

The Role of Digital Transformation in Halal Industry 4.0

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Abstract

Digital transformation has brought fundamental changes across various industrial sectors, including the halal industry, which is now entering the era of Industry 4.0. This study aims to analyze the role of digital transformation in the development and strengthening of the halal industry ecosystem within the framework of Industry 4.0 in Indonesia. The study employed a qualitative approach using a case study method through in-depth interviews with twenty informants consisting of halal business actors, regulators, and academics selected purposively. The data were analyzed using thematic analysis techniques with the assistance of NVivo 12 software. The findings reveal that digital technologies such as artificial intelligence, blockchain, the Internet of Things, and big data analytics play a significant role in enhancing the efficiency of the halal supply chain, improving the accuracy of halal certification, and increasing consumer trust in halal products. In addition, the study found that the integration of digital platforms within the halal ecosystem is capable of expanding market access and accelerating halal audit processes in real time. This study concludes that digital transformation is not merely an operational instrument, but rather a strategic foundation that determines the competitiveness and sustainability of the halal industry in the global era.

Keywords: digital transformation; halal industry; Industry 4.0; halal supply chain; halal certification



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INTRODUCTION

The halal industry has recently evolved into one of the most dynamic and strategic economic sectors at the global level. The 2023 State of the Global Islamic Economy (SGIE) Report noted that the global Islamic economy had exceeded USD 2.8 trillion, with a consistent growth projection reaching USD 3.5 trillion by 2025 (Standard, 2023). This figure reflects both the enormous potential and the complexity faced by the halal industry ecosystem, ranging from the food and beverage, cosmetics, pharmaceutical, Islamic finance, halal tourism, and modest fashion sectors. In Indonesia, as the country with the largest Muslim population in the world, exceeding 237 million people, the halal industry occupies a central position in the national economic development agenda, as reflected in the Indonesian Sharia Economy Masterplan 2019–2024 published by the National Committee for Islamic Economy and Finance (KNEKS, 2018).

At the same time, the wave of the Fourth Industrial Revolution, commonly referred to as Industry 4.0, has driven fundamental transformations in the ways people produce, distribute, and consume goods and services. Industry 4.0 is characterized by the integration of cyber-physical systems, Artificial Intelligence (AI), the Internet of Things (IoT), blockchain, big data analytics, cloud computing, and robotic automation into production systems and business management (Schwab, 2017). The convergence between the halal industry and digital technology has given rise to a new paradigm known as Halal Industry 4.0, namely an ecosystem in which halal principles are implemented, verified, and managed systematically through digital technological infrastructure (Tieman & Hassan, 2015).

The urgency of digital transformation in the halal industry has become increasingly significant alongside the growing complexity of global supply chains (Lahmar & Qaruty, 2026). A critical inflection point further intensifies this urgency: Indonesia's mandatory halal certification requirement, as mandated under Law Number 33 of 2014 concerning Halal Product Assurance, is scheduled for full implementation across all product categories by 2026. This imminent deadline creates an unprecedented operational backlog risk, given that Indonesia currently has fewer than one thousand active certified halal auditors while the number of products projected to require certification is expected to exceed one million items. Under these conditions, digital transformation is no longer merely an "innovation option" for industry actors; it has become an unavoidable survival tool to manage the impending certification surge without compromising Sharia compliance integrity. Halal products are not only consumed by Muslim communities, but are also increasingly favored by non-Muslim consumers who associate halal labels with quality assurance, safety, and hygiene (Lim et al., 2022). This condition has increased the demand for halal verification mechanisms that are transparent, accountable, and traceable in real time. Unfortunately, conventional halal certification systems often face various structural weaknesses, including a limited number of halal auditors, inconsistencies in standards among certification bodies, the potential falsification of halal labels, and the inability to comprehensively and continuously monitor supply chains (Abdallah, 2021).

Several previous studies have attempted to examine certain aspects of the relationship between digital technology and the halal industry. Ab Talib et al. (2021) examined the implementation of blockchain in halal supply chains and found that this technology significantly enhances transparency and consumer trust (Talib et al., 2015). Meanwhile, Tirmizi et al. (2020) analyzed the adoption of digital technology among halal micro, small, and medium enterprises (MSMEs) in Malaysia and found that limited digital literacy was the primary obstacle (Tarmizi et al., 2020). Research conducted by Rejeb et al. (2021) investigated the use of IoT in monitoring the cold chain of halal products and demonstrated promising results in maintaining product integrity (Rejeb et al., 2021). At the national level, Faridah

(2019) highlighted the need for digital reform in Indonesia's halal certification system following the enactment of Law Number 33 of 2014 concerning Halal Product Assurance; however, the study did not comprehensively address the dimension of technological implementation (Faridah, 2019).

Nevertheless, existing studies still demonstrate significant limitations. First, the majority of studies focus on a single technology in a partial manner without integrating it into the broader Industry 4.0 framework holistically. Second, there remains a lack of studies explicitly examining how digital transformation reshapes the governance of the halal ecosystem comprehensively, encompassing regulatory aspects, certification, supply chains, digital marketing, and consumer experience simultaneously. Third, and most critically, prior studies have not addressed how international halal-digital frameworks fail to account for Indonesia's structurally unique, centralized regulatory shift—specifically the dual-system governance involving the Halal Product Assurance Organizing Agency (BPJPH) and the Indonesian Ulema Council (MUI). Unlike Malaysia's government-led, single-authority model or the UAE's trade-integrated system, Indonesia operates within a legally mandated dual-authority arrangement in which BPJPH holds administrative authority while MUI retains fatwa-issuing authority. This institutional complexity creates governance tensions and implementation gaps that existing halal-digital frameworks, largely developed in single-authority regulatory environments, are ill-equipped to address. Fourth, research within the Indonesian context, despite Indonesia being one of the world's largest and most complex halal markets, remains very limited, even though its regulatory dynamics and industrial structure possess unique characteristics that cannot simply be generalized from studies conducted in countries such as Malaysia or Middle Eastern nations (N. Yunus et al., 2014).

