Journal Homepage: www.ijarpr.com ISSN: 3049-0103 (Online)

International Journal of Advance Research Publication and Reviews

Vol 03, Issue 11, pp 31-42, November, 2026

Coordinating Food Traceability Technology Projects Across Supply Chains Through Stakeholder Governance and Recall Readiness Testing

Pulka Atam

Texas A&M University, Texas, USA

ABSTRACT

Global food supply chains increasingly depend on effective traceability systems to strengthen food safety, regulatory compliance, product authenticity, and consumer protection. However, fragmented information systems, inconsistent data standards, limited interoperability, and inadequate stakeholder coordination can undermine product visibility and delay responses to contamination incidents. Emerging technologies, including blockchain, Internet of Things sensors, cloud platforms, and automated identification systems, offer opportunities to improve traceability, although successful implementation requires coordinated governance and rigorous operational validation. This study proposes an integrated project management framework for coordinating food traceability technology initiatives through stakeholder governance, data integration, and recall readiness testing. The framework examines stakeholder responsibilities, information exchange protocols, technology selection, supplier participation, data quality assurance, and regulatory reporting requirements. Performance indicators encompass traceability completeness, data accuracy, interoperability, recall identification time, retrieval effectiveness, and stakeholder response efficiency. A comparative evaluation approach is proposed to assess relationships between governance maturity, technology integration, information reliability, and simulated recall performance. The framework supports evidence-based technology investment, coordinated incident response, improved supply chain accountability, and stronger recall preparedness, contributing to resilient food safety systems and more effective contamination risk management.

Keywords: Food Traceability; Supply Chain Governance; Recall Readiness Testing; Digital Traceability Systems; Stakeholder Coordination; Food Safety Management.

1. INTRODUCTION

1.1 Food Supply Chain Complexity, Traceability and Consumer Protection

Global food supply chains have become increasingly interconnected, making traceability essential for protecting consumers, verifying product authenticity, and maintaining regulatory accountability [1]. Food products frequently move through multiple producers, processors, logistics providers, distributors, and retailers before reaching consumers, creating complex networks of transactions and responsibilities [2]. Within these networks, contamination incidents can spread across geographical boundaries, while fragmented movement records and delayed information exchange complicate investigations and corrective interventions [3]. Effective traceability enables organisations to reconstruct product histories, identify affected batches, locate distribution destinations, and coordinate timely recalls before further exposure occurs [4]. Digital technologies, including barcodes, radio-frequency identification, Internet of Things sensors, blockchain, and cloud-based platforms, offer mechanisms for capturing and exchanging product information across organisational boundaries [5]. Nevertheless, technological adoption alone cannot guarantee traceability effectiveness. Reliable product identification, accurate transaction records, interoperable information systems, and coordinated stakeholder participation remain fundamental requirements for maintaining supply chain visibility and strengthening consumer protection.

1.2 Challenges of Traceability Technology Project Coordination

Despite technological advancements, implementing integrated food traceability systems remains challenging because supply chain participants operate heterogeneous information platforms, inconsistent identification standards, and unequal digital capabilities [6]. These differences restrict interoperability and complicate the timely exchange of product movement information. Stakeholder coordination introduces additional difficulties involving data ownership, commercial confidentiality, supplier responsibilities, regulatory reporting, and contractual accountability [2]. Technology projects may

consequently encounter implementation delays, integration failures, escalating expenditure, and organisational resistance, particularly when participating organisations lack clearly defined governance arrangements [7]. Furthermore, successful platform deployment does not necessarily establish operational traceability readiness. Inaccurate batch identifiers, missing transaction records, incomplete supplier participation, and delayed recall notifications can undermine contamination investigations despite functioning digital infrastructure [4]. Such limitations demonstrate that technical integration must be accompanied by information quality verification, coordinated decision-making, and practical incident response testing. Consequently, effective traceability implementation requires an integrated approach combining stakeholder governance, disciplined project management, and systematic recall readiness evaluation [8].

1.3 Research Aim, Objectives and Proposed Contributions

This study aims to evaluate how stakeholder governance and technology integration influence food traceability performance and recall readiness across interconnected supply chains. Specifically, it examines governance maturity, organisational coordination, information interoperability, transaction accuracy, project delivery effectiveness, and simulated recall performance [7]. The proposed investigation focuses on technology implementation projects involving food producers, processors, logistics providers, distributors, retailers, and relevant regulatory stakeholders. A comparative evaluation framework is developed to integrate governance documentation, technology architecture records, product movement transactions, and structured recall exercises [5]. Performance indicators encompass stakeholder participation, system integration reliability, traceability completeness, information latency, recall identification time, and product reconciliation accuracy. The principal contribution is a multidimensional framework connecting organisational governance, digital traceability capabilities, and operational recall preparedness without assuming that technological adoption automatically produces improved food safety outcomes [8]. Subsequent sections establish the conceptual foundations, research design, data preparation procedures, analytical models, performance benchmarking approaches, and practical recommendations supporting evidence-based traceability project management.

2. CONCEPTUAL FOUNDATIONS OF FOOD TRACEABILITY AND STAKEHOLDER GOVERNANCE

2.1 Food Traceability Principles, Regulatory Requirements and Supply Chain Visibility

Food traceability refers to the capacity to identify and reconstruct food product movements, transformations, and ownership across successive supply chain stages [5]. Backward tracing establishes product origins and upstream suppliers, whereas forward tracking identifies downstream recipients and distribution destinations. End-to-end visibility integrates both functions across organisational boundaries [9]. Effective traceability depends on standardised product identifiers, batch records, transaction histories, processing events, and documented product transformations. Regulatory frameworks, including applicable food safety legislation and recognised traceability standards, establish requirements for retaining and retrieving relevant information [6]. Internal traceability documents movements and transformations within individual facilities, while external traceability connects transactions between trading partners [10]. Essential information includes production sources, processing histories, shipment dates, receiving organisations, and distribution locations. Consequently, complete and accurate records strengthen regulatory accountability, support contamination investigations, and facilitate targeted recalls by reducing uncertainty concerning affected products and their destinations [8].

