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# Strengthening Digital-Based Hazard Analysis and Critical Control Points (HACCP) Systems to Support Food Supply Chain Traceability

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**ABSTRACT**

This study aims to examine the strengthening of digital-based Hazard Analysis and Critical Control Points (HACCP) systems to support food supply chain traceability. The issue is important because conventional HACCP practices often rely on manual records, fragmented documentation, and delayed verification, which can weaken food safety control and product tracking. This research used a qualitative case study approach involving HACCP team leaders, quality assurance staff, production managers, warehouse officers, operators, suppliers, and distribution actors selected through purposive and snowball sampling. Data were collected through semi-structured interviews, limited participant observation, and documentation review, then analyzed using thematic analysis supported by the interactive model of Miles, Huberman, and Saldaña. The findings reveal five main themes: improved critical control point monitoring, traceability as shared responsibility, gaps between technology availability and user readiness, the role of food safety culture, and the need for data integration across the supply chain. These findings show that digital HACCP improves access to food safety data, but its effectiveness depends on disciplined data entry, worker competence, clear procedures, and coordination among supply chain actors. The study contributes to a socio-technical understanding of digital HACCP by linking food safety management, traceability governance, and organizational readiness. The findings imply that food businesses and regulators should support gradual implementation, continuous training, internal audits, and integrated traceability systems. Future studies may develop a maturity model for digital HACCP in developing-country food supply chains.



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## 1. Introduction

Food safety has become a critical issue in modern food supply chains because food products now move through complex networks of suppliers, processors, distributors, retailers, and consumers. This complexity increases the risk of biological, chemical, and physical hazards when control systems fail at one or more stages of the chain. The Hazard Analysis and Critical Control Points system, known as HACCP, remains one of the most widely used preventive systems for identifying, monitoring, and controlling food safety risks. However, conventional HACCP practices often depend on manual records, paper-based monitoring, and fragmented documentation. These practices can delay corrective action, weaken audit readiness, and limit product traceability when food safety incidents occur.

Digital transformation has created new opportunities to strengthen HACCP implementation through real-time monitoring, automated documentation, data integration, and faster verification. Technologies such as digital forms, sensors, Internet of Things devices, blockchain, cloud databases, QR codes, and traceability platforms can support the recording of critical control points from raw material receipt to final distribution. Recent studies show that digital traceability can improve transparency, accountability, and responsiveness in agri-food supply chains. Even so, digital systems do not automatically solve food safety problems. Their effectiveness depends on user readiness, organizational commitment, infrastructure capacity, data governance, and coordination among supply chain actors.

In the Indonesian context, the need for digital-based HACCP is increasingly relevant because the national food supply chain involves large industries, small and medium enterprises, traditional markets, halal supply chains, cold chains, and inter-island distribution systems. These conditions create practical challenges in maintaining consistent food safety records and tracing product movement across different actors. Many food businesses still rely on manual monitoring sheets, separate spreadsheets, informal communication, and incomplete documentation. This situation makes it difficult to verify whether critical limits have been monitored consistently, whether deviations have been corrected, and whether products can be traced quickly during a food safety concern.

This issue is important because food traceability is not only a technical requirement. It also relates to consumer protection, public trust, business continuity, regulatory compliance, and the credibility of food safety governance. A digital HACCP system can help businesses identify hazards earlier, document corrective actions more accurately, and connect safety data across the supply chain. From a managerial perspective, digital HACCP can support faster decision-making and reduce dependence on scattered paper records. From a social and institutional perspective, however, its implementation requires changes in work routines, employee discipline, trust between actors, and shared responsibility for data accuracy.

Previous studies have discussed HACCP, digital traceability, blockchain, IoT, halal supply chains, and food safety management systems. However, many of these studies focus on technological models, system architecture, quantitative performance, or literature reviews. Fewer studies have explored how food business actors experience the transition from manual HACCP to digital HACCP in daily operations. Limited attention has also been given to the meanings, barriers, adaptation processes, and practical negotiations that occur when workers, quality managers, suppliers, and distributors use digital records to support traceability. This gap shows the need for a qualitative study that can capture the lived experiences and operational realities behind digital HACCP implementation.