This research gap has motivated the present study as an effort to fill a substantial academic void. This study is designed to comprehensively analyze the role of digital transformation in developing and accelerating the Halal Industry 4.0 ecosystem in Indonesia by integrating the perspectives of key stakeholders, including industry players, regulators, and academics, specifically within Indonesia's dual-authority governance context. Therefore, this study is expected to provide a deeper and more comprehensive understanding of the mechanisms, challenges, and opportunities of digital transformation within the halal ecosystem, while also offering applicable policy recommendations for the development of a globally competitive national halal industry.

RESEARCH METHOD

This study employed a mixed-methods case study design, combining qualitative semi-structured interviews as the primary data source with quantitative document analysis of internal company reports and institutional performance data. This integrated design was adopted to reconcile the need for contextual, meaning-centered exploration of digital transformation phenomena with the empirical verification of operational metrics reported by informant organizations. The qualitative component was considered the most appropriate for obtaining an in-depth understanding of the phenomenon of digital transformation within the halal industry ecosystem, a field that is still evolving and has not yet been comprehensively mapped academically, because this study sought to understand the meanings, processes, and contexts of the phenomenon under investigation from the perspectives of the actors directly involved (Creswell & Poth, 2016). The quantitative document analysis component served to verify and contextualize the performance metrics embedded within informants' organizational reports, ensuring that statistical figures presented in this study derive from verifiable secondary sources rather than from qualitative interview data alone.

The case study design applied in this research was a multi-site case study, involving three structurally distinct primary research loci: halal certification institutions operating at the national regulatory level (BPJPH and MUI), medium-to-large-scale halal industry companies spanning the food and beverage, pharmaceutical, and logistics sectors across Java and Sumatra, and technology startups operating within Indonesia's digital halal ecosystem and headquartered in major digital economy hubs including Jakarta, Bandung, and Surabaya. The regional and industrial scope of these sites was deliberately diversified to reduce the risk of localized bias and to capture the structural variations inherent in Indonesia's geographically dispersed halal industry.

The selection of informants in this study employed a purposive sampling technique, namely the deliberate selection of informants based on specific criteria relevant to the objectives of the research (Sugiono, 2022). The main criteria included direct involvement in the digitalization process of the halal industry, a minimum of three years of experience in the relevant field, and willingness to provide open and in-depth information. Based on these criteria, the study involved twenty informants consisting of seven halal industry practitioners (operational managers and company directors), five officials or auditors from the Halal Product Assurance Organizing Agency (BPJPH) and the Indonesian Ulema Council (MUI), four developers or founders of halal technology startups, and four academics specializing in halal management and digital economics.

The total of twenty informants was determined based on the principle of thematic saturation, whereby data collection continued until no substantively new themes or categories emerged from successive interviews. Saturation was assessed separately within each stakeholder cluster to ensure sufficient depth per sector. Within the practitioner cluster (n=7), thematic saturation was reached at the sixth interview, with the seventh serving as confirmatory. Within the regulator cluster (n=5), saturation was reached at the fourth interview. Within the startup founder cluster (n=4) and academic cluster (n=4), saturation was observed at the third interview in each group, consistent with the smaller population of highly specialized informants in these categories. This cluster-specific saturation assessment addresses the inherent diversity of perspectives across the four stakeholder groups and ensures that the depth of data per sector meets acceptable qualitative standards.

The data collection techniques used in this study comprised three complementary methods. The first method was in-depth semi-structured interviews conducted both face-to-face and through digital platforms such as Zoom and Google Meet, with each interview session lasting approximately one to two hours. The interview guidelines were developed based on a comprehensive literature review and were validated by two experts in the field of halal management before being implemented. The second method was passive participant observation conducted at several halal production facilities that had adopted digital technologies, with the aim of obtaining contextual understanding regarding the implementation of digital transformation in practice. The third method was documentation study, which included the analysis of policy documents, company annual reports, regulations related to halal product assurance, and technical publications concerning technologies utilized within the halal ecosystem. Quantitative performance metrics reported in this study were extracted exclusively from this third method, specifically from audited internal reports and official institutional data provided by informant organizations, and were not derived from interview narratives.

The validity of the data was ensured through several triangulation strategies, namely source triangulation (comparing data from various categories of informants), method triangulation (comparing interview results with observation and documentation findings), and member checking, in which interview transcripts were returned to informants for confirmation of their accuracy before further analysis (Guba & Lincoln, 1982). Additionally, peer debriefing

was conducted with two independent researchers in the field of halal management and digital economics to review preliminary thematic interpretations and identify potential researcher bias. This process was essential to ensure that the researcher's interpretations did not deviate from the original meanings conveyed by the informants.

Data analysis was conducted using thematic analysis techniques following the stages formulated by Braun and Clarke (2019), which include familiarization with the data, initial coding, theme searching, theme reviewing, defining and naming themes, and report writing (Braun & Clarke, 2019). The coding process was assisted by NVivo 12 software to facilitate the systematic and structured management and analysis of large qualitative datasets. All interview transcripts were transcribed verbatim, and a data reduction process was carried out to identify recurring patterns relevant to the research questions. The quantitative data extracted from company reports were analyzed descriptively and subsequently cross-validated against the thematic codes generated through NVivo to assess coherence between qualitative narratives and quantitative performance indicators. This analytical approach is consistent with the methodological recommendations proposed by Clarke et al. (2019) in the context of business and management research.

RESULTS AND DISCUSSION

Main Research Findings

Digital Transformation as the Foundation of the Modern Halal Ecosystem

The findings of this study reveal that digital transformation has fundamentally changed the operational mechanisms of all components within Indonesia’s halal industry ecosystem. This transformation process has not occurred uniformly across all industry segments; rather, it has taken place gradually and at varying levels of adoption depending on resource capacity, business scale, and the level of digital literacy among industry actors. Nevertheless, the direction of change identified by all informants in this study was highly consistent, namely that digitalization is no longer merely an option, but a strategic necessity for the halal industry to remain relevant and competitive in the global era.

