

# Leveraging Digital Twin Technology to Enhance Transparency, Traceability, and Compliance in Halal Supply Chains

\*Anas Afandi Ahmad Apandi<sup>1</sup>, Irwan Ibrahim<sup>2</sup>

<sup>1</sup>Lecturer, School of Economics and Management, Xiamen University Malaysia, Sepang, Selangor, Malaysia

<sup>2</sup>Associate Fellow, Malaysia Institute of Transport, Universiti Teknologi MARA, Malaysia. Department of Technology and Supply Chain Management Studies, Faculty of Business and Management, UiTM Puncak Alam, Selangor, Malaysia

\*Corresponding Author

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## ABSTRACT

The Halal supply chain, which encompasses the sectors of food, medicines, cosmetics, has enormous challenges to comply with Islamic rules, maintain product traceability and combating fraud. Given the increasing global demand for Halal products, the demand for technology innovations to enhance supply chain transparency and ensure Halal compliance is growing. This paper explores the application of Digital Twin (DT) technology in Halal supply chain management, highlighting its ability to address these challenges. The main research question of this paper is as follows: How can Digital Twin technology facilitate transparency, traceability, and compliance in the Halal supply chains? The current study employs a qualitative methodology through a review of the extant literature and reviews of industrial case studies. The study reveals that the Digital Twin technology promises to considerably improve the operational excellence of Halal supply chains through real-time Halal status monitoring ensuring that products comply with religious and ethical requirements along the supply chain. The main applications include tracking Halal certification, preventing cross-contamination, and enhancing transparency for certification bodies, manufacturers, and consumers. The results indicate that Digital Twin technology has the potential to transform Halal supply chains by reducing fraud, improving operational efficiencies, and building consumer trust. As a comprehensive Halal compliance solution, Digital Twin can enable a more transparent and trustworthy Halal certification process on a global scale. The study extends the knowledge body on technology innovations in supply chain management especially with religious and ethical product certifications and sets the stage for future research in the area.

**Keywords:** Halal supply chain management, digital twin, halal certification, transparency, reducing fraud

## INTRODUCTION

Halal supply chain is a system of production related to the manufacturing, processing, distributing or retail of products sold as Halal according to Islamic law. These standards govern not just food and beverage, but also pharmaceuticals, cosmetics, textiles and financial services. In short, Halal products need to comply with very strict standards regarding the industry of the ingredients, the way they are processed and the ethical values, ensuring that they do not contain any of the forbidden ingredients like pork, alcohol, or any other non-Halal additives. With 1.9 billion Muslims around the world, Halal products have made it an integral part of international trade, so much that it has grown into a \$2.3 trillion industry per year (Dinar Standard, 2023). The global need of Halal certified goods is not limited just by Muslims dominated regions but to its applied globally secondary to increased consciousness and urge of effective and sustainable consumption.

However, the Halal business faces significant operational and legal challenges, especially in demonstrating compliance with Halal standards across a globalised supply chain. As products move through ever-dissolving

supply chains — from raw material providers to processing plants, shipping channels and retail businesses — the opportunities for contamination, fraud or non-compliance rises. This is particularly relevant in industries like food production, where the credibility of Halal certification can be compromised by cross-contamination with non-Halal products, improper handling while in transit or intentional mislabelling (Hasan et al., 2023). Without adequate traceability systems, ensuring that a product remains compliant through its lifecycle is difficult.

One of the main challenges in Halal supply chain management is the lack of transparency and traceability. With traditional supply chains, the ability to track a product's origin and handling is often limited to paper trails or disconnected digital systems, which are vulnerable to error, delay and even manipulation. Within Halal, these errors can lead to a serious lapse in adherence, customer distrust, and financial repercussions. Halal certification organisations and regulatory bodies often rely on audits that are intermittent, which reduces real-time supervision of the supply chain some concerning consequences in terms of compliance monitoring, reducing enforcement effectiveness.

This research is motivated by the increasing need for more efficient, transparent, and reliable solutions to address the problems in Halal Supply Chain Environments. While solutions like blockchain and RFID tracking have been explored to some extent, Digital Twin technology provides a more comprehensive, iterative solution. A Digital Twin—a virtual duplicate of a physical system—offers real-time monitoring, predictive analytics, and scenario simulations to ensure that Halal supply chains are compliant and maximised for operational efficiency, Digital Twin technology provides a holistic digital replica of the entire supply chain from source to customer which tackles major issues like traceability, fraudulent activities and compliance and helps make proactive decisions to mitigate the risks.

This paper aims to explore the potential use of Digital Twin technology to address the challenges of Halal supply chains thereby enhancing transparency, compliance, and overall efficiency in satisfying regulatory requirements and consumer demand. This study contributes to both the theoretical understanding of the role of technology in Halal supply chain management and the existing literature on how new technologies may be used to ensure supply chain integrity in contexts with complex religious and ethical requirements.

## **Problem Statement**

The global halal industry faces increasing demands for transparency, traceability, and compliance with strict religious and legal standards across its supply chains. Despite advances in systems for managing supply chains, halal supply chains still face challenges, such as limited visibility, lack of real-time monitoring, and difficulties in monitoring compliance with halal standards. Traditional supply chain systems often cannot provide accurate, real-time information about product status, which makes it challenging for companies to comply with halal certification requirements and meet customer's authenticity needs.

The Digital Twin (DT) technology which creates real-time digital replicas of physical assets, processes and systems has been successfully utilized in various industries to enable visibility and operational efficiency. However, its ability to fulfill the specific needs of halal supply chains is still insufficiently investigated. This paper aims to explore the application of Digital Twin technology to improve transparency, traceability, and compliance in halal supply chains. This research helps in understanding the integration of digital transformation in halal supply chains, proposing a framework to enhance operations whilst emphasizing halal compliance.

