The FinTech Center Working Paper Series: Paper # VA-202001

November 2020

A Study on Value Creation through Blockchain-based Supply Chain Networks in Lean Production System

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ABSTRACT

This study explores the impact of blockchain technology on Lean management system in supply chain networks. In the context of supply chain management, a blockchain-backed Lean system model and measurements for blockchain research have been developed. The research model and hypotheses were empirically tested using a survey sample of 219 practitioners and managers in the United States. The results show that blockchain is currently being adopted in a variety of use cases beyond industry-wide payments and transactions. Structural Equation Modeling (SEM) analysis was performed, and the results show that the adoption of a blockchain-backed supply chain network has a significant impact on both supplier-related and buyer-related Lean practices. The SEM results also indicate that the blockchain-backed Lean system has a significant positive impact on the company's operational performance, such as cost reduction, quality performance, delivery capacity and operational flexibility.

Keywords: *Blockchain technology, Lean management practices, Supply chain networks, Operational performance, Structural equation modeling, Survey, Empirical research*

1. Introduction

Lean management system is a concept that extends lean production philosophy beyond the company's scope to the entire supply chain network (Hines *et al*., 2004; Holweg, 2007; Liu *et al.*, 2013). However, at the supply chain level, it is much more challenging for the focal company to control and achieve optimal lean management system because it involves risks such as opportunistic behavior, uncertainty, power imbalance, and information asymmetry that are frequently caused by supplier-buyer relationships (Schmidt & Wagner, 2019). Also, if the supplier operates in a foreign country, the cost of additional trade documents (e.g., letter of credit, bill of lading) inevitably occurs in order to use third-party validation, which is estimated to about one fifth of the actual transportation costs (Gupta, 2018). On the Lean system side, all of these risks and costs are far from value-added activities, so they are considered "wastes" to be removed (Shah & Ward, 2007). However, to date, there is still a lack of understanding on how to systematically manage a global lean management system in supply chain networks. In response to this research problem, this study focuses on "blockchain technology" as a disruptive innovation that will transform the current trust-oriented supply chain management (SCM) to data-oriented SCM. In particular, the blockchain is expected to contribute to lean management systems by: (i) reducing transaction settlement time and cost through a single decentralized ledger, (ii) shortening lead times and delays through peer-to-peer transactions and smart contracts, and (iii) mitigating the cost of opportunistic behavior through transparent and temper-evident records. Further, in the current global supply chain crisis such as the COVID-19 pandemic, blockchain networks are expected to serve as a more efficient business operations platform to implement lean management practices. However, the literature lacks research on blockchain adoption in Lean systems. This study focuses on bridging this gap by developing and validating a blockchain-enabled lean system model in supply chain networks. In light of the arguments above, a key objective of this research is to answer the following research question: *how does blockchain technology affect the effectiveness of Lean management practices in supply chain networks?*

As the literature on this research topic is limited and there are no reports on implementation in the industry, we take a more empirical approach to answering our research question. Therefore, the first phase in this study is exploratory in nature. The case study of blockchain technology adoption in supply chain networks is conducted based on U.S. companies in a wide range of industries that have adopted blockchain technology and have created real revenue value and monetization. The case study will take a retrospective approach based on the use cases of blockchain technology at the firm level. The results of the case study will serve as the basis for developing theoretical frameworks and hypotheses along with a review of the existing literature. This stage also includes the development of reliable measurement scales for blockchain research, particularly in the context of SCM. Then, hypotheses are tested using a large sample of surveys to explore the impact of blockchain technology on the lean management practices in supply chain networks. Finally, using secondary data including the companies participating in this study as well as Forbes' Blockchain 50 list companies, this study validates the survey results. In addition, this study will compare the financial performance of blockchain companies and their competitors during the first half of this year (2020) to investigate how blockchain has actually helped to maintain a competitive advantage in a global supply chain crisis such as the COVID-19 pandemic.

2. Literature Review

2.1. Blockchain revolution

Blockchain is a specific type of database architecture based on the Distributed Ledger Technology (DLT) (Schmidt & Wagner, 2019). The core idea of blockchain technology (BT) is based on the Paxos protocol developed by Leslie Lamport (1998), a consensus model for reaching consensus in computer networks (Yaga *et al*., 2018). Later, BT was applied to electronic cash by Satoshi Nakamoto (2008), and BT received great attention with the launch of the Bitcoin network in 2009 (Yaga *et al*., 2018). Unlike traditional database networks, a blockchain network has the following four key characteristics:

> (i) *Distributed ledger*: A single digital ledger is shared by all nodes (entities in the network) and is updated with every transaction in near real time. As such, the blockchain network is not controlled by a single party, and all parties can access and verify transaction records directly without any trusted third-party intermediaries, such as banks and governments (Gupta, 2018).
>
> (ii) *Transparency with pseudonymity*: Every transaction is visible over the network. Each node has a unique 30+ alphanumeric address, and transactions occur between blockchain addresses (Casey & Wong, 2017).

(iii) *Immutability of records*: Once a transaction is recorded into the blockchain database, the record cannot be changed because it is cryptographically linked to all previous transaction records (Yaga *et al.*, 2018). That's why it's called "chain”
(iv) *Consensus protocol*: The blockchain maintains consensus among all participants using consensus protocols such as Proof of Work (PoW), Proof of Stake (PoS), and the Proof of Elapsed Time (PoET) - a set of rules that determine when to add new information to the blockchain (McQuinn, & Castro, 2019; Wang *et al*., 2019). This consensus protocol enables tamper-resistant transactions on blockchain networks.

Because of this nature of BT's decentralization, consensus-based, transparency, and immutability, blockchain is often seen as a disruptive technology that will become a “game changer." (Johnson, 2018). In other words, just as the Internet has revolutionized the way information is exchanged, BT can potentially revolutionize the way goods and services are traded (Schmidt & Wagner, 2019). According to Deloitte's 2020 Global Blockchain Survey (Pawczuk *et al.,*2020) of 1,488 executives and practitioners in 14 countries including the U.S., Germany, UAE, Israel, and China, 88% of respondents said that BT is broadly scalable and will eventually achieve mainstream adoption; 83% of respondents said that if they don't adopt BT, their companies will lose competitive advantage; 82% of respondents said that they plan to hire staff with blockchain expertise within the next 12 months. In addition, PwC's 2018 Global Blockchain Survey of 600 executives from 15 countries including the U.S., Denmark, India, Australia, and Japan, 84% of respondents said that their organizations have at least some involvement with BT.

