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Problematique Analysis of Blockchain Technology Adoption for Waste Management in Future Smart Cities: A Case Study in Phnom Penh, Cambodia

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By 2030, more than two-thirds of the global population will live in an urban environment, and an additional 70 M or more are projected to live in ASEAN cities. Sustainable urbanization will thus play an important role in the green economic growth of the ASEAN region, including Phnom Penh City, i.e., one of Southeast Asia's newest commercial hubs. However, rapid urbanization poses many prominent challenges such as waste management, energy management, and other environmental stresses that may lead to unsustainability. With the emergence of the fourth industrial revolution, building smart cities is an opportunity to embed and leverage technologies such as blockchain to promote sustainability, innovation, and inclusivity. Hence, this study focuses on understanding the problematique of blockchain adoption in the waste management sector through a systematic problem analysis using a novel T-Spherical Neutrosophic Fuzzy DEMATEL method. Potential barriers are identified through literature review and expert opinion. Linguistic assessments from the group of experts are aggregated to elucidate the causal map of the problematique. These present findings underscore the need for policy intervention to attract the initial capital investment for the physical blockchain infrastructure and strengthen the implementation of the legal framework of data privacy. Public awareness to increase the market acceptance of blockchain technology and the development of trustful cybersecurity systems are of great necessity. Further investigation should be done to understand how to attract the initial capital investment in high-tech industries by systematically analyzing the interaction among barriers in Cambodia's new context of science, technology, and innovation development.

1. Introduction

The rate of urbanization has increased globally, and so does the ASEAN region with a population of more than 660 M (Statista, 2022), with a projection of an additional 70 M, or more will be living in these ASEAN cities. With this large population and the scarcity of natural resources, long-term viability for the ASEAN region must be guaranteed to ensure the overall well-being of both the people and nature. Such harmonization could not be simpler for future smart cities, yet proper management of waste, energy, and other environmental concerns could provide a better solution for sustainability. For the past decade, cities worldwide have generated solid waste up to 1.3 Gt annually and are expected to increase to 2.2 Gt/y by 2025 (Kaza et al., 2018). In envisioning smart cities of the future, this huge amount of waste requires immediate attention to prevent its adverse effect on environmental pollution, e.g., microplastic and heavy metal contamination. Though many high-income countries have many initiatives toward integrated waste management, the majority of the world, especially those in low-to-middle countries like Cambodia, however, still lacks a proper waste management system. This disintegrated system of waste management could be attributed to the lack of waste-related data, trust, transparency, coordination, and collaboration among stakeholders, to name a few. One viable solution is to make the waste management infrastructure smarter by considering a unified distributed platform on which various stakeholders could share, check and verify the data. This is where blockchain technology could play an important role in enabling smart waste management technology. Blockchain technology provides a computationally practical solution where the digital document is cryptographically secured and could not be

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tampered or backdated. The opportunities for blockchain technology in waste management for future smart cities include tracing and tracking of waste, trustful channelization of waste, securing documentation, efficient waste resources management, penalties for non-compliance, transparency in waste collection and trucks route optimization, robots-assisted and reliable waste segregation, and accountability of waste management operations (Ahmad et al., 2021).
Note that the adoption of blockchain technology in waste management is still at its infancy stage. It is thus imperative to identify and understand the barriers of adopting blockchain technology in Cambodia to facilitate its adoption rate in waste management sector. As the fast pace of technological advancement continues to impact human life, one critical factor for technology adoption is the users' perception and behavior. This simply emphasizes the importance of understanding the perception of the stakeholders such as the policy maker, academia, private sectors, and the government agencies to facilitate coordination and collaboration among them. Accordingly, this study focuses on understanding the problematique of blockchain adoption for waste management through a structural model built by Decision Making Trial and Evaluation Laboratory (DEMATEL). A problematique is a term coined by Warfield and Perino (2000) to graphically portray a structural model of relationships among members of a set of problems. Understanding this problematique makes it possible to effectively formulate the policy intervention. Moreover, DEMATEL has been recently used in the problem analysis of promoting a circular economy through the public-private partnership of small and medium enterprises (Kuok and Promentilla, 2021). We integrated DEMATEL with a T-spherical neutrosophic set to capture the uncertainties attributed to the linguistic rating of the intensity of the interrelationship among the identified barriers. An illustrative case study in Phnom Penh, Cambodia, is presented to elucidate the proposed method.

