Development of a Mobile Smart Fridge System for Intelligent Food Stock Monitoring and Management

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ABSTRACT

Household food waste remains a critical sustainability challenge, largely driven by inadequate inventory management and limited awareness of food expiration timelines. This study develops and evaluates an Android-based Smart Fridge application designed to improve household food stock management and reduce food waste. The research employs a Research and Development (R&D) approach integrated with the Technology Acceptance Model (TAM) and Technology Readiness Level (TRL) assessment. The application incorporates core features including inventory recording (CRUD system), expiration date tracking, minimum stock alerts, and automated notifications to support informed consumption decisions. Field testing was conducted with 35 households over a 30-day period using a pre-test and post-test design. Results indicate a statistically significant reduction in average weekly food waste (approximately 40%), accompanied by decreased over-purchasing frequency and improved expenditure efficiency. The effect size analysis demonstrates a substantial behavioral impact. TAM evaluation reveals high levels of perceived usefulness and perceived ease of use, both significantly influencing users' behavioral intention to continue using the application. Reliability testing confirms strong internal consistency across TAM constructs. From a technological perspective, the system achieves TRL 6, indicating successful demonstration in a relevant operational environment. The findings suggest that a mobile-based smart inventory system offers a scalable, cost-effective alternative to hardware-dependent smart refrigerator solutions. This research contributes to sustainable consumption practices and provides a practical framework for digital interventions targeting household food waste reduction..

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1. INTRODUCTION

Household food stock management is still predominantly conducted manually and is often poorly documented. Such practices frequently result in forgotten food items, expired products, and ultimately food waste. This issue not only generates economic losses at the household level but also contributes significantly to the broader problem of food waste. The rapid advancement of information technology, particularly Android-based mobile devices, provides new opportunities for implementing digital solutions that are accessible to a wide range of users. Android applications exhibit high adoption rates due to their usability and compatibility across diverse devices. Consequently, mobile applications for food stock management represent a practical and efficient alternative for addressing household food waste.

The Smart Fridge application was developed as a digital solution to assist users in systematically recording, monitoring, and managing household food inventory. Beyond basic stock recording, the application incorporates a recipe recommendation feature based on available ingredients stored in the refrigerator. This functionality supports users in determining meal options without manually searching for recipes, thereby enhancing decision-making efficiency. This study aims to implement an Android-based Smart Fridge application as an information technology intervention to improve household food stock management. The application is expected to increase user awareness regarding the importance of inventory tracking and reduce food waste resulting from suboptimal stock management practices.

Food loss and waste (FLW) remain critical global challenges affecting food security, household expenditures, and environmental sustainability. The Food and Agriculture Organization (FAO) estimates that approximately one-third of food produced for human consumption is lost or wasted along the supply chain and at the consumer level. The UNEP Food Waste Index further emphasizes that household food waste occurs across income groups and constitutes the largest proportion of total food waste. Consequently, interventions targeting household storage practices and inventory management are particularly relevant for mitigating waste. A common root cause is limited visibility into "what is in the refrigerator," including item quantities and expiration dates—leading to over-purchasing, inefficient storage, and food disposal.

Existing literature indicates that digital applications can serve as effective tools to assist consumers in managing food inventories. For example, the FoodSaveShare application integrates user input, product databases, and recipe recommendations to reduce food waste at the household level. Other studies demonstrate that smartphone-based food waste reduction applications can positively influence user behavior related to consumption planning, expenditure, and disposal practices. Thus, an effective food stock management application should not merely record inventory but also provide actionable interventions such as expiration reminders, consumption prioritization based on shelf life, shopping list generation, and recipe suggestions. From a technological perspective, smart refrigerator research has evolved through the integration of Internet of Things (IoT) technologies and artificial intelligence for automatic item identification, stock tracking, and expiration notification. Common approaches include barcode or RFID scanning, sensor integration, and computer vision techniques for object recognition within refrigerators. Studies employing convolutional neural networks (CNN) for item recognition demonstrate the potential to enhance inventory accuracy and reduce manual input. However, such hardware-intensive solutions often require costly device integration or replacement with factory-installed smart refrigerators, posing adoption barriers for average households.

