International Journal of Business and Technology Management
e-ISSN: 2682-7646 | Vol.6, No. 1,357-368, 2024
http://myjms.mohe.gov.my/index.php/ijbtm

Blockchain Challenges in Halal Food Industry Using Technology-Organization-Environment (TOE) And FMEA Framework

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Received: 20 January 2024 | Accepted: 5 March 2024 | Published: 31 March 2024

DOI: https://doi.org/10.55057/ijbtm.2024.6.1.30

Abstract: *Blockchain has transformed various industries including finance, banking, and digital commerce by enhancing data transparency and security. This exploratory study aimed to comprehend the challenges in adopting blockchain within the food industry and offers constructive suggestions for future implementations to mitigate failure risks. The research employed surveys and interviews from ten respondents to gather insights from industry professionals directly engaged in the adoption of blockchain. The study focused solely on the halal food sector considering the various types of business within it. Analysis using the 'Technological Organizational Environmental' (TOE) theory revealed three primary challenges such as data integration, stakeholder management and data availability. Recommendations resulting from the Failure Mode Effect Analysis (FMEA) framework were discussed. The study identified that risk priority number (or RPN) for team competency, data unavailability and unstable adoption was 336, 256 and 245, respectively. These risks were considered as the most significant challenge to blockchain adoption in the food industry.*

Keywords: Blockchain Challenges, Food Industry, Technology Resistance, FMEA, TOE

1. Introduction

Blockchain, a disruptive technology introduced by Satoshi Nakamoto in 2008, is a decentralized and trust-based public transaction ledger outlined in the original white paper. This innovative system eliminates the need for third-party institutions in peer-to-peer electronic cash transactions (Elghaish, 2021). Originating from finance industry, the success of blockchain has prompted various sectors to explore and adopt its advantages including the halal food industry. Over the past decade, there has been a growing interest in digitally connecting supply chains across different businesses (Feng et al., 2020; Kamilaris et al., 2019). Recognizing its flexibility, major software and platform developers like IBM, Microsoft, JP Morgan, Amazon, and Accenture have heavily invested in blockchain-ready platforms, such as IBM Blockchain, Azure Blockchain Service, Blockchain Center of Excellence, Blockchain on AWS, and 'BlockchainX' (Batubara et al., 2018; Cai et al., 2018).

Traceability poses a significant challenge in the halal food industry (Ahmad et al., 2018). The journey from farm to table involves diverse transformations of ingredients, with various transportation and handling methods. Ensuring absolute hygiene and authenticity, particularly for specific dietary needs like halal and vegetarian requirements, becomes questionable due to

the critical importance of knowing the origin and handling of each food component (Nakyinsige et al., 2012). Unfortunately, the rapid growth of halal food industry often outpaces the capacity of regulatory and monitoring bodies overseeing food safety. The comprehensive validation and inspection of every food manufacturer throughout the supply chain are daunting and time-consuming, bordering on an almost impossible and endless mission. According to Food and Agriculture Organization of the United Nations (FAO), food fraud costs the global food industry an estimated USD 32 billion annually (FAO, 2022).

Exploring the vast potential of blockchain for seamless platform integration is crucial. Investigating this emerging technology, understanding its implementation challenges, and assessing the risks of adoption failure through real industry cases are essential (Zhao et al., 2019). Despite numerous studies addressing blockchain challenges, many rely on theoretical frameworks and literature reviews. Few have utilized industrial surveys and interviews for data collection. Given the rapid evolution of blockchain technology, insights from industry professionals are imperative to grasp the genuine obstacles in deploying the technology effectively.

This study aimed to concisely outline the challenges in implementing blockchain technology in the industry through surveys and interviews, aligning them with the 'Technological-Organizational-Environmental' (TOE) framework. The second objective involves analyzing the risks of failure in blockchain deployment using the Failure Mode and Effect Analysis (FMEA) method and proposing action items to mitigate such failures. Aligned with the '10/10 MySTIE Framework' introduced by the Ministry of Science and Technology in December 2020 to promote blockchain adoption, this study contributes to fostering shared economic prosperity and elevating Malaysia in the global innovation value chain (Academy of Sciences Malaysia, 2020).