## **Research Objectives**

This study examines the application of Digital Twin (DT) technology to enhance transparency, traceability, and compliance in halal supply chains. This research specifically seeks to explore how the use of digital technology could potentially address gaps surrounding the verification of halal certification, the real-time tracking of supply chain activities, and the consistent observance of halal protocols. The purpose of the study is to provide a framework for digital transformation in halal supply chains and useful insights to industries on how to use technology for improved operational efficiency and compliance.

## Research Questions

1. How Digital Twin Technology can improve transparency in halal supply chains? Why use digital technology for real-time monitoring and visibility throughout the halal supply chain?
2. What is the role of Digital Twin technology in ensuring compliance with halal certification standards in supply chains? How can DT ensure real-time monitoring for maintaining the halal integrity, from the point of sourcing all the way to the delivery, and allow the verification of the halal certification at every stage?
3. What are the challenges and barriers to implementing Digital Twin technology in halal supply chains? What are the technological, organisational and regulatory issues that need to be addressed for the effective integration of digital technologies into halal supply chains?
4. What is the impact of Digital Twin Technology on the Operations and Performance of Halal Supply Chains? How does digital twin technology enhance decision making and enable operational efficiencies like inventory management, logistics, and quality control?
5. What does using Digital Twin technology mean for consumer trust and market competitiveness of halal sector? How does Digital Twin technology influence consumer confidence in the authenticity and compliance of halal products?

## Significant of the Research

With the rapid growth of the digital world and the global demand for halal goods, this study is critical. However, with the growth in the halal industry, driven by a diverse set of customers who expect authenticity and conformance to religious practices, the challenges of sourcing halal components and preserving transparency in halal supply chains is becoming more pronounced. Halal supply-chains are complex and often involve multiple stakeholders in multiple geographies with legislatively different mandates and certification processes. In the absence of comprehensive traceability and real-time data on product status, vulnerabilities are created, particularly in verifying halal certification and compliance with ethical sourcing criteria.

Digital Twin (DT) technology, which allows to create digital clones of physical processes and products, provides a disruptive solution to these challenges. This research aims to understand in detail how the integration of digital technology in halal supply chains can enhance transparency, improve compliance to halal certification standards, and complement customer trust. Digital technology can track all the steps involved in the product lifecycle, from the source of raw materials to end-point delivery, providing unprecedented visibility into this process, and potentially reducing fraud, mislabeling, and illegal activity.

Because it links sophisticated digital solutions with the stakeholders' unique halal supply chains, this study is significant. It explores how technical advancements like digital transformation can improve operational efficiency and provide a competitive edge to companies committed to upholding high ethical and regulatory standards. This research will contribute to the wider debate about how emerging technologies could improve openness and accountability in global supply chains, with particular relevance for niche markets such as halal food, cosmetics, and medicines.

## LITERATURE REVIEW: CURRENT STATUS OF HALAL SUPPLY CHAIN

Halal Supply Chain (HSC) refers to the interconnected processes and entities involved in the production, processing and distribution of products that fit with Islamic dietary and ethical laws. Halal certification, traceability, fraud prevention, and quality assurance are the key concerns of this field because it is important to maintain the integrity or originality of halal products. However, there are a plethora of significant challenges facing the halal supply chain, notably certification issues, lack of transparency and traceability, fraud and mislabelling, and consistent quality assurance across all stages of the supply chain.

### Challenges in Halal certification

From obtaining raw materials to processing, packaging, and distribution, halal supply chain management helps to ensure that the final product adheres to Islamic dietary law and ethical values, with halal certification

playing a key role in this process. Halal certification flow is often complex and fragmented, with different standards and regulations in different countries and certifying bodies. According to researchers, the absence of a standardised global halal certification creates challenges for manufacturers and suppliers in the face of multiple regulations (Rezapour et al., 2021). In addition, inconsistent application of certification standards in different markets might lead to variations in certification quality, which could erode consumer confidence (Khan et al., 2020).

In particular, various quantitative studies have focused on the challenges of maintaining halal certification from farm to fork, particularly in multiparty supply chains where monitoring of each stage in the chain can often lack coordination (Sulaiman et al., 2019). Halal products undergo several processing stages and are transported across borders, making ongoing compliance difficult without a full compliance monitoring system. Without management and oversight, the risk of adulteration or contamination is increased, which could have substantial reputation and financial implications for businesses.

### **Traceability and Transparency**

Traceability is necessary to ensure halal authenticity and reduce fraud. Conventional supply chain management systems fail to provide real-time visibility of where products come from and how they are produced (Sudarsono et al., 2020). This makes it difficult for halal producers and retailers to guarantee the integrity of their products, especially when raw materials can come from a number of suppliers or when products may be subject to different stages of processing. A major contributor of achieving halal compliance is the absence of a reliable, online and end-to-end traceability system along the halal supply chain (Farrukh et al., 2021).

Studies have explored technological advancements, specifically in blockchain and the Internet of Things (IoT), as solutions in improving traceability (Zailani et al., 2020). These technologies allow making products visible across the supply chain and provide accurate and transparent information on the origins and management of raw materials, as well as on the manufacturing, storage, and distribution of the final product. Nonetheless, the broad adoption of these technologies is limited by high implementation costs and lack of interoperability among multiple systems, even though they have the potential to improve halal supply chains.

### **Fraud and Misrepresentation**

For producers and consumers alike, halal supply chain fraud and mislabelling present large problems. The complexity of the halal certification system and the potential for financial gain through dishonesty has led to cases of falsification, where non-halal products are marketed as halal (Abd Rahman et al., 2021). This problem is particularly pervasive in markets that are weak in regulatory supervision or in which halal consumers do not understand halal certifiers. Ali et al. (2021) carried out research (2022) and Zawawi et al. (2021) highlights incidents of products, including meat, beverage and cosmetics being misleadingly labelled or contaminated with non-halal substances, undermining consumer confidence and halal certification system process.