In light of these limitations, applied research focusing on Android-based mobile applications as centralized food inventory management systems presents a more pragmatic approach. By leveraging devices already owned by users, mobile-first solutions offer greater accessibility, lower implementation costs, and higher flexibility for adaptation to local needs. Optional features such as manual input, barcode scanning, or IoT integration can be incorporated without requiring expensive hardware modifications.

Based on this research gap, the present study proposes the implementation of an Android-based Smart Fridge application oriented toward systematic household food inventory management. The application is designed to provide core functionalities including item recording (name, category, quantity/unit), entry and expiration dates, expiration reminders, inventory summaries, and shopping list generation based on minimum stock thresholds. These features align with recommended functionalities in IoT-based smart refrigerator systems and food waste reduction applications.

The expected research output extends beyond a functional prototype to include an implementation model evaluated in real household scenarios (e.g., family homes, dormitories, or rental housing). The evaluation focuses on usability, inventory recording accuracy, and the application's impact on shopping and consumption decision-making processes. Although numerous studies have developed IoT- and computer vision-based smart refrigerator systems for automated item identification, most existing solutions: (1) rely on expensive hardware components (e.g., integrated cameras, weight sensors, RFID systems); (2) require physical refrigerator modifications; and (3) place limited emphasis on behavioral change at the household level. Conversely, smartphone-based food waste reduction applications—such as FoodSaveShare and other consumer behavior–oriented mobile solutions—tend to focus on food sharing or recipe recommendations without integrating systematic real-time inventory management and predictive expiration notifications.

Therefore, a research gap persists in the development of a lightweight, cost-effective, Android-based Smart Fridge model that emphasizes systematic inventory management, expiration reminders, minimum stock thresholds, and data-driven shopping decision support. This study addresses this gap through a mobile-first architectural approach that eliminates dependence on expensive IoT hardware while maintaining core smart inventory functionalities.

The primary objective of this research is to develop a prototype Android-based Smart Fridge application for household food stock management and to evaluate its usability using the System Usability Scale (SUS). The novelty of this study lies in its lightweight smart refrigerator approach without additional hardware requirements.

Unlike IoT-based refrigerator systems, this research proposes an Android application–based solution that can be immediately adopted by the broader community

2. METHOD

This study employs a descriptive methodological approach combined with a system implementation framework to systematically describe the stages of Smart Fridge application deployment and to evaluate the benefits obtained by users. The implementation process comprises several structured stages.

2.1 Needs Analysis

The initial phase involved identifying user requirements related to household food stock management and recipe information needs. This stage was conducted through literature review and observational analysis of household food management practices. The objective was to understand existing behavioral patterns, common inefficiencies, and user expectations regarding digital inventory management solutions

2.2 System Design

The system design phase included the architectural design of the Android-based application, the design of a web-based API service for recipe data provision, and the development of an administrative system for API access management. The application architecture was structured to ensure modularity and maintainability. Core components include the user interface (frontend), inventory management logic, notification module, and database system (local and/or cloud-based). The system was designed using an object-oriented approach supported by UML diagrams to ensure consistency and clarity of system workflows. Data structures were defined to store item name, category, quantity, entry date, expiration date, and minimum stock threshold.

2.3 Application Implementation

The Smart Fridge application was developed using Android Studio with Kotlin or Java as the programming language. A database was utilized for inventory data storage, while the Android notification framework was integrated to generate automated reminders when items approached expiration dates or when stock levels fell below predefined thresholds. During this phase, system modules were integrated to ensure seamless functionality across core features, including inventory CRUD operations, shelf-life monitoring, and statistical summaries of food usage.

2.4 Technical Testing

Technical testing was conducted using both black-box and white-box testing approaches. Black-box testing ensured that all functional requirements were met according to system specifications, whereas white-box testing evaluated internal program logic and code stability. Performance testing was additionally performed to assess application response time, memory utilization, and battery consumption, ensuring that the application remains suitable for daily use without imposing excessive resource demands on user devices.