2.2. Blockchain research in supply chain management

As blockchain is rapidly creating value in supply chains around the world, research on the applicability of BT in the supply chain has actively being conducted. Treiblmaier (2018) presented a framework for SCM's blockchain research from various theoretical perspectives such as principal agent theory, transaction cost analysis, resource-based view, and network theory. Another notable blockchain research in SCM is Dolgui *et al*. (2019), which developed BT-oriented computational algorithm and models for smart contract design and execution in the supply chain. Table 1 summarizes the main literature and findings of blockchain research in the field of SCM. Although theoretical research on blockchain has made significant progress, empirical research is still rare in SCM.

Table 1. Major studies on blockchain technology in supply chain management.

Author	Journal	Objective	Type	Key Findin
Saberi *et al.* (2019)	IJPR	To understand the benefits and challenges of adopting blockchain technology in SCM[a]	Conceptual	Four categories of barriers to ad organizational, intra-organizatio external barriers) are introduced.
Dolgui *et al.* (2019)	IJPR	To develop a control methodology for BT-oriented smart contract design in SCM	Mathematical modelling	Computational algorithm and mo contract design in SCM are intro
Chang *et al.* (2019)	IM&DS	To explore the applicability of BT in the international trade process	Conceptual	This study proposed a blockchai trade process model, especially i of credit (L/C) payment process.
Kamble *et al*. (2019)	IJPR	To understand user perception of BT adoption	Empirical *N = 181 in India*	Perceived usefulness, attitude, be subjective norms influence BT i intent.
Schmidt & Wagner (2019)	JPSM	To develop a theoretical framework for the impact of blockchain on transaction costs and supply chain governance	Conceptual	Using the transaction cost theory that blockchain reduces transacti opportunistic behavior and impro environmental/behavioral uncert
Kshetri (2018)	IJIM	To understand the role of blockchain in meeting key SCM goals	Conceptual	Using case studies of blockchain discussed how blockchain affects objectives such as cost, quality, risk reduction, sustainability, and
Banerjee (2018)	AIC	To understanding how ERP systems alongside BT improve supply chain operations	Conceptual	This study details how ERP and each other in all aspects of suppl that lead to transparency, efficien
Treiblmaier (2018)	SCM-J	To propose a theoretical framework for blockchain research in the context of SCM	Conceptual	This study presents blockchain-r questions derived from principal transaction cost analysis, resourc network theory.

Note: [a] Supply chain management, [b] Blockchain technology; IJPR = *International Journal of Production Research*, IM&DS = *Industrial Management & Data Systems*, JPSM = *Journal of Purchasing and Supply Management*, IJIM = *International journal of Information Management*, AIC = *Advances in Computers*, SCM-J: *Supply Chain Management: An International Journal*

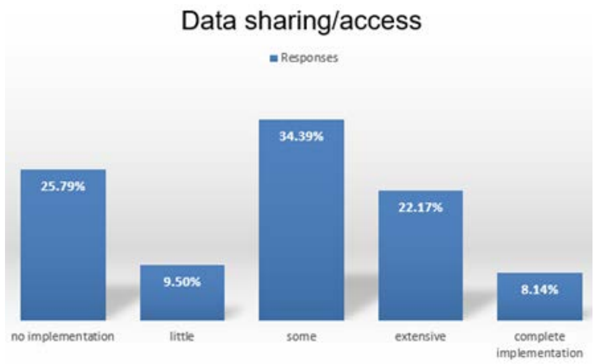
2.3. Blockchain technology case uses in supply chain networks

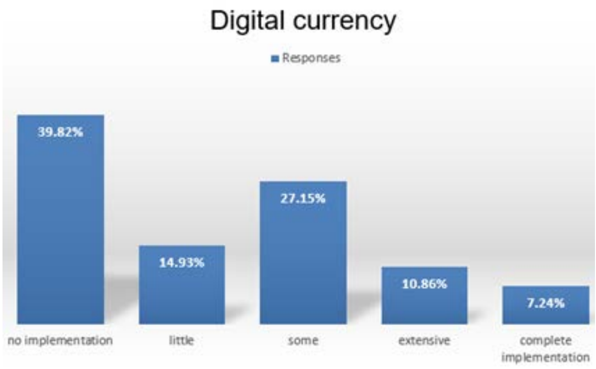
According to Deloitte's 2020 Global Blockchain Survey, BT is currently being adopted globally in a variety of use cases beyond industry-wide payments and transactions, as shown in Table 2. However, Deloitte's survey indicates the adoption and implementation of BT in all business activities of the enterprises but, the focus of this study is on SCM activities, so we surveyed BT use cases, especially in supply chain networks (a detailed explanation of this survey is discussed in the Methodology section). Figure 1 shows how blockchain technology is adopted and implemented in SCM of U.S. companies (N = 219). The two surveys generally showed similar trends in BT use cases, but our survey showed fewer digital currency use cases and higher certification use cases than Deloitte's. This difference seems to be due to Deloitte's survey being conducted in 14 countries, while our survey was limited to U.S. companies. As a result, it can be seen as a natural phenomenon where digital currency adoption tends to be low in the U.S., where the most stable currency, the dollar, is in circulation.

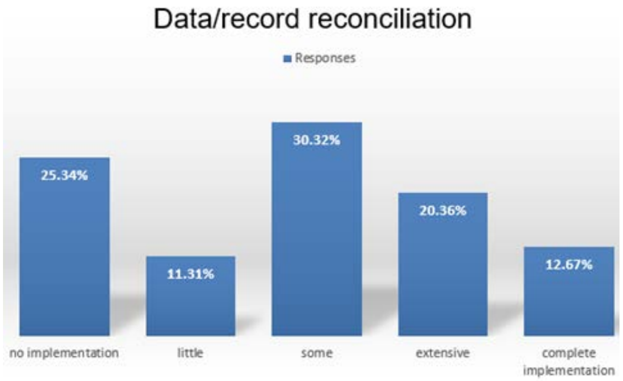
Table 2. Global blockchain technology use cases

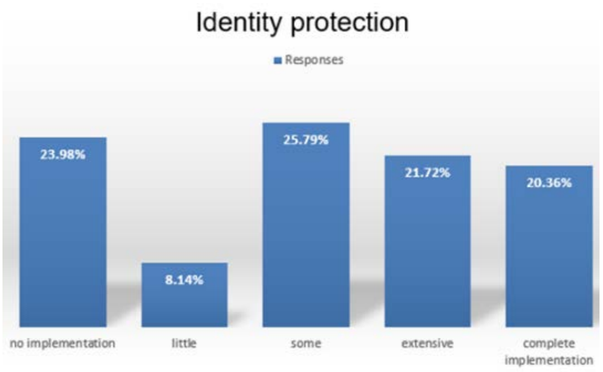
Ranking	Blockchain adoption	Percentage (%)
1	Digital currency	33
2	Data access/sharing	32
3	Data reconciliation	31
4	Identity protection	31
5	Payments	30
6	Track-and-trace	27
7	Asset protection	27
8	Asset transfer	25
9	Certification	23
10	Record reconciliation	23
11	Revenue sharing	23
12	Tokenized securities (equity, debt, and derivatives)	22
13	Access to IP	21
14	Asset-based tokens	21
15	Time stamping	18
16	Custody	18
	None	1