The issue of halal fraud underlines the need for more rigorous processes to verify halal claims, using new technologies that guarantee transparency and allow for real-time monitoring across the supply chain. According to researchers, the lack of sufficient traceability systems combined with reliable certification procedures makes companies more susceptible to fraud, threatening customer health and safety while also damaging the broader halal business (Alam et al., 2020).

### **Quality Assurance**

Ensuring consistency of quality assurance across the halal supply chain is a significant hurdle. In this respect, quality assurance in halal supply chains goes beyond the mere compliance with religious dietary laws but also guarantees that the halal products meet required safety, quality, and sanitation standards. Ehsani et al. (2022) point out that an integrated approach to simultaneously manage the quality assurance system (which usually goes hand in hand with halal food production) and halal requirements is not available in practice. This decoupling can create uneven product quality and a lack of halal accreditation.

Moreover, global supply chains and cross-border trading can challenge the halal integrity of food from farm to table because of variations in production processes, storage conditions and distribution systems (Ismail et al., 2021). This involves a need for more integrated and automated quality management systems so that halal compliance and product quality can be assured through continuous supervision.

### **Innovation in Technology within Halal Supply Chains**

Various problems have been explored being addressed by technological solutions, particularly through digital tools such as Digital Twin Technology. Digital Twin technology that enables creating real-time digital copies of physical operations may be used to enhance traceability, monitor halal compliance, and enhance operational efficiencies (Ahmad et al., 2022). The use of Digital Twin technology can boost transparency by tracking product flow across every stage of the supply chain, ensuring compliance to halal stipulations and providing stakeholders with reliable information to validate halal certification.

Despite the potential benefits, the integration of these technologies within halal supply chains is still embryonic. Many companies in the halal industry face challenges such as high implementation costs, inadequate digital infrastructure, and unwillingness to adopt (Farrukh et al., 2021). Therefore, although some digital solutions show promise, further research is still needed to understand how they can be effectively applied to the unique environment of halal supply chains.

Halal supply chain management is faced with multifaceted obstacles in terms of certification issues, traceability, fraud, and quality assurance deals in the present situation. Such issues undermine the ability of businesses to ensure product authenticity and maintain customer trust. While technical solutions such as blockchain and Digital Twin technology are promising approaches to address these challenges, their widespread adoption is limited by cost, technical limitations, and sector resistance. Further research is needed to explore how these technologies can be effectively integrated into halal supply chains to facilitate transparency, ensure compliance, and enhance operational efficiency.

### **How Digital Twin Technology Can Be Used for Supply Chain Management**

Digital Twins (DT) refer to the creation of a virtual replica of a real-world entity, system, or process. Originally developed by NASA in the early 2000s to monitor their space missions, the idea of a Digital Twin has since expanded and been adopted across many different sectors, such as manufacturing, healthcare and logistics. A Digital Twin is made up of three core elements: the physical asset (or system); the virtual model; and a data link that enables real-time communication between the world (digital and physical). And they use sensors, IoT devices, and complex analytics to monitor, virtually replicate, and forecast how physical assets behave and perform in real time, providing unprecedented visibility into operational processes (Grieves, 2014; Tao et al., 2018).

### **Advancement of Digital Twins Technology**

With the evolution of data analytics tools and sensor technologies, the concept of Digital Twins emerged as a new trend. It has transformed from simple representations of objects into advanced systems that enable real-time data synchronisation across both physical and digital worlds. Digital Twin technology was originally used mainly for monitoring complex systems like industrial devices, turbines, or aviation engines, where real-time data can improve maintenance procedures and reduce downtimes (Glaessgen & Stargel, 2012). Still, preparation of Digital Twins are enabled by the Internet of Things (IoT) sensors, cloud computing, artificial intelligence (AI), and machine learning, Digital Twins have transcended from being a monitoring system to predictive analytics, optimisation, and decision making.

At present, Digital Twins find application in various sectors, including smart cities, healthcare, automotive manufacturing, and supply chain management. Digital twin technology is being accelerated by the increasing need for operational transparency, efficiency, and predictive capabilities across industries, particularly in environments where precision and real-time data are crucial.

## **The Applications of Digital Twin Technology in Supply Chain Management**

One of the ways Digital Twin technology can have a transformative impact on supply chain management is through increased visibility, better process optimisation and improved decision making. Leading to enhanced visibility and control, making it a powerful tool to monitor and improve supply chain operations.

Supply chains to date are plagued with problems such as lack of transparency, inefficiencies, tracking of goods movements, which leads to delays, fraud, quality issues, etc. Digital Twins mitigate these issues by making a real-time, dynamic view of the entire supply chain available, allowing organizations to manage every step of their operations from the sourcing of raw material to final delivery.

Multiple studies also evidence the benefits of using Digital Twins for supply chain optimization. Digital twin technology has been applied in manufacturing to enhance inventory management, reduce stockouts, optimise logistics routes and enhance demand forecasting (Qin et al., 2016). Through mapping real-time data sourced from sensors on production lines, logistics systems, and warehouses, Digital Twins could create a comprehensive virtual representation of the whole supply chain, detecting potential bottlenecks, inefficiencies, and threats. With this live visibility, problems can be resolved proactively, resulting in more streamlined operations and reduced lead times.

### **Digital Twin in Halal Supply Chain Administration**

Such potential of Digital Twin technology to redesign halal supply chains is particularly high due to specific challenges relating to preserving halal integrity across multi-stage/multi-stakeholder path to market. The halal industry (which spans food, medicines, cosmetics and more industries), is deeply concerned with product authenticity, certification, and compliance with Islamic dietary and ethical standards. This could solve such problem by bringing certain openness and traceability that is currently lacking from many halal supply chains through Digital Twins.

