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Innovations in Digital-Based Hazard Analysis and Critical Control Points (HACCP) Systems for Transparency and Food Product Safety

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ABSTRACT

This study aims to analyze digital-based Hazard Analysis and Critical Control Points (HACCP) system innovations in improving transparency and food product safety. The study addresses the growing need for food businesses to strengthen traceability, accountability, and real-time monitoring in response to increasingly complex food safety risks. A qualitative case study approach was used in Makassar, South Sulawesi, Indonesia, from January to March 2026. Data were collected through semi-structured interviews, field observations, and documentation involving 12 key informants, including food safety managers, quality assurance staff, production operators, internal auditors, information technology staff, and business managers. The data were analyzed using thematic analysis. The findings reveal four main themes: digital transparency in food safety records, improved monitoring of critical control points, employee adaptation to digital work routines, and stronger accountability in corrective actions and audit readiness. These findings show that digital HACCP is not only a technical system, but also a socio-technical process shaped by employee competence, organizational culture, and managerial commitment. The study contributes to food safety management literature by explaining how digital innovation transforms HACCP practices in real industrial settings. Practically, the findings suggest that food businesses should combine digital tools with training, clear procedures, and continuous supervision. Future research may compare digital HACCP practices across different food sectors and business scales.

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1. Introduction

Food safety has become a central issue in modern food production because food supply chains are increasingly complex, data-driven, and exposed to public scrutiny. Consumers, regulators, and business partners now demand food products that are not only safe but also traceable and transparent. Hazard Analysis and Critical Control Points (HACCP) remains one of the most widely used preventive systems for identifying, controlling, and monitoring food safety hazards. However, conventional HACCP practices often still depend on manual forms, fragmented records, and delayed reporting. Radu et al. (2023) show that HACCP and modern quality

management systems continue to play an important role in public health and food safety. Sartoni et al. (2025) also explain that digitalisation can strengthen the design, operation, and maintenance of HACCP-related activities.

In Indonesia, the digital transformation of food safety systems has become increasingly relevant. Food industries, including small and medium-scale processors, are expected to comply with food safety standards, halal assurance, quality control, and product traceability. Yet many businesses still face limitations in digital infrastructure, employee competence, data integration, and organizational readiness. Vanany et al. (2024) found that Indonesian food industries need structured support when adopting blockchain-based halal and food traceability systems. This condition shows a gap between formal food safety requirements and the actual capacity of food businesses to implement transparent digital systems.

Field problems often appear in the recording, monitoring, and verification stages of HACCP. Temperature records, raw material data, sanitation reports, corrective actions, and distribution information are frequently stored in separate systems. This weak integration makes audits slower and limits the ability of companies to identify food safety problems in real time. Iftekhar and Cui (2021) argue that traditional food supply chain information systems often fail to provide strong transparency, security, and auditability. Digital HACCP can address these problems by improving data accuracy, reducing manual errors, and strengthening accountability across production stages.

Digital technologies such as the Internet of Things, blockchain, artificial intelligence, cloud-based dashboards, and real-time sensors create new opportunities for HACCP innovation. Fan et al. (2022) showed that blockchain and IoT can support HACCP-based food traceability by improving data credibility and product monitoring. Rejeb et al. (2020) emphasized that blockchain can enhance trust, traceability, and accountability in the food industry. Technology adoption, however, cannot succeed if it ignores human and organizational factors. Kayikci et al. (2022) explained that digital transformation in the food supply chain must consider people, process, performance, and technology.

Previous studies have discussed HACCP, food traceability, blockchain, and digital food safety systems. However, many of them focus on technical design, system performance, or quantitative evaluation. Few studies explore how food industry actors experience, interpret, and adapt to digital HACCP in daily work practices. Nakat et al. (2023) found that food safety culture is influenced by training, work position, organizational pressure, and motivation. Pai et al. (2024) also argued that leadership and organizational commitment shape how food safety practices are understood and maintained in food companies. This gap is important because the success of digital HACCP depends on human behavior, employee acceptance, organizational culture, and practical understanding of food safety responsibilities.

Based on this background, this study aims to analyze digital-based HACCP system innovations for improving transparency and food product safety. The study focuses on how food industry actors understand, implement, and experience digital HACCP practices in monitoring critical control points, recording safety data, tracing products, and strengthening accountability. Theoretically, this study contributes to the development of food safety management studies by viewing digital HACCP as a socio-technical process. Practically, the findings can support food businesses, auditors, regulators, and system developers in designing digital HACCP systems that are more transparent, usable, and suitable for real industrial conditions.

