The Effect of Blockchain Technology on Hospital Supply Chain Performance

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Abstract

There is an ongoing challenge in the healthcare sector to meet increased demand. Deployment of innovative technologies is one of the ways to enhance the level of service level in this sector. Blockchain technology has several advantages, such as immutability, security and transparency, which can address major issues in the healthcare supply chain. This research investigates the impact of blockchain technology on hospital supply chain performance in the Kingdom of Saudi Arabia. Underlined by task-technology fit theory, a conceptual framework of blockchain technology utilisation and its impact on hospital performance is developed. Responses are collected from managers working in both public and private hospitals. A fuzzy-set qualitative comparative analysis (fs-QCA) is used to analyse the impact of blockchain technology on hospital supply chain performance. The results revealed that causal conditions task characteristics (TC), blockchain characteristics (BC), Individual characteristics (IC), task-technology fit (TTF) and blockchain utilisation (BU) are necessary and sufficient for higher levels of hospital performance. The study findings also contribute to an in-depth understanding of how blockchain technology can enhance the healthcare supply chain system by improving its privacy, safety and transparency.

Keywords
Blockchain technology, Fuzzy-set qualitative comparative analysis, Hospital supply chain, Kingdom of Saudi Arabia, Task–technology fit theory.

1. Introduction
Globally, the healthcare sector is considered one of the most important and complex industries and is experiencing rapid growth. The healthcare management system refers to a wide range of processes that includes financial management, legal issues, employees, patients, supply chains, logistics, facilities and inventories (Khatoon 2020). In the Kingdom of Saudi Arabia (KSA), the Ministry of Health (MoH) monitors the overall management of public and private health facility services. Under the supervision of the MoH, the healthcare system in Saudi Arabia is organised into primary, secondary and tertiary healthcare (Ministry of Health 2018; Almalki et al. 2011). The aim of the healthcare system in the KSA is to provide an integrated network of health services for both citizens and residents (Khan et al. 2020).

In recent years, expenditure on Saudi healthcare has increased to meet the health needs of the population. As a result, healthcare organisations are facing significant pressure, and governments are investing large amounts of money to ensure the delivery of quality healthcare (Rahman and Al-Borie 2020; Al-Hanawi 2017). The healthcare system has started to implement digital transformation strategies to keep pace with technological advancements, improve service quality and align with Saudi Vision 2030 (Khashan 2017; Ministry of Health 2018). One of the technologies for augmenting and improving processes within healthcare system management is blockchain technology; which can help to address healthcare issues and increase the capability of organisations to better manage their systems (Ben Fekih and Lahami 2020). Blockchain technology is defined as a distributed ledger that enables all participants to exchange and store transactions in a database immutably. It is designed as linked 'blocks' that allow management of data records with transparency, security and privacy (Ben Fekih and Lahami 2020; Reda et al. 2020).

Recent research highlights that blockchain technology is one of the emerging technologies that will play a critical role in the digital health sector revolution (Khatoon 2020). These new technologies will deliver many advantages for achieving efficient and effective healthcare practice by increasing quality, authenticity, information transparency, traceability, safety and privacy (Gaynor et al. 2020).

Despite these developments, challenges exist regarding collaboration and cohesion between different healthcare organisations. These problems often contribute to wasted resources, duplicate data and a lack of privacy (Alraga 2017; Alazmi and Alrashidi 2019). Blockchain technology can be useful for addressing these issues and, therefore, the development of the Saudi healthcare system in line with Saudi Vision 2030. Blockchain technology addresses many problems associated with contemporary IT health applications, including data security, integrity, privacy and rigidity. It also validates identities to create a reliable audit trail which, in turn, improves patient and provider healthcare-related security (Gaynor et al. 2020; Le Nguyen 2018). It is anticipated that this technology will enable patients to avoid routine registration processes when interacting with healthcare systems and can effectively enhance the healthcare supply chain process. Based on a review of the literature, there is a lack of theoretically-grounded empirical studies designed to evaluate blockchain implementation in healthcare and its effect on the hospital supply chain. Therefore, this research investigates the impact of blockchain technology implementation on the system performance of hospital supply chains.