#### **Halal Food Supply Chains**

Ensuring that products meet halal standards at all stages of halal food manufacturing (from sourcing, processing, packaging, to distribution) is challenging. Digital Twin technology allows for the virtual simulation of the entire halal food supply chain, enabling each stage of production to be tracked and verified in real-time for halal compliance. With sensor data from manufacturing facilities, transportation networks and inventory management systems, a Digital Twin could help continuously monitor critical halal characteristics (animal killing techniques, ingredients, storage conditions, etc.). This ensures that the products remain free from non-halal chemicals and also the halal certification is preserved consistently (Bai et al., 2020).

#### **Halal Pharmaceuticals**

There are unique challenges in the halal pharmaceutical sector regarding sourcing of ingredients or raw materials, manufacturing processes, and avoidance of alcohol or pork-derived substances in medicines. Digital Twin Technology helps the pharmaceutical producers to assure that production cannot ever break halal determinism. According to Khan et al. (2021), Digital Twins can integrate data, manage real-time monitoring of information that guarantees religious compliance (halal) of ingredients, avoid allocation of halal and non-halal products in the same area, and validate that the final product meets the regulations (halal) and quality standards. This improves end-user trust in halal pharmaceutical products, which is particularly critical in globalized markets and industries where verification and traceability are paramount.

#### **Halal Cosmetics**

Halal cosmetics industry, which includes a range of skincare, haircare and personal hygiene products, has challenges in ensuring raw materials and also ingredients are halal certificate compliant. Digital Twin Technology provides an end-to-end solution for monitoring the flow of raw materials and products throughout the supply chain. Using DT to track the purchasing of materials, production methods and packaging prevents

these companies from producing nonhalal products. Moreover, DT can make logistical and distribution processes of halal cosmetics smoother, maintaining halal integrity throughout (Farrukh et al., 2021).

### **Technological Synergies and Challenges within the Halal Framework**

Integration Potential of Digital Twin and other Emerging Technologies in Halal Supply Chains Blockchain provides cryptographically secure and decentralised, tamper-proof records of transactions ensuring that data from the Digital Twin system is accessible and immutable. When Digital Twins technology is integrated with blockchain technology, members in the halal supply chain can authenticate and validate halal certification including the ability to track the movement of these certified products from source to table with complete transparency (Sundararajan et al., 2020).

There comes some issues with the application of Digital Twin technology in halal supply chains. The hurdles include the high implementation costs, especially for smaller businesses, the need for standardised systems across different regions, and the technical challenges of integrating existing supply chain systems with new digital solutions. Also, data security and privacy issues need to be resolved, particularly with areas with strict religious and cultural sensitivities (Zhou et al., 2021).

### **Incorporation of Digital Twin Technology in Supply Chains**

DT technology, or Digital Twin technology, has recently emerged as a powerful technology used in supply chain management, for creating real-time digital twins of physical supply chain operations. This digital twin of the supply chain enables stakeholders to monitor, model and optimize a variety of functions including manufacturing, inventory management, logistics and distribution. Accordingly, the main advantage of Digital Twin technology on supply chains is its ability to provide continuous real-time data for predictive analysis, risk mitigation, and process optimisation. DT merges the physical and digital worlds to allow end-to-end visibility and enhanced decision-making capability.

Digital Twin that deals with supply chains, involves data collection from sensors and Internet of Things (IoT) devices, analytics in real time, supply chain scenarios simulation, and predictive modelling for decision making (Zhou et al., 2021). This blend has shown massive benefits in sectors such as manufacturing, retail, logistics, and food production that help organisations to increase their operational efficiency, lessen the cost, and enhance consumer satisfaction.

### **Principal Advantages of Digital Twin Integration in Supply Chains**

#### **Immediate Transparency and Oversight:**

**Real-time Monitoring and Operational Visibility** The primary value achieved by implementing Digital Twin technology in the supply chain is the possible ability for real-time monitoring and operational visibility. This is especially important for monitoring complex, multi-tier supply chains, as disruptions or inefficiencies at any one tier can cause ripple effects across the entire network. Providing a virtual model reflecting the real world operations, enable enterprises to track shipment, inventory level and manufacturing processes at real-time, minimizing delays and improving resources distribution (Qin et al., 2016)

#### **Predictive Analytics and Risk Management:**

The predictive capabilities of the Digital Twin technology permit companies to predict and mitigate threats before their occurrence. By using historical data as well as real-time data, enterprises would then be able to simulate multiple scenarios and be able to predict possible disruptions, whether those be demand fluctuations, transport delays or even supply shortages. This enables management to decide in advance, thereby reducing the risk of costly supply chain disruptions and improving overall resilience (Tao et al., 2018).

#### **Improvements in Optimisation and Performance:**

Digital Twin solutions use real-time data to optimise key supply chain processes. As demonstrates through predictive analytics technology, DT can improve inventory control through demand forecasting and supply

order adjustments. It can similarly optimize logistics operations by suggesting better delivery paths or adjusting production schedules to meet changing market needs. This leads to better resource utilization, reduced waste and improved supply chain performance (Tao et al., 2020).

### **Gaps in Literature**

Despite the growing amount of literature available about Digital Twin (DT) technology and its applications across various sectors, there remains a lack of clarity surrounding how this novel technology can actually be applied to help further enhance Halal adherence in the supply chain. While existing studies have discussed the effectiveness of Digital Twins in areas like manufacturing, logistics and health care, little research has been dedicated to the potential of DT to keep the Halal integrity — a critical concern for the global Halal industry. Although DT is widely recognised for its prospective capacity to create transparency, efficiency, and reliability in supply chain management, no empirical evidence has yet been established on the real-world application of DT in Halal-certified processes. This is particularly relevant when it comes to complex, multi-layered supply chains where the ability to achieve near real-time monitoring and traceability is essential for maintaining Halal integrity. More research would be done to explore the specific benefits and challenges of implementing Digital Twin technology within Halal industries, especially its potential for providing more reliable real-time solutions for Halal assurance and compliance between stakeholders and within regions.

