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Industry 4.0 Adoption in Malaysian Halal Food Manufacturing: Opportunities, Challenges and Future Research for Strengthening Halal Tourism Competitiveness

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Abstract

Industrial Revolution 4.0 (IR4.0) is reshaping manufacturing systems through digital integration, automation, and real-time data analytics, with significant implications for halal food manufacturing in Malaysia. However, existing studies largely examine IR4.0 adoption in general manufacturing contexts, leaving limited integration of halal compliance requirements and the linkage to halal tourism competitiveness. This review paper aims to synthesize literature on IR4.0 adoption in Malaysian halal food manufacturing by identifying opportunities, challenges, and future research directions, while explicitly connecting these insights to halal tourism development. Using a structured narrative literature review approach, relevant theoretical and empirical studies were analyzed and categorized based on opportunities, barriers, and research gaps. The review highlights opportunities in digital traceability, smart monitoring, productivity enhancement, and tourism-linked trust building, alongside challenges related to cost, legacy integration, workforce readiness, compliance complexity, and policy awareness. Future research should focus on halal-centered digital

architectures, longitudinal adoption pathways, policy effectiveness, and tourism-driven environmental pressures.
Keywords: Industry 4.0, Adoption, Halal, Food, Manufacturers

Introduction

The Fourth Industrial Revolution (IR4.0) has emerged as a defining force shaping modern industrial development, particularly in manufacturing-driven economies. Broadly, IR4.0 refers to the digital transformation of manufacturing systems through the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, cloud computing, autonomous robots, simulation, augmented reality, system integration, and cybersecurity (Gilchrist, 2016; Pech and Vrchota, 2020). Unlike earlier waves of automation, these technologies do more than replace manual labor—they enable machines, systems, and processes to communicate and operate as interconnected networks. This connectivity allows manufacturers to monitor operations in real time, predict equipment failures, respond quickly to market changes, and improve overall efficiency. As a result, IR4.0 is widely recognized as a pathway to higher productivity, improved operational performance, and enhanced competitiveness at both firm and national levels (Sima et al., 2020; Manda and Dhaou, 2019). Recognizing these opportunities, many countries have introduced national strategies to accelerate IR4.0 adoption. In Malaysia, this transformation is particularly important because manufacturing remains a key pillar of the national economy and contributes significantly to gross domestic product (Ling et al., 2020). However, despite strong policy ambitions, the pace of adoption remains uneven. While some large firms have begun integrating advanced technologies, many small and medium-sized enterprises (SMEs) continue to rely on conventional production methods and legacy systems (Dalenogare et al., 2018; Hamim et al., 2021). To address this gap, the Malaysian government launched initiatives such as Industry4WRD and the Industry4WRD Adoption Assessment to support digital transformation through funding, readiness assessments, and capacity-building programs (MITI, 2019). Nevertheless, awareness, readiness, and implementation levels remain limited, indicating that the transition to IR4.0 is still ongoing.

Within Malaysia's manufacturing sector, halal food manufacturing represents a particularly important and unique segment. Beyond its economic contribution, halal manufacturing carries religious, ethical, and quality responsibilities that directly influence consumer trust. Producing halal food involves more than meeting technical production standards; it requires strict compliance with halal principles, including careful control of raw materials, hygiene, segregation, documentation, certification, and traceability throughout the supply chain. These requirements make transparency and process integrity essential, especially as halal products increasingly serve not only local consumers but also international markets.

This connection becomes even more significant when viewed in the context of halal tourism, which is one of the fastest-growing segments of the global tourism industry. Muslim travelers today place high importance on the availability, reliability, and credibility of halal food when choosing travel destinations. For Malaysia, halal tourism plays a strategic role in strengthening its reputation as a global halal hub and a Muslim-friendly destination. However, maintaining competitiveness in halal tourism depends not only on branding and promotion but also on the ability to provide trustworthy halal food systems. Tourists are more likely to

trust destinations where halal food can be verified through transparent certification, consistent quality control, and reliable traceability mechanisms.

In this regard, IR4.0 technologies offer significant potential to strengthen halal food manufacturing and, by extension, halal tourism ecosystems. For example, blockchain technology can enhance traceability and ensure the integrity of halal certification records, IoT sensors can monitor temperature and hygiene conditions in real time, and big data analytics can help manufacturers manage demand fluctuations associated with tourism while maintaining product quality (Chandra et al., 2019; Galati and Bigliardi, 2019). Through these applications, digital transformation can support not only operational efficiency but also the credibility and reliability of halal assurance systems.