2. Literature Review

2.1 Blockchain Technology

Blockchain technology is a public ledger system ensuring the integrity of transaction records for digital assets, for example, Bitcoin cryptocurrency (Swan 2015). Bitcoin is a new technology that might be able to allow banks to settle accounts among themselves without the help of central entities (Ateniese et al. 2017). The first application of blockchain technology was for Bitcoin cryptocurrency, which to date remains the most widely utilised application based on blockchain technology (Patil and Puranik 2019).

Blockchain technology is a fully distributed system that captures and stores a sequential, immutable, linear event log of the interactions among multiple parties. The functionality for this is like that of a distributed ledger, which is stored, updated and validated by all parties dealing with all transactions within the network. Blockchain technology is, therefore, an ideal solution to ensure transparency and permit a consensus across a system regarding all of a network's transactions (Risius and Spohrer 2017). Another formal blockchain definition was provided by de Leon et al. (2017) as a database of multi-parties without a central authority. A blockchain can be used to disintermediate third parties (Pilkington 2016); the unique difference is that when transactions are processed by blocks in accordance with a blockchain ordering, the distributed ledger is the result.

2.2 Blockchain Technology in the Healthcare Supply Chain

Using blockchain technology within the healthcare supply chain offers possible avenues for enhancing security, privacy, integrity, transparency, data provenance and functionality (Clauson et al. 2018). Moreover, in health care, as items travel along the supply chain, problems concerning IT and tracking costs arise (Kruse et al. 2016). Gaynor et al. (2020) confirm that blockchain-based ledgers can help solve these problems by providing instantaneous and transparent tracking of high-value items. Blockchain technology is also addressing significant concerns of individuals, researchers, various sectors and research organisations, where it can transform conventional transactions to be more secure and flexible when sharing and exchanging data via the network. Al-asmari et al. (2021) point to agreement among researchers that by using blockchain data can be exchanged between healthcare centres more securely. Therefore, the patient will be able to truly own and control their own data. Ahmad et al. (2021) explore a decentralised blockchain-based solution to automate the supply chain operations for COVID-19 medical devices, and the possibilities for sharing the information between stakeholders to manage COVID-19 medical waste with high levels of security, transparency, traceability and trustworthiness.

A review of recent research suggests that there is a lack of empirically designed and theoretically-grounded studies that focus on blockchain implementation in healthcare, despite the potential to transform health care system to a patient-centric ecosystem with increased security, privacy and interoperability of health data.

3. Methodology

The current research employs positivism as a central research philosophy to enable the collection of impartial data for the validation of hypotheses (Walsham 1995). This study employs quantitative methods that provide for the collection of data using closed questions (Creswell and Creswell 2017). The objective of the quantitative approach is to generalise about the sampled respondents by producing unbiased results (Newman et al. 1998). The key advantages of this approach are that it enables both randomisation and control of variables, utilises dependable and sound measures and emphasises the assessment and calibration of causal or correlation variable relationships (Denzin and Lincoln 2008). A survey is one of the tools commonly used for gathering quantitative data (Saunders et al. 2009), and this study used surveys to gather the sample data. In this regard, the questionnaire was conducted with managers and IT professionals in public and private hospitals across the KSA.

A survey questionnaire was employed to collect data. Questions included those addressing participant demographics and the constructs in the proposed research model. A seven-point Likert scale was employed to measure responses. Based on the literature review, items that can be used to measure each of the constructs in the model are identified and presented in Table 1.

Table 1. Constructs and sub-constructs of the model

Construct	Sub-construct
Task characteristics (TC)	• Task equivocality
	• Task interdependence
Blockchain characteristics (BC)	• Transparency
	• Immutability • Decentralisation
	• Trustworthiness
	• Security and privacy
Individual characteristics (IC)	• Skills and competencies
	• Experience • Knowledge
Task-technology fit (TTF)	• Quality
	• Locatability
	• Authorisation
	• Production timeliness
	• Systems reliability
	• Ease of use/training
	• Relationship with users
Blockchain utilisation (BU)	• Usage • Adoption
Hospital performance (HPERF)	• Efficiency
	• Satisfaction
	• Transparency