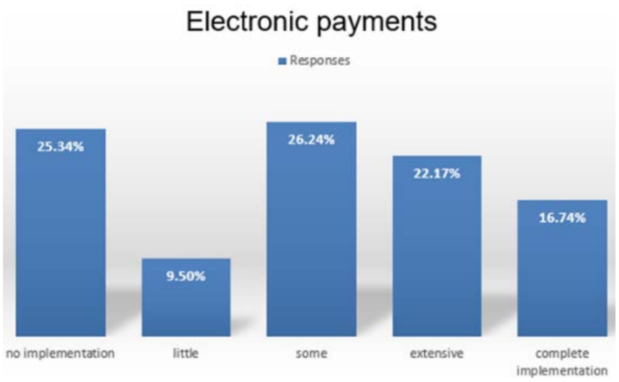
Note: N = 1,488; Since companies or projects can adopt more than one blockchain applications, the percentage is over 100%.
Source: adapted from Deloitte’s 2020 Global Blockchain Survey (p. 33).

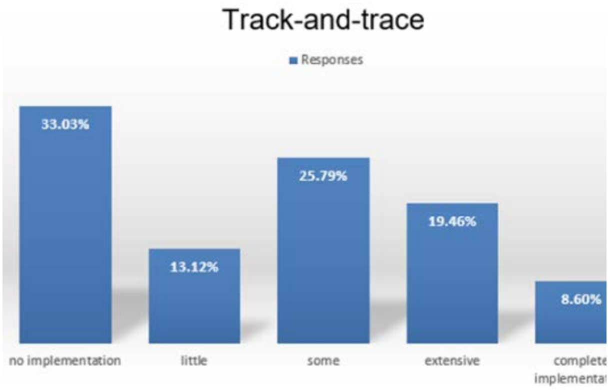

Data sharing/access
Responses
25.79%
9.50%
34.39%
22.17%
8.14%
no implementation
little
some
extensive
complete implementation

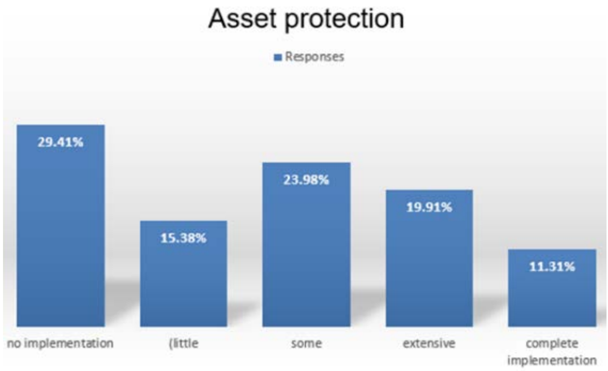

Digital currency
Responses
39.82%
14.93%
27.15%
10.86%
7.24%
no implementation
little
some
extensive
complete implementation


Data/record reconciliation
Responses
25.34%
11.31%
30.32%
20.36%
12.67%
no implementation
little
some
extensive
complete implementation

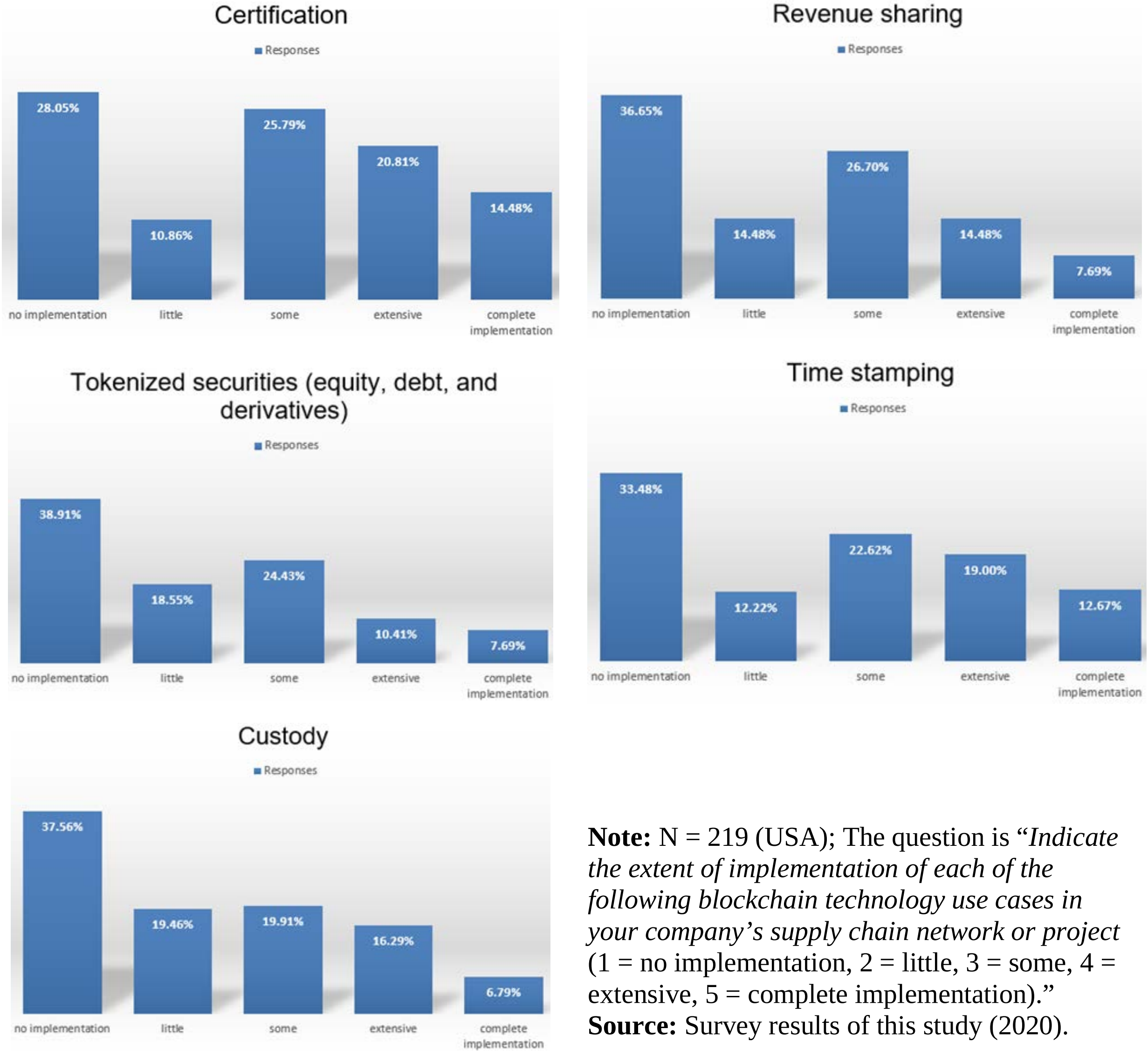

Identity protection
Responses
23.98%
8.14%
25.79%
21.72%
20.36%
no implementation
little
some
extensive
complete implementation