2. Materials and Methods

This study used a qualitative approach with a case study design. This design was selected because the study aimed to understand the process, experience, and meaning of digital-based HACCP implementation in a real industrial context. A case study allows the researcher to examine a complex phenomenon within its natural setting, especially when the boundaries between technology, work culture, and organizational practice are closely connected. Mtisi (2022) explains

that qualitative case studies are suitable for investigating contextual and process-based issues. Therefore, this approach was considered appropriate for examining digital HACCP as both a food safety system and an organizational change process.

The research was conducted in Makassar, South Sulawesi, Indonesia, from January to March 2026. The research site was selected because Makassar has growing food processing activities and increasing demand for quality assurance, halal compliance, and product safety. The study focused on food processing businesses that had implemented or were in the process of implementing digital-based HACCP practices. These practices included digital monitoring of critical control points, electronic record keeping, product traceability, and digital documentation for audits.

The participants consisted of food safety managers, quality assurance staff, production operators, internal auditors, information technology staff, and business managers involved in HACCP implementation. Participants were selected using purposive sampling because the study required informants with direct knowledge and experience of digital HACCP practices. Campbell et al. (2020) state that purposive sampling helps qualitative researchers select participants who can provide rich and relevant information. Snowball sampling was also used when initial participants recommended other informants who had important knowledge about the system, such as external auditors or digital system consultants.

The inclusion criteria covered participants who had at least six months of experience in food safety management, understood HACCP procedures, and were directly involved in monitoring, recording, auditing, or managing digital food safety data. The exclusion criteria covered participants who were not directly involved in HACCP activities or only had administrative roles without knowledge of food safety procedures. The number of participants was determined based on data adequacy and saturation. The study involved 12 key informants, consisting of three quality assurance staff, three production operators, two food safety managers, two internal auditors, one information technology staff member, and one business manager.

Data were collected through semi-structured interviews, field observations, and documentation. Semi-structured interviews explored participants' experiences with digital records, critical control point monitoring, corrective actions, traceability, and transparency. Field observations focused on production activities, sanitation practices, monitoring procedures, dashboard use, and employee interaction with digital tools. Documentation included HACCP plans, standard operating procedures, digital monitoring records, audit reports, corrective action records, and training materials. Chowdhury and Shil (2021) explain that case study research requires multiple sources of evidence to understand a phenomenon in its real context.

Data validity was maintained through source triangulation, method triangulation, member checking, and audit trail. Source triangulation was conducted by comparing information from managers, operators, auditors, and digital system users. Method triangulation was carried out by comparing interview findings with observation notes and company documents. Member checking was used by asking selected participants to review the summary of interview results. An audit trail was maintained by storing interview guides, transcripts, observation notes, coding records, and analytic memos. Ahmed (2024) emphasizes that credibility, dependability, confirmability, and transferability are key pillars of trustworthiness in qualitative research.

Data were analyzed using thematic analysis. The analysis began with transcription, repeated reading, and initial coding. The researcher then grouped similar codes into categories, such as digital transparency, monitoring accuracy, employee adaptation, technical barriers, audit readiness, and food safety accountability. These categories were developed into broader themes that explained how digital-based HACCP innovation shaped food safety practices. Kiger and Varpio (2020) explain that thematic analysis is useful for identifying, analyzing, and reporting patterns of meaning in qualitative data. The final themes were interpreted in relation to HACCP principles, digital traceability, and food safety culture.

3. Results and Discussions

The analysis produced four main themes. These themes explain how digital-based HACCP shaped food safety practices in the observed food processing businesses in Makassar. The themes include digital transparency, monitoring accuracy, employee adaptation, and food safety accountability. Each theme appeared repeatedly in interviews, observations, and company documents. The findings show that digital HACCP was not only used as a technical recording system. It also changed how employees understood risk, responsibility, and product safety.

The first theme was digital transparency in food safety records. Participants explained that digital HACCP made production data easier to trace and review. Before using digital records, temperature logs, sanitation notes, and corrective action forms were kept in separate paper files. This condition often made internal audits slower. After digital recording was introduced, managers could check data more quickly through dashboards or shared files. One quality assurance staff member stated, "Now we can see the record faster. If there is a problem in one batch, we do not need to search many paper forms." This finding shows that transparency emerged through easier access to data and clearer documentation flow.

The second theme was improved monitoring of critical control points. Observations showed that digital tools helped staff record temperature, processing time, and sanitation status more consistently. Operators also received reminders when data had not been entered. This reduced the risk of missing records during busy production hours. One production operator said, "The system reminds us when we forget to input the temperature. It helps because production work is often fast." However, the system did not remove the need for human control. Several participants emphasized that digital records still depended on employee discipline, device availability, and supervisor verification.