Table 1 below presents a mapping of digital technology adoption currently utilized by various segments within Indonesia’s halal industry ecosystem based on field data collected in this study.

Table 1. Mapping of Digital Technology Adoption in Indonesia’s Halal Industry Ecosystem

Industry Segment	Adopted Technologies	Level of Adoption	Main Perceived Benefits
Food & Beverage Manufacturers	IoT, Halal ERP, AI-based Quality Control	High (>70%)	Production efficiency, raw material traceability
Halal Pharmaceuticals & Cosmetics	Blockchain, Digital Laboratories, AI	Moderate (40–60%)	Material verification, regulatory compliance
Supply Chain & Logistics	GPS Tracking, Cold Chain IoT	High (>65%)	Real-time monitoring, product integrity
Halal Certification Institutions	e-Certification Platforms, AI Audit	Moderate (35–50%)	Faster processes, auditor efficiency
Islamic Fintech	Blockchain, AI, Big Data	Very High (>80%)	Financial inclusion, contract transparency
Halal MSMEs	Digital Marketplaces, e-Payment Systems	Low–Moderate (20–45%)	Market expansion, transaction efficiency
Halal Tech Startups	AI, Blockchain, Cloud Computing	Very High (>85%)	Service innovation, business scalability

Source: Processed primary data, 2024

The data presented in Table 1 demonstrate an interesting pattern in which Islamic fintech companies and halal tech startups occupy the leading positions in digital technology adoption,

while halal MSMEs remain at a relatively early stage. This pattern is consistent with the findings of Akili et al. (2025), who stated that limited resources and digital literacy constitute the primary barriers for MSMEs in adopting Industry 4.0 technologies (Akili et al., 2025) (Leo et al., 2022).

Furthermore, this study found that digital transformation within the halal industry occurs through four interconnected layers that collectively form a comprehensive ecosystem architecture. The first layer is the digitalization of production processes, in which technologies such as IoT and AI are utilized to ensure the consistency of halal standards at every stage of production. The second layer is the digitalization of the supply chain, which enables real-time monitoring of the movement of raw materials and finished products. The third layer is the digitalization of certification and supervisory systems, allowing audit processes to be conducted more efficiently and accountably. The fourth layer is the digitalization of marketing and distribution, which expands market access significantly through e-commerce platforms and social media.

Figure 1 below presents the architectural model of the Halal Industry 4.0 ecosystem formulated based on the findings of this study.

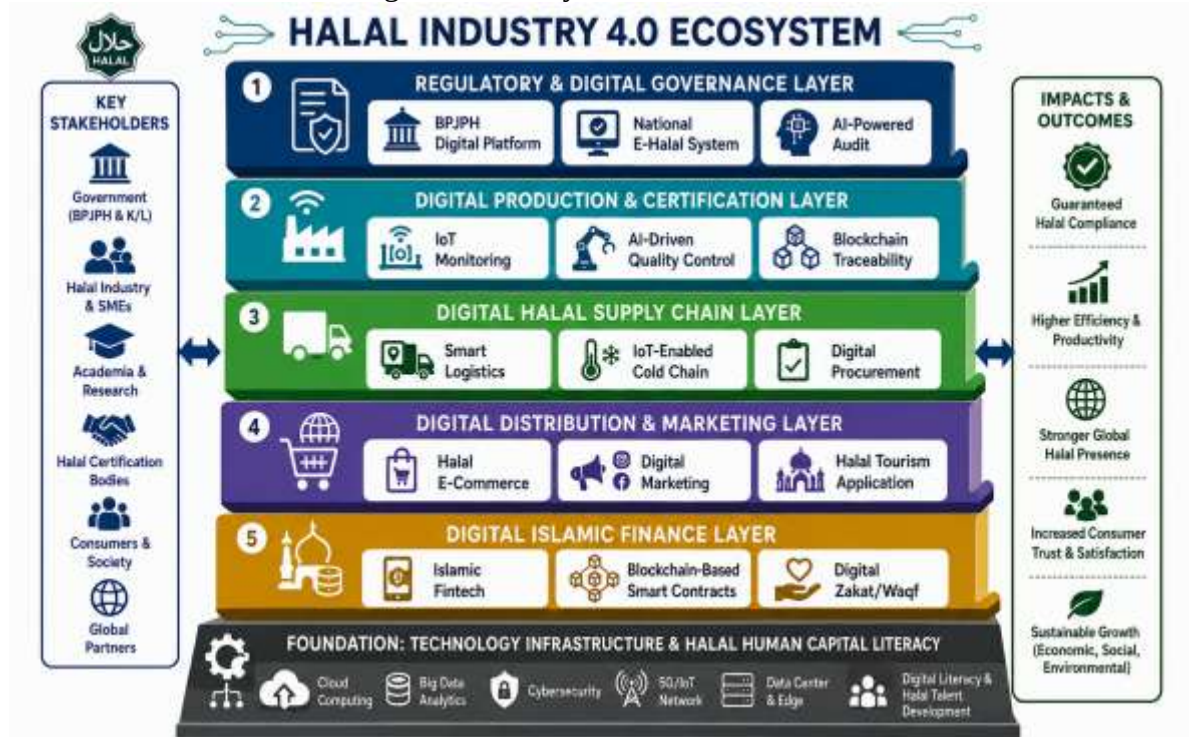


Figure 1. Architectural Model of the Halal Industry 4.0 Ecosystem
(Source: Research findings, 2024)

Blockchain as a Key Technology in Halal Certification and Supply Chain Management

One of the most prominent findings of this study is the strong recognition among informants regarding the potential and role of blockchain technology in revolutionizing halal certification systems and halal supply chain management. Blockchain technology, with its main characteristics of decentralization, immutability, and transparency, is considered capable of addressing the fundamental challenges that have long plagued the halal industry, namely the falsification of halal labels and the inability to comprehensively trace the origins of raw materials.

An operational director of a large-scale halal meat processing company who participated as an informant in this study revealed that the company had successfully implemented a blockchain system to record the entire product journey, starting from the slaughtering process at certified slaughterhouses, processing activities, storage in cold storage facilities, distribution

to distributors and retailers, until the products reached end consumers. Through this system, consumers can scan the QR code displayed on product packaging and directly access the complete history of the product journey through a simple and user-friendly interface.