Despite these potential benefits, the adoption of IR4.0 in halal food manufacturing remains challenging. Many firms face financial constraints, technological integration difficulties, workforce readiness issues, and organizational resistance to change (McKinsey, 2020; Musofiana et al., 2021). Furthermore, while existing studies have examined IR4.0 adoption in general manufacturing, limited attention has been given to its role in halal food manufacturing and its broader implications for halal tourism development. This gap highlights the need for a comprehensive review that brings together existing knowledge, identifies key challenges and opportunities, and provides direction for future research.

Research Gap

Although IR4.0 adoption has been widely discussed in manufacturing literature, several gaps remain clear when the focus shifts to halal food manufacturing in Malaysia and its relationship with halal tourism. First, many IR4.0 adoption studies treat manufacturing firms as technologically similar, but halal food manufacturers face an additional and non-negotiable layer: halal compliance and certification integrity. Technology adoption in this context must align with religious requirements and certification systems, which is not always addressed explicitly in general IR4.0 models (Musofiana et al., 2021). Second, existing discussions often emphasize technological potential (automation, IoT, analytics) without sufficiently explaining how halal-specific requirements—such as segregation, ingredient verification, audit documentation, and traceability—shape the feasibility and design of IR4.0 systems. This is particularly important for trust-building in halal tourism, where tourists may base consumption decisions on perceived reliability and transparency.

Third, adoption barriers are frequently listed (cost, skills, legacy systems), but fewer studies explain the *mechanisms* of why these barriers are especially severe for halal food SMEs. For example, a conventional manufacturer may adopt automation without needing to align new systems with halal audit trails, whereas halal manufacturers may need digital systems that prove compliance continuously, not only at inspection points (Chandra et al., 2019). Fourth, research rarely connects IR4.0 adoption in halal manufacturing to tourism competitiveness outcomes. Halal tourism depends on the destination's ability to deliver reliable halal food services across hotels, attractions, airports, and retail networks. Manufacturing modernization could strengthen this ecosystem, but the literature is still thin in linking upstream production digitalization with downstream tourism trust and destination reputation. Finally, policy implementation gaps (such as limited awareness of Industry4WRD channels and confusion around support agencies) suggest the need for more research on

governance, institutional coordination, and adoption ecosystems (MITI, 2019). The central objective of this review paper is to synthesize and analyze existing literature on IR4.0 adoption in Malaysian halal food manufacturing by exploring (i) opportunities created by IR4.0 technologies, (ii) challenges that hinder adoption and implementation, and (iii) future research directions—while explicitly relating these insights to the requirements and competitiveness of halal tourism.

Literature Review

R4.0 and Halal Food Manufacturing: Concepts and Context

IR4.0 is widely described as the digital transformation of manufacturing, enabling smart production systems that are automated, connected, and data-driven (Schwab, 2016; Nagy et al., 2018; Zhou et al., 2015). The value of IR4.0 lies in its ability to connect machines, people, processes, and supply chains so that decisions can be optimized continuously. Big data analytics supports strategic decision-making, cloud computing enables scalable IT services, cybersecurity protects sensitive data, and IoT supports real-time monitoring of operations (Alcácer and Cruz-Machado, 2019; Kleindienst and Ramsauer, 2016). These capabilities can translate into improved visibility, product customization, dynamic design, and real-time analytics (Bahrin et al., 2016; Dalenogare et al., 2018).

For halal food manufacturing, these features are especially meaningful because halal integrity depends on process transparency, traceability, and continuous control. Unlike many other food segments, halal food must meet compliance standards that involve religious, ethical, and procedural requirements. Therefore, the "quality" of halal products includes not only taste and safety but also compliance credibility. This intersects strongly with halal tourism. Muslim travelers often choose destinations that reduce uncertainty about food authenticity. If halal supply chains are digitally verifiable, the destination's halal tourism offering becomes stronger, not only because halal food is available, but because it is *trusted*.

Yet Malaysia's adoption level remains uneven. Many SMEs are still at early stages of digitalization and may only have basic ICT capabilities, while advanced IR4.0 elements remain limited (Dalenogare et al., 2018). This gap matters because halal tourism growth requires scalable and consistent halal supply—across regions, seasons, and service providers. If upstream manufacturing does not modernize, downstream tourism services may face supply inconsistencies, cost pressures, or difficulty assuring tourists of halal integrity.

Theory-Based Foundation

A strong theoretical lens is essential for explaining why some halal food manufacturers adopt IR4.0 while others remain behind. The Technology–Organization–Environment (TOE) framework developed by Tornatzky et al. (1990) is one of the most widely used models for analyzing organizational innovation adoption because it captures the multi-dimensional nature of technology decisions. TOE proposes that adoption is influenced by (1) technological context (the characteristics of the technology and its perceived value), (2) organizational context (internal capabilities, resources, and leadership support), and (3) environmental context (external pressures such as competition and regulation).