## **METHODOLOGY OF RESEARCH**

### **Methods: Qualitative Case Study Design**

This study will use a qualitative design using a case study methodology. Qualitative research lends itself particularly well to the exploration of complex events in their real-world settings, especially when the goal is to achieve a deep understanding of underlying processes, perceptions and interactions. Using a qualitative approach allows for the opportunity to conduct a comprehensive exploration into the experiences, challenges, and opportunities of Digital Twin integration in halal supply chains.

A case study technique is ideal, allowing the researcher to investigate real examples and learn from specific cases in which Digital Twin technology has been implemented in halal supply chains. With the help of various case studies, this research study investigates similar current trends, hurdles and success factors that will help further generalize toward the halal market with appropriate recommendations. The case study method allows us to explore different aspects of halal supply chains, including halal food, halal medicines and halal cosmetics, thereby enabling an in-depth understanding of the various applications of Digital Twin in each sector.

### **Data Collection: Data Sources**

The research conducted in this study involves a directed literature survey and case studies focus to type in the halal context regarding the integration of Digital Twin technology in supply chain management. The main data sources will be as follows:

1. Key Academic Papers: Peer-reviewed journals, conference proceedings, or books on Digital Twin Technologies, Supply Chain Management, Halal certification, traceability, and the issues regarding maintaining halal integrity across diverse industries. These articles will provide theoretical perspectives, settings, and empirical evidence to clarify the function of Digital Twin in halal supply chains.
2. Case Studies: Sourcing for Documented Use of Digital Twin Technology Across Supply Chains in Many Industries including food, pharma and cosmetics Case studies can include industry reports, white papers, corporate publishing of leading organizations that have implemented or are exploring Digital Twin technology in their organizations.

Data will be gathered through a comprehensive literature review and a secondary data analysis of these sources. During the literature review process, databases (Google Scholar, ERA, Scopus, IEEE Xplore and



ScienceDirect) will be systematically searched to gather related studies. The search process will employ terms such as “Digital Twin technology in supply chains,” “halal supply chain,” “traceability,” “halal certification,” and “supply chain management.”

### **Instruments for Qualitative Analysis**

The collected data will be analyzed qualitatively to obtain meaningful insights relevant to the research questions and objectives. The following instruments and approaches will be used:

**Thematic Analysis.** This method will help to identify and analyze the patterns within the data. The themes that will be identified through the processes of the categorization of the data include “integration challenges”, “benefits of Digital Tsidwin”, “halal certification and compliance” and “consumer trust”. Thematic analysis allows the researcher to systematically analyze complex qualitative data revealing the opportunities and issues related to the integration of Digital Twin in halal supply chains.

**Content Analysis.** Content analysis will analyze the frequency of repetition of specific concepts, terms, or references in the collected articles and case studies. An example of such an analysis is determining how frequent words and phrases identifying halal compliance, certification, traceability, fraud protection in terms of Digital Twin activities appear in the relevant literature. This analysis helps the researcher to determine the trends and gaps in the existing research.

**Cross-Case Synthesis.** This approach helps to compare and integrate the ideas from several case studies. Comparing the similarities and differences of the cases, the researcher can draw generalized conclusions about the efficiency of Digital Twin technology throughout different segments of the halal supply chain. Additionally, the researcher can highlight the specific issues or approaches relevant to the halal industry but not applicable to other supply chains.

### **Scope of the Study**

This study focuses on the integration of the Digital Twins technology in halal supply chains in the food, pharmaceutical, and cosmetic sectors. The study will include:

**Halal Food Supply Chains:** A Study on the use of Digital Twin Approach to ensure requirements of halal certification, monitor food safety, and prevent contamination at halal food processing.

**Halal Pharmaceuticals:** Exploring the use of Digital Twin technology in maintaining halal integrity during pharmaceutical production process to ensure that raw materials and production processes adhere to halal requirements.

**Halal Cosmetics:** Exploring how Digital Twin technology can be used to ensure the halal compliance of ingredients, production processes, and final products in the cosmetics market.

It will focus on both global case studies and academic studies discussing the use of the Digital Twin in the supply chain, with a keen focus on halal-related sectors. Specific regions or countries may be included based on the availability of case studies or examples of the application and challenges of Digital Twin technology within halal supply chains.

### **Study Limitations**

This study will provide much insight into the incorporation of Digital Twin technology within halal supply chains; however, several limitations need to be acknowledged:

1. **Geographic Limitations:** The study will mainly focus on global case studies; however, it will not cover all geographical regions or countries with considerable halal supply chains. Due to the novelty of Digital Twin systems, the literature on halal certification and compliance will be limited to available case studies and research articles.

2. **Industry Specific Focus:** The study proposal targets the halal food, medicines and cosmetics sectors, while other halal industries such as logistics or finance are outside this research scope but could also potentially reap benefits from Digital Twin technologies. The focus of this study is also limited to the halal food sector which might limit the generalizability of findings to the other sectors of halal industry.
3. **Data Availability:** The research is built on secondary information from existing case studies and academic papers. Case studies or industry reports are publicly available on the adoption of Digital Twin technologies in halal supply chains around the world as few as possible, especially in regions or sectors with sub-par digital infrastructure.
4. **Technological Limitations:** The adoption of Digital Twin technologies in halal supply chains is in its infancy. So, opioid implementation may have little data on long-term effects and challenges. The results may thus reflect early stages of acceptance and not the entire potential of this technology.