2. Methodology

In the proposed method, the complexity of the problematiques on blockchain technology adoption in waste management is addressed by decomposing the problem into potential barriers and elucidating their interrelationships through the DEMATEL framework. Output from the structural model is a problematique causal map to visualize such a relationship. The intrinsic vagueness in human judgments is also captured through the recent extensions of the fuzzy set originally proposed by Zadeh in the 1960s to model such uncertainty. We introduced in this study the T-spherical neutrosophic fuzzy set built from the new structure proposed by Mahmood et al. (2019) to represent the human opinion while enlarging the space of the uncertainty component pertaining to the degree of membership or satisfaction, the degree of nonmembership or dissatisfaction, and the degree of abstention or indeterminacy.

2.1 Preliminaries

This section introduces the definitions related to the T-spherical neutrosophic fuzzy set.
Definition 1. Let X be in a finite domain and $x \in X$. Neutrosophic set (Smarandanche, 2006) is defined as:

$$A = \{x, \mu(x), v(x), \pi(x) \ \forall x \in X\} \tag{1}$$

Here the neutrosophic components $\mu, v, \pi: X \rightarrow [0,1]$ represents the degree of membership, degree of nonmembership, and degree of indeterminacy, respectively, provided that the $0 \le Sum(\mu, v, \pi) \le 3$, i.e., $0 \le \mu(x) + v(x) + \pi(x) \le 3$.
Definition 2. Let X be in a finite domain and $x \in X$. T-spherical neutrosophic fuzzy set is defined as:

$$T = \{x, \mu(x), v(x), \pi(x) \ \forall x \in X\} \tag{2}$$

With the condition that $0 \le Sum(\mu^t, v^t, \pi^t) \le r^t \ \forall t \in Z \ge 1$. Here Z refers to positive integers and $r^t \rightarrow [1, 3^{1/t}]$ wherein a particular case of T in X is a spherical fuzzy set (SFS) at t = 2 with the condition of $0 \le Sum(\mu^2, v^2, \pi^2) \le 1$.
For ease of computation, a T-spherical fuzzy number is designated as an ordered triple:

$$\widetilde{T} = (\mu, v, \pi) \tag{3}$$

Definition 3. TSWAM is an aggregation operator for n T-spherical fuzzy numbers using weighted arithmetic mean such that the weights $w_i \in [0,1]$, $\sum_{i=1}^{n} w_i = 1$.

$$\begin{aligned} \mathrm{TSWAM}_w(\widetilde{T}_{s1} \ldots \widetilde{T}_{sn}) &= w_1\widetilde{T}_{s1} + w_2\widetilde{T}_{s2} + \ldots + w_n\widetilde{T}_{sn} = \sum_{i=1}^{n} w_i \widetilde{T}_{Si} \\ &= \left\{ \left[1 - \prod_{i=1}^{n} \left(1 - \mu_{\widetilde{T}_{si}}^{t}\right)^{w_i}\right]^{\frac{1}{t}}, \prod_{i=1}^{n} v_{\widetilde{T}_{si}}^{w_i}, \prod_{i=1}^{n} \pi_{\widetilde{T}_{si}}^{w_i} \right\} \end{aligned} \tag{4}$$

Definition 4. Defuzzification of T-spherical fuzzy number is defined as follows:

$$\text{Score}(\widetilde{T}) = 1-\left[\frac{1}{3}\left\{(1-\mu^t)^{\beta}+(v^t)^{\beta}+(\pi^t)^{\beta}\right\}\right]^{1/\beta} \quad (5)$$

Where $\beta \geq 1$ is the distance parameter. Here is the Score($\widetilde{T}$)→ [0,1].

2.2 Proposed DEMATEL with T-spherical Fuzzy Number

Step 1: Barriers are identified from the literature review and key informant interview.
Step 2: Data is collected via linguistic ratings to describe the intensity of influence of one barrier over the other barriers. The T-spherical fuzzy number is used to describe the linguistic scale for the intensity of influence, as described in Table 1.

