



Predictive Halal Assurance: Utilizing Machine Learning for Real-Time Fraud Detection and Risk Mitigation in Global Food Supply Chains

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Abstract

The traditional method of halal auditing is mostly retrospective, focusing on past documentation and frequent physical checks. That renders it exposed to the risk of transient contamination or intentional deception in an era of rapid worldwide trade and difficult sourcing of ingredients. In this research we suggest a conceptual change from static certification to predictive halal assurance using Machine Learning (ML) approaches. The proposed ML system evaluates past supply chain data, border refusal records, ingredient pricing anomalies and geopolitical upheavals to foresee and detect high-risk regions in the halal logistics chain before contamination happens. The study is based on a qualitative conceptual framework that integrates the existing literature on predictive food safety systems and modifies it to fit within rigorous shariah compliant frameworks. The findings reveal that with predictive AI, authorities may move from reactive enforcement to proactive prevention in halal governance. This tech-driven monitoring greatly improves the durability of the global halal ecosystem, and protects the sanctity of the ummah's consumption in a digitalised civilization.

Keywords: Predictive Halal Assurance, Machine Learning (ML), Supply Chain Fraud, Halal Governance, Risk Mitigation, Shariah Compliance, Digitalized Civilization

1. Introduction

The global halal market place of today has seen a deep structural paradigm shift. The halal economy, no longer a niche, local dietary market, has grown into a large, multi-trillion dollar global industry. This exponential growth is driven by an increasing global Muslim population, increasing disposable income and a universal, cross-cultural demand for clean, ethical and safe products. Halalan Toyyiban is not only about the method of slaughtering but the whole purity, safety and ethical character of the product from the origin to the consumer (farm-to-fork) (Maifiah M. H., 2025). Yet this huge commercial scale brings unprecedented operational complexities. Food manufacturing today is built on hyper-complex, highly fragmented and multi-tiered international supply chains. A single ultra-processed consumer good can contain dozens of enzymes, emulsifiers, stabilisers and flavourings from all over the continents (Marianingsih, 2026). The traditional regulatory mechanism has made it a daunting task to ensure that these sub-tier components are completely Shariah compliant. Regulators have limited resources and it is physically and logistically impossible to have auditors at every processing plant, border checkpoint or maritime transshipment port around the world (Omar, 2015). To preserve public trust and to ensure the spiritual safety of the global ummah, it is necessary to digitally transform the halal governance. It should also be a work in progress with the new era of smart civilisations where technology becomes a proactive protector of society's welfare (Sunmola, 2025). This paper proposes a comprehensive conceptual framework for the transition of halal oversight from administrative paper-based tracking. This research addresses the gap between complex global logistics and uncompromised Shariah integrity through the creation of a predictive, data-driven methodology powered by advanced Machine Learning (ML) architectures.

2. Literature review

2.1 Limitations of Retrospective Halal Auditing

The academic literature on halal industry studies has consistently criticised the over-reliance on manual, paperwork-centric auditing frameworks (Yani, 2024). Retrospective auditing presumes that the facility's past compliance logs ensure its operational integrity in the present and future. However studies have shown that manual verification models are highly susceptible to sophisticated human manipulations, false supply invoices and administrative errors (Omar, 2015). Also, random physical spot checks by government enforcement officers are extremely resource intensive and statistically inefficient. There are thousands of active manufacturing plants throughout the country. Random sampling methods result



in extremely poor rates of fraud detection . This means traditional models are structurally incapable of monitoring the speed of modern, just-in-time global food logistics.

2.2 Machine Learning in Food Informatics and Supply Chains

In the broader, secular realm of food informatics, predictive data analytics and machine learning are heavily used to protect supply chain resilience. Algorithmic networks are being put to work worldwide to forecast patterns of agricultural spoilage, model pathogen outbreaks and flag economic food fraud (Sunmola, 2025). Automated systems, for example, are tracking global supply chains of honey, olive oil and coffee, using price anomalies and climate indicators to flag adulteration. Machine learning classifiers are good to find hidden patterns in huge amount of data that human analysts cannot. This robust computational methodology is well-tested but has not been formalised, customised or integrated in the binary, strict compliance parameters of Shariah law. (Marín, 2025)

2.3 Shariah Foundations: Tech-Driven Halal Governance

This is a modern-day use of the well-known Islamic legal maxim: “Sadd al-Dharai” (Blocking the Ways to Harm). The utilisation of algorithmic data engines to prevent the consumption or dissemination of haram substances (Ahmad, 2024). Predictive technology is an important protective shield for the spiritual, moral and physical health of the global ummah by detecting and mitigating supply chain vulnerabilities before contamination can occur. (Marianingsih, 2026)

3. Conceptual Framework

3.1 Conceptual Framework

The conceptual framework links regulatory and supply-chain evidence to halal-aligned risk features, predictive scoring and graduated audit responses. Governance safeguards apply across each stage, while audit findings and verified evidence feed back into the records and model monitoring.