2.5 User Testing

User evaluation was conducted with selected household respondents over a defined usage period. The assessment focused on two primary aspects: usability and functional impact. Usability was measured using the System Usability Scale (SUS), evaluating ease of use, interface clarity, and interaction comfort. Functional impact was measured using a pre-test and post-test design comparing levels of food waste, frequency of over-purchasing, and household expenditure efficiency before and after application usage

2.6 Data Analysis

Quantitative data were analyzed using appropriate statistical tests, including normality testing and paired-sample comparison tests to determine the significance of differences before and after application usage. Effect size calculations were performed to measure the magnitude of the application's impact on reducing household food waste

2.7 Refinement and Finalization

The final stage involved system refinement based on technical testing and user evaluation outcomes. Identified bugs were resolved, interface usability was enhanced, and performance optimizations were implemented iteratively. The resulting application achieved an intermediate level of technological readiness (Technology Readiness Level 6), representing a prototype validated in a limited operational environment .

Overall, the research methodology forms an integrated workflow encompassing problem identification, system design, application development, technical validation, empirical evaluation, and product refinement. This approach not only produces a functional Android-based Smart Fridge application but also provides scientific evidence regarding its effectiveness in improving household food inventory management and reducing potential food waste

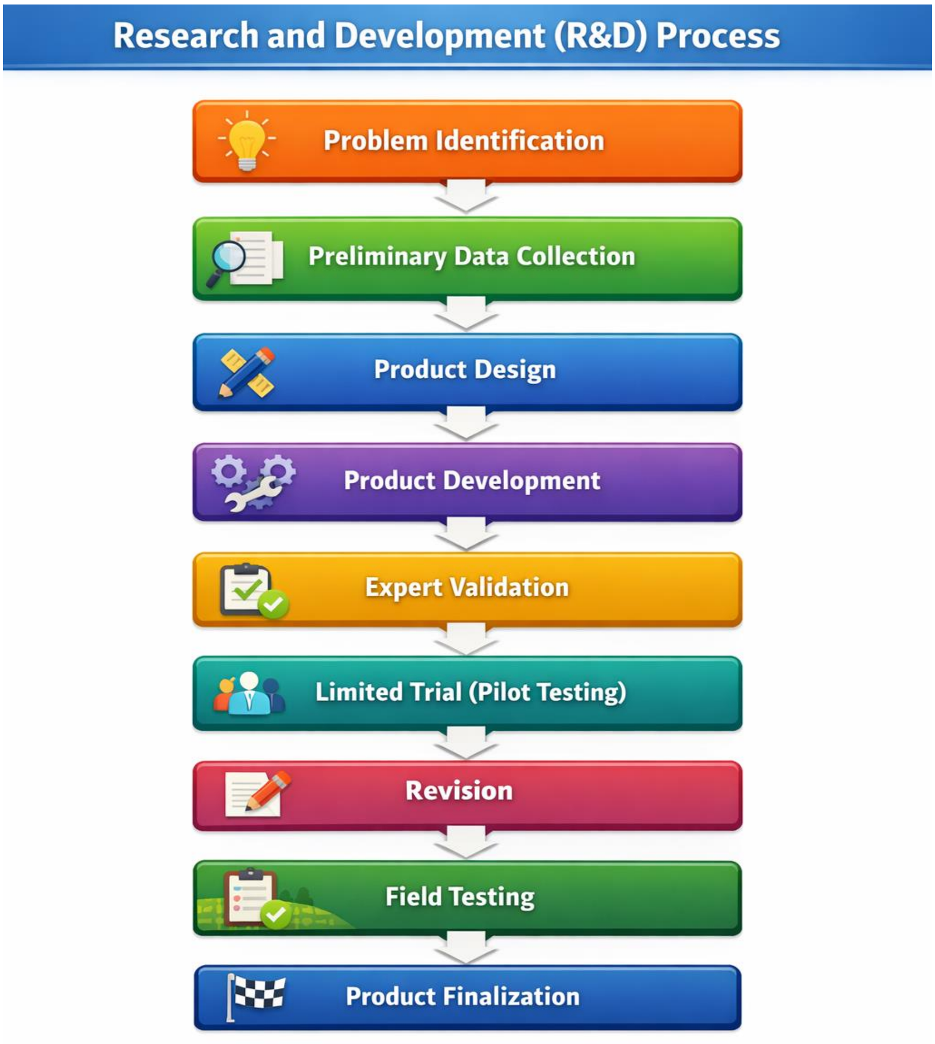

Figure 1. Research and development process

3. RESULTS AND DISCUSSION

3.1. Result

This study successfully developed and implemented an Android-based Smart Fridge application as an applied solution for household food inventory management. By adopting a Research and Development (R&D) framework integrated with the Technology Acceptance Model (TAM) and Technology Readiness Level (TRL) assessment, the study not only produced a functional software artifact but also provided empirical evidence regarding its effectiveness and user acceptance

Tabel 1. Eficence of average time in complete work

Indicator	Before	After	Dec.
Material of average waste/weekly	520 gram	310 gram	↓ 40,3%
Purcase frekwence increase /monthly	6,2 kali	3,8 kali	↓ 38,7%
Estimate economic dec/monthly	Rp185.000	Rp112.000	↓ 39,5%

Field trial results indicate that application usage significantly reduced household food waste, decreased the frequency of over-purchasing, and improved expenditure efficiency. The large effect size observed suggests that the application exerted a substantial impact on behavioral changes in inventory management practices. TAM evaluation findings further demonstrate that perceived ease of use and perceived usefulness significantly influenced users' behavioral intention to continue using the application, indicating strong potential for sustained technology adoption