2.2 Digital Traceability Technologies and Information Interoperability

Digital traceability infrastructure incorporates barcodes, radio-frequency identification, Internet of Things sensors, cloud databases, enterprise resource planning systems, and blockchain-based platforms to capture and exchange product information [11]. Automated identification reduces manual recording requirements and improves the accessibility of transaction histories across participating organisations. However, incompatible software architectures, inconsistent data structures, proprietary interfaces, and limited supplier capabilities can interrupt information continuity [7]. Standardised identifiers, common data models, and event-based information exchange provide mechanisms for linking product movements across heterogeneous systems [12]. Nevertheless, technological sophistication does not independently guarantee accurate records, complete transaction capture, or effective recall execution. Integration architecture must accommodate data validation, secure transmission, role-based access permissions, cybersecurity controls, and operational resilience. System availability and synchronisation reliability are equally important because inaccessible or delayed information can compromise traceability during contamination investigations. Accordingly, interoperability must be evaluated alongside information quality and operational accessibility [9].

2.3 Stakeholder Governance and Cross-Organisational Project Coordination

Stakeholder governance encompasses the allocation of decision-making authority, operational responsibilities, accountability mechanisms, and coordination procedures among organisations participating in traceability initiatives [13]. Producers, processors, logistics providers, retailers, technology vendors, and regulatory authorities contribute different capabilities and information obligations. Effective governance establishes arrangements for data sharing, integration oversight, implementation monitoring, and dispute resolution [8]. Supplier onboarding procedures, contractual requirements, data stewardship responsibilities, and confidentiality safeguards determine how consistently participants exchange reliable information. Governance maturity may therefore influence implementation schedules, transaction completeness, and cooperation during operational disruptions [14]. However, formal agreements alone cannot establish effective coordination without measurable participation and documented compliance. Clearly defined escalation pathways, incident communication protocols, and responsibility matrices are necessary for resolving integration failures and managing contamination investigations. Consequently, governance effectiveness should be assessed through both documented organisational arrangements and observable

coordination performance across supply chain participants [10].

2.4 Recall Readiness, Food Safety Risk Management and Integrated Governance Value

Recall readiness represents the combined organisational and technological capability to identify affected products, determine distribution destinations, communicate corrective instructions, and support timely product withdrawal [14]. Mock recalls, traceability exercises, incident simulations, and regulatory notification procedures provide structured opportunities to assess preparedness before actual contamination events [6]. Relevant performance dimensions include batch identification time, traceability coverage, stakeholder notification speed, and product reconciliation accuracy. Importantly, functional traceability software does not necessarily demonstrate operational recall effectiveness when supplier records remain incomplete or communication responsibilities are unclear [12]. Coordinated governance and reliable information exchange can improve the conditions required for effective incident response, although actual performance must be verified through testing. Accordingly, governance quality, digital information reliability, and recall readiness represent interconnected but independently measurable components of integrated food safety risk management [13].

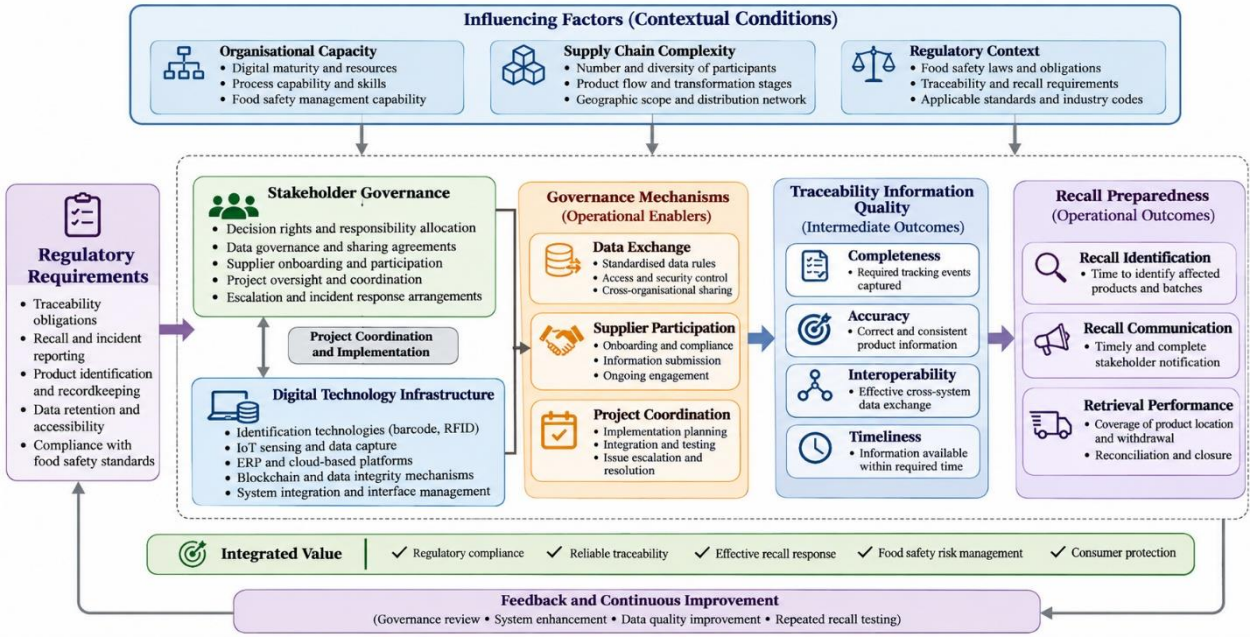


Figure 1. Integrated conceptual framework linking stakeholder governance, digital food traceability systems and recall readiness.