2. Methodology

Table 1: Summary of method and outcomes

Eight steps deployed in the study	Outcome of each step
1. Systematic literature review on abstracts discussing challenges in blockchain adoption	158 abstracts
2. Outcome of review-questionnaire establishment	26 questions
3. Validation of questionnaire Expert review Readability test Cronbach test	0.86, 80 score
4. Pilot of questionnaire	10 pilot samples
5. Full release-questionnaire & interviews	25 respondents
6. Data analysis (Challenges)-TOE theory	10 challenges identified
7. Data analysis (Recommendations)-FMEA framework	11 risks analyzed
8. Discussion & conclusion: Outcome TOE factors and risk index adoption	10 recommendations proposed

The approach for this investigation employed a mixed method, encompassing document analysis and a survey questionnaire. A comprehensive literature review was conducted on journals and publications from 2010 to 202. It is to comprehend existing challenges related to blockchain in the food industry. This paper aimed to categorize challenges and analyze the methods used for their examination. The results of this current study then informed the design of the survey. A total of 158 abstracts was screened using the keywords 'blockchain challenges'

and 'food industry.' From this pool, the top 10 most recent and pertinent papers from 2018 to 2021 were scrutinized to identify common themes surrounding challenges. Of these 10 papers, 90% identified challenges through literature review, while one paper employed the Systematic Literature Network Analysis method, offering a comprehensive overview of existing challenges. Notably, one study utilized a survey method, aligning with the approach planned for this investigation.

a. Data Collection

To achieve the primary objective of assessing challenges in the actual implementation of blockchain technology, a one-time survey was conducted. Respondents consisted of food partners and software providers actively engaged in the development of blockchain technology. The choice of a survey method in this study aligns with its widespread use in understanding technological resistance among industry players as observed in studies by Ali et al. (2017), Idoje et al. (2021), Mohanta et al. (2019, 2021) and Rather et al. (2021). Similarly, Friedman and Ormiston (2022) and Sanka et al. (2021) employed survey methods to grasp real challenges from industry experts. This approach was reinforced by Kauffman's study, where field research and survey methods were identified as common in organizational and behavioral research designs (Kauffman and Techatassanasoontorn, 2011). The analysis of relevant articles indicated that researchers investigating technology adoption predominantly used two research methods: survey and case study. Notably, 74% of the articles employed the survey approach as depicted in Figure 1, underscoring its prevalence in technology adoption research an observation consistent with previous findings emphasizing the dominance of the survey method in this domain (Sanka et al., 2021).

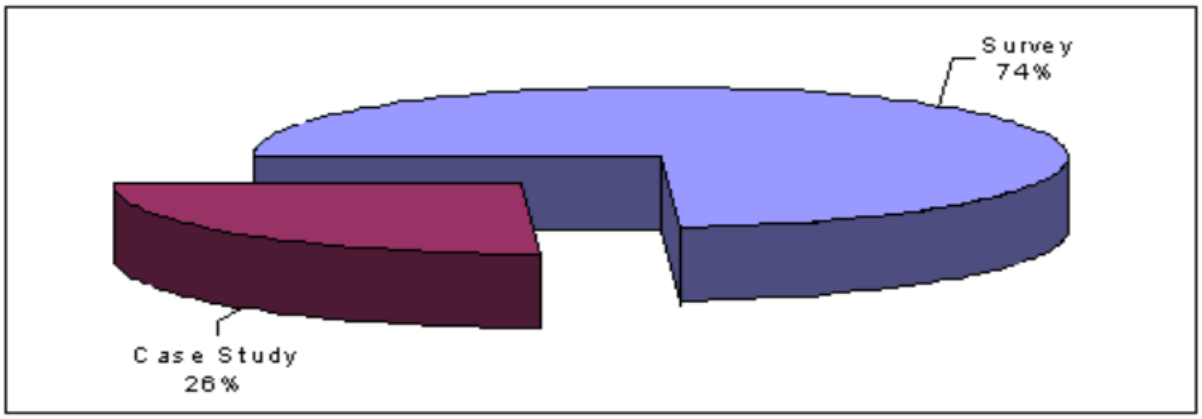

Figure 1: Research approach used in technology adoption research (Sanka et al., 2021).