Fuzzy-set qualitative comparative analysis (fs-QCA) combines variable-oriented quantitative analysis with case-oriented analysis. It relies on a joint causal system where each characteristic interacts with another within a case instead of considering the independent variables as constants and examining how a cause affects the dependent variables (Ragin 1998). There are several characteristics of the fs-QCA approach. The first characteristic is that it gives researchers freedom in examining the involved causal complexity in causal conjuncture. The second characteristic is analysing each case in its entirety and not dissecting it into variables. Third, fs-QCA allows for flexibility when characterising cases (Lee 2014). Furthermore, fs-QCA can be applied to various data types (e.g. Likert-scales, clickstreams and multimodal data), provided that the researchers can convert the data into fuzzy sets (Pappas and Woodside 2021). These characteristics of fs-QCA provide advantages, such as an accurate calibration that allows quantitative analysis and application to a range of sample sizes from small (less than 50 cases) to large samples (thousands of cases). Using fs-QCA, researchers can explore complex causal patterns among different causal or independent variables by studying a small number of cases. Furthermore, this methodology is particularly applicable to an investigation into the use of digital technology in health and medical services. This is because different digital technologies and use support mechanisms may have different impacts based on the task type and the nature and traits of individual users (Mikalef and Torvatn 2019). Hence, the fs-QCA approach is deemed to be an appropriate approach in this study context to develop a theoretical model that conceptualises blockchain utilisation in hospital supply chains and its impact on hospital performance.

4. Results and Discussion

Among the participants, the majority (90%) were males and held post-graduate or master's degrees. Most of the participants worked in an administration department and had less than 5 years of managerial experience (70%). In terms of IT experience, the largest group of respondents had 6 or more years of experience in IT systems (80%).

In this study, items as a measure of reliability were tested utilising Cronbach's alpha coefficient to measure the reliability of each scale and assess the overall reliability coefficient of the measurement. Cronbach's alpha values of 0.7 or above were considered reliable, and the items had internal consistency by measuring each factor (Santos 1999). The survey used six scales: task characteristics, blockchain characteristics, individual characteristics, task-technology fit, utilisation and hospital performance. The results found the reliability coefficients were: 0.845 for task characteristics (items=5); 0.918 for blockchain technology characteristics (items=7); 0.864 for individual characteristics (items=3); 0.949 for task-technology fit (items=21); 0.863 for blockchain utilisation (items=6); 0.974 for hospital performance (items=11) and the overall reliability was 0.961. Table 2 illustrates that all constructs exceeded the value of 0.70, and reliability testing based on Cronbach's Alpha and the composite reliability indicator was acceptable.

Table 2. Reliability and validity test of survey variables

Scale	Number of items	Cronbach's alpha	Composite reliability	AVE
Task characteristics (TC)	5	0.845	0.914	0.683
Blockchain technology characteristics (BC)	7	0.918	0.887	0.531
Individual characteristics (IC)	3	0.864	0.862	0.616
Task-technology Fit (TTF)	21	0.962	0.965	0.534
Blockchain utilisation (BU)	6	0.863	0.913	0.638
Hospital performance (HPERF)	11	0.974	0.946	0.624

This study also employed average variance extracted (AVE) with the purpose of analysing the convergent validity of the constructs (Fornell and Larcker 1981; Hair et al. 2014). AVE indicates the average variance shared between constructs, in addition to their measures and relative to the amount of measurement error (Hulland 1999; Chin 2010). Adequate convergent validity is attained when the AVE value of a construct is at least 0.5 (Fornell and Larcker 1981). The results show AVE for each variable was more than 0.50, indicating the validity of the constructs (see Table 3). The results also demonstrate that the square roots of AVE, as the diagonal elements, were greater than the off-diagonal correlations in rows and columns. Consequently, the result of the analysis suggested that discriminant validity was not a concern in this study. Table 3 describes the Fornell-Larcker criteria of all constructs.