3. RESEARCH DESIGN AND MULTISOURCE DATA ACQUISITION

3.1 Study Setting, Project Population and Sampling Design

The proposed study will examine food traceability technology projects involving multiple organisations across production, processing, storage, transportation, distribution, and retail operations [12]. Eligible projects will demonstrate documented implementation activities, identifiable stakeholder participation, accessible transaction records, and evidence of recall readiness testing [15]. Analytical units will include individual projects, participating organisations, product movement transactions, and recall exercises, depending on the evaluation objective. Project characteristics will encompass investment scale, supply chain complexity, product perishability, technological architecture, and applicable regulatory requirements [13]. Stratified sampling will support comparisons across organisational sizes, product categories, technology types, and digital maturity levels. Where representative sampling proves impractical, purposive selection will prioritise information completeness and project diversity. These procedures will establish a comparative population suitable for examining governance arrangements, technological integration, information reliability, and recall preparedness while documenting potential selection limitations [16].

3.2 Stakeholder Governance, Coordination and Project Management Data

Stakeholder governance information will be obtained from organisational registers, governance charters, responsibility matrices, contractual agreements, implementation plans, and coordination meeting records [14]. Extracted variables will describe decision rights, supplier onboarding requirements, information ownership, escalation procedures, and dispute resolution arrangements. Participation records, training completion, governance reviews, and unresolved coordination issues will provide evidence of actual stakeholder engagement beyond formal documentation [17]. Project management datasets will capture approved milestones, implementation expenditure, integration delays, change requests, and corrective actions. Governance events will be linked chronologically to project activities using common project identifiers and documented reporting periods. This linkage will support examination of whether coordination practices correspond with implementation consistency, integration performance, and operational readiness [15]. Differences

between prescribed responsibilities and demonstrated stakeholder participation will be retained as distinct analytical measures to avoid overstating governance effectiveness.

3.3 Digital Traceability Systems and Technology Integration Records

Technology integration data will be acquired from architecture specifications, system configuration documents, interface inventories, deployment reports, and operational event logs [18]. Relevant components may include barcode identification, radio-frequency identification, Internet of Things sensors, blockchain platforms, enterprise resource planning systems, and cloud databases. Recorded variables will encompass interface completion, integration defects, data exchange failures, synchronisation latency, system downtime, and recovery events [12]. Standardised communication protocols and product identification structures will be documented to assess interoperability across heterogeneous platforms. Cybersecurity policies, access permissions, authentication arrangements, and system resilience records will provide additional operational context [16]. Deployment readiness will be distinguished from verified functionality through commissioning evidence and transaction testing. These records will enable comparative evaluation of technology integration quality, operational reliability, and the extent to which deployed infrastructure supports accessible, consistent, and timely traceability information.

3.4 Product Movement, Transaction and Traceability Data

Product traceability datasets will incorporate unique product identifiers, batch numbers, production dates, processing events, shipment documentation, receiving confirmations, and distribution records [19]. Critical tracking events and associated key data elements will be identified according to applicable regulatory obligations and agreed information standards. Transaction completeness will be evaluated by comparing required records against documented product movements, while identifier accuracy and timestamp consistency will support information quality assessment [17]. Common product and organisational identifiers will link transactions across producers, processors, logistics providers, distributors, and retailers. Particular attention will be given to missing traceability links, duplicate transactions, inconsistent batch transformations, and unverified receiving events [18]. Commercially sensitive information will be protected through controlled access, pseudonymisation where appropriate, and restricted reporting. These procedures will support reconstruction of product movement histories without exposing unnecessary proprietary information.

3.5 Recall Readiness Testing, Incident Records and Research Governance

Recall readiness evidence will be collected from mock recall protocols, exercise scenarios, incident reports, stakeholder notifications, and corrective action registers [15]. Recorded measures will include recall initiation time, affected batch identification, distribution destination verification, communication delays, and product reconciliation completeness. Actual recall records will be incorporated where available but analysed separately from simulated exercises because operational conditions and incident severity may differ [19]. Retrieval effectiveness will be assessed using documented product location and withdrawal confirmations rather than identification records alone. Exercise complexity, incomplete supplier participation, and inconsistent testing procedures will be recorded as potential sources of measurement bias [16]. Research governance will address confidentiality agreements, authorised data access, ethical oversight, secure information handling, and reproducible analytical documentation. These safeguards will support credible comparisons while protecting commercially sensitive and potentially identifiable operational information.

Table 1. Multisource Data Acquisition and Measurement Framework for Food Traceability Technology Projects

Data dimension	**Representative variables**	**Data sources**	**Analytical purpose**
Stakeholder governance	Responsibility allocation, participation, escalation, training	Governance charters, meeting records, responsibility matrices	Assess governance maturity
Project management	Milestones, implementation costs, delays, change requests	Project plans, financial records, progress reports	Evaluate delivery performance
Technology integration	Interface completion, downtime, integration failures, synchronisation delays	System logs, architecture specifications, commissioning records	Assess interoperability and reliability
Traceability transactions	Product identifiers, batch records, movement events, receiving confirmations	ERP systems, RFID records, barcode databases, traceability platforms	Measure traceability completeness and accuracy
Recall readiness	Identification time, notification time, retrieval coverage, reconciliation completeness	Mock recall reports, incident records, corrective action registers	Evaluate operational recall preparedness
Contextual factors	Supply chain complexity, product category, regulatory requirements, organisational maturity	Organisational documentation, regulatory records, external datasets	Support contextual adjustment and confounding assessment

4. DATA PREPARATION, TRACEABILITY INDICATORS AND RECALL READINESS MEASUREMENT

4.1 Data Cleaning, Standardisation and Cross-System Alignment

Data preparation will begin with duplicate removal, missingness assessment, transaction validation, and standardisation of product identifiers across participating organisations [17]. Stakeholder governance records, project milestones, system events, and product movements will be linked using consistent organisational identifiers and chronological references. Batch numbers, timestamps, measurement units, and transaction classifications will be harmonised across enterprise resource planning systems, supplier databases, and traceability platforms [20]. Automated validation rules will identify inconsistent records, impossible event sequences, and conflicting product transformations. Missing transactions will be distinguished from verified absence of movement to prevent misleading completeness estimates [18]. Chronological processing will preserve original event timestamps, restrict future information from earlier assessments, and maintain auditable transformation logs. These procedures will establish a reproducible analytical dataset suitable for comparative performance measurement.