The third theme was employee adaptation to digital work routines. The shift from manual HACCP to digital HACCP created different responses among workers. Younger employees adapted faster because they were familiar with mobile devices and digital forms. Some older employees needed repeated training because they were more comfortable with paper-based records. One internal auditor explained, "The main challenge is not the system. The challenge is changing the habit of writing everything manually." This finding indicates that digital HACCP requires cultural adjustment in daily work practices. Training, mentoring, and simple system design became important factors in employee acceptance.

The fourth theme was stronger accountability in corrective action and audit readiness. Digital documentation made it easier to identify who recorded data, when the record was submitted, and what corrective action was taken. This created a stronger sense of responsibility among staff. Internal audit documents also showed that digital records reduced missing forms and improved preparation for external inspections. One food safety manager stated, "Every action is recorded. So, the team becomes more careful and more responsible." This finding suggests that accountability was strengthened because digital HACCP created visible records of decisions and actions.

Discussion

The findings show that digital-based HACCP improves transparency by making food safety data more accessible, organized, and traceable. This result supports Iftekhar and Cui (2021), who argued that traditional food supply chain information systems often face weaknesses in transparency and auditability. The finding also aligns with Rejeb et al. (2020), who stated that blockchain and digital traceability systems can strengthen trust and accountability in the food industry. However, this study adds a qualitative perspective by showing that transparency is not only produced by technology. It also depends on how employees use, understand, and trust the system.

The improvement of critical control point monitoring supports the view that digitalization can strengthen HACCP implementation. Fan et al. (2022) found that IoT and blockchain integration can improve HACCP-based traceability and monitoring. Sartoni et al. (2025) also explained that digital tools can support the design, verification, and maintenance of food safety management systems. The present study confirms these findings in a practical setting. Digital reminders, structured records, and faster data access helped employees monitor critical control points more consistently. Still, the findings also show that digital tools cannot replace human judgment. Supervisors still need to verify data and ensure that corrective actions are truly implemented.

Employee adaptation emerged as a critical factor in digital HACCP implementation. This result is consistent with Kayikci et al. (2022), who emphasized that Industry 4.0 adoption in food supply chains must consider people, process, performance, and technology. The finding also supports Nakat et al. (2023), who found that food safety culture is shaped by training, work position, pressure, and motivation. In this study, digital HACCP succeeded better when employees received practical training and when the system was simple to use. This finding highlights that digital transformation in food safety is not only a technical process. It is also a learning process within the organization.

The study also found that digital HACCP strengthened accountability in corrective actions and audits. This result aligns with Pai et al. (2024), who emphasized the role of leadership and organizational commitment in maintaining food safety culture. When every record has a clear time, user identity, and action history, employees become more aware of their responsibility. This finding offers a new perspective on HACCP digitalization. Accountability does not only come from formal rules. It also emerges from the visibility of work processes and the ability to trace decisions.

Theoretically, this study contributes to food safety management literature by framing digital HACCP as a socio-technical system. Technology provides the infrastructure for transparency, traceability, and monitoring. Human actors provide interpretation, discipline, and ethical responsibility in using the system. This perspective extends previous studies that focus mainly on system design or technical performance. It shows that the value of digital HACCP depends on the interaction between digital tools, organizational culture, employee competence, and management commitment.

Practically, the findings suggest that food businesses should not implement digital HACCP only by purchasing software or installing devices. They need to prepare training programs, clear standard operating procedures, simple user interfaces, and regular supervision. Regulators and auditors should also consider the readiness of small and medium food businesses when encouraging digital food safety systems. Future studies can compare digital HACCP implementation across different food sectors, such as seafood, dairy, bakery, and ready-to-eat products. Further research can also examine the experiences of small enterprises that face limited budgets and low digital literacy.

4. Conclusions

This study concludes that digital-based HACCP innovation strengthens food product safety by improving transparency, monitoring accuracy, employee accountability, and audit readiness. The findings show that digital HACCP does not only function as a recording tool, but also changes how food industry actors understand risk, responsibility, and compliance in daily production practices. The main contribution of this study lies in its qualitative explanation of digital HACCP as a socio-technical process, where technology, work culture, employee adaptation, and managerial commitment interact to support safer and more transparent food production.

Theoretically, this study expands food safety management literature by emphasizing the human and organizational dimensions of HACCP digitalization. Practically, the findings suggest that food businesses need to support digital HACCP with training, clear procedures, simple digital

interfaces, and regular supervision. From a policy perspective, regulators and auditors should consider the readiness of small and medium food enterprises when encouraging digital food safety systems. Future studies can compare digital HACCP implementation across different food sectors and examine the challenges faced by enterprises with limited digital literacy and infrastructure.

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