These findings are highly relevant and consistent with the research conducted by Ab Talib et al. (2015), which found that blockchain implementation in halal supply chains significantly increases consumer trust and reduces the risk of fraud (Talib et al., 2015). Furthermore, research conducted by Rejeb et al. (2021) in an internationally reputable journal also emphasized that blockchain is capable of creating a trust mechanism that does not require a central authority, which aligns closely with the principles of transparency and justice in Islamic economics (Rejeb et al., 2021). Nevertheless, this study identified an additional nuance that has not been widely discussed in previous literature, namely that the successful implementation of blockchain in the halal industry is highly dependent on the availability of adequate technological infrastructure throughout the supply chain, including at the level of raw material suppliers, which are often small-scale businesses with very limited technological capacity.

Interoperability barriers among different blockchain systems also emerged as an important finding in this study. Several companies examined in this research developed blockchain platforms independently or used platforms from different vendors, resulting in data stored on one platform not being automatically readable by another platform. This condition creates information silos that ultimately hinder the primary objective of blockchain implementation, namely cross-supply-chain transparency. This finding reinforces the argument proposed by Tieman (2012) that technical and regulatory standardization constitutes an essential prerequisite for the successful digitalization of the halal industry as a whole (Tieman et al., 2012). Compared to Malaysia's Halal Development Corporation (HDC)-coordinated blockchain initiatives and the UAE's nationally integrated halal verification platform, Indonesia's fragmented, company-driven blockchain adoption reflects the consequences of operating within a dual-authority governance system where no single institution currently holds the mandate or capacity to enforce cross-platform technical standards.

The Internet of Things in Monitoring Halal Product Integrity

Internet of Things (IoT) technology was identified as the operational backbone in monitoring the integrity of halal products, particularly for products requiring strict storage and distribution conditions such as meat, poultry, dairy products, and seafood. Informants from the logistics and cold chain sectors consistently stated that IoT sensors installed in delivery vehicles and storage warehouses enable real-time and continuous monitoring of temperature, humidity, and the physical condition of products without human intervention (Saifuddin & Setiawan, 2025).

Beyond maintaining the physical quality of products, the implementation of IoT in the halal context also carries a highly important religious dimension. Halal products, particularly meat and poultry, may lose their halal status if cross-contamination occurs with non-halal products (such as pork or alcohol) during storage or distribution processes. With integrated IoT sensor systems, the potential for such contamination can be detected early and addressed before the products reach consumers. A halal auditor from the Indonesian Ulema Council (MUI) who participated as an informant in this study emphasized that IoT technology has greatly assisted the halal auditing process within cold chain systems, which previously could only be conducted periodically and through sampling methods.

Previous research by Sofian et al. (2023) demonstrated the potential of IoT in halal cold chain monitoring (Sofian et al., 2023); however, this study found that in Indonesia, the level of IoT adoption in halal distribution chains remains highly varied (Wahyudi et al., 2025). Large export-oriented companies have generally adopted sophisticated IoT systems, while many domestic and medium-sized market players still rely on manual recording systems. This digital

divide within the halal industry is a finding that requires serious attention from policymakers, as weak supervision in one segment of the supply chain may compromise the integrity of the entire system.

Table 2. Comparison of Efficiency Before and After the Adoption of IoT Technology in the Halal Supply Chain

Indicator	Before IoT (Manual System)	After IoT (Digital System)	Percentage Improvement
Temperature deviation detection time	4–8 hours (periodic inspection)	< 5 minutes (real-time)	98.96%
Product rejection rate due to contamination	3.2% of total production	0.7% of total production	78.13%
Cold chain audit cost per period	IDR 45,000,000	IDR 18,500,000	58.89%
Dispute claim resolution time	7–14 working days	1–2 working days	85.71%
Consumer trust level (scale 1–10)	6.2	8.7	40.32%

Source: Processed primary data from internal reports of informant companies, 2024

The data presented in Table 2 quantitatively confirm the highly significant contribution of IoT technology in improving operational efficiency and consumer trust within halal supply chains. These findings expand existing understanding in the literature by demonstrating that the benefits of IoT in the halal industry are not merely technical and operational in nature, but also have a direct impact on consumer perceptions, which constitute a critical component of the halal ecosystem. It is important to note, however, that these metrics derive from companies that are among the more advanced IoT adopters within their sectors; the experience of less digitally mature organizations may differ substantially, and this boundary condition should be considered when interpreting these results.

Artificial Intelligence in Accelerating the Halal Certification Process

Artificial Intelligence (AI) was identified as the technology with the most transformative potential in the halal certification process, a process that has long been recognized as lengthy, complex, and highly dependent on the availability of competent halal auditors. The findings of this study indicate that several digital halal certification platforms currently being developed in Indonesia have begun integrating AI capabilities to automate several stages of the certification process, ranging from the initial review of application documents, analysis of raw material compositions based on comprehensive halal databases, to risk assessment based on historical patterns.

A senior official from the Halal Product Assurance Organizing Agency (BPJPH) interviewed in this study revealed that within the Sihahal system (Halal Information System), which is currently being continuously refined by BPJPH, an AI-based module is under development to provide preliminary recommendations regarding the halal status of raw materials based on a regularly updated database. Although final decisions remain under the authority of qualified halal auditors and the Fatwa Commission of the Indonesian Ulema Council (MUI), the automation of these initial stages is projected to dramatically reduce the halal certification process time, from the current average of three to four months to approximately four to six weeks.