## **DIGITAL TWIN TECHNOLOGY IN A SUPPLY CHAIN CASE STUDIES / APPLICATIONS: SPECIAL EMPHASIS ON HALAL INDUSTRIES**

Digital Twin (DT) technology remains a developing domain in halal supply chains; however, many case studies and applications exist in conventional supply chain management and can be tailored towards halal supply chains. Such case studies clarify how the use of Digital Twin technology could increase transparency, traceability, and compliance within supply chains, particularly in industries such as food, pharmaceuticals, and cosmetics that are integral to halal (permissible within Islamic law) standards. Following are some examples of how Digital Twin is being applied, with an emphasis on their application in halal supply chains.

**Nestlé: Food Manufacturing and Distribution Digital Twin Industry Halal food production Geography: International (e.g., Middle East, Southeast Asia)**

a. **Based on Context: Digital Twin Technology:** Nestlé, a leading global food manufacturer, uses Digital Twin Technology to improve the efficiency, traceability and sustainability of its production and supply chains. The corporation uses real-time monitoring technologies to create digital models of its production processes, logistics networks and product life cycles. This range includes tracking ingredient supply, overseeing production lines, and directing distribution routes.

b. **Importance to Halal Supply Chains:** Halal certification and avoidance of contamination are critical for halal food products. Nestlé uses Digital Twin technology to manage every stage of the food manufacturing process, ensuring that halal-certified ingredients are acquired and that the manufacturing plants meet halal slaughter guidelines. Furthermore, as it has helped to monitor the products during the production phase with the help of IoT sensors and real-time data analytics, which reduces the risk of contamination (non-halal).

c. **Key Benefits:**

- **Traceability:** Real-time access to the entire food supply chain ensures that all ingredients and processes comply with halal requirements, eliminating problems related to fraud and contamination.
- **Operational Efficiency:** Digital Transformation optimises production scheduling, reducing downtime and waste, which is critical to maintaining the quality of the product.
- **Consumer Trust:** They facilitate customers food safety by enabling them to know from where the ingredients were sourced and whether the goods comply with halal or not.

d. **Challenges:**

- **Cultural Sensitivity:** The employment of the Digital Twin in halal food supply chains requires local halal certification to be carefully considered, as this tends to vary by area.
- **Data Sharing & Privacy:** The sharing of real-time data may lead to privacy challenges especially in regions with stringent limitations related to food safety and halal certification.

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## **DHL — Digital Twin for Smart Logistics and Supply Chain Improvement**

Sector: Halal Food and Pharmaceutical Logistics

Region : Global (particularly regions with a strong halal demand, including but not limited to the Middle East and Southeast Asia)

It includes Digital Twin technology deployed by the global logistics service DHL to optimize their supply chain processes. This includes the creation of digital twins of logistics networks which simulate and manage transportation routes, warehouse management systems, and inventory tracking.

Importance for Halal Supply Chains:

There are many industries, like halal food and pharmaceutical, where shipment and storage need to be halal compliant. DHL uses Digital Twin technology to track real time transit conditions, including temperature and humidity to ensure that products such as halal-certified food and pharmaceuticals are properly used and handled. This ensures that halal products do not sit in cross-contaminated environments or non-halal compliant surroundings.

Key Benefits:

**Compliance Monitoring** — Regular monitoring of transport and storage conditions ensures that halal products are kept under suitable conditions as they travel.

**Predictive Analytics:** Digital Twins allow DHL to predict potential disruptions or delays within logistical processes, ensuring on-time delivery and minimizing the chances of sensitive halal products arriving faulty.

**Operational Efficiency:** By optimising delivery routes and warehousing operations, DHL reduces expenses and improves the effectiveness of the halal product distribution process.

Challenges:

**Scalability:** The adoption of Digital Twin systems into diverse halal supply chains can be demanding in terms of resource investments especially for small-scale firms or regions with limited technological infrastructure.

## **Unilever: Digital Twin in the Supply Chain for Halal Cosmetics**

Industry: Halal Cosmetics

Geography: Global (including markets in the Middle East and Southeast Asia).

Unilever, a multinational company in food, personal care, and household products, has explored men's digitized twin implementation to create virtual models of its production lines at personal care and cosmetics. Another element of Unilever's pursuit of precision is the realization of IoT devices in their production lines, validated in all phases, from raw materials through final product packaging, to guarantee compliance with high-quality standards.

**A. Related to Halal Supply Chains:** Products that are free of alcohol, animal parts, and other non-halal products must be included in the halal cosmetics supply chain. Using Digital Twin technology, the process start from tracking source to the ingredient to monitoring the production process to ensure compliance with the halal rules to also be used for validating that end products meet halal qualification standards. Digital Twin systems ensure the absence of contamination through real-time production conditions monitoring.

Key Benefits:

**Ingredient Traceability:** Digital Twins ensure only halal-certified ingredients are used in production, alleviating concerns of cross-contamination with non-halal substances.

**Regulatory Compliance:** Unilever ensures compliance with local legislation on halal products by incorporating halal certification requirements in the production process.

**Supply Chain Transparency:** Digital Twin allows customers and regulators to follow the product back to its origin, providing confirmation of halal compliance.

**Challenges:**

**Halal Certification Intricacy:** Ensuring compliance with halal certification requirements across all vendors can be challenging, especially in countries with differing certifying organizations for halal.

**Data Integration:** When integrating diverse data from many manufacturers and industrial locations, advanced systems need to be capable of managing complex data flows.

### **Johnson & Johnson: Digital Twin in Halal [email protected]**

**Leading Sector:** Halal Pharmaceuticals

**Region:** Global, focused regions including Middle East, South East Asia and Europe

Johnson & Johnson has pioneered the use of Digital Twin technology to improve the quality and safety of its pharmaceutical products. Digital Twin technologies allow the organisation to create real-time digital twins of manufacturing processes including the preparation of pharmaceutical ingredients, packaging and quality control.