Table 1: 5-point spherical fuzzy linguistic scale for T-spherical fuzzy

Linguistic scale	TSFN (μ,v,π)
No influence (NI)	(0.01, 0.99, 0.10)
Weak influence (WI)	(0.25, 0.75, 0.30)
Moderate influence (MI)	(0.50, 0.50, 0.50)
Strong influence (SI)	(0.75, 0,25, 0.30)
Very strong influence (VS)	(0.99. 0.10, 0.10)

Step 3: The ratings of the respondents are aggregated using Eq(4). For the purpose of illustration, t = 2 is used in the calculations.
Step 4: The initial direct relation matrix (Z) is populated by the crisp values obtained from defuzzifying the aggregated T-spherical fuzzy numbers where:

$$Z = \left[z_{ij}\right]_{nxn} \quad (6)$$

Here n is the number of barriers identified in the study. The distance parameter is set to 19/8 to yield a score of 0.50 for TSFN (0.50, 0.50, 0.50) at t = 2 using Eq(5).
Step 5. The initial direct relation matrix is then normalized using:

$$D = \frac{1}{s}[Z] \quad (7)$$

Where $s = \max\left(\max_{1\leq i\leq n} \sum_{j=1}^{n} z_{ij}, \max_{1\leq i\leq n} \sum_{i=1}^{n} z_{ij}\right)$
Step 6: The total relation matrix is computed using:

$$T = D + D^2 + D^3 + \ldots + D^{\infty} = D(1\text{-}D)^{-1} \quad (8)$$

Step 7: The problematique causal map is then constructed by plotting the ordered pair of prominence index and net relation index for each barrier. The prominence index is computed from the sum of R and C, whereas the net relation index is the difference between R and C where:

$$R = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1}, i,j = 1, 2,\ldots, n \quad (9)$$

$$C = \left[c_j\right]_{n\times 1} = \left[\sum_{i=1}^{n} t_{ij}\right]_{n\times 1}, i,j = 1, 2,\ldots, n \quad (10)$$

In order to filter out the minor influences in the total relation matrix and simplify the causal relationship among barriers, a threshold is employed. This threshold value is calculated by averaging the entries in the total relation matrix, and the inner dependency matrix is obtained by removing cells lower than the threshold value in the total relation matrix.

3. Results and discussion

To understand the possibility of adopting blockchain technology for waste management in future smart cities- the case of Phnom Penh, the capital city of Cambodia, barriers were identified through an exhaustive literature review and consultation with experts. For example, the deployment of smart contracts to monitor real-time the waste transportation, illegal waste discharge, and payment of service fee could offer the potential use of blockchain technology; however, the deployment of these IoT-based sensors and communication require large amount of energy and reliable supply of energy which Cambodia is lacking (Sang, 2015). Also, per experts' advice, the lack of public awareness on blockchain technology is another barrier since the majority of the public perceives blockchain technology as financial technology that is applicable to solely financial section. Table 2 presents the barriers' description and summary of T-spherical Fuzzy and DEMATEL analysis results. Among all barriers of concern, "Lack of reliable supply of energy (B1)" is ranked the first problematique, followed by "Lack of network infrastructure (B2)" and "Lack of initial capital investment (B3)". In fact, so as to build a digital government, the Royal Government of Cambodia has launched the Cambodia Digital Economy and Society Policy Framework 2021-2035 in which the development of blockchain infrastructure is entailed (RGC, 2021a).

Table 2: Barriers description and summary of results

Label	Description	Rank [j]	Cause/Effect [k]
B1	Lack of reliable supply of energy [a,b,c,d]	1	Effect
B2	Lack of network infrastructure [a,b,c,d]	2	Effect
B3	Lack of trustful cybersecurity [a,e]	7	Causal
B4	Lack of data privacy [a,e]	5	Causal
B5	Lack of initial capital investment [a,b]	3	Causal
B6	Lack of market acceptance [f,g]	6	Causal
B7	Lack of government policy and legal framework [a,e,h]	4	Effect
B8	Lack of public awareness on blockchain technology [i]	8	Effect

Source: [a] (Deloitte, 2018), [b] (Kshetri, 2019), [c] (Zhao et al., 2019), [d] (Thakur et al., 2020), [e] (Biswas and Gupta, 2019), [f] (Abramova and Bohme, 2016), [g] (Li and Wang, 2017), [h] (PwC, 2018), [i] (Expert Advice), [j] (TSF), [k] (DEMATEL)

Table 3 describes the direct relation matrix represented by Bn x Bn, which was populated by the crisp values calculated from the defuzzification of the T-spherical fuzzy values of the responses from the experts. The zero value is placed in the diagonal of the matrix, assuming that no direct influence is applied from one barrier to another at this initial stage. The direct relation matrix is then normalized by the maximum value of row and column sums, and represented by NBn x NBn (See Table 3). This normalized direct relation matrix is used for the computing of the total relation matrix.