These findings are consistent with the study conducted by Maisaroh & Asnawi (2026), which proposed an AI-based framework for halal risk management (Maisaroh & Asnawi, 2026). However, this study provides a more concrete empirical contribution by demonstrating that AI implementation in halal certification has entered an active development stage rather than remaining merely an academic discourse. On the other hand, this study also identified concerns expressed by several senior halal auditors regarding the potential of AI to replace the judgment of Islamic scholars and Sharia experts in the halal fatwa process. These concerns reflect the tension between technological efficiency and religious authority, which must be managed very carefully within the context of halal certification. This tension is particularly

acute within Indonesia's dual-authority system, where the institutional boundary between BPJPH's administrative functions and MUI's fatwa authority means that any AI deployment must be designed to operate exclusively within BPJPH's administrative domain, with unambiguous firewall protections preventing algorithmic encroachment into MUI's normative determinations.

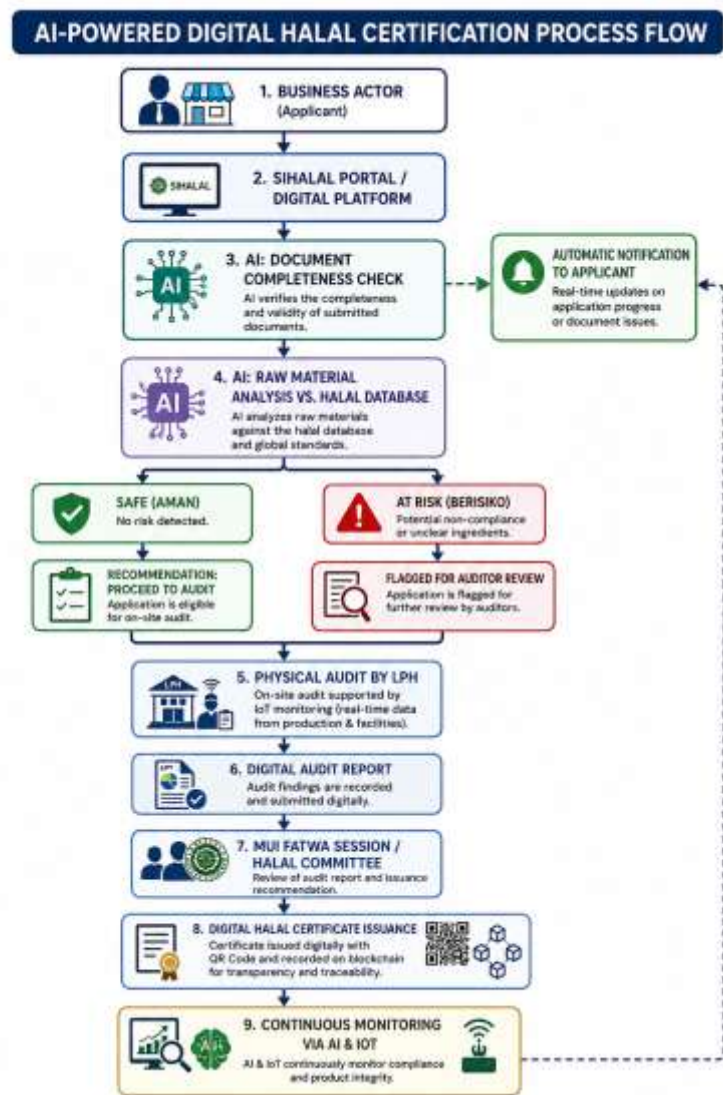


Figure 2. AI-Based Digital Halal Certification Workflow
(Source: Research findings, 2024)

[Figure 2: A fully rendered visual depicting the AI-based digital halal certification workflow, showing sequential stages from application submission through AI-assisted document review, raw material composition analysis, risk assessment, human auditor review, fatwa commission determination, and certificate issuance. To be inserted in final layout.]

Big Data Analytics and Digital Marketing in the Halal Ecosystem

This study found that the utilization of big data analytics and digital marketing has opened new dimensions in the development of the halal industry, transcending traditional geographical and demographic boundaries. Halal e-commerce platforms, such as those developed by several startups serving as informants in this research, employ large-scale data analytics algorithms to understand the consumption patterns, preferences, and purchasing behaviors of Muslim consumers with a level of precision that conventional marketing methods cannot achieve.

A founder of a halal marketplace startup interviewed in this study revealed that his platform processes more than two million data points per day to generate personalized product recommendations for each user based on purchase history, browsing behavior, geographical location, and temporal context. The system is also capable of identifying emerging halal consumption trends across various regions in Indonesia, which subsequently serve as the basis for business decisions made by halal producers partnering with the platform.

These findings offer a fresh perspective that has received limited attention in the existing halal management literature. While most previous studies have focused on the compliance aspect of halal digitalization, this research demonstrates that digital transformation also possesses a strong growth dimension, namely the ability to expand market reach, enhance consumer engagement, and create a halal ecosystem that is more dynamic and responsive to changing consumer preferences. This dimension aligns with the argument proposed by Asdar et al. (2023), who assert that the development of the Islamic economy in the digital era must harmoniously integrate Sharia compliance with business innovation (Asdar et al., 2023).

Table 3. The Impact of Digital Marketing on the Business Growth of Halal Industry Actors

Growth Indicators	Before Digital Transformation	After Digital Transformation	Growth (%)
Market reach (number of cities)	5–8 cities	50+ cities	525–900%
Monthly sales volume	IDR 850 million	IDR 4.2 billion	394%
Number of active customers	2,500 customers	38,000 customers	1,420%
Customer acquisition cost	IDR 125,000/customer	IDR 32,000/customer	-74.4%
Customer retention rate	42%	71%	69%
Time required for new product launches	3–6 months	3–6 weeks	75%

Source: Primary data processed from informants' business reports, 2024.

Barriers to Digital Transformation in the Halal Industry

Although the findings above illustrate highly significant positive impacts, this study also identifies a series of structural barriers that may hinder the acceleration of digital transformation within Indonesia's halal industry. These barriers are multidimensional and interconnected, meaning they cannot be addressed partially but instead require a holistic and coordinated approach.

The first and most frequently mentioned barrier by informants is the wide gap in digital literacy among halal industry actors, particularly micro, small, and medium enterprises (MSMEs). The majority of halal MSMEs still operate using traditional methods and do not yet possess adequate understanding of the available digital technologies, let alone how to integrate them into their business processes. This condition creates a risk of digital exclusion that may further widen the competitiveness gap between large technology-oriented companies and MSMEs that continue to lag behind.

