability, responses were

Table 2. Convergent validity and reliability

Scales	Items	Factor Loadings	Cronbach Alpha	Composite Reliability	AVE
SCRM culture			0.704	0.835	0.628
	SCRMC2	0.812			
	SCRMC3	0.765			
	SCRMC4	0.800			
SCRM team			0.783	0.860	0.606
	SCRMT1	0.779			
	SCRMT2	0.805			
	SCRMT3	0.722			
	SCRMT4	0.804			
SCRM strategy			0.781	0.873	0.696
	SCRMS1	0.857			
	SCRMS2	0.830			
	SCRMS3	0.815			
Perceived usefulness of blockchain			0.843	0.905	0.761
	PUBC1	0.859			
	PUBC2	0.883			
	PUBC3	0.875			
Perceived usability of blockchain			0.904	0.933	0.777
	PU1	0.885			
	PU2	0.886			
	PU3	0.883			
	PU4	0.871			
Supply chain resiliency			0.853	0.911	0.773
	SCR1	0.912			
	SCR2	0.901			
	SCR3	0.822			
Supply chain adaptability capability			0.814	0.880	0.634
	SCRC1	0.703			
	SCRC2	0.854			

continued on following page

Table 2. Continued

Scales	Items	Factor Loadings	Cronbach Alpha	Composite Reliability	AVE
Digital awareness			0.853	0.891	0.576
	DA1	0.725			
	DA2	0.735			
	DA3	0.774			
	DA4	0.807			
	DA5	0.756			
	DA6	0.754			
Degree of digital transformation			0.818	0.891	0.733
	LDT1	0.841			
	LDT2	0.883			
	LDT3	0.843			
Intention to use blockchain			0.834	0.889	0.667
	ITUBC1	0.769			
	ITUBC2	0.847			
	ITUBC3	0.822			
	ITUBC4	0.828			

Note. AVE = Average variance extracted. A detailed explanation of survey items can be found in Appendix B.

mostly clustered and did not span the full range of the Likert scale. These descriptive statistics bolster the validity of the findings, indicating that the survey items effectively captured the respondents' perceptions.

Assessment of Measurement

According to Ammad et al. (2021) and Sarstedt & Cheah (2019), construct validity in this research involves Cronbach alpha and composite reliability values greater than 0.70. Convergent validity is indicated by factor loadings above 0.70 and average variance extracted (AVE) exceeding 0.50. Factor loadings in Table 2 show the correlation level between each item and its assigned latent variable, with 0.7 as a common cutoff for strong influence on the underlying factor.

We used algorithm techniques with 5000 subsamples and removed items such as SCRMC1, SCRMS4, and PUBC4, with factor loadings below 0.7. The remaining items in the table, with loadings above 0.7, demonstrate a close link to their latent constructs. AVE, a measure of variance captured by the construct relative to measurement error, is considered adequate at 0.5 or more, indicating that at least half of the indicators' variance is accounted for.

Cronbach's alpha, a measure of internal consistency, is regarded as good, with a value of 0.7 or higher (Mohd Thas Thaker et al., 2021). All scales in the table exceed this threshold, showing strong internal consistency. Composite reliability similarly assesses the internal consistency of scale items, with values above 0.7 indicating satisfactory construct reliability (Fornell & Larcker, 1981; Sarstedt & Cheah, 2019). The scales meet this criterion, confirming high internal consistency. These results collectively demonstrate the study's convergent validity and reliability.