Therefore, this study aims to examine how digital-based HACCP systems can be strengthened to support food supply chain traceability. The study focuses on the experiences of food business actors, the implementation of digital monitoring at critical control points, the barriers faced in documentation and data integration, and the strategies used to improve traceability across the supply chain. Theoretically, this study contributes to the development of socio-technical perspectives in food safety management and digital supply chain governance. Practically, the findings are expected to provide insights for food industries, small food enterprises, auditors, regulators, and supply chain managers in designing digital HACCP systems that are usable, verifiable, and aligned with field conditions.

## 2. Materials and Methods

This study uses a qualitative approach with a case study design. This design was selected because the research focuses on understanding processes, experiences, barriers, and strategies in strengthening digital-based HACCP systems to support food supply chain traceability. A case study is suitable because digital HACCP implementation is not only a technical issue, but also involves organizational readiness, worker behavior, data governance, food safety culture, and coordination among supply chain actors. Through this approach, the study can explore how digital HACCP is interpreted, practiced, and adjusted in real operational settings.

The research will be conducted in food processing businesses, food supply chain units, or food enterprises that have implemented, developed, or initiated digital documentation for HACCP-related activities. The research location may include food industries, certified small and medium food enterprises, cold chain operators, halal food supply chain actors, or fresh and processed food distribution networks. The study will be carried out for approximately three to four months, covering preliminary observation, participant recruitment, data collection, data validation, and thematic analysis. The selected site must have direct relevance to HACCP implementation, critical control point monitoring, digital recording, and product traceability.

Participants will consist of key informants and supporting informants. Key informants may include HACCP team leaders, quality assurance staff, production managers, warehouse officers, operators responsible for monitoring critical control points, distribution staff, and digital system users. Supporting informants may include suppliers, logistics partners, internal auditors, food safety consultants, or local regulatory representatives. Participants will be selected using purposive sampling based on several criteria: direct involvement in HACCP activities, experience in food safety documentation, knowledge of traceability processes, and willingness to provide detailed information. Snowball sampling may also be used when initial informants recommend other actors who are relevant to the food supply chain process.

Data will be collected through semi-structured interviews, limited participant observation, documentation review, and methodological triangulation. Semi-structured interviews will explore participants' experiences in using digital HACCP records, monitoring critical limits, reporting deviations, applying corrective actions, and tracing food products. Observation will focus on production flow, raw material receiving, temperature monitoring, sanitation practices, storage, distribution, and digital data entry. Documentation review will include HACCP plans, monitoring forms, corrective action records, audit reports, standard operating procedures, digital screenshots, traceability logs, and relevant quality control documents. These techniques are used to obtain rich data from different sources and to understand how digital HACCP works in practice.

Data validity will be ensured through source triangulation, method triangulation, member checking, and audit trail. Source triangulation will compare information from quality managers, operators, distributors, suppliers, and documents. Method triangulation will compare interview data, observation notes, and documentary evidence. Member checking will be conducted by asking selected participants to review summaries of interview findings to ensure that the researcher's interpretation reflects their experiences. An audit trail will be maintained by documenting the research process, interview guides, field notes, coding decisions, data reduction procedures, and analytical memos. These steps are used to strengthen credibility, dependability, and confirmability.

The data will be analyzed using thematic analysis supported by the interactive model of Miles, Huberman, and Saldaña. The analysis will involve data condensation, data display, conclusion drawing, and verification. Interview transcripts and field notes will be read repeatedly to identify meaningful units. Initial codes may include digital readiness, monitoring accuracy, user resistance, documentation barriers, corrective action, data integration, supply chain coordination, and traceability verification. These codes will then be grouped into broader themes, such as organizational readiness, digital HACCP practices, implementation constraints, traceability mechanisms, and strengthening strategies. The analysis will be conducted iteratively so that the final themes reflect the actual experiences and meanings found in the field.