Electronic payments
Responses
25.34%
9.50%
26.24%
22.17%
16.74%
no implementation
little
some
extensive
complete implementation


Track-and-trace
Responses
33.03%
13.12%
25.79%
19.46%
8.60%
no implementation
little
some
extensive
complete implementa


Asset protection
Responses
29.41%
15.38%
23.98%
19.91%
11.31%
no implementation
(little
some
extensive
complete implementation


Asset transfer
Responses
33.03%
15.84%
28.96%
12.22%
9.95%
no implementation
little
some
extensive
complete implementation



Note: N = 219 (USA); The question is "*Indicate the extent of implementation of each of the following blockchain technology use cases in your company's supply chain network or project* (1 = no implementation, 2 = little, 3 = some, 4 = extensive, 5 = complete implementation)."
Source: Survey results of this study (2020).

Figure 1. Blockchain use cases in supply chain networks.

3. Hypotheses and Research Model

The lean production, pioneered by the Toyota Motor Company in the mid-1970s, seek to minimize any waste that does not add value, such as unnecessary space, waiting time, excessive inventory, defects, over-production, motion or transportation (Bozarth & Handfield, 2016; Krajewski *et al*, 2013). Lean Management System is an extended concept of the lean philosophy from a single plant to an entire supply chain network (Hines *et al*., 2004; Holweg, 2007). However, as decision makers at each stage of the supply chains may have different decision preferences and priorities, it becomes more difficult to achieve an integrated lean management system across the supply chain network (Liu *et al.*, 2013). In addition, lean practices in supply chain networks are inevitably accompanied by risks often arising from supplier-buyer relationships, such as opportunistic behavior, uncertainty, power imbalances, and information asymmetry (Schmidt & Wagner, 2019). Therefore, it is believed that the key solution to coping with this situation is to build a systematic platform capable of integrated lean management practices in the entire supply chain network, and blockchain technology has the potential to become such a key solution for the following reasons:

First, supply chains are a complex network of systems, logistics, data and relationships, so even minor errors can cause the bullwhip effect, resulting in massive delays. Blockchain is a digital ledger shared by all entities on the network and is updated with every transaction in near real time (Casey & Wong, 2017). This allows all records and processes to be visible throughout the supply chain, enabling all participants in the network to manage and supervise errors and problems in real time. In a blockchain network, data is synchronized and shared across the supply chain via a single digital ledger, which contributes to cost savings by eliminating unnecessary time and effort that can be caused by document duplication in traditional supply chain process (Gupta, 2018).

Second, blockchain acts as a digital platform to execute the smart contracts, which are self-validating and self-executing agreements between entities in the supply chain process when certain conditions (e.g. the arrival of a product at a carrier) are met (Min, 2019; Dolgui *et al.,* 2020). For example, ADEPT (Autonomous Decentralized Peer-to-Peer Telemetry), developed by Samsung and IBM, is used for smart contract-based ordering and payments (Kamble *et al.*, 2019). Smart contracts allow entities in the supply chain network to exchange money, share, or property in a transparent and accurate way, avoiding expensive services of third-party brokers such as banks (Min, 2019). As a result, smart contracts help organizations speed up order fulfillment by minimizing delays between delivery and payment and reduce transaction costs by eliminating intermediaries.

Third, when a new transaction occurs on the blockchain network, the record is encrypted and linked with all previous transaction records, making it impossible to change. In this way, blockchain can enhance trust between all parties in the supply chain network (e.g. sellers, buyers and focal companies). The blockchain’s temper-evident nature also mitigate the cost of opportunistic that often occurs among stakeholders in the supply chain network (Saberi *et al.*, 2019).

Lastly, blockchain also provides an accurate way to forecast demand and measure inventory in supply chain processes. For example, stakeholders in the supply chain can use shared and real-time transaction records to analyze travel paths and durations. Thus, in this way, blockchain-backed platforms provide more flexible flow shop scheduling at the planning stage (Kshetri, 2018; Dolgui *et al.*, 2020).

In short, BT, adopted into the supply chain network, is expected to help all parties in the supply chain to achieve lean practices effectively while trusting each other.

Therefore, taking into account all the impacts of blockchain-backed supply chain network on Lean management system discussed above, we propose the following hypothesis and research model (Figure 2):

H1: The adoption of a blockchain-backed supply chain network has a positive impact on supplier-related Lean practices.

H2: The adoption of a blockchain-backed supply chain network has a positive impact on buyer-related Lean practices.

H3: Supplier-related Lean practices are positively associated with in-plant Lean practices.

H4: Buyer-related Lean practices are positively associated with in-plant Lean practices.

H5a: In-plant Lean practices positively affect cost savings.

H5b: In-plant Lean practices positively affect quality performance.

H5c: In-plant Lean practices positively affect delivery capacity.

H5d: In-plant Lean practices positively affect operational flexibility.