Table 3. Cross-Loadings

Items	1	2	3	4	5	6	7	8	9	10	11
DA1	**0.725**	0.426	0.380	0.398	0.282	0.376	0.308	0.377	0.420	0.407	0.408
DA2	**0.735**	**0.501**	0.492	**0.502**	0.371	0.416	0.345	0.409	0.428	0.474	0.460
DA3	**0.774**	0.485	0.455	0.453	0.400	0.420	0.358	0.392	0.437	0.471	0.459
DA4	**0.807**	0.473	**0.513**	0.450	**0.534**	0.458	0.456	0.454	0.466	0.470	**0.535**
DA5	**0.756**	**0.549**	0.462	0.348	0.389	0.489	0.413	0.390	0.471	**0.518**	**0.504**
DA6	**0.754**	**0.540**	0.450	0.341	0.422	0.430	0.404	0.437	0.473	**0.535**	0.492
ITUBC1	0.477	0.769	**0.524**	0.470	0.397	0.448	0.415	0.444	0.498	**0.704**	**0.506**
ITUBC2	**0.539**	**0.847**	**0.595**	**0.534**	0.478	0.483	0.429	0.462	**0.622**	**0.659**	**0.536**
ITUBC3	**0.580**	**0.822**	**0.570**	0.419	0.421	0.464	0.403	0.381	0.533	**0.641**	0.484
ITUBC4	**0.541**	**0.828**	**0.550**	0.463	**0.535**	**0.535**	0.482	0.456	**0.551**	**0.634**	**0.569**
LDT1	0.453	**0.514**	**0.841**	0.493	0.412	0.422	0.395	0.505	0.583	0.469	0.522
LDT2	**0.595**	**0.624**	**0.883**	**0.521**	**0.531**	0.476	**0.520**	**0.539**	**0.648**	**0.604**	**0.611**
LDT3	**0.502**	**0.615**	**0.843**	**0.537**	0.445	0.433	0.392	0.438	**0.656**	**0.546**	0.499
PU1	0.467	**0.510**	**0.528**	**0.885**	0.455	0.439	0.468	0.420	0.482	0.434	**0.525**
PU2	0.467	**0.504**	**0.564**	**0.886**	0.465	0.425	0.454	0.427	**0.509**	0.426	0.519
PU3	**0.525**	**0.544**	**0.533**	**0.883**	0.467	0.453	0.490	0.495	**0.511**	**0.527**	**0.563**
PU4	0.476	0.481	**0.503**	**0.871**	0.470	0.403	0.453	0.432	0.460	0.466	0.504
PUBC1	0.467	0.478	0.423	0.444	**0.859**	0.478	**0.562**	**0.515**	0.387	0.441	**0.628**
PUBC2	0.438	**0.527**	0.493	0.455	**0.883**	**0.526**	**0.637**	0.467	0.405	0.470	**0.649**
PUBC3	0.492	0.468	**0.508**	0.480	**0.875**	**0.519**	**0.630**	**0.517**	0.466	0.412	**0.660**
SCR1	**0.567**	**0.648**	**0.696**	**0.538**	0.480	0.464	0.444	0.485	**0.912**	**0.633**	**0.551**
SCR2	**0.524**	**0.614**	**0.666**	**0.506**	0.468	0.441	0.452	0.410	**0.901**	**0.661**	**0.517**
SCR3	0.466	**0.517**	**0.571**	0.417	0.301	0.384	0.326	0.410	**0.822**	**0.544**	0.439
SCRC1	0.466	**0.533**	0.395	0.354	0.304	0.355	0.338	0.363	0.437	**0.703**	0.412
SCRC2	**0.572**	**0.679**	**0.573**	0.459	0.463	0.493	**0.539**	0.466	**0.647**	**0.854**	**0.584**
SCRMC2	0.443	0.440	0.416	0.393	0.492	**0.812**	**0.551**	**0.549**	0.333	0.433	**0.718**
SCRMC3	0.419	0.447	0.383	0.357	0.414	**0.765**	0.472	0.491	0.382	0.374	**0.649**
SCRMC4	0.494	**0.521**	0.436	0.411	0.476	**0.800**	0.495	**0.525**	0.454	0.477	**0.683**
SCRMS1	0.448	0.429	0.416	0.426	**0.559**	**0.568**	**0.857**	0.467	0.388	0.441	**0.726**
SCRMS2	0.425	0.472	0.419	0.439	**0.555**	**0.526**	**0.830**	0.430	0.394	0.496	**0.697**
SCRMS3	0.390	0.426	0.451	0.462	**0.638**	**0.505**	**0.815**	0.450	0.388	0.448	**0.698**
SCRMS4	0.388	0.380	0.432	0.392	**0.556**	0.396	0.499	0.394	0.398	0.376	**0.588**
SCRMT1	0.433	0.441	0.498	0.395	0.393	0.478	0.387	**0.779**	0.434	0.428	**0.638**
SCRMT2	0.398	0.397	0.466	0.416	0.499	0.533	0.454	**0.805**	0.331	0.375	**0.698**
SCRMT3	0.339	0.357	0.370	0.318	0.372	0.473	0.307	**0.722**	0.317	0.346	**0.580**
SCRMT4	**0.502**	0.462	0.460	0.430	**0.502**	**0.562**	**0.507**	**0.804**	0.452	0.464	**0.735**