The TOE framework is particularly suitable for halal food manufacturing because adoption decisions are rarely driven by technology alone. In the technological context, firms evaluate

whether IR4.0 offers a relative advantage and whether it is compatible with existing production systems and compliance routines (Rogers, 2003; Gibbs et al., 2007). Relative advantage is critical because halal manufacturers must justify investment not only in productivity terms but also in compliance integrity and market trust (Baker, 2012; Nimfa et al., 2020). Compatibility becomes even more complex in halal settings because IR4.0 technologies must align with legacy machinery and established halal procedures; if not, adoption may require expensive process redesign and workforce retraining (Leonard-Barton, 1988; Kamble et al., 2018).

Organizational factors are equally decisive. Organizational readiness refers to the firm's ability and willingness to assess, plan, implement, and manage technology adoption, including IT capabilities and specialized knowledge (Haddad et al., 2018; Senarathna et al., 2018). For halal manufacturers, readiness also includes competence in aligning digital systems with halal audit requirements. Top management support is often the "activation switch" that determines whether digital transformation moves beyond intention into execution (Barham et al., 2020). Without leadership commitment, firms may adopt fragmented tools that do not scale into full IR4.0 systems.

Environmental factors strongly shape halal manufacturing adoption. Competitive pressure encourages digitalization when competitors adopt smart systems or when customers demand traceability (Hussain et al., 2020). Government regulations and policies can both push and support adoption through subsidies, tax incentives, and national initiatives (Liang et al., 2007; Li, 2018; Zhang et al., 2018). In Malaysia, Industry4WRD represents a key environmental driver, but limited awareness reduces its impact (MITI, 2019).

Importantly, TOE can also be extended conceptually to halal tourism. Tourists and tourism operators (hotels, airlines, restaurants) represent downstream market pressure for credible halal supplies. Therefore, halal tourism demand can be viewed as an environmental force influencing manufacturers' technology adoption decisions—especially when destination branding relies on trust and transparency.

Opportunities of IR4.0 Adoption for Halal Food Manufacturing

IR4.0 adoption creates opportunities that are not only operational but also strategic for halal tourism competitiveness. One major opportunity is the strengthening of halal assurance through real-time monitoring and digital traceability. IoT sensors can monitor critical parameters such as temperature, hygiene conditions, and equipment status, reducing contamination risk and supporting consistent compliance. This strengthens consumer confidence and is particularly valuable for halal tourism, where visitors need reliable halal food access across travel locations and service points.

A second opportunity lies in advanced traceability and documentation. Technologies such as blockchain and integrated data platforms can record ingredient sourcing, certification status, and process logs in ways that reduce fraud risk and improve audit readiness (Chandra et al., 2019). For halal tourism, traceability is a "trust amplifier." A destination that can demonstrate credible halal supply chains may attract more Muslim travelers and strengthen repeat visitation because tourists feel lower uncertainty when consuming local products.

Third, IR4.0 enables productivity and cost improvements through automation and process optimization (Balakrishnan et al., 2021). When halal manufacturers reduce waste and improve efficiency, they can potentially supply tourism markets more consistently and competitively—especially during peak travel seasons where demand spikes. Big data analytics can support demand planning and forecasting, helping manufacturers align production volumes with tourism cycles while maintaining quality (Alcácer and Cruz-Machado, 2019).

Fourth, IR4.0 supports innovation and customization. Halal tourism markets are diverse, involving travelers from different countries with varied preferences. Smart manufacturing supports flexible production and faster product development, allowing halal manufacturers to tailor packaging, portion sizes, or product variants for tourism retail environments such as airports and hotels (Ghadge et al., 2020).

Finally, supportive policies can reduce adoption burdens. Government programs such as Industry4WRD Adoption Assessment can provide structured readiness evaluation and subsidies, potentially accelerating adoption (MITI, 2019). If policy support becomes more visible and coordinated, it could strengthen Malaysia's halal manufacturing capacity and indirectly support halal tourism growth by enhancing product integrity and supply chain trust.