4.2 Stakeholder Governance and Project Coordination Indicators

Stakeholder governance performance will be measured through participation rates, responsibility clarity, governance review completion, escalation effectiveness, and compliance with information-sharing obligations [21]. Supplier onboarding and training completion will be calculated relative to eligible participating organisations, while unresolved coordination issues will be assessed against agreed resolution deadlines. A governance maturity index will combine standardised indicators using transparent weights established through documented expert judgement or sensitivity testing [19]. Formal governance structures will be evaluated separately from observable participation and response performance to avoid equating documentation with effectiveness. Project coordination measures will include milestone adherence, outstanding stakeholder dependencies, and the duration of unresolved integration issues [22]. Comparisons across organisations and implementation phases will account for differences in project scale, contractual complexity, and reporting practices, ensuring that governance scores remain interpretable within their operational contexts.

4.3 Traceability Completeness, Accuracy and Information Quality

Traceability completeness will represent the proportion of required product movement records successfully captured across applicable supply chain stages [23]. Identifier accuracy, transaction consistency, missing critical tracking events, and batch transformation continuity will provide complementary information quality measures. For project \(i\), completeness will be calculated as:

$$TC_i(\%) = \frac{N_{\text{valid},i}}{N_{\text{required},i}} \times 100$$

where $N_{\text{valid},i}$ denotes validated required records and $N_{\text{required},i}$ represents the total records expected under applicable tracking requirements. The denominator will be established independently using operational and regulatory documentation [20]. Information latency will measure elapsed time between physical product movement and corresponding digital record availability. Complete records will not automatically be classified as accurate without independent verification [24]. Differences in supplier reporting obligations, technology capabilities, and transaction volumes will be considered when interpreting results. Together, these indicators will distinguish recorded information coverage from verified traceability reliability.

4.4 Technology Interoperability and Operational Reliability Indicators

Technology interoperability will be assessed using interface availability, successful data exchange rates, synchronisation delays, system downtime, and integration coverage across participating organisations [22]. Interface availability will represent the proportion of scheduled operating time during which required connections remain functional. Data exchange success will measure validated transmissions relative to attempted exchanges, excluding duplicates and unsuccessful retries from accepted transactions [25]. Integration coverage will identify the proportion of required trading partners connected through operational information interfaces. Automated identification reliability will be examined through barcode scanning failures, RFID reading errors, and incomplete event capture where relevant [18]. Unresolved integration defects, incompatible data formats, and delayed synchronisation will be documented separately. These measures will establish whether deployed infrastructure supports dependable information exchange, recognising that successful installation does not necessarily demonstrate end-to-end traceability functionality.

4.5 Recall Readiness and Response Performance Indicators

Recall readiness will be evaluated through affected batch identification time, stakeholder notification duration, traceability coverage, product reconciliation accuracy, and corrective action closure [24]. Identification time will measure the interval between exercise initiation and verified recognition of affected product batches. Notification performance will reflect elapsed time before designated stakeholders receive actionable recall instructions [21]. Traceability coverage will quantify affected distribution destinations successfully identified relative to independently established expected destinations. Product reconciliation will compare documented affected quantities with verified inventories, withdrawals, and outstanding units [25]. System-generated identification will be distinguished from confirmed physical isolation or retrieval. Exercise complexity, supply chain size, product characteristics, and scenario severity will inform contextual comparisons. Missing responses and incomplete supplier participation will be reported

explicitly, with sensitivity analyses assessing their influence on estimated recall preparedness.

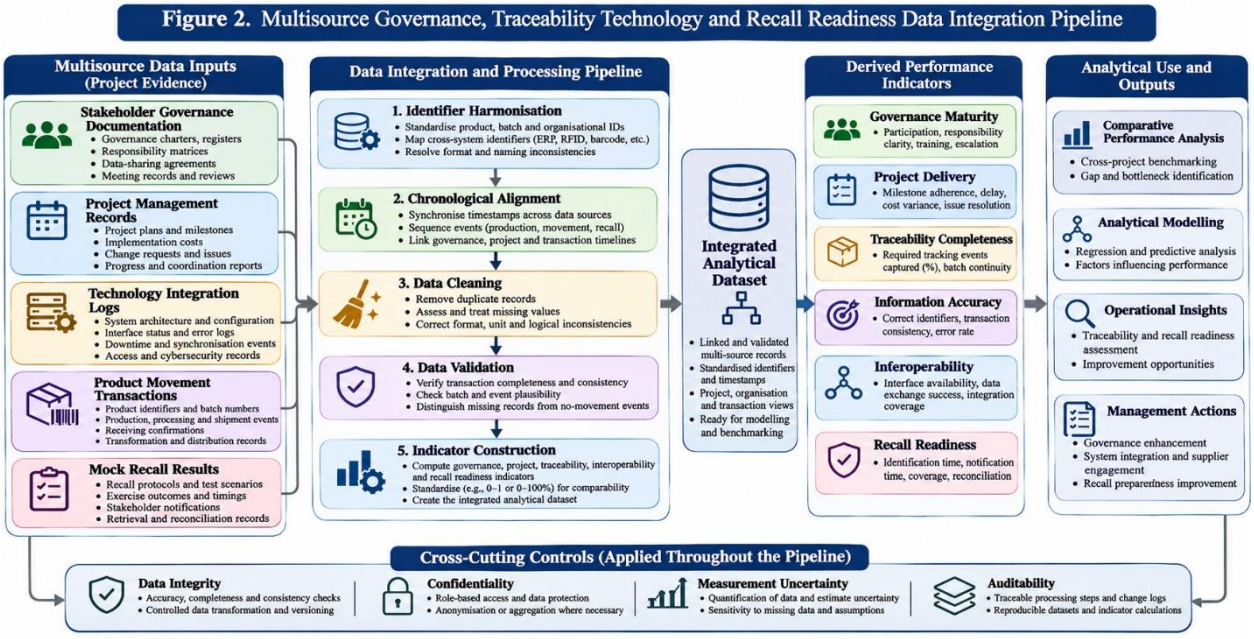


Figure 2. Multisource governance, traceability technology and recall readiness data integration pipeline.