b. Selection of organizations

Identifying suitable survey respondents involves two key steps: first, pinpointing an organization or partnership, and second, selecting employees or professionals involved in the identified partnership's blockchain activities. Notably, blockchain adoption in the current landscape is characterized by collaborative efforts among various parties, primarily food retailers and software developers. Given the novelty of blockchain technology, this study does not confine partnerships to specific business types within the food ecosystem. The identification and examination of partnerships drew from five sources: recent blockchain-related news and publications, blockchain forums and blogs, social networks like LinkedIn for challenges identification, the authors' professional networks registered in official company databases, and platforms of global technology leaders such as Microsoft, IBM, Google, and Amazon to gauge the scale of investment in blockchain development. This approach yielded a

shortlist of 14 active blockchain projects in the food industry, showcasing partnerships on both local and international fronts.

c. Selection of respondents

The subsequent step involved the identification of suitable respondents, with 25 individuals selected from the 14 projects identified. The selection criteria considered direct involvement in project discussions or execution, along with experience as industry professionals or researchers specializing in real cases of industry adoption. A well-defined target audience facilitated the selection process, ensuring accurate responses aligned with the research objectives.

To enhance value, diverse roles from different projects were deliberately chosen to explore potential variations in responses and gain distinct perspectives on challenges. This approach aimed to prevent bias stemming from a singular role or department (Berg et al., 2020; Gray and Downer, 2021). Varied roles also promised unique insights valuable to the study, potentially reflecting differences in access and privileges (Jones, 2020; Vasileiou et al., 2017).

The study categorized participants into two overlapping expert groups: 'blockchain experts,' knowledgeable about blockchain technology's sustainability capabilities, comprising consultants, researchers, IT experts, entrepreneurs, and managers in relevant digital technology companies. The second group, 'food supply chain experts,' included individuals implementing blockchain technology in food and agriculture supply chains. LinkedIn' served as a primary platform for identifying relevant expertise, resulting in 10 participants agreeing to be interviewed. The results section presented the full demographic details of the respondents and participating projects with certain information kept confidential.

d. Questionnaire's validity

The construction of the questionnaire drew on an examination of literature sources discussing qualitative data collection methods. Three survey validation methods were incorporated based on the insights derived from the literature review.

e. Content validity and expert review

Content validity is primarily addressed in academic and vocational testing, where test items must accurately represent the essential knowledge for a specific topic. In clinical settings, the correlation between test items and the symptom content of a condition is termed content validity (Dworkin, 2012). Subject matter experts play a vital role in evaluating whether test questions effectively measure defined content. This process is crucial for ensuring the correct use of terminology, question relevance, and capturing important segments. The evaluation involved a survey pilot phase conducted via online video calls with three blockchain experts, who provided valuable feedback. Minor adjustments were made based on their input, shaping the final version distributed to participants.

f. Readability

The consideration of readability aimed to prevent questionnaire misinterpretation, especially since half of the respondents are non-native English speakers. Assessing the comprehensibility of questions is crucial (Berg et al., 2020; Vasileiou et al., 2018), and the readability test employed the built-in feature of Microsoft Word programme. The 'Flesch Kincaid' calculation yielded a score of 8.6, indicating a high level of clarity. This formula, one of several methods for gauging text difficulty, involves analyzing sample passages or questions.

g. Cronbach alpha test

Cronbach alpha test was also conducted to assess on inter-related, sequencing and structure of questionnaire and sections (Berg et al., 2020). However, as most of the questions were open ended, only two questions were able to be tested with three different reviewers. A score of 0.8 was obtained equivalent to "good" level. However, this validation was excluded as only two questions was able to be validated using this method hence cannot be conclusive. To compensate, the questionnaire was shared for review by a former staff of 'The Malaysian Psychometrics Association' in terms of questionnaire's format, method of analysis and section relevancy. The comments received were minor.