**A. Importance to the Halal Supply Chains:**

In case of halal medicines, it is critical to ensure that production processes do not use non-halal ingredients or anything that is contaminated. Through Digital Twin technology, Johnson & Johnson can track every stage in the pharmaceutical production process, ensuring that materials and processes comply with halal requirements. Digit twin technology also offers the prospect of monitoring the temperature and storage conditions of sensitive halal pharmaceutical products, ensuring strict halal requirements are met during storage and transport.

**Key Benefits:**

1. **Halal Certification Compliance:** Strict monitoring of ingredient sourcing and production methods ensures all pharmaceuticals comply with halal requirements, thus, enhancing integrity of the products.
2. **Quality Assurance:** By employing Digital Twin technology, production processes can be modelled and optimised, assuring high quality halal products.
3. **Supply Chain Efficiency:** Mapping out its manufacturing and distribution networks digitally can help Johnson & Johnson shorten production timelines and improve logistics, ensuring timely and safe delivery of halal pharmaceutical products.

**Challenges:**

1. **Discrepancies in Halal Policy Worldwide:** Governments or bodies set halal standards in various nations. However, compliance with halal standards among different geographies is complex.
2. **Financial Constraints and Complexity of Implementation:** The initial cost of investing in Digital Twin technology and integrating it with existing systems can be prohibitive, particularly for small-scale halal pharmaceutical manufacturers.

### **Almarai: Digital Twin in Middle East Halal Food Production**

**Sector:** Halal Food Production

**Region:** Middle East (Saudi Arabia, UAE, etc.)

One case study comes from Almarai, one of the largest dairy and food companies in the Middle East, which explored the adoption of Digital Twin technology in order to improve its supply chain processes focusing on halal food processing. It uses IoT sensors and real-time data analytics to track every step of the process, from sourcing the milk to processing and distribution.

#### Importance to Halal Supply Chains:

It is a must for Almarai to have halal certification along the whole supply chain — from animal nutrition to slaughtering techniques to food processing. With Digital Twin technology, Almarai gets to monitor the entire process and ensure halal compliance and contamination-free delivery. The company monitors each batch of product to make sure that only halal-certified ingredients are used and the final product meets all halal certification requirements.

#### Key Benefits:

1. **No Gap in Traceability in Halal Assurance:** Digital Twin provides optimum transparency and traceability which ensures that every stage in the food making process is halal certified.
2. **Updated Data for Decision Making:** The technology allows Almarai to change production plans and distribution on the fly, ensuring the proper allocation of resources and food quality.
3. **Consumer Confidence:** Using data from Digital Twin systems, Almarai can publish transparency reports that can be disseminated to consumers thereby increasing trust in its halal foods.

#### Challenges:

1. **Complexities in Supply Chain Management:** The food supply chain is highly complex, and managing all elements (especially those related to halal compliance) through such a wide network of vendors can pose various challenges.
2. **Regulatory Compliance:** Different countries enforce different halal certification regulations, which must be closely monitored in terms of certifications and paperwork.

### Challenges and Opportunities in the Adoption of Digital Twin Technology

#### Challenges

**High Upfront Infrastructure Pay:** A primary barrier associated with the use of Digital Twin technology in the Halal supply chain is the high upfront infrastructure investment required. Implementing Digital Twin systems requires:

- **Instantaneous Data acquisition and Sensors.** Complex software platforms for data capture and analysis. Especially within small and medium-sized organisations (SMEs), this can prove resource-heavy when integrating with existing systems. The Halal food factory in Malaysia got stuck on how the initial capital investment must take place to set up the necessary hardware and software required to carry out the operations. The deployment of the Digital Twin to legacy systems had to be step-by-step to build the twinning process without affecting the ongoing operation.
- **Integration with Legacy Systems:** Many Halal businesses (especially those with a significant operational presence) rely on legacy systems for inventory management, compliance monitoring, and logistics. The integration of legacy systems with Digital Twin technology is difficult, expensive and long when it comes to compatibility between old and new technologies. The Middle Eastern pharmaceutical company needed customized interfaces and software solutions to connect its enterprise resource planning (ERP) systems to the new Digital Twin architecture. This posed challenges on both technical and operational fronts but was critical in ensuring continuous data flow throughout the supply chain.
- **Data Privacy and Security Concerns:** Digital Twin technology requires large quantities of real-time data to function, which can lead to challenges with data privacy and security. Halal supply chains, therefore, often include sensitive religious, ethical, and cultural information that needs to be handled

with care. Southeast Asia halal cosmetics companies needed to implement strict cybersecurity measures to protect the data generated by their Digital Twin systems, thus ensuring compliance with local and international data protection laws. This added security step might add to operational complexity and costs.

## Opportunities

- **Improved Transparency & Trust:** The fundamental explanation for digital twin in services is an extraordinary advantage with improved openness inside the logistics. The Halal food company in Malaysia shows how Digital Twin technologies can be utilized to observe and validate every stage of product's lifecycle and ensure adherence of Halal regulations at all times. Such transparency encourages consumer trust which is a precondition in the Halal market. The incorporation of this technology enables effective supply chain management by providing real-time data of operations, inventory, and transportation logistics. If they use predictive analytics and resource optimisation, halal food businesses can improve production schedules, reduce waste, and ensure time of delivery of halal products.
- **Scalability and Global Expansion:** The worldwide expansion of the Halal business makes Digital Twin technology a valuable opportunity for improving operations in numerous fields, all while adhering to rigorous Halal compliance standards. This is more relevant to enterprises in emerging economies moving to be part of the global Halal supply chain ecosystem. The use of Digital Twin technologies thus allows these organisations to align with multiple regulatory standards effectively, and track Halal certification across multiple suppliers and marketplaces.
- **Supporting Halal Certification Organisations:** The data-oriented nature of Digital Twin technology provides Halal certification organisations with new tools to check and corroborate compliance. Having real-time data at production processes, storage conditions and transit logistics, certification bodies might execute remote inspections, ensure compliance in real-time, and upkeep integrity and transparency throughout the Halal certification process.