Table 1
Opportunities and Supporting References

Opportunities	References
Automation and efficiency improvements that stabilize supply during tourism peaks	Balakrishnan et al., 2021; Sima et al., 2020
Digital traceability and stronger halal assurance that improves tourist trust	Chandra et al., 2019; Galati & Bigliardi, 2019
Smart monitoring (IoT) supporting hygiene and compliance credibility	Alcácer and Cruz-Machado, 2019; Pech and Vrchota, 2020
Real-time analytics improving demand forecasting linked to tourism seasonality	Ghadge et al., 2020; Dalenogare et al., 2018
Policy programs and subsidies supporting adoption acceleration	MITI, 2019

Challenges of IR4.0 Adoption

Although IR4.0 offers compelling advantages, halal food manufacturers—especially SMEs—face challenges that are structural, capability-based, and compliance-specific. These challenges are not simply "barriers," but interconnected constraints that explain why adoption often remains partial or delayed.

A central challenge is financial feasibility, not only because IR4.0 technologies are expensive, but because halal manufacturers must often invest in *additional compliance-aligned systems* beyond standard automation. For example, the cost of adopting advanced digital systems can be prohibitive for SMEs (McKinsey, 2020). Yet in halal contexts, investment may also need to cover traceability platforms, documentation systems, and audit-ready infrastructure, increasing perceived risk. Many SMEs operate on tight margins and cannot absorb high upfront costs, particularly when the return on investment is uncertain or long-term. This is

why financial limitations are often amplified in halal food manufacturing compared to other manufacturing segments (Galati & Bigliardi, 2019).

A second challenge is integration with legacy systems, which is a practical technical problem with strategic consequences. Many halal manufacturers use older equipment that is not designed to interface with IoT devices, data platforms, or automated control systems (McKinsey, 2020). Integration failures can lead to production disruptions, data gaps, and inconsistent process control—issues that directly threaten halal compliance because compliance credibility depends on consistent documentation and controlled processes. When a firm cannot integrate new systems smoothly, it may face downtime, increased errors, and fragmented data, which discourages deeper adoption and keeps firms stuck in partial digitalization (Galati & Bigliardi, 2019).

Third, workforce capability constraints explain why adoption may fail even when technologies are purchased. IR4.0 systems require employees who can interpret data dashboards, manage digital workflows, maintain automated equipment, and respond to system alerts. Research highlights the need for continuous learning programs tailored to workforce needs (Chandra et al., 2019). In halal manufacturing, workforce training must also embed halal compliance understanding so that technology use does not inadvertently violate halal procedures. Without this dual competence—technical plus halal compliance—employees may resist new systems, use them incorrectly, or revert to manual workarounds, reducing adoption effectiveness.

Fourth, organizational resistance and cultural inertia often emerge because IR4.0 changes job roles, workflows, accountability systems, and decision-making authority. Traditional halal manufacturers may worry that new technologies disrupt established practices that have "worked" for years, especially when these practices are deeply tied to halal integrity and company identity (Musofiana et al., 2021). Resistance grows when staff fear job displacement from automation, when leaders doubt ROI, or when the organization lacks a structured change management approach. This is why top management support becomes decisive—without leadership commitment, IR4.0 adoption remains fragmented or symbolic (Barham et al., 2020).

Fifth, halal compliance complexity creates a unique challenge that standard IR4.0 adoption literature often underestimates. Halal certification requires traceability, documentation, segregation, and assurance mechanisms. Digital systems must be aligned with certification requirements and audit processes, which can be costly and technically complex (Chandra et al., 2019). Manufacturers may hesitate because any compliance failure can damage brand trust and threaten certification status. This fear of unintended non-compliance can cause firms to delay adoption, adopt slowly, or require extensive validation before implementing new systems—making adoption cycles longer and more expensive than in non-halal sectors.
Finally, institutional and policy awareness gaps reduce adoption momentum. Even when government programs exist, manufacturers may not know how to access them, may be confused by multiple agencies, or may not understand eligibility pathways. Evidence indicates that many manufacturing firms lacked awareness of Industry4WRD Adoption Assessment and related support channels (MITI, 2019). This matters because SMEs often depend on external support to reduce financial and technical burdens. If support is not visible and easy to

navigate, adoption becomes a private struggle rather than an ecosystem-driven transformation.

From a halal tourism perspective, these challenges matter because weaknesses in upstream manufacturing trust systems can affect downstream tourism confidence. If traceability remains manual, if compliance documentation is inconsistent, or if product integrity scandals occur, tourist trust can decline, directly harming Malaysia's halal tourism brand. Thus, addressing adoption challenges is not only an industrial policy issue but also a destination competitiveness issue.