Note. 1=Digital awareness, 2=Intention to use blockchain, 3=Degree of digital transformation, 4=Perceived usability of blockchain, 5=Perceived usefulness of blockchain, 6=SCRM culture, 7=SCRM strategy, 8=SCRM team, 9=Supply chain resiliency, 10=Supply chain adaptability capability, 11=Supply chain risk management.

Table 4. Fornell-Larcker criteria

Constructs	1	2	3	4	5	6	7	8	9	10
Digital awareness	0.759									
Intention to use blockchain	0.654	0.817								
Degree of digital transformation	0.608	0.686	0.856							
Blockchain's perceived usability	0.549	0.579	0.604	0.881						
Blockchain's perceived usefulness	0.533	0.563	0.545	0.527	0.873					
SCRM culture	0.571	0.591	0.520	0.489	0.583	0.792				
SCRM strategy	0.505	0.530	0.514	0.530	0.699	0.639	0.834			
SCRM team	0.542	0.534	0.578	0.504	0.572	0.659	0.539	0.778		
Supply chain resiliency	0.592	0.678	0.736	0.557	0.480	0.490	0.468	0.495	0.879	
Supply chain adaptability capability	0.633	0.805	0.635	0.527	0.506	0.541	0.553	0.520	0.700	0.792

Note. 1=Digital awareness, 2=Intention to use blockchain, 3=Degree of digital transformation, 4=Perceived usability of blockchain, 5=Perceived usefulness of blockchain, 6=SCRM culture, 7=SCRM strategy, 8=SCRM team, 9=Supply chain resiliency, 10=Supply chain adaptability capability.

On the other hand, the study found discriminant validity in terms of Cross-loadings and Fornell-Larkcer criteria (1981). Table 3 displays the results of a discriminant validity analysis, explicitly using Cross-loadings and Fornell & Larcker's (1981) criteria, which propose that the square root of the AVE of each construct should be greater than the correlations with other constructs. Cross-loadings showed that the loadings of one construct are higher than the loadings of another construct. Items marked in bold indicate cross-loadings above the threshold of 0.5, suggesting a stronger association with the respective factor.

In Fornell-Larcker criteria, the diagonal values representing the square root of AVEs are generally more significant than the off-diagonal values in their respective rows and columns in Table 4, indicating acceptable discriminant validity. This supports the conclusion that each construct in the model is distinct from the others (Ammad et al., 2021; Sarstedt & Cheah, 2019). Finally, the study also meets discriminant validity.

Assessment of Path Model

Structural equation modeling (SEM), a multivariate technique including aspects of multiple regression, was used in this study to assess the relationships between constructs. This involved calculating regression coefficients (Beta values), with statistical significance determined by a p-value less than 0.05 and a t-value higher than +1.96 at a 5% level.

The data supported all proposed hypotheses from H1 to H10. The robust and well-fitted model shows that all variables have a meaningful impact on their respective dependent variables. The results are detailed in Table 5.