5. ANALYTICAL MODELLING, GOVERNANCE EVALUATION AND RECALL READINESS TESTING

5.1 Evaluation Objectives, Analytical Framework and Model Selection

The analytical framework was developed to evaluate relationships between stakeholder governance, technology implementation, traceability information quality, and operational recall preparedness [23]. Three interconnected evaluation modules were established to examine governance and project coordination, information reliability and interoperability, and recall response effectiveness. Descriptive analysis was used to characterise implementation patterns, while predictive models were specified to estimate performance relationships and identify operational vulnerabilities [26]. Causal evaluation was considered where credible comparison groups and appropriate identification assumptions were available. Explanatory variables included governance maturity, supplier participation, integration coverage, and transaction completeness, with adjustments for organisational size, product characteristics, and supply chain complexity [24]. Model selection was guided by data structure, sample size, and temporal coverage. Technology adoption was distinguished from verified traceability functionality and demonstrated recall readiness.

5.2 Stakeholder Governance and Project Coordination Modelling

Governance effectiveness was examined by modelling associations between stakeholder participation, responsibility clarity, supplier onboarding, and technology project delivery outcomes [27]. Multivariable regression was specified to estimate relationships with implementation delays, milestone deviations, and unresolved integration defects, while hierarchical models accommodated observations nested within organisations or supply chains. Nonlinear specifications were considered where governance effects exhibited thresholds or interactions [25]. Organisational size, project investment, supply chain complexity, technology architecture, and regulatory environment were incorporated as contextual controls. Particular attention was directed toward whether documented escalation procedures and active stakeholder participation corresponded with fewer coordination failures [28]. Alternative governance index weights and measurement definitions were examined through sensitivity analysis. Estimated coefficients, confidence intervals, and model diagnostics were designated for reporting where empirical data permitted. Because governance arrangements were not randomly assigned, observed associations were not interpreted as definitive causal effects.

5.3 Traceability Information Quality and Interoperability Analysis

Traceability information quality was evaluated through relationships between integration coverage, interface availability, transaction completeness, identifier accuracy, and synchronisation latency [26]. Regression models were developed to examine whether standardised identifiers and reliable data exchanges corresponded with fewer missing critical tracking events. Where transaction structures permitted, network analysis represented organisations as nodes and documented product movements as directed connections [29]. Graph-based measures were applied to identify disconnected suppliers, incomplete distribution pathways, and vulnerable information exchange interfaces. Supplier participation, digital maturity, product perishability, and transaction volumes were incorporated as explanatory or contextual variables [24]. Comparative analyses distinguished technology platforms from their

implementation quality, recognising that identical architectures could produce different operational outcomes. Robustness testing examined alternative completeness thresholds, missing-record assumptions, and product categories. These procedures provided a basis for assessing whether integration improvements corresponded with verifiable continuity across supply chain transactions.

5.4 Recall Readiness Testing and Operational Response Evaluation

Recall readiness was assessed using structured mock scenarios involving suspected contamination, incorrect labelling, and affected batch identification [30]. Each exercise followed documented initiation, backward tracing, forward tracking, stakeholder notification, product location, and reconciliation procedures. Identification time, notification duration, affected destination coverage, and verified retrieval performance were recorded [27]. Recall coverage for exercise j was calculated as:

$$RC_j(\%) = \frac{D_{\text{verified},j}}{D_{\text{expected},j}} \times 100$$

where $D_{\text{verified},j}$ represented correctly identified affected destinations and $D_{\text{expected},j}$ denoted independently established affected destinations. Comparative models examined whether governance maturity, transaction completeness, and interoperability predicted recall performance [25]. Repeated exercises supported assessment of corrective action effectiveness where testing conditions remained comparable. However, simulated response outcomes were not interpreted as demonstrated effectiveness during actual emergencies. Scenario severity, supply chain size, incomplete stakeholder participation, and exercise familiarity were considered when interpreting performance differences.

5.5 Integrated Governance–Technology–Recall Performance Assessment

An integrated evaluation framework combined governance maturity, project delivery, traceability completeness, interoperability, and recall preparedness into a multidimensional performance profile [28]. Individual indicators were initially assessed separately to preserve distinctions between organisational coordination, technological functionality, and operational response. Comparative scenarios examined alternative supplier participation levels, integration architectures, governance arrangements, and implementation expenditure [30]. Where reliable cost and performance information was available, cost-effectiveness analysis compared incremental expenditure against improvements in verified traceability coverage or recall response time. Financial efficiency was distinguished from consumer protection outcomes, which could not be inferred solely from operational indicators [26]. Minimum regulatory requirements, information integrity obligations, and mandatory recall procedures were treated as non-negotiable evaluation constraints. Sensitivity testing examined whether project rankings changed under alternative indicator weights. This approach provided a structured basis for evaluating technology investment, governance improvements, and supply chain accountability without treating regulatory compliance as interchangeable with financial or schedule performance.

5.6 Model Validation, Sensitivity Analysis and Analytical Robustness

Predictive models were evaluated using project-level or chronological training, validation, and independent testing partitions to minimise information leakage [29]. Cross-project validation was employed to assess generalisability across organisations, product categories, and technology architectures. Model fit, prediction errors, confidence intervals, and calibration were assessed where appropriate [23]. Sensitivity analyses examined alternative governance weights, traceability completeness definitions, missing transaction assumptions, and recall scenarios. Additional tests considered incomplete supplier participation, measurement uncertainty, and contextual differences [30]. Potential confounding, selection bias, and limited sample representativeness were documented. Transparent reporting of modelling assumptions and robustness results distinguished defensible findings from exploratory relationships requiring further validation.