Table 2
Challenges and Supporting References

Challenges	References
High cost of digital systems and investment burden for SMEs	McKinsey, 2020; Galati & Bigliardi, 2019
Legacy system integration complexity causing disruption and data fragmentation	McKinsey, 2020; Galati & Bigliardi, 2019
Skills shortages and training needs for IR4.0 + halal compliance alignment	Chandra et al., 2019
Organizational resistance and need for innovation culture	Musofiana et al., 2021; Barham et al., 2020
Low awareness and confusion about policy support channels	MITI, 2019

Future Research Directions

Future research should move beyond general adoption discussions and develop deeper halal-specific and tourism-linked insights. One essential direction is halal-compliance-centered digital architecture research. Studies should examine how IR4.0 technologies can be designed to embed halal compliance requirements into system logic. For example, research can explore how blockchain traceability frameworks can map halal certification checkpoints, how IoT-based monitoring can validate segregation and hygiene requirements, and how digital audit trails can be standardized to align with certification authorities (Chandra et al., 2019). This line of research matters because halal integrity is not an optional feature—it is the foundation of market trust and tourism confidence.

Second, longitudinal adoption research is needed to understand how firms evolve from awareness to partial adoption to full integration, and what performance outcomes appear over time. Many firms do not fail because they reject technology outright; they stall during implementation due to cost overruns, skill limitations, or integration difficulties (Sima et al., 2020; Galati & Bigliardi, 2019). Longitudinal studies could identify adoption pathways, stages, and tipping points. This would help policymakers design support that targets the specific stage where SMEs typically stall, rather than offering general incentives that do not address bottlenecks.

Third, future research should expand the TOE framework in halal contexts by examining how halal tourism demand acts as an environmental pressure. Competitive pressure is commonly studied in manufacturing adoption (Hussain et al., 2020), but halal tourism creates a distinctive type of pressure: destinations must provide reliable halal food ecosystems, and

tourism operators may demand stronger assurance from suppliers. Research could investigate how hotels, airlines, airports, and tourism retailers influence manufacturers' adoption decisions. This would create a more integrated view of halal value chains—from production to visitor consumption—and clarify how digital transformation upstream strengthens destination branding downstream.

Fourth, research should examine policy effectiveness and governance coordination, especially in contexts where adoption support exists but awareness and uptake remain low (MITI, 2019). Studies could explore why SMEs are unaware of programs, how institutional fragmentation affects adoption, and which communication or subsidy mechanisms are most effective. This is particularly important because SME transformation typically requires coordinated ecosystem support, including training, finance, technical advisory, and compliance guidance.

Fifth, there is a need for research on human capital and hybrid skill development. Halal food manufacturing requires employees who understand both digital systems and halal compliance logic. Future research can evaluate what training models work best (industry-led, government-supported, university partnership), how to reduce skill gaps, and how to build leadership capabilities for digital transformation (Chandra et al., 2019; Barham et al., 2020).
Finally, future research should examine risk, cybersecurity, and trust in halal digital ecosystems. As data becomes central to compliance and traceability, cybersecurity becomes a halal integrity issue, not only an IT issue. If traceability data is manipulated or systems are compromised, consumer trust and tourism reputation can be harmed. Research should therefore analyze cybersecurity readiness and governance mechanisms in halal manufacturing adoption (Alcácer and Cruz-Machado, 2019).

Table 3
Future Research Directions and Supporting References

Future Research Directions	References
Digital halal compliance systems (traceability, audit trails, monitoring)	Chandra et al., 2019; Galati & Bigliardi, 2019
Longitudinal adoption pathways and post-adoption outcomes	Sima et al., 2020
TOE extensions: halal tourism as environmental pressure influencing adoption	Tornatzky et al., 1990; Hussain et al., 2020
Policy effectiveness, awareness, and institutional coordination	MITI, 2019; Liang et al., 2007
Hybrid workforce skills: digital + halal compliance capabilities	Chandra et al., 2019; Barham et al., 2020

Conclusion

This review paper highlights that IR4.0 adoption in Malaysian halal food manufacturing offers opportunities that extend beyond factory efficiency into the credibility and competitiveness of halal tourism. Smart manufacturing can strengthen halal assurance, transparency, and traceability—features that directly shape tourist trust and destination branding. However, adoption is constrained by financial limitations, legacy integration barriers, workforce readiness challenges, organizational resistance, and compliance complexity, compounded by limited awareness of policy support. Future research should deepen halal-specific adoption

theory, examine tourism-linked environmental pressures, evaluate policy ecosystems, and develop practical models that integrate IR4.0 technologies with halal certification integrity. By addressing these areas, Malaysia can strengthen its halal manufacturing ecosystem and reinforce its position as a leading halal tourism destination supported by trusted, modern, and transparent halal supply chains.

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