Figure 3 shows the path coefficients using SEM. The model was run to estimate the regression effects of independent constructs on dependent constructs.

R-squared and adjusted R-squared values are outputs of regression analysis performed in SPSS, indicating the proportion of variance in the dependent variable that the independent variables can explain. According to the R-squared and adjusted R-squared values shown in Table 6, each dependent variable's independent factors account for a sizable portion of the variance in each dependent variable. The "intention to adopt blockchain" and the "perceived usefulness of blockchain" both provide a significant explanatory power of the predictors (R2 and adjusted R2 of 0.557/0.554 and 0.556/0.554, respectively) (Ammad et al., 2021). Other variables such as the "degree of digital transformation," "supply chain resiliency," "blockchain's perceived usability," and "supply chain adaptability

Table 5. Structural equation modeling (path model)

Hypotheses Testing	Beta Values	t-value	p-value
H1. Supply chain Risk Management -> Blockchain's perceived usefulness	0.662	12.839	0.000
H2. Supply chain Risk Management -> Blockchain's perceived usability	0.362	5.670	0.000
H3. Blockchain's perceived usefulness -> Intention to use blockchain	0.241	5.481	0.000
H4. Blockchain's perceived usability -> Intention to use blockchain	0.202	3.886	0.000
H5. Digital Awareness -> Degree of digital transformation	0.608	17.579	0.000
H6. Degree of digital transformation -> Blockchain's perceived usefulness	0.122	2.308	0.021
H7. Degree of digital transformation -> Blockchain's perceived usability	0.373	6.166	0.000
H8. Degree of digital transformation -> Supply chain adaptability capability	0.635	16.186	0.000
H9. Supply chain adaptability capability -> Supply chain resiliency	0.700	22.239	0.000
H10. Supply chain resiliency -> Intention to adopt blockchain	0.450	9.374	0.000

Figure 3. Structural equation modeling model fitness (R-Squared)

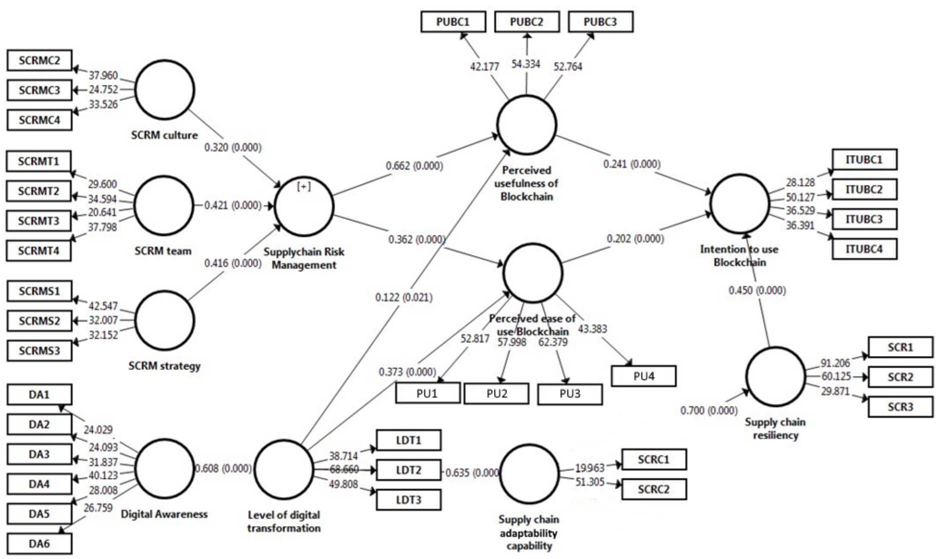


Table 6. R-Squared

Variable	R Squared	R Squared Adjusted
Intention to adopt blockchain	0.557	0.554
Degree of digital transformation	0.370	0.369
Blockchain's perceived usability	0.442	0.439
Blockchain's perceived usefulness	0.556	0.554
Supply chain resiliency	0.489	0.488
Supply chain adaptability capability	0.403	0.402
Supply chain risk management	0.989	0.989

capability," have moderate to R-square strong values, indicating a good-to-excellent fit of the model and significant influence of the predictors (Sarstedt & Cheah, 2019).