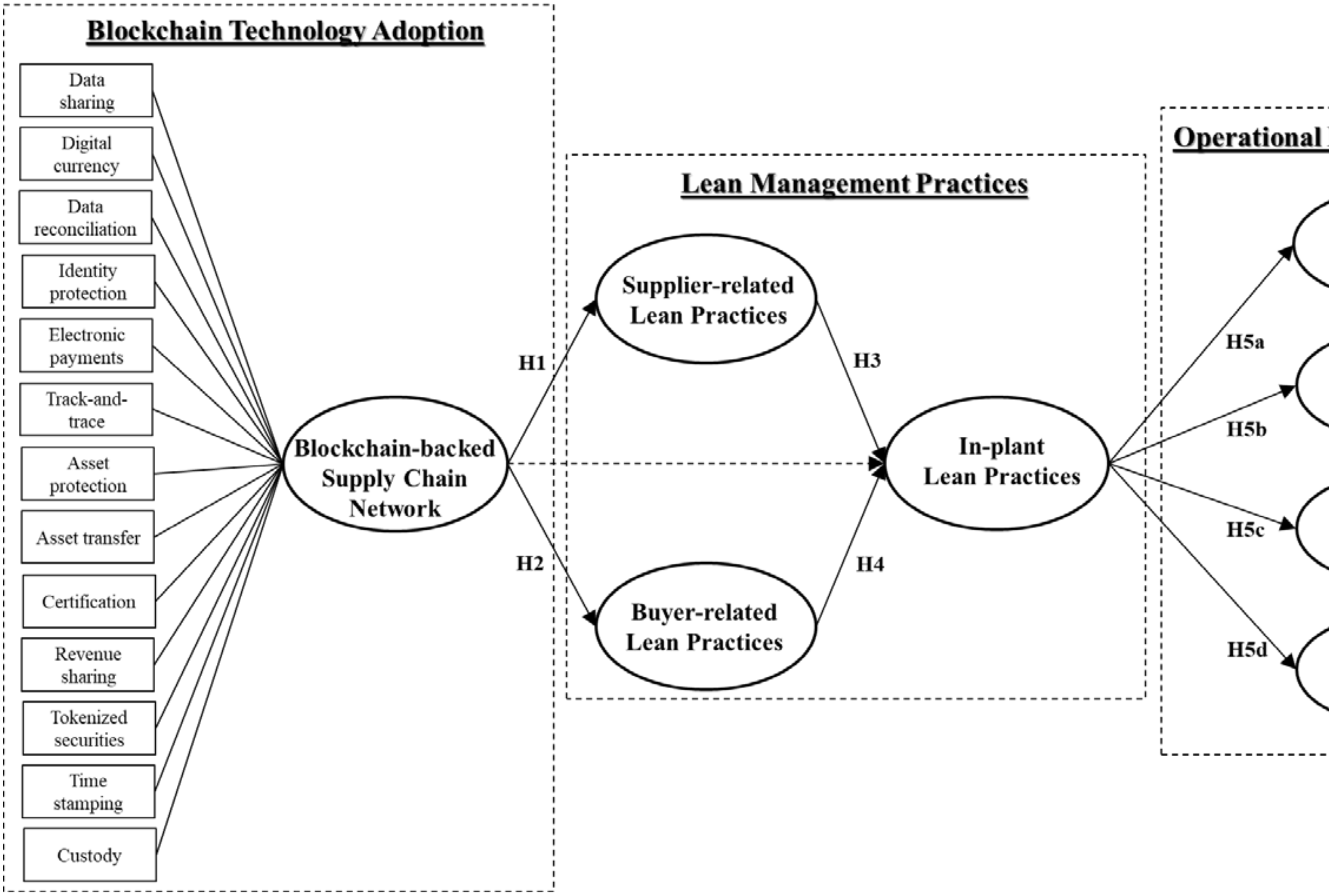


Figure 2. Research Model

4. Methodology

4.1. Measure development

4.1.1. Adoption of blockchain-backed supply chain network

Since blockchain research is relatively new in the context of the operations management literature, there are no widely adopted reliable instruments that can be used to measure the degree of implementation of blockchain technology in supply chain networks. However, blockchain research in the industry is much more advanced and practical. Deloitte LLP has been conducting a global survey on attitudes and investments in blockchain technology every year since 2018 with N = 1,053 (2018 survey) N = 1,386 (2019 survey), N = 1,488 (2020 survey) executives and practitioners in various countries around the world, including the U.S., UAE, Germany, Switzerland, South Africa, Singapore, and China. In particular, the 2020 report contains a survey of blockchain cases that are being used in industry, as previously presented in Table 2. Given (i) the expertise and scale of the survey conducted by 1,488 executives and practitioners and (ii) the longitudinal nature of it lasting more than three years, it is considered to meet the content validity required when developing new measurement for adoption of blockchain technology. Therefore, by benchmarking these categories of blockchain use cases, we developed a survey instrument that can measure how blockchain technology is being utilized on supply chain networks or projects. Survey participants were asked to indicate the extent of implementation of each blockchain use case in the supply chain network or project on a 5-point Likert type scale: 1 = no implementation, 2 = little, 3 = some, 4 = extensive, 5 = complete implementation. More details on blockchain measurements can be found in Appendix A.

4.1.2. Lean management practices

Regarding Lean management practices, we employed items from Shah & Ward (2007). Respondents were asked to indicate the extent of implementation of Lean management practices in their supply chain network or project. All items were presented on a 5-Likert scale, ranging from 1 = no implementation to 5 = complete implementation.

4.1.3. Operational performance

Operational performance was captured by four widely adopted metrics: cost, quality, delivery, and flexibility (Naor *et al.*, 2010; Kristal *et al.*, 2010). Respondents were asked to rate their operational performance compared to their competition on 5-point Liker type scale: 1 = low end of the industry, 2 = worse than industry average, 3 = average, 4 = better than average, 5 = superior

4.1.4. Marker and control variables

To mitigate the risk of common method variance (CMV), the questionnaire included a marker variable that measures the severity of respondents' insomnia problems (Bastien *et al.*, 2001). Several control variables were adopted, such as firm age and industry type (Vickery *et al.*, 2013; Kach *et al.,* 2016). Specifically, Firm age was measured by counting the duration of the business (Cho & Linderman, 2019). In addition, to examine the impact of the COVID-19 pandemic on financial performance, respondents were asked to indicate their sales performance and net profit margin compared to industry competitors, using a 5-point Likert scale, ranging from 1 = low end of the industry to 5 = superior (Cho & Linderman, 2020). Details of all measurements used in the survey are given in the Appendix A.

4.2. Data collection

Data was collected through internet-based surveys to empirically test the hypothesis of this study. A contact list obtained from a large commercial business data provider were used as the primary source for data collection, and each respondent was selected based on job function. Email invitations with links to web surveys were sent to full-time practitioners and managers in the United States. We received a total of 219 viable samples, resulting in a response rate of 84%. This high response rate was made possible by using a list of verified participants, and by giving participants the option of providing a feedback report as a benefit (Naor *et al.*, 2010). However, above all, it is presumed to be a result of the high interest of companies in blockchain technology. The demographic profile of the sample is shown in Table 3.

Table 3. Sample profile.