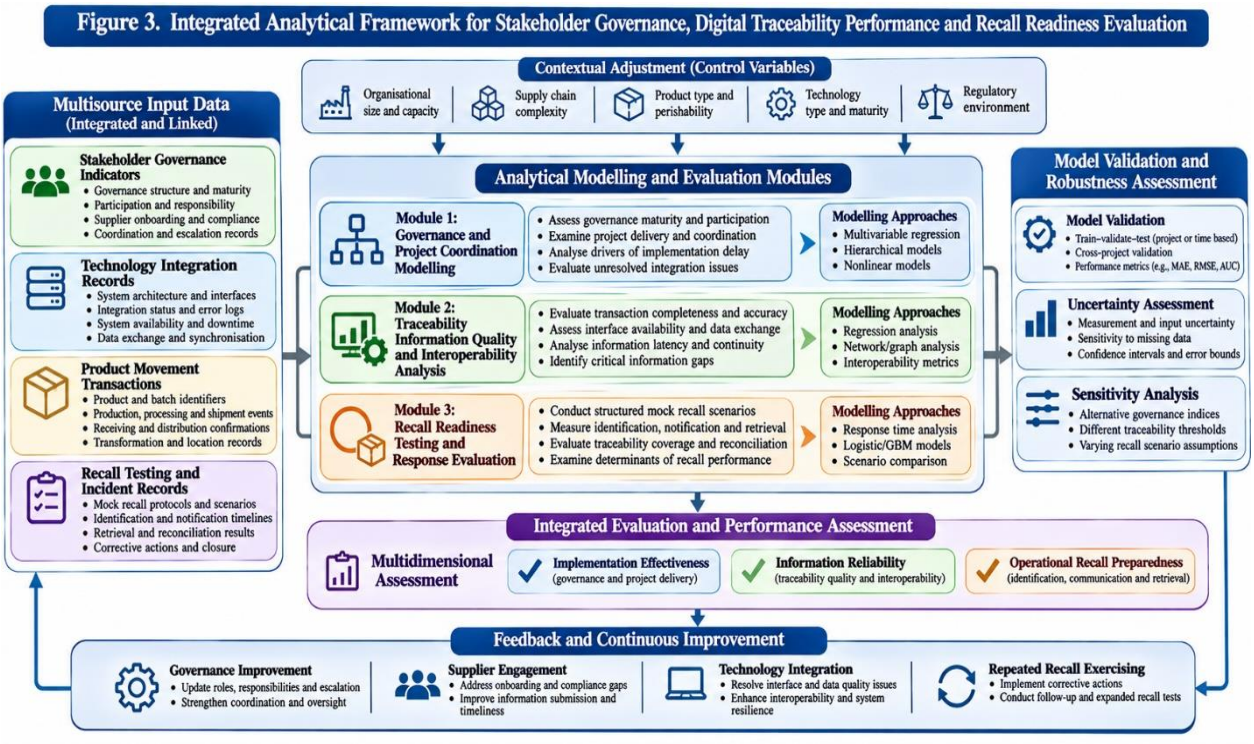


Figure 3. Integrated analytical framework for stakeholder governance, digital traceability performance and recall readiness evaluation.

6. PERFORMANCE BENCHMARKING AND MANAGERIAL IMPLICATIONS

6.1 Stakeholder Governance and Project Delivery Performance

Stakeholder governance performance was assessed through governance maturity, participation rates, responsibility allocation, supplier onboarding, and compliance with coordination requirements [28]. Project delivery indicators included milestone adherence, implementation delays, unresolved integration issues, and documented corrective actions. Comparative assessments examined differences across organisational sizes, technology architectures, and supply chain configurations [31]. Particular attention was directed toward whether stronger governance arrangements corresponded with fewer integration delays and more effective stakeholder coordination. Recurring vulnerabilities involving unclear accountability, inconsistent communication, and incomplete contractual obligations were incorporated into the evaluation framework [29]. Formal governance documentation was distinguished from demonstrated participation and operational responsiveness. These comparisons provided a basis for interpreting how organisational coordination influenced technology implementation and established contextual foundations for subsequent traceability reliability and recall preparedness assessments.

6.2 Traceability Data Quality and Technology Interoperability Benchmarking

Traceability performance was benchmarked using transaction completeness, identifier accuracy, information latency, and continuity of product movement records across participating organisations [32]. Technology interoperability was assessed through interface availability, successful data exchange rates, integration coverage, and operational reliability. Comparisons accounted for product complexity, transaction volumes, organisational digital maturity, and differences in technology platforms [30]. The evaluation examined whether greater integration coverage corresponded with more complete and reliable traceability information. Particular emphasis was placed on identifying missing critical tracking events, inconsistent batch identifiers, and disconnected supplier records [33]. Operational system functionality was distinguished from verified end-to-end traceability capability because successful data transmission did not necessarily establish information accuracy. These indicators supported identification of information gaps that could delay contamination investigations, compromise affected product identification, and weaken coordinated recall responses across supply chains.

6.3 Mock Recall Performance and Operational Readiness

Recall readiness was evaluated using affected batch identification time, stakeholder notification duration, traceability coverage, and product reconciliation accuracy [34]. Comparative assessments considered differences across testing cycles, product categories, participating organisations, and supply chain configurations. Relationships between information quality and recall performance were examined to determine whether more complete transaction records corresponded with faster identification and improved response coverage [31]. Potential bottlenecks included missing supplier information, delayed notifications, inconsistent distribution records, and incomplete product location verification. Simulated recall effectiveness was distinguished from demonstrated performance during actual contamination incidents because operational pressures and stakeholder behaviour could differ substantially [35]. Repeated exercises were incorporated into the assessment framework to support corrective action verification, identify persistent coordination

weaknesses, and strengthen operational preparedness.

6.4 Integrated Governance–Traceability–Recall Benchmarking

Integrated benchmarking combined governance maturity, project delivery, traceability completeness, information reliability, interoperability, and recall readiness into comparable multidimensional performance profiles [33]. The evaluation examined whether projects characterised by stronger stakeholder coordination also demonstrated more reliable transaction records and improved recall preparedness. Potential trade-offs involving implementation expenditure, system complexity, supplier participation, and operational capability were assessed through alternative benchmarking scenarios [29]. Indicator weighting assumptions were examined to determine whether comparative interpretations remained stable under different evaluation priorities. Regulatory compliance, mandatory traceability requirements, and information integrity were maintained as minimum performance conditions rather than interchangeable scoring dimensions [35]. Comparative findings were organised to inform technology investment prioritisation, supplier governance improvements, integration planning, and incident response procedures. This approach supported systematic evaluation without assuming that favourable project delivery indicators necessarily established effective consumer protection.