The second barrier is the high initial investment cost required for the implementation of technologies such as blockchain and the Internet of Things (IoT). Although these technologies have proven capable of generating significant cost savings in the long term, the initial investment required often exceeds the financial capacity of small- and medium-scale industry actors. This finding is consistent with the study conducted by Widyaningrum (2018), which states that limited access to financing is one of the primary obstacles to the digitalization of halal MSMEs in Indonesia (Widyaningrum, 2018).

The third barrier is regulatory uncertainty surrounding several aspects of implementing digital technologies within the halal certification system. Although BPJPH has developed the Sihahal platform, regulations governing the legal recognition of blockchain records as evidence of halal compliance are not yet fully established. This regulatory ambiguity has made many

industry actors hesitant to invest heavily in technologies whose legal validity has not yet been fully guaranteed by regulatory authorities.

The fourth barrier concerns data security and privacy issues, which have become serious concerns, particularly regarding sensitive information related to product formulas, raw material compositions, and production processes that constitute business secrets. Several informants expressed reluctance to share production data digitally due to concerns over the potential leakage of confidential information to business competitors.

Figure 3 presents a mapping of the barriers to digital transformation in the halal industry based on the frequency with which they were mentioned by informants.

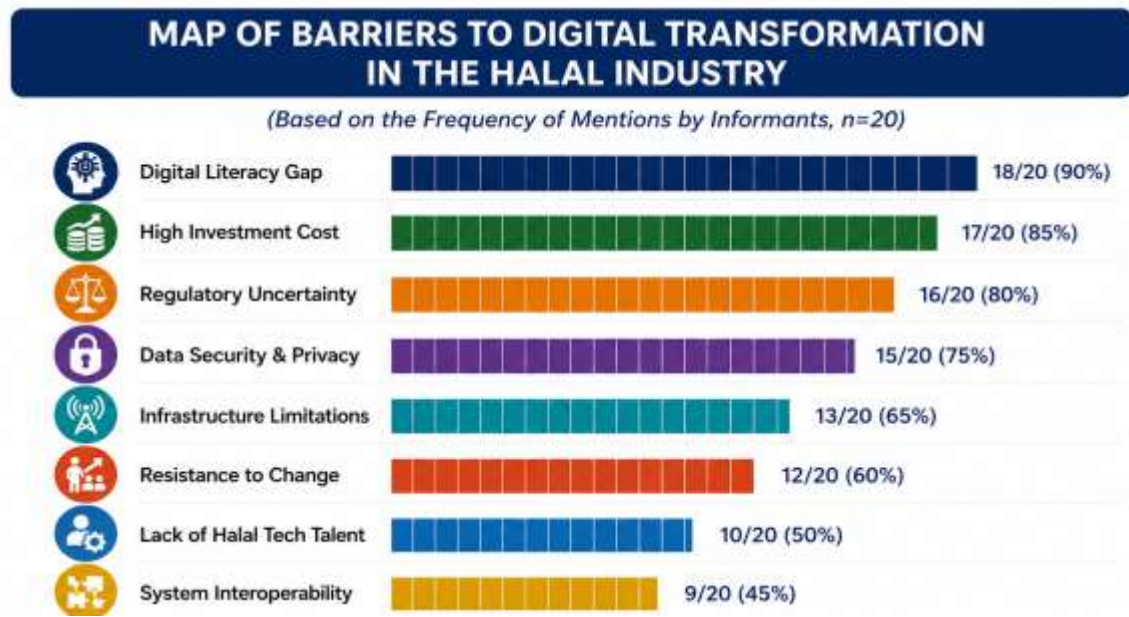


Figure 3. Map of Barriers to Digital Transformation in the Halal Industry
(Source: Primary Data, 2024)

Analysis and Implications of the Research Findings
Repositioning the Role of Technology in the Halal Paradigm: From Tool to Strategic Foundation

An in-depth analysis of the overall findings of this study reveals a highly fundamental paradigmatic shift in the way the halal industry community perceives digital technology. Whereas in previous eras technology was treated merely as an operational tool to improve the efficiency of existing processes, within the context of Halal Industry 4.0, technology has undergone a transformation in its role into a strategic foundation that determines the architecture, capabilities, and competitiveness of the entire halal ecosystem.

This paradigmatic shift carries broad and profound implications. Within the framework of strategic management, this transformation changes the logic of competition in the halal industry from one that was previously based on product superiority and physical distribution networks to one centered on data superiority, analytical capabilities, and the speed of digital innovation. Companies that are able to master and optimize their digital assets, including consumer data, proprietary AI algorithms, and integrated blockchain infrastructure, will possess a competitive advantage that is extremely difficult for competitors who have not yet undergone transformation to replicate.

These implications strongly resonate with the Dynamic Capabilities Theory developed by David Teece et al. (1997) and later expanded within the context of the digital era by David Teece (2019). According to this theory, an organization’s ability to sense, seize, and reconfigure its resources in response to rapid environmental changes constitutes the primary

determinant of sustainable competitive advantage (Teece et al., 1997) (Teece, 2019). The findings of this study indicate that, within the context of the halal industry in the Industry 4.0 era, the key dynamic capability that industry actors need to develop is the ability to integrate digital technology into halal management processes in a holistic and sustainable manner. Critically, this study finds that sensing capabilities are most visibly exercised by halal tech startups, which rapidly identify unmet market needs; seizing capabilities are most prominently demonstrated by large-scale halal manufacturers through systematic blockchain and IoT investments; and reconfiguring capabilities are most urgently needed at the regulatory level, where BPJPH must restructure existing certification workflows to accommodate AI-assisted processing without compromising MUI's fatwa authority.

Furthermore, this study finds that the role of digital technology in the halal industry extends beyond mere business efficiency. From the perspective of Islamic economics, transparency, justice, and anti-deception (anti-gharar) are fundamental principles that must be upheld in every economic transaction (Qaraḍāwī et al., 1984). Blockchain technology, with its immutable and transparent characteristics, is inherently aligned with these principles. These findings confirm the argument proposed by Yusuf al-Qaradawi that digital technology, when implemented properly, can serve as an instrument that strengthens rather than threatens Sharia values within the Islamic economic ecosystem.