Category		N	Percentage (%)
Firm's age (length of time in business)	Less than 10 years	54	24.66
	11 ~20 years	37	16.89
	21 ~ 30 years	36	16.44
	31 ~ 40 years	27	12.33
	More than 40 years	65	29.68
Firm's size (# of employees)	(1) Less than 10	39	17.81
	(2) 11 ~ 100	39	17.81

	(3) 101 ~ 1,000	58	26.48
	(4) 1,001 ~ 10,000	44	20.09
	(5) More than 10,000	39	17.81
Respondent's age	18-29	62	28.31
	30-44	70	31.96
	45-60	75	34.25
	> 60	12	5.48
Industrial classification [2-digit SIC]	Agriculture, Forestry & Fishing [01-09]	9	4.31
	Construction [15-17]	16	7.66
	Apparel & Fabricated Textile Products [23]	10	4.78
	Papers & Allied Products [26]	4	1.91
	Printing & Publishing [27]	6	2.87
	Pharmaceuticals [28]	5	2.39
	Chemical Products [28]	5	2.39
	Semiconductors & Related Devices [36]	2	.96
	Transportation Services [47]	14	6.70
	Communications Services [48]	15	7.18
	Wholesale Trade [50-51]	4	1.91
	Retail Trade [52-59]	20	9.57
	Financial Services [60-64]	8	3.83
	Hotels & Other Lodging Places [70]	7	3.35
	Prepackaged Software [73]	2	.96
	Healthcare [80]	27	12.92
	Legal Services [81]	2	.96
	Education [82]	18	8.61
	Accounting & Business Consulting Services [87]	4	1.91
	Other	32	15.31

5. Results (Preliminary)

5.1. Measurement validity and reliability

Table 4 reports the correlations, means, and standard deviations of the study variables. Cronbach's alpha values for all constructs met an acceptable reliability level of .70 or higher, ranged from .802 to .957 (Cronbach, 1951; Nunnally, 1967), as shown Table 5. Next, confirmation factor analysis (CFA) was conducted to evaluate the psychometric properties of the measurements. All latent variables were included in a single multifactorial model and the standardized factor loadings were estimated. The CFA results indicated that goodness-of-fit statistics for the measurement model satisfied the desirable thresholds for each fit index (Chi-square = 1179.295, *d.f.* = 566, Normed χ^2 = 2.084, Comparative fit index = .910, Parsimony normed fit index = .757, RMSEA = .071 RMSEA 90% confidence interval: .065 ~ .076). All measure items met the suggested threshold of .50 factor loading (Hair *et al*., 2010, p.686), ranging between .717 and .867, as shown in Table 5. Additionally, we computed the average variance extracted (AVE) to investigate the convergent validity of the scales (Dillon & Goldstein 1984). The AVE estimates of all constructs were higher than the minimum tolerance of 50% (Hair *et al*., 2010, p.700) and ranged between 57.89% and 70.78%. Taken together, the evidence supports the construct validity of the measure scales.

5.2. Common method variance assessment

Since the data for this study were from a single source for each company, this study may not be free from common method variance (CMV) (Podsakoff *et al*., 2003). So, we included a marker variable in the survey questionnaire as an ex-ante remedy to minimize the CMV threat (Williams *et al*., 2010; Craighead *et al*., 2011). The insomnia severity index developed by Bastien *et al*. (2001) was chosen as a marker variable for this study because the variable was theoretically unrelated to other variables (Simmering *et al*., 2015). Further, as an ex-post approach, we performed a common latent factor analysis after completing data collection (Podsakoff *et al*., 2003; Richardson *et al*., 2009). As such, we examined changes in the structural parameters when adding the common latent factor (CLF) to the measurement model. The test results demonstrated that the changes in parameters were minimal and insignificant, indicating that the CMV threat is not a pervasive problem in our data.

Table 4. Correlations and descriptive statistics.

Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Blockchain network[a]										
2. Supplier-related lean practices	.723**									
3. Buyer-related lean practices	.662**	.831**								
4. In-plant lean practices	.775**	.868**	.809**							
5. Cost savings	.566**	.702**	.674**	.729**						
6. Quality performance	.502**	.614**	.614**	.688**	.804**					
7. Delivery capacity	.433**	.571**	.596**	.624**	.773**	.772**				
8. Operational flexibility	.545**	.547**	.623**	.618**	.708**	.720**	.751**			
9. Firm age[b]	.089	.148*	.076	.119	.237**	.184**	.149*	.161*		
10. Industry type[c]	-.036	-.003	.000	.012	.089	.105	.010	.103	.058	
11. COVID-19[c]	.425**	.495**	.470**	.526**	.626**	.606**	.619**	.563**	.253**	.03

Note: ** $p < .01$ (2-tailed), * $p < .05$ (two tailed), [a] Adoption of blockchain-backed supply chain network, [b] Length of time in business, [c] 2-digit SIC, [c] Financial performance during the COVID-19 pandemic.

Table 5. CFA test results of the measurement model.

Factor	Item no.	Loading[a]	S.E.[b]	*t*-value	*p*-value	AVE[c]
Blockchain-backed supply chain network (Cronbach's α = .957)	q04	.802	.107	11.813	***	63.42%
	q10	.851	.098	12.567	***	
	q03	.836	.100	12.340	***	
	q11	.787	.096	11.585	***	
	q02	.668	.096	9.796	***	
	q01	.717	-	-	-	
	q12	.760	.106	11.186	***	
	q13	.771	.097	11.351	***	
	q09	.844	.105	12.459	***	
	q08	.847	.098	12.513	***	
	q07	.846	.102	12.498	***	
	q06	.842	.100	12.427	***	
	q05	.757	.105	11.134	***	
Supplier-related lean practices (Cronbach's α = .892)	q14	.821	-	-	-	67.56%
	q15	.852	.065	15.326	***	
	q16	.815	.072	14.345	***	
	q17	.799	.071	13.926	***	
Buyer-related lean practices (Cronbach's α = .867)	q20	.844	-	-	-	69.13%
	q19	.867	.064	16.175	***	
	q18	.781	.070	13.703	***	
In-plant lean practices (Cronbach's α = .908)	q26	.720	-	-	-	62.82%
	q25	.829	.090	12.233	***	
	q24	.812	.095	11.983	***	
	q23	.823	.091	12.150	***	
	q22	.803	.094	11.846	***	
	q21	.763	.089	11.224	***	
Cost savings (Cronbach's α = .802)	q27	.748	-	-	-	57.89%
	q28	.786	.092	12.098	***	
	q29	.748	.094	11.430	***	
Quality performance (Cronbach's α = .852)	q30	.802	-	-	-	65.72%
	q31	.813	.076	13.482	***	
	q32	.817	.073	13.568	***	
Delivery capacity (Cronbach's α = .804)	q33	.813	-	-	-	67.32%
	q34	.828	.072	14.124	***	
Operational flexibility (Cronbach's α = .828)	q35	.864	-	-	-	70.78%
	q36	.818	.067	14.533	***	

Note: N = 219; [a] Standardized factor loading; [b] Standard error (not estimated when loading set to fixed value: i.e., 1.0); [c] Average Variance Extracted; *** $p < 0.001$.