Table 2. Integrated Benchmarking of Stakeholder Governance, Traceability Technology Performance and Recall Readiness

Evaluation dimension	**Performance indicator**	**Comparison basis**	**Interpretation**
Stakeholder governance	Governance maturity and participation rate	Defined governance requirements	Coordination effectiveness
Project delivery	Implementation delay and cost variance	Approved project baselines	Delivery efficiency
Traceability completeness	Required tracking events captured (%)	Applicable traceability requirements	Information coverage
Data quality	Identifier accuracy and transaction consistency	Validated source records	Information reliability
Technology interoperability	Successful data exchange rate (%)	Required system interfaces	Integration effectiveness
Recall readiness	Identification time and recall coverage	Standardised mock recall scenarios	Operational preparedness

6.5 Sensitivity Analysis and Practical Management Recommendations

Sensitivity analysis examined whether comparative interpretations remained stable under alternative governance indices, traceability completeness thresholds, and recall testing assumptions [32]. Particular attention was directed toward supply chain segments requiring improved supplier onboarding, stronger information exchange controls, and additional system integration support. Early stakeholder engagement, clearly assigned data responsibilities, and documented escalation procedures were identified as important management priorities [34]. The framework enabled project managers to prioritise corrective actions according to verified information gaps and operational vulnerabilities. Implications extended to food manufacturers, logistics providers, retailers, technology vendors, and regulatory authorities. Recommendations derived from established performance evidence were distinguished from proposed interventions requiring prospective evaluation.

7. DISCUSSION, LIMITATIONS AND CONCLUSIONS

7.1 Integrated Contribution and Supply Chain Management Implications

The study established an integrated framework for evaluating food traceability technology projects through stakeholder governance, information reliability, system interoperability, and recall readiness. Its principal contribution involved connecting digital infrastructure implementation with organisational accountability and operational food safety preparedness. The framework demonstrated how governance arrangements, supplier coordination, and information quality could be evaluated alongside technology performance and incident response capabilities. Importantly, successful system deployment was distinguished from verified end-to-end traceability and demonstrated recall effectiveness. Integrated performance indicators provided a structured basis for technology investment decisions, regulatory compliance monitoring, and corrective action prioritisation. These contributions offered practical guidance for project managers, food supply chain organisations, technology vendors, and regulatory authorities seeking accountable traceability implementation.

7.2 Methodological Limitations and Future Research

The proposed evaluation framework was subject to limitations involving incomplete transaction records, inconsistent data standards, restricted commercial information, and uneven supplier participation. Selection bias and contextual confounding complicated attribution of recall performance differences to particular technologies or governance arrangements. Simulated recall exercises also provided imperfect representations of actual

contamination incidents, particularly where observation periods were short or stakeholder participation was incomplete. Additional uncertainties arose from heterogeneous system architectures, inconsistent governance reporting, and differences in regulatory requirements. Future research should incorporate longitudinal project assessments, repeated recall simulations, and independent validation across product categories and jurisdictions. Further investigation of lifecycle technology expenditure, cybersecurity resilience, cross-border interoperability, and supplier inclusion would strengthen the framework's applicability.

7.3 Conclusions and Conditions for Responsible Implementation

Effective food traceability projects required coordinated stakeholder governance, reliable information exchange, interoperable technologies, and independently verified recall preparedness. The study integrated conceptual foundations, multisource data acquisition, performance indicator development, analytical modelling, and comparative benchmarking into a coherent evaluation framework. Traceability effectiveness was assessed through information reliability and operational testing rather than assumed from technology deployment. Sustainable implementation therefore depended on transparent accountability, standardised data practices, continuous performance monitoring, and repeated recall exercises to strengthen supply chain resilience and consumer protection.

REFERNCE

1. Razak GM, Hendry LC, Stevenson M. Supply chain traceability: a review of the benefits and its relationship with supply chain resilience. Production planning & control. 2023 Aug 18;34(11):1114-34.

2. Sriranjani S, Adeyeye SA. Internet of Things and blockchain applications in food audit, authenticity, and traceability: A systematic review. Food Biomacromolecules. 2026.

3. Bekkouche S, de-Magistris T. Digitalization in the European agri-food supply chain: A scoping review of traceability, transparency, and sustainability. Frontiers in Blockchain. 2025 Nov 21;8:1701872.

4. Hallak JC, Tacsir A. Traceability systems as a differentiation tool in agri-food value chains: A framework for public policies in Latin America. Journal of Agribusiness in Developing and Emerging Economies. 2022 Aug 2;12(4):673-88.

5. Solarin A, Chukwunweike J. Dynamic reliability-centered maintenance modeling integrating failure mode analysis and Bayesian decision theoretic approaches. *International Journal of Science and Research Archive*. 2023 Mar;8(1):136. doi:10.30574/ijsra.2023.8.1.0136.

6. Pham HT, Huang C, Jiang F, Elphick-Darling R, Bonti A, Pan L, Abdelrazek M. Blockchain-empowered unified services for streamlined traceability implementation in food supply chain: a demonstration in Australian seafood traceability. Scientific Reports. 2026 Mar 23;16(1):18281.

7. Nnabueze SB, Ike PN, Olatunde-Thorpe J, Aifuwa SE, Oshoba TO, Ogbuefi E, Akokodaripon D. End-to-end visibility frameworks improving transparency, compliance, and traceability across complex global supply chain operations. International Journal of Multidisciplinary Futuristic Development. 2021 Jul;2(2):50-60.

8. Gooch M, Dent B, Sylvia G, Cusack C. Rollout strategy to implement interoperable traceability in the seafood industry. Journal of food science. 2017 Aug;82(S1):A45-57.