3. Data Analysis

Analysis of challenges using Technological-Organizational-Environmental'(TOE) Framework

This study employed the TOE framework for analysis previously utilized by Batubara et al. (2018) in their examination of blockchain challenges within the e-government sector, as illustrated in Figure 2. Originating in the 1990s, the TOE framework has been widely employed by researchers, including Wong et al. (2020), to scrutinize the adoption of information technology. This framework incorporates technological, organizational, and environmental elements to pinpoint pivotal factors influencing the adoption process. The technical context encompasses crucial technological aspects for the adopting company, such as availability. The organizational context pertains to the organization's qualities and resources relevant to technology adoption, such as preparedness, managerial structure, and size. The environmental context scrutinizes the characteristics of the business's service execution environment, including industry structure, technology support infrastructure, and regulatory environment. By leveraging these three contexts, the challenges to adoption gleaned from the responses were identified and categorized.

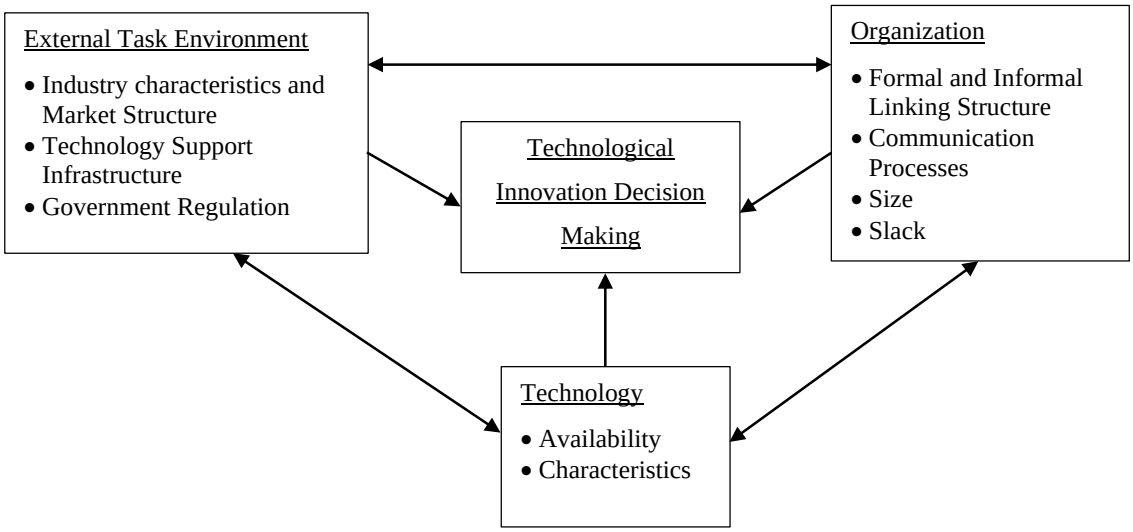

Figure 2: Technology organization environment (TOE) framework
Source: Batubara et al., 2018)

Failure Mode Effect Analysis (FMEA)

The challenges identified were then analyzed using FMEA, a systematic risk assessment method. FMEA is a step-by-step approach used to identify failures in design, manufacturing, assembly processes, or products/services (ASQ, 2023; Varzakas, 2011). Varzakas (2015) emphasized its common use as an analysis tool to establish a robust framework for minimizing

or preventing process failures. FMEA maps consist of steps evaluating the severity, potential causes, frequency of occurrence, and detectability levels, with the outcome measured as the Risk Priority Number (RPN) to prioritize critical steps (Trafialek & Kolanowski, 2014).

Potential risks are qualitatively determined and assessed using three variables: Severity (S), Occurrence (O), and Detection (D). Severity assesses the impact on the final outcome, rated on a scale of 1 to 10, with 10 indicating the worst impact. Occurrence evaluates the probability of a risk cause, and Detection assesses the ability to detect a risk or control a causal factor (Indrarespati et al., 2021). Both Occurrence and Detection are evaluated on a scale of 1 to 10.