Table 3. Fornell-Larcker criteria

	AVE	TC	BC	IC	TTF	BU	HPERF
TC	0.683	**0.914**					
BC	0.531	.723(**)	**0.887**				
IC	0.616	.736(**)	.695(*)	**0.862**			
TTF	0.534	.782(**)	.779(**)	.675(*)	**0.965**		
BU	0.638	.727(**)	.742(**)	.693(*)	.743(**)	**0.913**	
HPERF	0.624	.770(**)	.609(*)	.794(**)	.757(**)	.795(**)	**0.946**

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

After testing the reliability and validity of the constructs, a typical dataset was analysed using fs-QCA software. The first step was to undertake data calibration of the dependent and independent variables by forming fuzzy sets with value ranges from 0 to 1 (Ragin 2009). Care was taken to ensure that thresholds were chosen based on each of the corresponding values. Since this study used seven-point Likert scales (1=Not at all, 7=Very much), the values of 6, 4, and 2 were used as threshold values, as suggested in previous studies (Ordanini et al. 2014; Pappas et al. 2016). Table 4 shows the dataset after calibration.

Table 4. Dataset after calibration

TC	BC	IC	TTF	BU	HPERF
0.96	0.96	0.95	0.95	0.97	0.98

0.92	0.93	0.95	0.95	0.95	0.95
0.99	0.55	0.62	0.49	0.78	0.53
0.50	0.50	0.50	0.97	0.50	0.98
0.82	0.66	0.50	0.66	0.50	0.53
0.92	0.93	0.88	0.91	0.90	0.96
0.92	0.96	0.50	0.90	0.95	0.95
0.29	0.96	0.95	0.67	0.96	0.88
0.82	0.87	0.18	0.79	0.82	0.82
0.82	0.95	0.92	0.90	0.92	0.95

Next, an analysis of necessary conditions (or configuration elements) was performed. Conditions are considered necessary when the consistency score of a condition is more than 0.75, while its coverage value is more than 0.5 (Ragin 2008). Table 5 indicates that all the configuration elements, namely TC, BC, IC, TTF and BU are necessary to improve the level of hospital performance.

Table 5. Analysis of the necessary conations

Configurations	Consistency	Raw coverage
TC	0.845252	0.905779
BC	0.935522	0.964933
IC	0.796014	0.976978
TTF	0.944900	0.984127
BU	0.928488	0.960000

The third step of fs-QCA is running the algorithm a truth table of 2k rows to compute all possible configurations, where k is the number of predictor outcomes and each row represents a possible combination. The truth table was then sorted by frequency and consistency; with consistency levels not less than 0.75 and the coverage level more than 0.5 (Ragin 2008). Consistency levels indicate the degree to which subset relations are approximated, whereas the coverage value is the empirical relevance of a consistent superset.
The results in Figure 1 illustrate that a combination of BC, TC, IC, TTF and BU are necessary and sufficient for enhancing higher scores of hospital performances for both private and public hospitals.

```
Model: HPERF = f(TC, BC, IC, TTF, BU)
Algorithm: Quine-McCluskey

--- TRUTH TABLE SOLUTION ---
frequency cutoff: 1
consistency cutoff: 1
Assumptions:
                   raw        unique
                 coverage    coverage    consistency
                ----------  ----------   ----------
TC*BC*IC*BU      0.711606    0.00468928  0.996716
TC*BC*TTF*BU     0.827667    0.12075     1
BC*IC*TTF*BU     0.762016    0.0550996   1
solution coverage: 0.887456
solution consistency: 0.997365
```

Note: f denotes function; * denotes interaction between conditions

Figure 1. Sufficiency analysis

Fs-QCA software usually provides three sets of solutions, complex, parsimonious and intermediate solutions. These solutions are defined by necessary and sufficient conditions, which can be distinguished based on essential and peripheral conditions. Core conditions are configurations which strongly affect the outcome and usually appear in parsimonious and intermediate solutions. Peripheral conditions are configurations that weakly affect the outcome and usually appear in intermediate solutions (Pappas et al. 2016; Kourouthanassis et al. 2017).