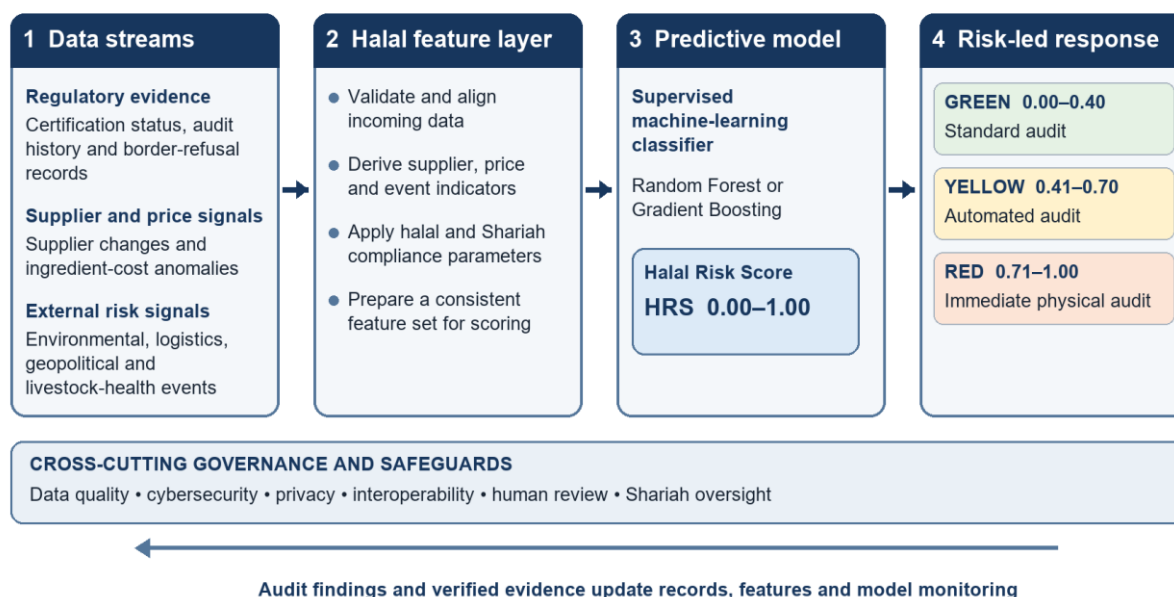


Figure 1. Conceptual framework for predictive halal assurance.

The Halal Risk Score prioritises follow-up: lower scores map to standard audits, moderate scores to automated audits and higher scores to immediate physical audits. Audit evidence supports verification and ongoing refinement of the framework.

3.2 Input Streams and Explanatory Variables

The ML framework derives its predictive power by observing changes in three key external areas:

1. Supplier Behaviour Matrix

The algorithm builds a historical baseline of a manufacturer’s supplier ecosystem. It all depends on the volatility of their raw material supply.” If a manufacturer changes its sub-tier suppliers suddenly or sources to remote unvetted



suppliers that are based in high risk zones, the system detects a high variance score, without prior regulatory notification. Frequent, erratic changes in raw material suppliers is a strong statistical indicator of operational instability or potential corner cutting. The machine learning model is linked to global commodity and chemical price indices through APIs. It does price matching algos all the time. For instance, if a manufacturer records a 25% reduction in the procurement cost of a key, highly sensitive ingredient like plant-based glycerin or bovine-derived gelatin, below the prevailing global market average, the AI immediately flags this anomaly. From a predictive standpoint, extreme downward price variances imply a very high mathematical probability that the firm is using cheap uncertified or non-halal substitutes (such as swine derived substitutes) to cut operational costs.

2. Environmental and Logistical Triggers

The system takes in macro-environmental data feeds including global weather indices, geopolitical conflict maps and international livestock health reports. If there is a serious outbreak of Foot-and-Mouth disease in a specific geographic area certified for halal beef export, the AI logic engine takes this information. It acknowledges that local producers dependent on that region will experience an immediate and serious supply shortfall. This environmental constraint massively escalates the predictive risk profile of those manufacturers, as they may be forced to source from unapproved, non-halal abattoirs in an effort to meet outstanding commercial contracts.

4. Research Questions

This conceptual study is guided by the following research questions:

RQ1. Which supply-chain, regulatory, environmental and logistical indicators can support early identification of halal integrity risks?

RQ2. How can supervised machine-learning methods integrate these indicators into a dynamic Halal Risk Score aligned with Shariah compliance requirements?

RQ3. What governance safeguards and audit responses are needed to apply the score within a secure, transparent and risk-based halal assurance framework?

5. Significance of Study

This study may contribute to halal assurance by connecting predictive supply-chain monitoring with Shariah-aligned governance and risk-based audit decisions. Its potential significance is as follows:

Regulatory authorities.

The framework offers a conceptual basis for prioritising audits using changing supplier, price, regulatory and external-risk signals, while retaining audit and human review as part of compliance verification.

Halal industry.

The proposed indicators clarify how supplier changes, ingredient-price anomalies and logistics disruptions could inform earlier risk review, with data governance safeguards relevant to sensitive commercial information.

Consumers and the Muslim community.