5.3. SEM analysis of the research model

Structural equation modeling (SEM) analysis was performed to examine the research model and hypotheses proposed in this study. Figure 3 shows SEM test results computed by IBM AMOS 26. The test results present that the adoption of blockchain-backed supply chain network has a significant impact on both the supplier-related lean practices ($\beta = .799$, $t = 10.053$, $p < .001$) and the buyer-related lean practices ($\beta = .758$, $t = 9.693$, $p < .001$), while blockchain network adoption does not directly affect the in-plant lean production ($\beta = .080$, $t = .936$, $p = .349$). These results strongly support hypotheses 1 and 2. The SEM results also indicate that both supplier-related ($\beta = .550$, $t = 6.752$, $p < .001$) and buyer-related ($\beta = .404$, $t = 5.781$, $p < .001$) lean practices are significantly associated with the in-plant lean practices, supporting hypotheses 3 and 4. In addition, the results show that the in-plant lean approach is significantly related to a company's operational performance, such as cost saving s ($\beta = .917$, $t = 9.900$, $p < .001$), quality performance ($\beta = .844$, $t = 10.109$, $p < .001$), delivery capacity ($\beta = .812$, $t = 9.546$, $p < .001$) and operational flexibility ($\beta = .788$, $t = 10.010$, $p < .001$). Thereby, hypotheses 5a, 5b, 5c and 5d are also fully supported. Table 6 shows detailed results of SEM conducted by IBM AMOS 26.

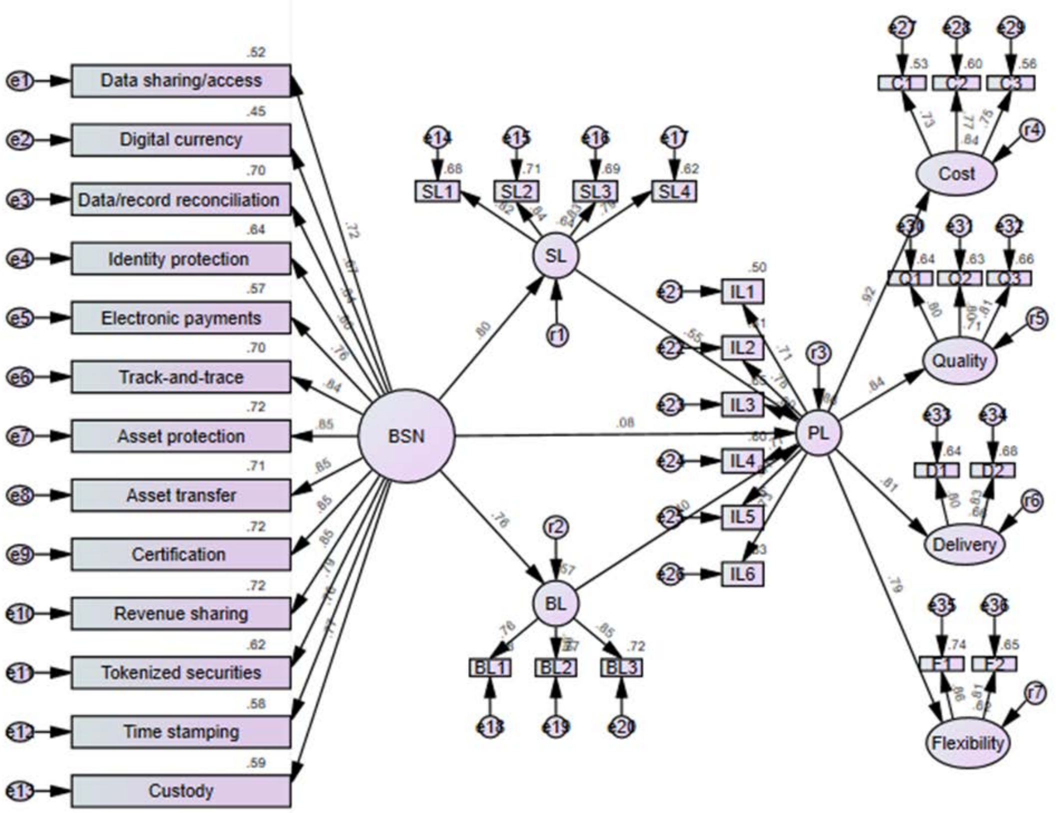


Figure 3. SEM analysis of the research model.

Note: N = 219, Chi-square = 1595.285, *d.f.* = 585, Normed χ^2 = 2.727, Probability level = .000, BSN = adoption of blockchain-backed supply chain network, SL = supplier-related lean practices, BL = buyer-related lean practices, PL = in-plant lean practices.

Table 6. Hypothesis test results.

Hypothesis	**Path**			**Beta**	**S.E.**[a]	***t*-value**	**Sig.**	**Result**
			Factors (Latent variables)					
H1	SL	←	BSN	.799	.091	10.053	***	*Supported*
H2	BL	←	BSN	.758	.091	9.693	***	*Supported*
H3	PL	←	SL	.550	.073	6.752	***	*Supported*
H4	PL	←	BL	.404	.061	5.781	***	*Supported*
	PL	←	BSN	.080	.087	.936	.349	
H5a	Cost	←	PL	.917	.074	9.900	***	*Supported*
H5b	Quality	←	PL	.844	.079	10.109	***	*Supported*
H5c	Delivery	←	PL	.812	.080	9.546	***	*Supported*
H5d	Flexibility	←	PL	.788	.076	10.010	***	*Supported*
			Scales (Measurement items)					
	q0004	←	BSN	.801	.106	11.831	***	
	q0010	←	BSN	.847	.097	12.544	***	
	q0003	←	BSN	.836	.099	12.371	***	
	q0011	←	BSN	.785	.095	11.597	***	
	q0002	←	BSN	.668	.096	9.810	***	
	q0001	←	BSN	.719				
	q0012	←	BSN	.762	.106	11.234	***	
	q0013	←	BSN	.769	.097	11.337	***	
	q0009	←	BSN	.847	.104	12.537	***	
	q0008	←	BSN	.845	.098	12.517	***	
	q0007	←	BSN	.846	.101	12.527	***	
	q0006	←	BSN	.835	.099	12.365	***	
	q0005	←	BSN	.756	.105	11.153	***	
	q0014	←	SL	.825				
	q0015	←	SL	.843	.067	14.732	***	
	q0016	←	SL	.831	.072	14.437	***	
	q0017	←	SL	.790	.073	13.415	***	
	q0020	←	BL	.846				
	q0019	←	BL	.878	.067	15.582	***	
	q0018	←	BL	.764	.073	12.882	***	
	q0026	←	PL	.728				
	q0025	←	PL	.806	.087	12.008	***	
	q0024	←	PL	.774	.093	11.498	***	
	q0023	←	PL	.804	.089	11.972	***	
	q0022	←	PL	.780	.092	11.591	***	
	q0021	←	PL	.710	.087	10.497	***	
	q0027	←	Cost	.726				
	q0028	←	Cost	.773	.104	10.789	***	
	q0029	←	Cost	.747	.105	10.425	***	
	q0030	←	Quality	.797				
	q0031	←	Quality	.796	.082	12.296	***	
	q0032	←	Quality	.813	.079	12.601	***	
	q0033	←	Delivery	.799				

q0034	←	Delivery	.827	.089	11.508	***
q0035	←	Flexibility	.861			
q0036	←	Flexibility	.808	.080	12.084	***

Note: N = 219, *** $p < 0.001$, [a] Standard error (not estimated when loading set to fixed value: i.e., 1.0), BSN = adoption of blockchain-backed supply chain network, SL = supplier-related lean practices, BL = buyer-related lean practices, PL = in-plant lean practices.