## FINDINGS AND ANALYSIS

### Findings

The case studies illustrate how Digital Twin technology is poised to revolutionize Halal supply chains with real-time visibility, traceability, and predictive functionalities. It addresses important issues such as product integrity assurance, risk management, and compliance adherence. Being able to track an entire process of a Halal product, from sourcing of raw materials to end distribution, allows organizations to enhance operational efficiencies, reduce fraud, and ensure compliance to Halal processes and standards.

Additionally, the predictive capabilities of Digital Twin technology allow enterprises to take action before disruptions arise in the supply chain, whether due to logistics, quality, or environmental factors. This gives companies a competitive edge in maintaining continuous adherence to Halal requirements, an essential aspect in industries ranging from food to pharmaceuticals and cosmetics.

### Comparison with Existing Solutions

Compared to the likes of blockchain and RFID, Digital Twin has multiple benefits but it provides an overall, real-time and interactive view of the entire supply chain. While blockchain provides enhanced traceability and RFID offers real-time visibility of items, neither can compare to the dynamic monitoring and predictive analytics features of Digital Twin. Blockchain ensures data integrity but lacks real-time operating information; RFID supports monitoring but does not provide a full picture of the product lifecycle or the factors affecting it.

### Implications for the Halal Industry

Integrating Digital Twin technology into Halal supply chains could revolutionise the market by enhancing transparency, reducing fraud, and optimising supply chain efficiency. As the Halal market grows in

unconventional areas, Digital Twin technology acts as a crucial enabler for Halal businesses wishing to optimize operations and reach global markets. There are significant consequences for Halal certifying organisations too. Efficient auditing and compliance assessments through the use of real time data and digital verification methods, with the added benefit of making the certification process quicker and more robust. Moreover, the growing utilization of Digital Twin technology by enterprises will likely lead to the creation of new global standards for Halal supply chains, thereby creating the opportunity for certification methods to become aligned amongst countries and industries. In conclusion, despite of the challenges such as initial capital investment and implementation complexities, Digital Twin technology presents a bright future for Halal supply chains, and efforts need to be made to leverage this technology to its potential in future.

## Summary

The aim of this study was to investigate the potential of Digital Twin technology in enhancing the efficiency, transparency, and compliance of Halal supply chains, within a range of industries, such as food, pharmaceuticals, and cosmetics. The main findings highlight the important value and opportunities associated with the implementation of Digital Twin systems:

1. **Real-Time Traceability and Monitoring of Compliance:** Digital Twin technology devprovides extraordinary visibility of the supply chain, ensuring HALAL compliance at every stage of production, from raw materials to finished products delivery. This technology allows automated checking of real-time data received from IoT sensors integrated into the production and supply chain parameters to control temperature and contamination of food, allowing companies to comply with Halal certification.
2. **Risk Mitigation and Predictive Analytics:** Digital Twin technology allows firms to proactively manage risks, from potential supply chain bottlenecks to contamination and delays, by simulating expected disruptions and using predictive analytics. This predictive ability helps avoid compliance problems and increases the ability to quickly respond to changes in the supply chain.
3. **Operational Efficiency:** The adoption of Digital Twin technologies has led to improved operational efficiency that assists organisations in optimising the usage of resources, reducing wastage, and streamlining inventory management. In the cases analysed, organisations that leveraged Digital Twin technology were able to optimise processes and reduce operating costs while guaranteeing sustainable Halal compliance.
4. **Improved Transparency & Confidence:** With the creation of digital clones of real-world supply chains, Digital Twin tech helps enterprises provide proof of Halal compliance and ensure consumer confidence. Particularly in such markets where Halal certification serves as a major driver of consumer decisions.

The emerging results demonstrate the potential for Digital Twin technology to transform the Halal industry by fostering a more transparent, efficient, and reliable way to ensure Halal-ready supply chains.

## Future Direction

The case studies presented in this study demonstrate the diversity and potential applications of Digital Twin technology in Halal supply chains and they present many avenues for future research and practices to improve its contribution.

**Diversification into Untapped Halal Communities:** Further research can explore the application of Digital Twin technology in emerging Halal markets, particularly in regions like Africa, Southeast Asia, and Latin America. Understanding how Digital Twin systems can be scaled to meet the needs of these rapidly growing markets will be critical for global adoption.

**Integration with Other Emerging Technologies:** In the future research the integration of Digital Twin technology with other emerging technologies such as blockchain, artificial intelligence and machine learning may be explored. Combining Digital Twin technology with blockchain could provide better transparency and accuracy in data exchange, and artificial intelligence could refine predictive analytics for enhanced risk evaluation.

Standardisation of Digital Twin Models for Halal Supply Chains — A significant area that requires future research is the formulation of standardised platforms for developing Digital Twin models for Halal supply chains. This involves the roles that guides on data interoperability, certification protocols as well as best practices for firms operating these systems.

Cost-Benefit Analysis for Digital Twin Deployment: until now, we know very little about how cost-effective it could be to deploy Digital Twin systems, especially in the Halal sector SMEs. Conducting a comprehensive cost-benefit analysis not only allows firms to understand the financial impact of investing in this technology, but also offers insight into how to overcome the roadblocks of initial investment.

These papers can have a longitudinal view on the enduring effects of Digital Twin technologies on Halal certification organisations and the regulatory environment. These research would assess the capacity of digital technology to optimise and enhance the Halal certification process and make it more efficient and less error-prone.

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