RPN is calculated by multiplying the three variables (i.e. RPN = S x O x D), and the values are prioritized in descending order. The maximum targeted RPN value is set at 100 to reduce and prevent the impact of risks (SMI Asia Australia, 2023). Mitigation or prevention strategies are implemented for activities exceeding this threshold, while control or monitoring measures are applied if the RPN value is below 100.

5. Results and Discussion

A total of 10 respondents participated in the survey, which met the minimum target set in the initial study. The respondent's demographic and other key findings were illustrated and discussed in the below section. A sum of 45 adoptions challenges by the respondents received and are grouped based on common themes as seen in Figure 3. Data integration tops the list followed by stakeholder management persuasion and data availability. Other challenges identified through the responses are blockchain knowledge or skills incompetency, budget, failure to understand business and customer needs, sustainability issues, lack of support from local players and government, lack of regulations and project management incompetency.

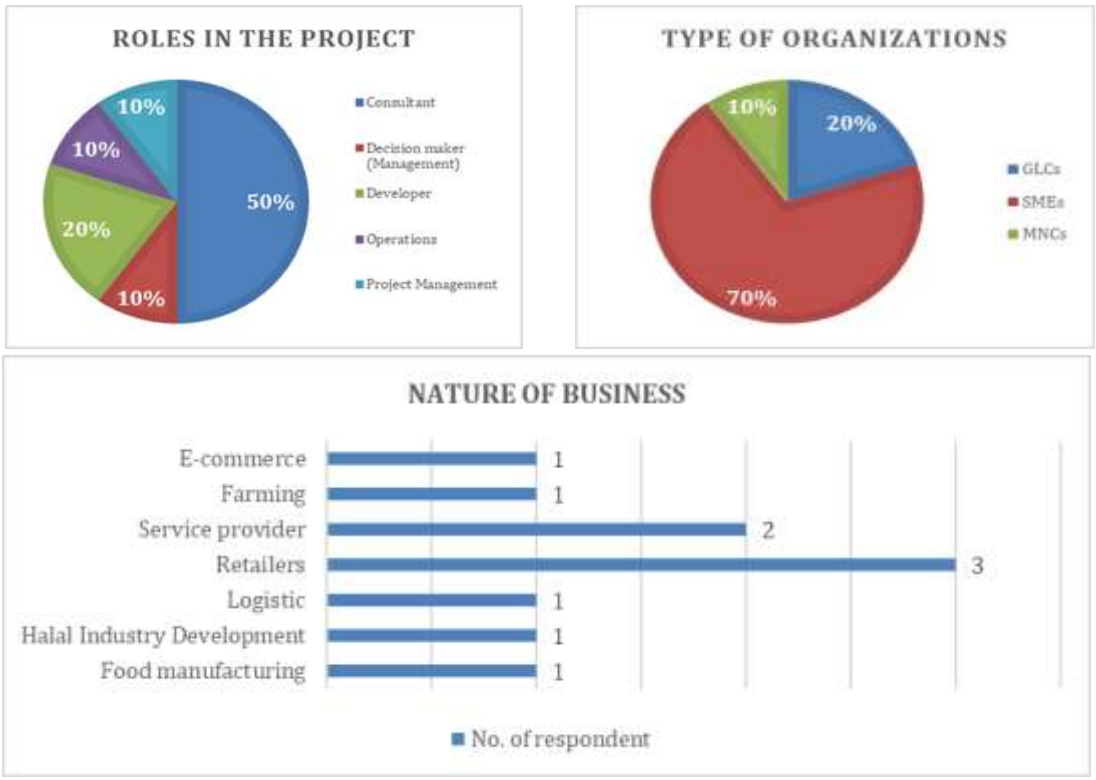

Figure 3: Demographic distribution of respondents and organizations

Challenges to Technological-Organizational-Environmental' (TOE) Elements

The challenges identified then were mapped to the TOE framework to identify the key driver in the adoption as shown in Table 2. One respondent was allowed to vote for the same challenge more than once including technological, organizational and environmental challenges.