Grounding the Halal Digital Transformation (HDT) Model in Empirical Findings and Dynamic Capabilities

Before examining the broader implications of this study's findings, it is necessary to explicitly demonstrate how the Halal Digital Transformation (HDT) Model proposed in this research emerges directly from the empirical data and aligns with the Dynamic Capabilities framework. The four progressive stages of the HDT Model were not deductively imposed; rather, they emerged inductively from NVivo-assisted thematic coding of interview transcripts and were subsequently validated against the organizational documentation data.

During the coding process, informants' narratives consistently clustered around four distinct experiential phases of their organizations' digital journeys. The Basic Digitization stage emerged from codes generated by MSME practitioners and early-stage company informants who described their primary digital activities as administrative record transfer, online registration, and basic reporting. The System Integration stage emerged from codes generated by mid-scale manufacturers who described the challenges and outcomes of connecting previously siloed digital systems, with Halal ERP implementation appearing as the most cited defining experience. The Intelligent Automation stage was grounded in codes generated by large manufacturers and BPJPH officials who described ongoing or completed deployments of AI-assisted certification screening, automated quality control, and machine-learning-based compliance monitoring. The Connected Ecosystem stage was articulated most consistently by halal tech startup founders, who described their vision and early-stage implementation of interoperable platforms linking all supply chain stakeholders through blockchain-based trust infrastructure.

Mapped against the Dynamic Capabilities framework (Teece et al., 1997), the Basic Digitization and System Integration stages correspond primarily to the sensing capability dimension, as organizations develop the informational infrastructure needed to perceive market signals and internal inefficiencies. The Intelligent Automation stage corresponds to the seizing capability dimension, as organizations deploy AI and automation to act decisively on identified opportunities and process bottlenecks. The Connected Ecosystem stage corresponds to the reconfiguring capability dimension, as organizations restructure their inter-organizational relationships and governance architectures in response to accumulated technological competencies. This grounding demonstrates that the HDT Model is not a conceptual imposition but a theoretically coherent representation of the phased capability development trajectories observed empirically across this study's informant organizations.

Implications for the Governance of the National Halal Certification System

The findings of this study carry highly significant implications for the reform of the governance of the national halal certification system. The current halal certification system, although significantly strengthened through the enactment of Law Number 33 of 2014 concerning Halal Product Assurance and its implementing government regulations, still faces various capacity-related challenges that hinder the effectiveness of supervision and monitoring.

Data obtained from this research indicate that the ratio of halal auditors to the number of products requiring certification remains highly disproportionate. Indonesia currently has no more than one thousand active certified halal auditors, while the number of products required to obtain halal certification is projected to exceed one million items as the expanded scope of mandatory halal certification is scheduled to be fully implemented in 2026. This dramatic capacity gap cannot possibly be bridged merely by increasing the number of human halal auditors, and this is where AI technology and digital automation become unavoidable solutions.

These findings reinforce the recommendations proposed by Faridah (2019) regarding the need for digital reform within Indonesia's halal certification system (Faridah, 2019). However, this study goes further by providing a more concrete blueprint based on empirical evidence from the field. The implementation of AI in the early stages of the certification process, combined with blockchain systems for post-certification recording and monitoring, as well as IoT for real-time supervision of production and distribution conditions, forms a halal supervision ecosystem that is far more comprehensive, efficient, and reliable than the existing conventional system.

Nevertheless, this study also finds that digital reform within the halal certification system must be carried out with great caution and must not sacrifice the religious dimension that constitutes the core of the entire system. The process of issuing halal fatwas, which involves in-depth examination of Qur'anic texts, hadith, and scholarly ijtihad, cannot and should not be fully delegated to AI algorithms. Technology must be positioned as an assistant that enhances the capacity and efficiency of auditors and Islamic scholars, rather than as a substitute that eliminates their role. This balance between technological efficiency and religious authority represents a critical point that must become a primary concern for policymakers, particularly given Indonesia's dual-authority governance structure in which BPJPH and MUI hold institutionally distinct and legally delineated responsibilities

Implications for the Development of the Halal Tech Startup Ecosystem

This study identifies the significant growth of the technology startup ecosystem operating within the halal sector (halal tech startups) as one of the most interesting and promising phenomena in the development of Indonesia's halal industry. These startups occupy a highly strategic position as a bridge between advanced technological capabilities and the specific needs of the halal ecosystem, which possesses unique characteristics and specialized regulations.

Informants from the halal tech startup category interviewed in this study revealed various innovations currently under development, ranging from AI-based image recognition applications for halal product verification that allow consumers to check the halal status of a product simply by photographing its packaging, integrated halal supply chain management platforms that combine blockchain, IoT, and AI within a unified interface, halal marketplaces utilizing Sharia-based recommendation algorithms, to digital zakat and waqf management platforms that employ blockchain-based smart contracts.

This emerging halal tech startup ecosystem possesses enormous potential; however, the study also identifies that this ecosystem faces unique challenges that differ from those encountered by startups in general. The most crucial challenge is the need for integrated

expertise combining digital technology competencies with a deep understanding of Islamic Sharia. Human resources possessing this rare combination of expertise (technology-savvy and Sharia-literate) remain extremely limited in Indonesia, and this condition has become a bottleneck hindering the scalability of the halal tech ecosystem.

These findings imply the necessity of educational curriculum reform that explicitly integrates digital technology literacy into halal management and Islamic economics study programs, while simultaneously incorporating knowledge of Islamic economics and Sharia business principles into information technology programs. Collaboration between Islamic universities and leading technological institutions in developing genuinely interdisciplinary academic programs has become highly urgent and strategic in order to build the human resource pipeline required by the Halal Industry 4.0 ecosystem.