6. Conclusion

6.1. Summary of research findings

This study explores the impact of blockchain technology on Lean management system in supply chain networks. In the context of supply chain management, a blockchain-backed Lean system model and measurements for blockchain research have been developed. The research model and hypotheses were empirically tested using a survey sample of 219 practitioners and managers in the United States. The results show that blockchain is currently being adopted in a variety of use cases beyond industry-wide payments and transactions. Structural Equation Modeling (SEM) analysis was performed, and the results show that the adoption of a blockchain-backed supply chain network has a significant impact on both supplier-related and buyer-related Lean practices. The SEM results also indicate that the blockchain-backed Lean system has a significant positive impact on the company's operational performance, such as cost reduction, quality performance, delivery capacity and operational flexibility.

6.2. Future Research Direction

This paper contains only preliminary findings, and this research project is still in progress. In particular, using secondary data including some companies participating in this study as well as Forbes' Blockchain 50 list companies, this study will validate the survey results. In addition, this study will compare the financial performance of blockchain companies and their competitors during the first half of this year (2020) to investigate how blockchain has actually helped to maintain a competitive advantage in a global supply chain crisis such as the COVID-19 pandemic.

6.3. Significance and Dissemination

This study will not only provide an initial cornerstone of the theoretical development of blockchain-backed Lean management system, but also provide first empirical insight into the relationship between blockchain and Lean practices. The initial results of the project will first be disseminated through presentations at the 2020 *Decision Science Insistitute* annual meeting. The final results will be submitted to high qualtiy journals, such as the *Journal of Supply Chain Management* or the *Journal of Operations Management.* However, the results of this project are expected to be not only descriptive, but also prescriptive. Therefore, some findings can also be incorporated into teaching cases and practional outlets such as *Harvard Business Review* and *Sloan Management Review*.

Acknowledgments

I am very grateful to Dr. Paul Hong (Distinguished university professor at the University of Toledo) and the survey participants for giving insightful comments on the earlier draft of this paper.

Appendix A. Survey Questionnaire

A.1. Adoption of blockchain-backed supply chain network (Source: adapted from Deloitte's 2020 Global Blockchain Survey) (Cronbach's α = 0.957)

Please indicate the extent of implementation for each of the following blockchain technology use cases in your company's supply chain network or project (1 = no implementation, 2 = little implementation =, 3 = some implementation, 4 = extensive implementation, 5 = complete implementation).

q01. Data sharing/access
q02. Digital currency
q03. Data/record reconciliation
q04. Identity protection
q05. Electronic payments
q06. Track-and-trace
q07. Asset protection
q08. Asset transfer
q09. Certification
q10. Revenue sharing
q11. Tokenized securities (equity, debt, and derivatives)
q12. Time stamping
q13. Custody

A.2. Lean management practices (Source: adapted from Shah & Ward, 2007)

Please indicate the extent of implementation of each of the following Lean management practices in your supply chain network or project (1 = no implementation, 2 = little implementation =, 3 = some implementation, 4 = extensive implementation, 5 = complete implementation).

Supplier-related Lean practices (Cronbach's α = 0.892)

q14. We give our suppliers feedback on quality and delivery performance.

q15. Our suppliers are involved in the new product/service development process.

q16. Our key suppliers deliver to plant/store on Just-In-Time basis.

q17. Our suppliers are committed to annual cost reductions.

Buyer-related Lean practices (Cronbach's α = 0.867)

q18. Our buyers/customers give us feedback on quality and delivery performance.

q19. Our buyers/customers are actively involved in current and future product/service offerings.

q20. Our buyers/customers frequently share current and future demand information with marketing department.

In-plant Lean practices (Cronbach's α = 0.908)

q21. We use a “pull” production system.

q22. Equipment is grouped to produce a continuous flow of families of products.

q23. Our employees practice setups to reduce the time required.

q24. Extensive use of statistical techniques to reduce process variance.

q25. Shop-floor employees lead product/process improvement efforts.

q26. We maintain excellent records of all equipment maintenance related activities.

A.3. Operational performance (Source: adapted from Naor *et al*., 2010; Kristal *et al*., 2010).

Please indicate your opinions about how your business unit’s performance compares to competitors in your industry. (1 = low end of the industry, 2 = worse than industry average, 3 = average, 4 = better than average, 5 = superior).

Cost savings (Cronbach's α = 0.802)

q27. Unit cost of product/service

q28. Inventory turnover

q29. Cycle time (from receipt of raw materials to shipment)

Quality performance (Cronbach's α = 0.852)

q30. Product/service features

q31. Product/service performance

q32. Conformance to product/service specifications

Delivery capacity (Cronbach's $\alpha = 0.804$)

q33. Order fulfillment speed

q34. Delivery as promised

Operational flexibility (Cronbach's $\alpha = 0.828$)

q35. Flexibility to change output volume

q36. Flexibility to change product/service mix

A4. Insomnia (Source: Bastien *et al*., 2001) (Cronbach's $\alpha = 0.816$)

Please rate the current severity of your insomnia problem.

mk1. Difficulty falling asleep (1 = none, 2 = mild, 3 = moderate, 4 = severe, 5 = very severe)

mk2. Difficulty staying asleep (1 = none, 2 = mild, 3 = moderate, 4 = severe, 5 = very severe)

mk3 How satisfied are you with your current sleep patterns? (1 = very satisfied, 2 = satisfied, 3 = moderately satisfied, 4 = dissatisfied, 5 = very dissatisfied)

A5. Financial performance during the COVID-19 pandemic (Source: adapted from Cho & Linderman, 2020) (Cronbach's $\alpha = 0.835$)

Please indicate your opinions about how your business unit’s performance compares to competitors in your industry (1 = low end of the industry, 2 = worse than industry average, 3 = average, 4 = better than average, 5 = superior).

cv1. During the COVID-19 pandemic, your company's "Sales" performance

cv2. During COVID-19 pandemic, your company's "Net Profit Margin"

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