In this study, fs-QCA analysis was performed using TC, BC, IC, TTF and BU as conditions and hospital performance as the outcome. The researcher also selected ‘present or absent’ at all times to get every possible

configuration. The outcomes of the fs-QCA analysis for improving the levels of hospital performance had five solutions. In all cases, blockchain technology was present as a core condition. All the solutions demonstrated a high level of consistency, signifying their reliability.
Figure 2 and Figure 3 show the overall solution coverage is 0.887 (more than 0.5), and the solution consistency is 0.997 (more than 0.75) which indicates how strongly the condition related to outcome.

```
--- COMPLEX SOLUTION ---
frequency cutoff: 1
consistency cutoff: 1
                     raw        unique
                   coverage    coverage    consistency
                  ----------  ----------  ----------
TC*BC*IC*BU       0.711606    0.00468928  0.996716
TC*BC*TTF*BU      0.827667    0.12075     1
BC*IC*TTF*BU      0.762016    0.0550996   1
solution coverage: 0.887456
solution consistency: 0.997365



Cases with greater than 0.5 membership in term TC*BC*IC*BU: A (0.95,0.98),
  B (0.92,0.95), F (0.88,0.96), K (0.82,0.95),
  C (0.55,0.53)
Cases with greater than 0.5 membership in term TC*BC*TTF*BU: A (0.95,0.98),
  B (0.92,0.95), F (0.9,0.96), G (0.9,0.95),
  K (0.82,0.95), I (0.79,0.82)
Cases with greater than 0.5 membership in term BC*IC*TTF*BU: A (0.95,0.98),
  B (0.93,0.95), K (0.9,0.95), F (0.88,0.96),
  H (0.67,0.88)
```

Figure 2. Complex solution

```
--- INTERMEDIATE SOLUTION ---
frequency cutoff: 1
consistency cutoff: 1
Assumptions:
                     raw        unique
                   coverage    coverage    consistency
                  ----------  ----------  ----------
TC*BC*IC*BU       0.711606    0.00468928  0.996716
TC*BC*TTF*BU      0.827667    0.12075     1
BC*IC*TTF*BU      0.762016    0.0550996   1
solution coverage: 0.887456
solution consistency: 0.997365
```

Figure 3. Intermediate solution

The findings of the fs-QCA analysis revealed that the study's independent variables (TC, BC, IC, TTF and BU) were all necessary to escalate hospital performance. Consequently, BC, IC and BU are sufficient for hospital performance. Further, it was proved that when TC, BC and IC are combined with TTF, it would be both necessary and sufficient to increase hospital performance. This result reinforces the full mediating role in the relationship between TTF and hospital performance, and the relationship between BU and hospital performance. Moreover, the analysis revealed the presence of necessary conditions. All the configurations exceeded the acceptable consistency level (i.e. consistency values ranged between 0.996 and 1, which is more than 0.90), which suggests that improving hospital supply chain performance is necessarily determined by these elements. The results of this study generally suggest that blockchain technology can improve hospital supply chain performance. Enabling blockchain to support the supply chain system of both public and private hospitals could enhance performance in terms of privacy, safety and transparency, leading in turn to increased hospital performance.

5. Implications and Conclusions

This paper investigated the effect of blockchain technology on hospital supply chain performance. The study also aimed to present a framework for assessing healthcare system performance if using blockchain technology within this sector. Based on seminal work conducted by Goodhue and Thompson (1995), application of the TTF model was applied to blockchain technology to evaluate its application and influence on healthcare system performance. Drawing on task-technology fit theory (Goodhue 1995), this study contributed to understanding of the applications of blockchain technology by proposing a research model in which the combination of TC, BC, IC, TTF and BU

were used to assess hospital supply chain performance, and identified and supplied what is required in the context of the healthcare industry. It conducted an in-depth understanding of blockchain technology implementation on hospital performance. The findings revealed that TC, BC and IC combined with TTF and BU to increase the system performance of hospitals. It also proved that it is possible to achieve a high level of performance in the hospital system with the adoption of blockchain technology. The findings also refer that there is a positive relationship between TTF and hospital system performance, and between BU and hospital system performance.
This paper has important implications for managers and decision-makers to establish best practices for enhancing healthcare performance and devising systems that improve hospital performance through adoption of blockchain technology to achieve high levels of privacy, safety and transparency in hospital systems. Moreover, this research included a set of guidelines on the implementation of blockchain technology in the health system in the KSA that may result in increased blockchain adoption throughout the healthcare industry. Overall, configurational approaches to fuzzy sets theory provide novel contributions to this research field.

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