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This study provides insights into factors influencing blockchain adoption in the U.S. critical minerals sector but has limitations. Its focus on U.S. companies limits its generalizability globally. Its industry-specific approach may not translate to other sectors. Additionally, reliance on self-reported data could introduce social desirability bias.

Future research should expand in scope. Including data from critical minerals companies across various countries could reveal cultural or geographic differences in blockchain adoption. Examining other industries would assess if similar patterns exist. Longitudinal studies would also be valuable to track changes in blockchain attitudes and usage over time.

CONCLUSION

This study confirms the pivotal role of SCRM in facilitating blockchain technology adoption within the U.S. critical minerals industry and unveils novel insights into the interplay between digital transformation and SCRM practices. Among the new findings, the research uniquely demonstrates how digital literacy and transformation act as critical enablers of blockchain adoption, highlighting that organizations with advanced digital capabilities are more inclined to integrate blockchain into their supply chains. This insight extends the current understanding of the prerequisites for technology adoption in supply chains by emphasizing the importance of a digital-first strategy.

For supply chain managers in the critical minerals industry, these findings offer actionable guidance on prioritizing investments in digital skills and infrastructure as a foundation for blockchain adoption. The study suggests that enhancing digital literacy across the organization can significantly impact perceptions of blockchain's usefulness and ease of use, thereby facilitating a smoother integration process.

Moreover, this research provides empirical evidence supporting the strategic importance of aligning blockchain adoption with broader digital transformation initiatives. This alignment is shown to improve supply chain adaptability and resilience and address industry-specific challenges such as ethical sourcing and sustainability. Supply chain managers can leverage these insights to advocate for blockchain standards that reinforce SCRM culture, encourage effective team dynamics, and refine strategic approaches toward technology adoption.

In practical terms, the study advises managers to consider blockchain as a tool for overcoming the unique challenges faced by the critical minerals sector. By adopting blockchain, companies can enhance transparency, traceability, and efficiency within their supply chains, contributing to sustainable and ethical mineral sourcing practices.

Our research contributes to the existing body of knowledge by elucidating the nuanced effects of SCRM elements and digital transformation on blockchain adoption. It underscores the necessity for critical minerals companies to adopt a holistic view of technology integration, considering both the technological and organizational dimensions of blockchain adoption. Supply chain managers can better navigate the complexities of the digital era.

DATA AVAILABILITY STATEMENT

Raw data were generated at an independent research location. Derived data supporting the findings of this study are available from the corresponding author IK on request.

COMPETING INTERESTS

The author of this publication declares there are no competing interests.

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APPENDIX A

Table 7. Demographic variables

Gender	Male
	Female
Age	21-27 Years
	28-35 Years
	36-45 Years
	46 Years and more
Company age	1–5 years
	6–10 years
	11+ years
Years of experience	2-3 Years
	4-5 Years
	6-7 Years
	8 Years and above
Qualification level	Bachelor’s
	Master’s degrees
	PhD