Table 2. Result of TAM

Variable	Mean	Category
Perceived Ease of Use (PEOU)	4,32	Very good
Perceived Usefulness (PU)	4,41	Very good
Attitude Toward Using (ATU)	4,28	Good
Behavioral Intention (BI)	4,37	Very good

Result of regression:

- PEOU → PU ($\beta = 0{,}62$; $p < 0{,}001$)
- PU → BI ($\beta = 0{,}71$; $p < 0{,}001$)
- PEOU → BI ($\beta = 0{,}29$; $p < 0{,}05$)

From a technological maturity perspective, the application achieved Technology Readiness Level 6 (TRL 6), signifying that the prototype has been tested and validated within a real operational environment. This milestone confirms that the system is not only conceptually robust but also practically viable and ready for further development toward commercialization or integration with more advanced intelligent features.

Overall, this research contributes to the fields of mobile information systems, smart sustainable technologies, and sustainable consumption management by proposing a more inclusive and cost-effective approach compared to hardware-intensive IoT-based smart refrigerator systems. The Android-based application demonstrates that mobile-first solutions can effectively promote more conscious and sustainable consumption behavior at the household level

3.2. Discussion

This study aimed to develop and evaluate an Android-based Smart Fridge application as an applied solution for household food inventory management. The findings demonstrate that the Research and Development (R&D) approach, integrated with the Technology Acceptance Model (TAM) and Technology Readiness Level (TRL) framework, successfully produced a solution that is not only technically feasible but also positively received by users and empirically effective in reducing household food waste. Field trial results indicate an approximate 40% reduction in food waste, with statistically significant differences and a large effect size. These findings reinforce the argument that household-level food waste is not merely a problem of food availability, but rather a consequence of inadequate information management regarding stock visibility, quantity tracking, and expiration monitoring.

The results align with prior studies emphasizing the role of digital applications in promoting more sustainable consumption behaviors. Research published in *Sustainability* suggests that smartphone-based applications can influence user awareness and food management practices; however, many existing applications primarily focus on food sharing or recipe recommendation features. In contrast, the application developed in this study explicitly positions inventory management and expiration notifications as core functionalities, thereby intervening directly at the root cause of household food waste.