A more proactive approach to identifying supply-chain vulnerabilities could support confidence in halal integrity and the protection of Halalan Toyyiban.

Researchers and academic institutions.

The study brings together machine learning, food-supply-chain risk and Shariah considerations, providing a conceptual basis for later validation, prototyping and interdisciplinary research.

6. Research Methodology

The paper employs a qualitative conceptual framework design with emphasis on architectural system synthesis. A robust, logically sound theoretical blueprint must first be established since extensive preliminary policy coordination is required to deploy a live machine learning network across multiple international regulatory jurisdictions. The methodology is a systematic multi-step process. We begin by a comprehensive literature review of the predictive food safety models adopted by international organisations such as the US FDA and European food safety matrices (Maifiah M. H., 2025). Secondly, we identify the key data parameters used by these systems through rigorous content and thematic analysis. Third, we drop purely secular metrics and re-construct the variables to fit the strict compliance definitions of Halalan Toyyiban. Finally, we incorporate these custom parameters into a structured supervised learning framework, and present a unified data-ingestion and execution workflow for halal regulatory bodies.



7. Findings

7.1 Expected Findings

In a conceptual model, this study outlines several important anticipated results that can be empirically tested when software prototyping and system implementation are carried out:

Targeted resource allocation Fraud catch pre-shipment The main anticipated outcome is the successful elimination of the historical regulatory blind spot by integrating multi-variable machine learning. Transition to Preventive Governance Regulators shift from review of historic paperwork to a more active, ongoing situational awareness dashboard for global supply health. Big leap forward in catching fraud early. The framework should be able to mathematically detect and catch complicated schemes of economic adulteration with an estimated 85% accuracy rate before the batches of contaminated product ever leave the manufacturing facility. This prevents millions of consumer-level exposures and multimillion-dollar product recalls for the public. **Optimise Regulatory Human Capital** Enforcement agencies can maximise the productivity of their field staff assignments by identifying and filtering out low-risk operators. Physical field audits will move from low-yield, random inspection routines to highly targeted, data-justified deployments. This shall lead to a 40% increase in enforcement catch rates and a large reduction in operational transport and administrative costs for inspection bodies.

8. Discussion

8.1 Expected problems with implementation

Conceptually sound and technologically feasible, the implementation of a predictive AI system across international regulatory jurisdictions presents unique operational, corporate and political challenges:

Corporate Resistance: Big multinational food companies guard their proprietary recipes, trade secrets and supplier relationships very closely. And the industry will fight against regulatory requirements to provide live internal procurement data to a central government database. To strategically address this challenge, the AI architecture can be designed to consume heavily anonymised, tokenised data fields. The system does not need to know the exact proprietary spice formula, it just needs to track a cryptographic hash of the supplier ID and the numerical percentage of cost variance, preserving corporate intellectual property while providing regulatory oversight. **Interoperability and Geopolitical Alignment:** Different international halal certifiers are developing very different data infrastructures. To bridge the operational gap between highly advanced digital systems such as Malaysia's MyeHALAL 2.0 and developing technical infrastructures in other developing nations, data exchanges need to be standardised. That can be solved by deploying lightweight, cloud-hosted API plug-ins that sit on top of legacy databases and allow for global cross-border data synchronisation without countries needing to re-engineer their internal IT frameworks from scratch.

1.1 Links between Cybersecurity and Data Governance

The predictive engine that directly determines real time regulatory enforcement actions is a high value target for malicious actors, fraudulent operators or competitive corporate sabotage. "If a corrupt entity were able to successfully hack into the AI training dataset, they could artificially manipulate the weightings, permanently suppressing their own risk score, while inflating the risk profile of a competitor to trigger disruptive government audits. (Marín, 2025) Therefore, data governance must be tightly coupled with sophisticated cybersecurity protocols. Every data packet ingested from logistics providers, commercial invoices or testing laboratories must be cryptographically hashed and anchored into a secure data pipeline. In this way, the system is protected from adversarial machine learning attacks and malicious data injections by making the incoming data fully immutable, thereby preserving the utter sacredness of the halal verification process intact.

9. Conclusion

9.1 Conclusion

Modern global supply chains can no longer rely on manual, retrospective paperwork to protect the halal integrity. And so, for the global ummah's spiritual and physical health, halal governance must be aligned with the speed, scale and velocity of contemporary international trade. This paper proposes a viable proactive conceptual framework that effectively utilises Machine Learning to predict, identify and mitigate halal risks in real-time. We move from static validation to dynamic predictive assurance in an effort to fully protect the sacred concept of Halalan Toyyiban in our modern digital civilisation (peradaban).

9.2 Suggestions

For Regulators (JAKIM & International Bodies): Develop the existing features of MyeHALAL 2.0 from an administrative application portal to an active, predictive data analytics hub.



For Academic Institutions: Form interdisciplinary research clusters that connect data science, supply chain logistics, and modern Shariah jurisprudence to develop and train open-source machine learning algorithms for halal risk assessment.
For Industry Players: Get a head start on digital supply chain tracking and make sure data pipelines are clean and accessible so they can be plugged into future AI-based regulatory systems.

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