Table 2: TOE mapping to challenges

Aspect	Challenges
Technological	Data Integration
	System incompatibility between parties and departments requires long time for data integration and streamlining.
	Internet of Things (IoT) technological use and customization to different needs.
	Data availability
	Lack of reliable data sources/data inputs.
	Manual data input.
Organizational	Budget
	Limited budget allocation.
	Stakeholders' management and persuasion
	Fail to understand Voice of Business (VoB) and Voice of Customers (VoC).
	Poor understanding on organizations' s priority e.g. scope and revenue's sources.
	Failure to understand business and customer's needs
	Project management incompetency
Environmental	Lack of regulations
	Lack of support from local players and government
	Sustainability controversies
	Blockchain knowledge/Skills incompetency
	Lack of competent personnel with specific blockchain experience in food industry.

Risk assessment & recommendations using FMEA.

There were 10 challenges identified and mapped to the phases of adoption and the risk was identified for each phase. The summary of the mitigation of adoption failure was discussed in the preceding section. The outcomes of FMEA analysis rank the risks from highest to lowest using the RPN index by using the total multiplication of three values of the variables S, O and D. The higher the RPN, the bigger impact it would have on the adoption process.

Recommendations to reduce adoption failure.

The risks identified in FMEA were further elaborated in terms of its impact to adoption process and the recommendations to reduce the failure or risk severity were discussed. This serves as a guide for future adoption locally or internationally as shown in Table 3.

Table 3: Seven failure mode identified coupled with risk severity and its RPN value.

1.	Team members are not competent in blockchain technology (RPN:336)
	Risk 1: Incompetency of team members could cause incorrect deployment, extension of project duration and project failure. The recommended solution is upskilling. There has been a more advanced movement of blockchain in certain countries such as China and the USA. In these countries, small-scale pilot run and investment has the biggest market segment with good expertise. Cross-skills and training could be held before project execution for knowledge transfer. Risk 2: Most respondents recommended that several pilot runs need to be carried out before execution. Given the complexity of the technology, nature of food products and social resistance from partners, more investment in sample runs will benefit the end adoption.
2.	Data required is not available and supply chain complexity (RPN:256)
	Risk 3: Project failure, extension of project duration and data is not reliable. The recommended solution is the integration of IoT as part of the project's requirement which is to ensure data reliability and sustainability,

an adoption of IoT at a certain point in the transaction must be compulsory. The more commonly adopted technologies are cloud-based storage to store all the data points, and artificial intelligence to predict trends and forecast the supply chain to help execute standard transactions efficiently. Without the integration of IoT, blockchain adoption remains a challenge.

Risk 4:
Full value stream mapping (VSM) analysis is also to be conducted on the supply chain: A supply chain will only appear complex if the data points are not identified and visible. VSM is a method used in business operations to study the door-to-door journey of a product, and to determine the critical control points in each process and the time-bound metric performance (e.g. lead time, cycle time, process time etc.). These will help project members to understand the entire process flow from farm to table, highlight crucial control points and ultimately, eliminate the perception of a complex supply chain.

3. Adoption is not sustainable (RPN:245)

Risk 5:
Unstable and unsustainable adoption could lead to a loss of market trust and customer interest in the long run. This risk usually ties back to the challenges in maintaining the ecosystem and commitment from the consortium members. Educating consumers on the impact and environment of blockchain technology on food traceability can increase the demand for blockchain products in the market. Investors and partners will then be willing to invest in the technology at a mass level, which can encourage organic sustainability and growth of the blockchain-food market.

Risk 6:
Enforcement and government support for critical products such as halal meat in Malaysia need to play a role in enforcing certain regulations to be adhered to by respective parties. For examples, laws around halal blockchain and traceability first need to be established before adopting blockchain. To help small businesses participate, sufficient resources and education also need to be provided so that a strong and comprehensive halal ecosystem can be developed locally.