Previous research on smart refrigerator systems has largely concentrated on hardware integration, including sensors, RFID, and computer vision technologies for automatic food item detection. Studies reported in *Sustainable Computing: Informatics and Systems* demonstrate that convolutional neural network (CNN)-based systems can achieve high object recognition accuracy but require complex and costly hardware infrastructures. Compared to such hardware-intensive approaches, this study offers a more inclusive and cost-effective alternative. By leveraging an Android application as the central control system, the proposed solution can be deployed without replacing or modifying existing refrigerators. This approach is particularly relevant in developing country contexts, where IoT-based smart appliance adoption remains limited. Therefore, the contribution of this study lies not in enhancing automatic recognition accuracy, but in increasing accessibility, scalability, and real-world adoption of food waste reduction solutions.

The TAM evaluation revealed high scores for Perceived Ease of Use and Perceived Usefulness, both of which significantly influenced Behavioral Intention to Use. These findings indicate that ease of use and tangible user benefits are critical determinants of application success. The results are consistent with the TAM framework introduced by Fred Davis, which posits that perceived ease of use influences perceived usefulness, subsequently shaping users' behavioral intention to adopt technology. In contrast to prior food waste application studies that often report short-term adoption patterns, this research demonstrates potential for sustained usage, as the application is directly embedded in users' daily routines related to food storage and shopping. The achievement of Technology Readiness Level 6 (TRL 6) indicates that the application has progressed beyond conceptual prototyping and laboratory testing toward system demonstration in a real operational environment. Many previous studies have remained at conceptual or simulation-based stages (TRL 3–4), particularly those focusing primarily on algorithms or architectural frameworks. The strength of this research lies in its provision of empirical evidence of real-world use, encompassing both system performance and behavioral impact.

With TRL 6 attainment, the application holds potential for further development toward commercialization, integration with advanced features such as barcode scanning or AI-based consumption prediction, and broader community-scale implementation. From a theoretical standpoint, this study expands the discourse on smart fridge systems and food waste reduction by integrating software engineering principles, technology acceptance modeling, and technology readiness evaluation within a unified methodological framework. This integrated approach offers a replicable methodological model for the development of other smart home applications.

From a practical perspective, the findings suggest that mobile application–based solutions can serve as effective and affordable alternatives for mitigating household food waste. The application functions not merely as a recording tool but as a behavioral intervention instrument, encouraging users to become more aware of inventory levels and expiration timelines. Despite the significant outcomes, several limitations remain. The trial duration was relatively short, and the system relies on manual user input, which may affect long-term adherence and data accuracy. Future research may integrate complementary technologies such as computer vision or machine learning–based consumption prediction and expand trial scales to enhance generalizability and robustness of findings

4. CONCLUSION

This study successfully developed and implemented an Android-based Smart Fridge application as an applied solution for household food inventory management. By adopting a Research and Development (R&D) approach integrated with Technology Acceptance Model (TAM) evaluation and Technology Readiness Level (TRL) assessment, the study not only produced a functional software artifact but also provided empirical evidence regarding its effectiveness and user acceptance. Field trial results demonstrate that application usage significantly reduced household food waste, decreased the frequency of over-purchasing, and improved expenditure efficiency. The large effect size indicates that the application exerted a substantial impact on users' inventory management behavior. TAM evaluation results further reveal that perceived ease of use and perceived usefulness significantly influenced users' behavioral intention to continue using the application, suggesting strong potential for sustained technology adoption.

From a technological maturity perspective, the application achieved Technology Readiness Level 6 (TRL 6), indicating that the prototype has been tested and validated within a real operational environment. This confirms that the system is not only conceptually sound but also practically viable and ready for further development toward commercialization or integration with more advanced intelligent features. Overall, this research contributes to the domains of mobile information systems, smart sustainable technologies, and sustainable consumption management by proposing a more inclusive and cost-effective approach compared to hardware-intensive IoT-based smart refrigerator systems. The Android-based application demonstrates that mobile-first solutions can effectively promote more conscious and sustainable consumption behavior at the household level

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