APPENDIX B

Table 8. Questionnaire

Survey Items		
SCRM culture	SCRMC1	My company considers risk management requirements thoroughly.
	SCRMC2	My company creates a shared, organizational-wide understanding of supply chain risk.
	SCRMC3	SCRM culture promotes a transparent and safe environment.
	SCRMC4	My company promotes a culture that emphasizes risk management to our employees.
SCRM team	SCRMT1	My company employs multi-functional teams to facilitate our firm's SCRM efforts.
	SCRMT2	There is a specialized risk management group in my company.
	SCRMT3	Top management (top administrator and major department heads) is involved in developing the SCRM.
	SCRMT4	My company has supply chain risk-related training for our partners.
SCRM strategy	SCRMS1	SCRM's strategy fits with the company's overall business strategy.
	SCRMS2	SCRM's strategy is in sync with the supply chain strategy.
	SCRMS3	SCRM strategy is an integrated part of the supply chain strategy in my company.
	SCRMS4	The decisions related to risk management fully consider the company's strategies.
Perceived usefulness of blockchain	PUBC1	I think blockchain (BC) is easy and understandable.
	PUBC2	It would be easy for me to become skillful at using BC for risk management.
	PUBC3	I think integrating BC will be easier compared to conventional risk management practices.
	PUBC4	I would find getting BC to do what I need for risk management easy.
Perceived usability of blockchain	PU1	BC facilitates tracing and tracking information related to processes for risk management.
	PU2	BC allows us to perform secure transactions for risk management.
	PU3	BC allows us to communicate with customers and suppliers to manage risks effectively.
	PU4	BC enhances information quality and reliability for risk management.
Supply chain resiliency	SCR1	My company can anticipate and overcome disruptions in the supply chain network.
	SCR2	I can react quickly to interruptions by reconfiguring resources and re-establishing usual operations.
	SCR3	Operations would be able to continue after the occurrence of disruptions.
Supply chain adaptability capability	SCRC1	My company actively implements strategies to mitigate operational risks, enabling adaptation in complex environments. This includes selecting dependable suppliers and establishing clear safety protocols.
	SCRC2	My company possesses the capability to proactively identify operational risks, ensuring timely adjustments are made. This involves robust monitoring and inspection processes both internally and across our supply chain network.

continued on following page

Table 8. Continued

Survey Items		
Digital awareness	DA1	Digital awareness requires strategic leadership from within the organization.
	DA2	Digital awareness requires a vision and long-term plan that are effectively communicated across the organization.
	DA3	Digital awareness can enhance a business's reputation in the sector and amongst consumers.
	DA4	Digital awareness requires engaging the employees and establishing trust amongst the workforce.
	DA5	Digital awareness requires developing relations with business partners and stakeholders to engage them effectively.
	DA6	Requires awareness of technology needs and developing skills through training.
Level of digital transformation	LDT1	My company is engaging in digital transformation.
	LDT2	My company employs technology solutions to transform data into a usable format to help understand the collected information.
	LDT3	My company employs technology solutions to use the data to make forecasts that will help prepare for the future.
Intention to use blockchain	ITUBC1	I predict my organization will adopt BC for risk management in the future.
	ITUBC2	I plan to integrate BC for risk management shortly.
	ITUBC3	I expect that my organization will integrate BC to enhance risk management.
	ITUBC4	My company plans to digitally transform risk management operations by integrating BC.

APPENDIX C

Surveyed Companies

- Albemarle Corporation
- Tesla
- Clarios
- EnerSys
- A123 Systems
- SK Battery America
- Stryten Salina
- Lithium Americas Corp.
- Ultium Cells
- East Penn Manufacturing Co.
- Piedmont Lithium Limited
- American Battery Metals Corporation
- Envision AESC
- Romeo Power
- Lithium Werks
- Freeport-McMoRan Inc.
- Newmont Corporation
- Southern Copper Corporation
- Stillwater Critical Minerals
- Cleveland-Cliffs Inc.
- MP Materials Corp.
- Steel Dynamics, Inc.

Ivan Kudrenko graduated with a bachelor's degree in electrical engineering, a master's degree in electrical engineering, and a master's degree in business administration (MBA) from the University of Michigan with a concentration in operations and supply cha<in management. Having spent a decade managing supply chain operations and continuous improvement projects in the manufacturing and aerospace industries, Ivan focuses on researching cutting-edge sustainable supply chain management practices and innovations in operations and supply chain management. Ivan is a senior supply chain analyst at The Boeing Company (Charleston, SC).