Table 3: Direct relation matrix (Bn) and normalized direct relation matrix (NBn)

Bn	B1	B2	B3	B4	B5	B6	B7	B8	NBn	NB1	NB2	NB3	NB4	NB5	NB6	NB7	NB8
B1	0.000	0.299	0.130	0.105	0.235	0.080	0.244	0.123	NB1	0.000	0.172	0.075	0.061	0.135	0.046	0.140	0.071
B2	0.187	0.000	0.130	0.048	0.080	0.126	0.210	0.362	NB2	0.107	0.000	0.075	0.028	0.046	0.072	0.121	0.208
B3	0.221	0.200	0.000	0.099	0.161	0.109	0.133	0.133	NB3	0.128	0.115	0.000	0.057	0.093	0.063	0.077	0.077
B4	0.304	0.158	0.119	0.000	0.247	0.207	0.243	0.113	NB4	0.175	0.091	0.069	0.000	0.142	0.119	0.140	0.065
B5	0.434	0.252	0.185	0.223	0.000	0.219	0.212	0.121	NB5	0.250	0.145	0.107	0.128	0.000	0.126	0.122	0.070
B6	0.231	0.278	0.211	0.153	0.110	0.000	0.096	0.217	NB6	0.133	0.160	0.121	0.088	0.063	0.000	0.055	0.125
B7	0.242	0.296	0.125	0.119	0.170	0.097	0.000	0.208	NB7	0.139	0.171	0.072	0.069	0.098	0.056	0.000	0.120
B8	0.117	0.177	0.070	0.040	0.041	0.082	0.144	0.000	NB8	0.067	0.102	0.040	0.023	0.024	0.047	0.083	0.000

Table 4 presents the total relation matrix and the calculated prominence and net relation index. The prominence index (R+C) represented the linkage among barriers within the network of problems is calculated by adding the sum of the row sum and the column sum for each barrier. The higher the value of the prominence index, the more influential the barrier is, i.e., "Lack of initial capital investment (B5)" in the present study (See Table 4). The network relation index (R-C), on the other hand, is calculated by the difference between the row sum and column sum for each barrier. The analysis of this network relation index determines the cause-and-effect relation among barriers: the causal cluster barriers are indicated by the positive sign and, otherwise, the effect cluster of barriers. Such elucidation of network relation of barriers is essential to ensure that the causal barriers are properly and timely addressed for the benefit of the national strategic development; for instance, the (R-C) values of "Lack of trustful cybersecurity (B3)", "Lack of data privacy (B4)", "Lack of initial capital investment (B5)", and "Lack of market acceptance (B6)" are positive suggesting that these barriers have an effect on other barriers and need immediate policy intervention. To prioritize the barriers requiring short and intermediate intervention, the threshold value, the average value of the entries in the total relation matrix, is used. By highlighting the values greater than the threshold value, the prominent relation among barriers is depicted and indicated by green cells.

Table 4: Total relation matrix and the calculated prominence and net relation index

	B1	B2	B3	B4	B5	B6	B7	B8	R+C	R-C
B1	0.277	0.427	0.233	0.188	0.294	0.197	0.347	0.297	5.254	-0.735
B2	0.323	0.239	0.206	0.136	0.189	0.192	0.295	0.378	4.961	-1.047
B3	0.351	0.344	0.142	0.168	0.237	0.190	0.264	0.267	3.743	0.184
B4	0.474	0.407	0.255	0.156	0.334	0.284	0.380	0.318	4.040	1.177
B5	0.576	0.497	0.314	0.289	0.239	0.312	0.404	0.361	4.902	1.084
B6	0.390	0.418	0.274	0.209	0.235	0.152	0.277	0.343	3.954	0.643
B7	0.394	0.425	0.229	0.192	0.262	0.203	0.222	0.337	4.650	-0.122
B8	0.209	0.245	0.128	0.093	0.119	0.126	0.197	0.129	3.675	-1.185