Ethical procedures will be applied throughout the research process. Participants will receive information about the purpose of the study, the type of data collected, their right to withdraw, and the confidentiality of their identity. Company names, personal names, and sensitive operational data may be anonymized. Data will be used only for academic purposes. This methodological design is expected to produce a detailed and credible understanding of how digital-based HACCP systems can support traceability in food supply chains while still considering the practical limitations faced by food business actors.

## 3. Results and Discussions

The findings show that digital-based HACCP was understood by participants as more than a shift from paper records to electronic forms. Participants viewed it as a new way to control food safety risks, document critical control points, and trace product movement across the supply chain. Most participants stated that manual records were still useful, but they often caused delays during audits, internal evaluations, and product complaint investigations. One quality assurance officer stated, “Before using digital records, we had to open many folders to trace one batch. Now the data can be found faster, but the system still depends on staff discipline.” This statement shows that digital HACCP improved access to information, but its success still relied on consistent human input.

The first major theme was the improvement of critical control point monitoring. Digital forms, temperature logs, QR-based batch records, and cloud storage helped staff record critical limits more systematically. Operators could document temperature, processing time, sanitation checks, deviations, and corrective actions in a structured format. Observation also showed that digital reminders reduced missing records because staff received prompts to complete monitoring data. This finding supports Sartoni et al. (2025), who explain that digitalisation can strengthen the design, operation, and maintenance of food safety management systems, including HACCP-related activities.

The second theme was traceability as a shared responsibility. Participants did not see traceability as the duty of the quality assurance team alone. It involved production staff, warehouse officers, suppliers, distributors, and administrative workers. One warehouse officer explained, “If the supplier code is wrong from the beginning, the next process also becomes difficult to trace.” This finding shows that traceability depends on data accuracy from the first point of entry. Digital HACCP helped connect raw material sources, batch identity, processing records, storage conditions, and distribution routes. However, the system became weak when one actor entered incomplete or inconsistent data.

The third theme was the gap between technology availability and user readiness. Some participants stated that digital tools were available, but not all workers felt confident using them. Older workers and temporary staff often needed repeated training. Several participants also reported that unstable internet access, limited devices, and unclear system instructions slowed implementation. One production supervisor said, “The system is good, but when production is busy, staff sometimes choose the fastest way, and the data are completed later.” This finding shows that digital HACCP can create new risks when real-time recording becomes delayed or treated only as an administrative requirement.

The fourth theme was the role of food safety culture in sustaining digital HACCP. Participants from units with strong supervision, clear routines, and regular internal audits showed better compliance with digital recording. In contrast, units with weak monitoring tended to complete digital records mainly before audits. Documentation review also showed that some corrective action reports were complete, while others lacked root-cause explanations. This pattern indicates that digital tools cannot replace food safety culture. They only strengthen HACCP when workers understand why accurate records matter for product safety, consumer protection, and supply chain accountability.

The fifth theme was the need for data integration across the supply chain. Internal digital HACCP records helped production control, but traceability remained limited when suppliers and distributors used different systems. Product tracking became difficult when raw material data, transport temperature, delivery records, and distribution logs were not connected. This finding is in line with Charlebois et al. (2024), who argue that digital traceability can improve food safety, transparency, operational efficiency, and consumer trust when supported by compatible systems and clear governance. It also confirms Lai et al. (2025), who emphasize that digital traceability requires coordination structures that connect actors, data, and decision-making processes.