4. System incompatibility and partner refuse to share certain data (RPN:224)

Risk 7:
Although partners agree to collaborate in building a blockchain ecosystem, at the end of the day, partners are still competitors. Based on respondents, there have been cases whereby certain partners refuse to share data interrupting the chain of the data network. This could lead to project failure, extension of project duration, and the receipt of unreliable data.

5. Voice of Business is not captured correctly (RPN:168)

Risk 8:
Voice of Business (VoB) is the requirements, wants, expectations, and preferences of the individuals who operate the business, both stated and unspoken. A failure to understand VoB has failed in adoption. As a solution, a VoB workshop before project execution to map VoB to VoC before project execution with critical stakeholders is essential to understand the business requirements. In the workshop, important areas such as revenue sources, margins desired from blockchain products, and short-term and long-term goals need to be understood clearly. A consumer's perception towards blockchain should be conducted to assess the interest and market demands. Understanding consumer purchasing behaviour is important to set the strategy and approach that appeals to the market.

6. Client is not interested in blockchain (RPN:160)

Risk 9:
There was resistance to business proposals by the clients despite the enormous potential of blockchain technology. This could be due to knowledge barriers, lack of understanding on black chain technology in the market, the complexity of the technology, which requires strong partnership between stakeholders, high budget and low margin of food products. Therefore, a an end-to-end blockchain model prototype should be developed specifically to food traceability applications.

7. Suitable vendor with right competency is not in the list and platform selected is not sustainable in the long run (RPN:96)

Risk 10:
There were several platforms observed during the study that were not sustainable. They started with blockchain services and later moved on to another type of product or business. It is a common trend for

service and platform providers as they need to adapt to market demands. Performing longevity analysis of platforms could potentially see the reliability of the partner selected. This exercise can be done with a group of technical experts with a combination of blockchain-related professionals.

The recommendations were then mapped back to the phases of execution so future adoptions could learn from the failure at each stage. As seen in Figure 4, the initial stage of the project plays a very critical role in deciding the success of the adoption. There were four risks identified during the business proposal phase whereby a strong knowledge of blockchain is required to convince partnerships. During the proof-of-concept phase and pilot run, it is very critical to adopt the applications of IoT and understand the end-to-end process of a particular product. Also, managing partnerships through tokenization can be suggested. Lastly, customers need to be included in the discussion and educated during real case rollout. Authorities also need to provide a strong barrier for partners against other digital manipulations and food fraud through legislation and enforcements.