9. Bhandari, Ambika Baniya. 2026. “Quality Control Frameworks for Electronic Health Record Data Workflows in Resource-Constrained Settings: A Structured Review With Implications for Global Health Information Management”. *Current Journal of Applied Science and Technology* 45 (8):1-16. https://doi.org/10.9734/cjast/2026/v45i84728.

10. Dasaklis TK, Voutsinas TG, Tsoulfas GT, Casino F. A systematic literature review of blockchain-enabled supply chain traceability implementations. Sustainability. 2022 Feb 20;14(4):2439.

11. Duan K, Pang G, Park Y. Traceability and Transparency in Global Food Value Chains. InGlobal Food Value Chains: An In-depth Exploration of International Trade Dynamics 2026 Jan 11 (pp. 217-242). Cham: Springer Nature Switzerland.

12. Chatzinikolaou S, Vassiliou G, Gianniou M, Vassalos M, Papadakis N. Integrating Veterinary Public Health Data into EPCIS-Based Digital Traceability for Dairy Supply Chains. Foods. 2026 May 1;15(9):1566.

13. Hastig GM, Sodhi MS. Blockchain for supply chain traceability: Business requirements and critical success factors. Production and Operations Management. 2020 Apr;29(4):935-54.

14. Sharma S, Patil SV. Development of holistic framework incorporating collaboration, supply-demand synchronization, traceability and vertical integration in agri-food supply chain. International Journal of Information Systems and Supply Chain Management (IJISSCM). 2011 Oct 1;4(4):18-

45.

15. İndap Ş, Tanyaş M. Blockchain applications for traceability and food safety in agri-food supply chain: cherry product application. Journal of Enterprise Information Management. 2023 Jul 26.

16. Bhatt T, Cusack C, Dent B, Gooch M, Jones D, Newsome R, Stitzinger J, Sylvia G, Zhang J. Project to develop an interoperable seafood traceability technology architecture: issues brief. Comprehensive Reviews in Food Science and Food Safety. 2016 Mar;15(2):392-429.

17. Cao S, Xu H, Bryceson KP. Blockchain traceability for sustainability communication in food supply chains: an architectural framework, design pathway and considerations. Sustainability. 2023 Sep 8;15(18):13486.

18. Bosona T, Gebresenbet G. The role of blockchain technology in promoting traceability systems in agri-food production and supply chains. Sensors. 2023 Jun 5;23(11):5342.

19. Anastasiadis F, Apostolidou I, Tsolakis N. Challenges and opportunities of supply chain traceability: insights from emergent agri-food sector. Supply Chain Management: An International Journal. 2025 Feb 3;30(1):106-26.

20. Hoang TT, Bell JE, Goldsby TJ. Making supply chain traceability strategic: insights from the food industry. International Journal of Physical Distribution & Logistics Management. 2023 Sep 7;53(9):913-45.

21. Kechagias EP, Panayiotou NA, Gayialis SP, Papadopoulos GA. A scoping review on digital technology-enabled food supply chain traceability for food fraud prevention. Logistics. 2026 Aug;10(8):184.

22. McEntire J, Bhatt T. Pilot Projects for Improving Product Tracing along the Food Supply System–Final Report. Chicago, IL: Institute of Food Technologists. 2013.

23. Pulita JG, Pereira CR, Silva AL. How does traceability support stakeholders in food recall management? A case study of the beef chain. Gestão & Produção. 2024 Dec 6;31:e3324.

24. Iyanuoluwa Oluwafemi. (2024). ENVIRONMENTAL MONITORING STRATEGIES INTEGRATING MOLECULAR DETECTION TECHNOLOGIES TO ENHANCE AGRICULTURAL BIOSECURITY AND SUSTAINABLE CROP PRODUCTION SYSTEMS. International Journal Of Engineering Technology Research & Management (IJETRM), 10(12), 757–772. https://doi.org/10.5281/zenodo.21152414

25. Hall DC, Johnson-Hall TD. The value of downstream traceability in food safety management systems: an empirical examination of product recalls. Operations Management Research. 2021 Jun;14(1):61-77.

26. Bhatti A, Marqui A. Cross-sector Collaboration for Digital Food Safety. Food Safety in the Digital Age: Fundamentals to Applications. 2026 Jul 28:271-86.

27. Kumar S, Heustis D, Graham JM. The future of traceability within the US food industry supply chain: A business case. International Journal of Productivity and Performance Management. 2015 Jan 12;64(1):129-46.

28. Dashti L. *Modelling halal meat traceability in Kuwait: a stakeholder-informed traceability framework using discrete-event simulation* (Doctoral dissertation, Loughborough University).

29. Uyar H, Papanikolaou A, Kapassa E, Touloupos M, Rizou S. Blockchain-enabled traceability and certification for frozen food supply chains: A conceptual design. Smart Agricultural Technology. 2025 Dec 1;12:101085.

30. Kanchanasuwan S, Jindabot T, Lau KH. Blockchain adoption and food traceability governance in export-oriented agri-food supply chains: evidence from Thailand. British Food Journal. 2026 Sep 8:1-9.

31. Patel MP, Thiyagarajan S, Borse D. Transforming traceability as a strategic lever of resilient and efficient supply chains. Operations Management Research. 2026 Sep;19(3):43.

32. Lai MB, Vergamini D, Brunori G. Food supply chain: a framework for the governance of digital traceability. Foods. 2025 Jun 9;14(12):2032.

33. Bhatt T, Hickey C, McEntire JC. Pilot projects for improving product tracing along the food supply system. Journal of food science. 2013 Dec;78(s2):B34-9.

34. Gaffari MA. Explainable machine learning for predicting depression risk using sleep patterns, self-esteem, and psychosocial factors. International Journal of Computer Applications Technology and Research. 2026;15(11):26–37. doi:10.7753/IJCATR1511.1003.

35. Cordeiro M, Ferreira JC. Beyond traceability: Decentralised identity and digital twins for verifiable product identity in agri-food supply chains. Applied Sciences. 2025 May 28;15(11):6062.