Comparison with the Global Halal Tech Landscape

To place the findings of this study within a broader context, it is necessary to compare them with developments occurring in other countries that are also major players in the global halal industry. Malaysia, as a country that consistently ranks at the top of the Global Islamic Economy Indicator, has demonstrated more rapid progress in integrating digital technology into its halal industry.

The Malaysia Digital Economy Blueprint (MyDIGITAL), launched in 2021, explicitly includes the digitalization of the halal industry as one of its priority pillars, supported by substantial government funding and a clearer and more comprehensive regulatory framework (Akili et al., 2025). In the United Arab Emirates (UAE), halal authorities have implemented a blockchain-based halal certification system integrated with the national digital trade platform, enabling instant verification of the halal status of products by importers and consumers worldwide.

Compared to Malaysia and the United Arab Emirates, Indonesia remains at an earlier stage in the digital transformation journey of its halal industry. However, Indonesia's significantly larger market size, combined with its rapidly growing digital economy and dynamic startup ecosystem, provides equally substantial potential for becoming a global leader in Halal Industry 4.0. The key differentiating factor lies in the country's ability to establish supportive policy frameworks, adequate technological infrastructure, and a competent human resource ecosystem. Critically, both Malaysia and the UAE operate under single-authority halal governance structures, meaning their digital transformation lessons cannot be directly transplanted to Indonesia without substantial adaptation for the dual-authority BPJPH-MUI system. This structural distinction constitutes the most important boundary condition when applying internationally derived halal-digital frameworks to the Indonesian context, and it represents the primary original contribution of this study to the international halal management literature.

This comparison expands the insights of the research conducted by R. Yunus et al. (2014), which comparatively examined the development of the halal industry across various countries, by providing updated data relevant through 2024 and adding a more comprehensive dimension of digital transformation analysis (R. Yunus et al., 2025). This study finds that, unlike Malaysia, which relies heavily on strong government support as the primary driver of digital transformation within its halal industry, Indonesia demonstrates a more market-driven pattern, in which initiatives from the private sector and startups serve as the main catalysts, while government regulations tend to be adaptive and reactive to developments occurring in practice.

A Digital Transformation Model for Indonesia's Halal Industry: A Theoretical Proposition

Based on the synthesis of the overall findings of this study and their comparison with the existing literature, this research proposes a conceptual model that formulates the stages of digital transformation within the halal industry relevant to the Indonesian context. The model, referred to by the researcher as the Halal Digital Transformation (HDT) Model, consists of four progressive and continuous stages, each of which is grounded in the empirical findings described above and mapped against the Dynamic Capabilities framework as elaborated in the preceding subsection.

The first stage is Basic Digitization, in which halal industry actors begin transferring fundamental administrative processes such as registration, reporting, and record-keeping into digital formats. At this stage, the primary focus is on building digital literacy capacity and providing basic technological infrastructure. Empirically, this stage was most prominently described by MSME practitioners and early-stage halal companies among this study's informants.

The second stage is System Integration, in which various existing digital systems begin to be integrated with one another in order to create smoother information flows and reduce data redundancy. The implementation of Enterprise Resource Planning (ERP) systems customized for halal compliance requirements constitutes a defining characteristic of this stage. This stage was consistently described by mid-scale manufacturer informants who had completed initial digitization and were experiencing the challenges of data fragmentation.

The third stage is Intelligent Automation, in which AI technologies, machine learning, and robotic process automation begin to be applied to automate complex and repetitive processes, such as certification document verification, raw material content analysis, and real-time compliance monitoring. This stage was articulated by large manufacturer informants and BPJPH officials involved in the ongoing development of the Sihalal AI module.

The fourth stage is Connected Ecosystem, in which all stakeholders within the halal ecosystem, ranging from raw material suppliers, manufacturers, certification institutions, distributors, retailers, to end consumers, are connected within an integrated digital platform that operates harmoniously and interoperably, facilitated by blockchain technology as the backbone of trust. This stage was most fully described by halal tech startup founders, representing the aspirational frontier currently being pursued within Indonesia's halal digital landscape.

The HDT Model provides an original theoretical contribution by offering a phased framework that can be used by industry actors and policymakers as a guide for planning and implementing digital transformation within the halal ecosystem. The model also integrates the dimension of Sharia compliance as a constant element that remains unchanged throughout all stages of transformation, emphasizing that digitalization within the halal industry must always be grounded in principles aligned with Islamic values.

CONCLUSION

This study's principal finding is that digital transformation within Indonesia's halal industry has undergone a fundamental paradigmatic shift: technology is no longer a peripheral operational tool but has become the strategic foundation determining the competitive architecture of the entire halal ecosystem. This shift is most sharply evidenced by the convergence of blockchain-enabled supply chain traceability, AI-assisted certification processing, and IoT-based integrity monitoring, all of which were found to generate significant operational, compliance, and consumer trust improvements among the informant organizations examined.

The original theoretical contribution of this study is the Halal Digital Transformation (HDT) Model, a four-stage progressive framework (Basic Digitization, System Integration, Intelligent Automation, and Connected Ecosystem) grounded in empirical interview data, validated through NVivo thematic coding, and theoretically anchored in the Dynamic

Capabilities framework. This model offers an applicable and context-specific guide for industry actors and policymakers planning the digitalization of Indonesia's halal ecosystem in a structured and sustainable manner.

The key practical implication of this study is directed at policymakers: the impending 2026 mandatory halal certification deadline creates an operationally unsustainable auditor-to-product ratio that cannot be resolved through human resource expansion alone, making AI-assisted certification processing within the Sihalal platform an institutional priority rather than an aspirational enhancement. However, any such deployment must be constitutionally designed to preserve MUI's exclusive fatwa authority within Indonesia's dual-authority governance system, a boundary condition that distinguishes Indonesia from Malaysia and the UAE and that prior international halal-digital frameworks have not addressed.

A primary limitation of this study is that the quantitative performance metrics reported derive from a small number of organizationally advanced informant companies and are not statistically representative of the broader Indonesian halal industry. Future research employing large-scale survey methods across diverse organizational sizes and regions is needed to establish the generalizability of these findings and to test the HDT Model's stage progressions under varied institutional conditions.

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