Figure 2a presents the chord graph of the inner dependency of all barriers after filtering out the minor influences among barriers. This chord diagram is plotted using the platform developed by Martin (2008) to visualize the tables. By using this informative and simplified Chord diagram or Circos diagram, the rows and columns are represented by the circularly arranged and colored segments to represent each barrier; moreover, the size of the segment is proportional to the cell value for the row or column. Most importantly, the ribbons between a row and column segment illustrate the total relations among barriers, while the dominant color of both segment and ribbon signifies the dominant influence of a barrier on other barriers. For example, the colors of ribbons and segments of B3, B4, B5, and B6 are dominant and emphasize the influence of B3, B4, B5, and B6 to other barriers. Note also that only B1 with red segment and ribbon has the self-loop. Such cyclic interaction of B1 suggests that "Lack of reliable supply of energy" takes back the effect and aggravates the degree of its prominence. Although this B1 is not the causal barrier, yet it seems that high-priority attention should be given to B1. In fact, during the 15th East Asia Summit Energy Ministers Meeting session on Cambodia's Policy Plan Challenges and Transitional Energy Efforts towards Carbon Reduction, the Royal Government of Cambodia included the integration of more renewable energy development projects into the power development plan; this plan also includes the development of a utility-scale battery energy storage system with the capacity to accommodating more variable renewable energy development while adopting policies and action plans for energy efficiency (Thou, 2021).

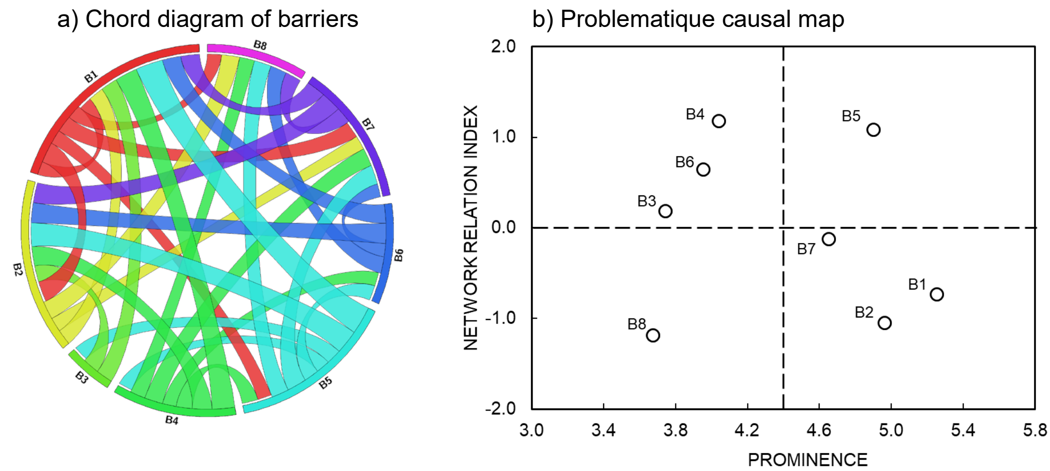

Figure 2: Interrelationship of barriers based on the respondents

Figure 2b shows the problematique causal map of all barriers by plotting the degree of prominence of barriers versus the network relation index. By categorizing all barriers in terms of prominence and causal status, immediate policy initiatives are required to address "Lack of initial capital investment (B5)", "Lack of data privacy (B4)", "Lack of market acceptance (B6)" and "Lack of trustful cybersecurity (B3)" in a step-wise manner. Note that the recent promulgation of a new law on investment entails investment incentives, including high-tech industries, digital industries, and physical infrastructures, to name a few (RGC, 2021b). Under this new investment law, all qualified investment projects are entitled to the investment incentives: either an income tax exemption for three to nine years or the right to offset capital expenditures via special depreciation for up to nine years. It is likely that this new government initiative will intervene in the causal barriers to the adoption of blockchain technology for waste management in future smart cities.

4. Conclusions

The novel T-Spherical Neutrosophic Fuzzy DEMATEL method is used to understand the problematique of blockchain adoption in waste management in the future smart cities of Cambodia. The systematic analysis of the problematique causal map and chord diagram provides an informative visualization of all barriers' interrelationships. Such illustration of complex barriers simplifies the understanding of the immediate policy initiatives needed and the urgency to align the government intervention in the context of progressive advancement of technology adoption. These present findings emphasize the importance of attracting the initial capital investment (B5) for the physical blockchain infrastructure under the new opportunity of the new law on investment while strengthening the implementation of the legal framework of data privacy (B4). Moreover, the necessity to increase the market acceptance (B6) of blockchain technology and the development of trustful cybersecurity (B3) need to be taken into proper consideration. Further study should be conducted to understand how to attract the initial capital investment in high-tech industries by systematically analyzing the interaction among barriers to the productive economy and economic diversification at the moment of physical and human capital and technological progress.

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