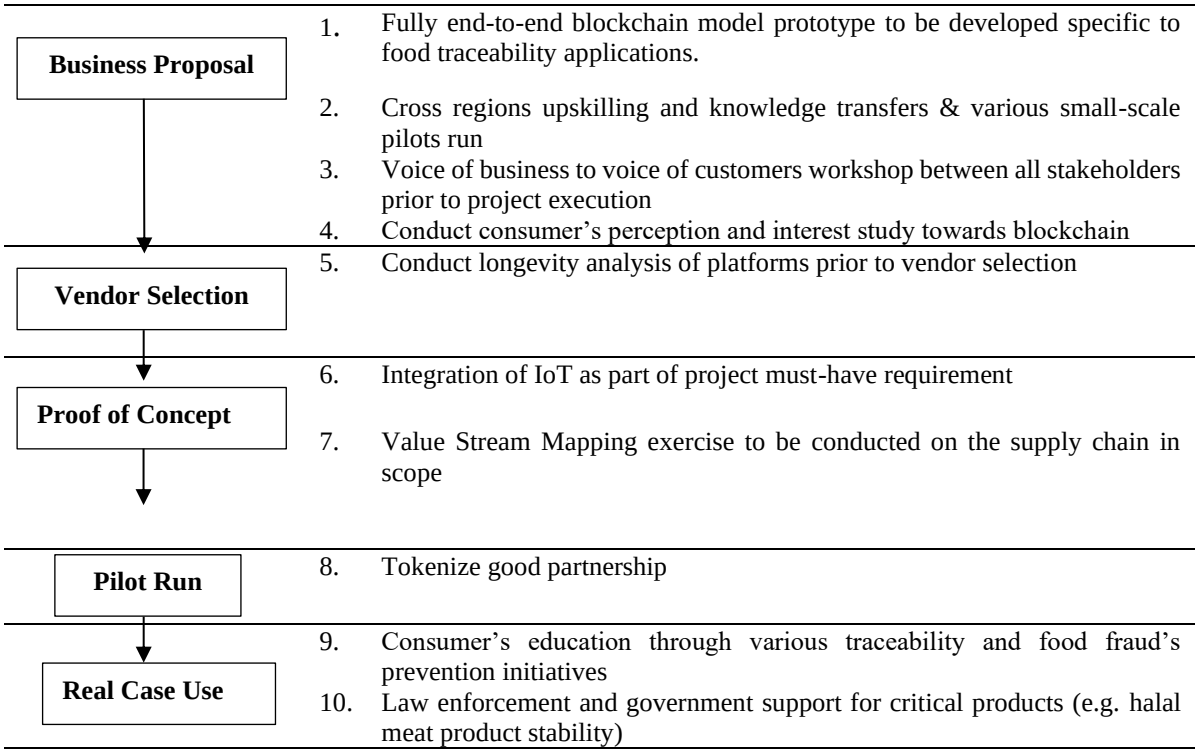

Figure 4: Recommendations at phases of blockchain deployment

6. Conclusion

Blockchain, a novel technology rooted in decentralization and immutability, contributes to theoretical advancements by delving into its practical and industrial dimensions. This study examined both upstream and downstream conditions, engaging real stakeholders to enhance understanding of blockchain practice, policy and theory. The findings highlighted technological elements, such as product customization, data availability and integration as pivotal factors in adoption. Analytical methods such as TOE theory and FMEA framework proven effective in providing calculated guidance. This exploratory study designed to address specific objectives, successfully collected responses that align with expectations, concluding decisively on the topic.

Ten challenges hindering blockchain deployment, with technical understanding and convincing partnerships emerging were identified as significant obstacles. Additionally, 11 adoption risks were pinpointed, revealing the top three risks as team competency (RPN value: 336), data unavailability (RPN value: 256), and unsustainable adoption (RPN value: 245). In response to these findings, the study proposed 10 robust recommendations to mitigate the risk of failure in blockchain adoption within the food industry.

The study suggested that blockchain may not be the optimal solution at present due to the low digitization index in the local market in the context of Malaysia's food industry. However, it advocates for channeling efforts into developing blockchain for product traceability, given Malaysia's unique role as a leading advocate and contributor to the global halal supply chain ecosystem. This recommendation stems from the country's distinct position as the first to assign a government agency to regulate halal matters and certification.

7. Recommendations for Future Research

Blockchain has displayed significant potential as a disruptive technology. However, there remain unexplored areas, unsubstantiated hype, and numerous claims needing validation within the blockchain domain. The study suggests addressing critical issues for a conclusive understanding of overall blockchain adoption challenges. Firstly, there is a lack of research on consumer awareness, perception, and interest in the technology. Secondly, despite various case studies on existing deployments, it is uncertain whether these platforms are suitable for supporting halal-related products. While each platform offers unique customization, their efficacy in addressing halal traceability concerns remains unclear. Thirdly, assessing the perceptions of small players, such as small farmers and suppliers, is essential for developing the ecosystem. They are the primary data contributors crucial for maintaining the reliability and integrity of the supply chain. Fourthly, conducting a comprehensive comparison among major blockchain service providers like IBM, Google, and Amazon is imperative to assist newcomers in making informed decisions. Understanding common elements such as cost, integration duration, system compatibility, security and privacy, after-sales support, as well as demo and assistance, would significantly benefit new developers in blockchain technology.

Acknowledgement

We thank all the respondents for their cooperation and time spent to provide responses and insights which have made this research successful.

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