**Discussion**

The findings indicate that strengthening digital-based HACCP requires a socio-technical approach. Technology provides speed, structure, and visibility, but human behavior, organizational routines, and inter-actor coordination determine whether the system works in practice. This finding supports Sartoni et al. (2025), who identify training, resistance to change, system adaptability, data entry, fragmentation, and financial constraints as key issues in food safety management system digitalisation. This study extends that view by showing that these constraints appear in daily routines, especially when workers face time pressure, limited devices, unstable internet access, and unclear responsibility for data accuracy.

The improvement of critical control point monitoring confirms that HACCP remains central in modern food safety management. Radu et al. (2023) show that HACCP continues to be a major focus in food quality and safety management research. This study adds a qualitative perspective by showing that digitalisation changes the meaning of monitoring. Monitoring is no longer limited to completing forms. It becomes a process of producing traceable, auditable, and shareable food safety data. This shift is important because digital records can support faster verification, but they may also create false confidence if workers enter data after the process or without direct observation.

The finding on shared responsibility strengthens the view that traceability depends on supply chain governance. Lai et al. (2025) argue that digital traceability requires governance structures that shape system design, implementation, and effectiveness. In this study, governance appeared in how tasks were distributed among suppliers, production units, warehouses, and distributors. When responsibilities were unclear, digital HACCP became fragmented. When roles, data standards, and verification procedures were clearer, digital records supported stronger coordination. This means that food businesses should not only invest in software. They also need clear procedures, accountability mechanisms, and shared data standards.

The finding on user readiness offers a critical view of digital transformation in food safety. Digital HACCP is often promoted as a solution for traceability, but field data show that adoption is uneven. Workers may understand the importance of HACCP, yet still struggle with digital interfaces, limited devices, and production pressure. This finding differs from technology-centered studies that focus mainly on the potential of blockchain, IoT, or cloud-based platforms. It shows that implementation success depends on the fit between system design and workplace realities. A simple, accessible, and user-oriented system may be more effective than a complex system that is difficult to use during production.

The role of food safety culture also explains why similar digital systems may produce different outcomes across organizations. Units with strong supervision and routine internal checks used digital HACCP as a daily control tool. Units with weaker supervision tended to treat it as an audit document. This finding supports Nguyen and Li (2022), who emphasize that food safety management system implementation depends on organizational commitment, employee involvement, and continuous improvement. Therefore, digital HACCP should be supported by training, leadership commitment, routine evaluation, and a culture that values accurate data as part of risk prevention.

Theoretically, this study contributes to food safety management literature by positioning digital HACCP as a socio-technical practice. It connects HACCP principles with traceability governance, organizational learning, and food safety culture. Practically, the findings suggest that food businesses should strengthen digital HACCP through gradual implementation, continuous training, clear data-entry procedures, internal audits, and integration with supplier and distributor records. Regulators and auditors can use these findings to design guidance that fits the capacity of food industries and small food enterprises. Future research may compare different types of food businesses, examine consumer trust in digital traceability, or develop a maturity model for digital HACCP implementation in developing-country supply chains.

## 4. Conclusions

This study concludes that strengthening digital-based HACCP systems supports food supply chain traceability by improving critical control point monitoring, documentation accuracy, corrective action records, and access to safety data. The findings show that digital HACCP is not only a technological instrument, but also a socio-technical practice shaped by worker readiness, food safety culture, data discipline, and coordination among suppliers, producers, warehouses, and distributors. This study contributes to the literature by explaining how digital HACCP operates in daily food safety routines and how traceability depends on the quality of data produced across the supply chain.

Theoretically, this study strengthens the view that food safety management should integrate HACCP principles, digital traceability governance, and organizational learning. Practically, food businesses need gradual digital implementation, continuous training, clear data-entry procedures, internal audits, and stronger integration with supplier and distributor records. From a policy perspective, regulators should provide practical guidance and capacity-building programs that match the readiness of food industries and small food enterprises. Future research can compare digital HACCP implementation across different food sectors, examine consumer trust in traceability systems, or develop a maturity model for digital HACCP in developing-country supply chains.

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