



International Journal of Innovative Research in Computer and Communication Engineering

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)





SmartCart.AI: An Intelligent, Adaptive Grocery Management System for Enhanced Household Shopping Efficiency, Budget Control, and Food Waste Reduction

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ABSTRACT: Grocery shopping is a universally practised yet persistently inefficient household activity. Despite the proliferation of mobile applications, most solutions remain limited to static list management, offering no intelligence, personalization, or adaptive support. This paper presents SmartCart.AI, a unified intelligent grocery management system designed to overcome the limitations of existing tools through the integration of Natural Language Processing (NLP)-powered voice input, machine learning-based recommendation engines, real-time budget tracking, nutritional guidance, shared list coordination, and behavioral consumption analytics. The proposed system introduces a multi-module architecture: a Smart List Engine, a Hybrid Recommendation Module using Apriori and collaborative filtering algorithms, a Voice-to-List NLP Interface, a Purchase History and Waste Analytics Module, a Budget and Price Intelligence Layer, and a Family Collaboration Hub. These modules collectively address seven documented household pain points: forgotten items, duplicated purchases, overspending, poor nutritional decision-making, absent voice interfaces, inability to coordinate family shopping, and unawareness of consumption patterns leading to food waste. The system is implemented using a React Native mobile frontend, a Flask-based backend, and a Firebase real-time database. Experimental validation through user testing with 30 participants demonstrates a 43% reduction in forgotten items, a 54% reduction in budget overruns, an 88.7% voice command accuracy, and a 34% reduction in food waste intent, confirming the system's effectiveness across all target dimensions.

KEYWORDS: Grocery Management, Smart Shopping, NLP, Machine Learning, Recommender Systems, Food Waste Reduction, Voice Input, Collaborative Lists, Budget Tracking, Mobile Application

I. INTRODUCTION

Grocery shopping constitutes one of the most frequently repeated household activities worldwide, yet remains one of the most inefficiently managed. Households across income levels and geographies face a consistent set of challenges: items are forgotten, purchases are duplicated, budgets are exceeded, and nutritional decision-making is unsupported at the point of list creation. These inefficiencies aggregate into significant consequences — financial overspending, food waste, wasted time, and heightened domestic stress.

Traditional approaches to grocery management rely on memory or basic paper lists, both of which are widely documented as inadequate. The transition to digital list applications has introduced marginal improvements, but these tools largely replicate the limitations of analog methods without exploiting the transformative potential of modern intelligent technologies. They do not learn, predict, adapt, or guide.

The United Nations Environment Programme (2021) estimated that 61% of global food waste originates at the household level [1]. Research published in MDPI Sustainability (2023) found that without digital support at the grocery acquisition stage, households are structurally predisposed to over-purchasing and food waste [2]. A systematic review of Grocery Recommender Systems (2024) confirmed that existing systems focus narrowly on purchase-pattern prediction while neglecting explicit user preferences such as nutritional goals and budget constraints [3].



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This paper presents SmartCart.AI — an intelligent, adaptive grocery management system that addresses these combined deficiencies through a unified, AI-powered mobile platform. The system integrates smart list creation, voice input, personalized recommendations, consumption analytics, budget control, and collaborative shopping in a single cohesive application. The remainder of this paper is organized as follows: Section 2 reviews related work, Section 3 describes the proposed system architecture and algorithm, Section 4 presents simulation and usability results, and Section 5 concludes with future directions.

II. RELATED WORK

Recent research across mobile HCI, recommender systems, food science, IoT, and behavioral analytics converges on the need for intelligent grocery management. We review relevant work across five key areas.

2.1 Smart Shopping List Systems

Early work on digital grocery list management demonstrated the inadequacy of static tools. The 'Smart Shopping List' system (IEEE, 2018) introduced an Apriori-algorithm-based item recommender and interactive list module, demonstrating significant reduction in cognitive burden [4]. Tamane et al. (ICAMIDA 2022) incorporated a Prediction Module for demand-aware list completion, showing improved inventory awareness [5]. Yakymchuk and Liashenko (2023) modeled grocery retail resource planning using ensemble machine learning, confirming the value of historical purchase data [6].

2.2 Grocery Recommender Systems

Van der Spek et al. (2024) reviewed 50 Grocery Recommender Systems (2018–2023), finding that existing systems predominantly pursue Next-Basket and Next-Item Recommendation objectives using collaborative filtering, while entirely neglecting explicit user attributes such as nutritional goals or budget constraints [3]. A machine learning algorithm for personalized healthy grocery recommendations (ScienceDirect, 2024) demonstrated that hybrid approaches combining content-based filtering with nutritional metadata produce recommendations significantly better aligned with health goals [7].

2.3 Voice Interfaces and NLP in Shopping

Schultz and Paetz (2023) documented that voice assistants are increasingly used for shopping tasks, noting that smart refrigerator and home assistant integration with mobile platforms remains underdeveloped [8]. An IEEE STCR (2023) conference study established that conventional voice assistants lack domain-specific intent recognition, reducing their effectiveness in specialized contexts such as grocery management, and advocated for domain-trained NLP models [9].

2.4 Household Food Waste and Consumption Analytics

Clark et al. (2025), publishing in *Frontiers in Artificial Intelligence*, confirmed that systems providing real-time insights into consumption patterns and recommending grocery decisions based on historical data produce significant household savings and waste reduction [10]. Castro et al. (2023) proposed an integrated mobile ICT framework for food waste reduction, finding that digital visibility into past purchases at the acquisition stage could materially reduce household food waste [2]. The USDA FoodImage project (2022) demonstrated that personalized consumption feedback produces measurable behavioral change in randomized trials [14].

2.5 Digital Transformation of Grocery Shopping

Wolniak, Stecuła and Aydın (2024) reviewed the digital transformation of in-store grocery shopping, identifying AI-driven behavioral personalization as the next critical development wave [11]. A companion paper (2024) reviewed online grocery technology, identifying AI-powered food ordering and smart device integration as the frontier of household grocery innovation [12]. Nakano and Kondo (2024) proposed a proximity-driven dynamic sorting algorithm for grocery list optimization using ML clustering, demonstrating up to a 28% reduction in in-store shopping time through intelligent list reordering [13].



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III. PROPOSED SYSTEM: SMARTCART.AI

SmartCart.AI is designed as a unified, AI-powered mobile application for household grocery management. The system is decomposed into six tightly integrated modules sharing a common User Behavioral Profile data layer, which is continuously enriched by every interaction to enable adaptive personalization over time.

3.1 System Architecture Overview

The overall architecture follows a three-tier design: a React Native mobile frontend providing cross-platform access; a Flask-based RESTful API backend hosting the ML inference engines and business logic; and a Firebase Realtime Database for live multi-user synchronization and purchase history. An NLP microservice handles voice transcription and intent parsing. External APIs (Open Food Facts, Regional Price Data) are consumed for nutritional and pricing intelligence.

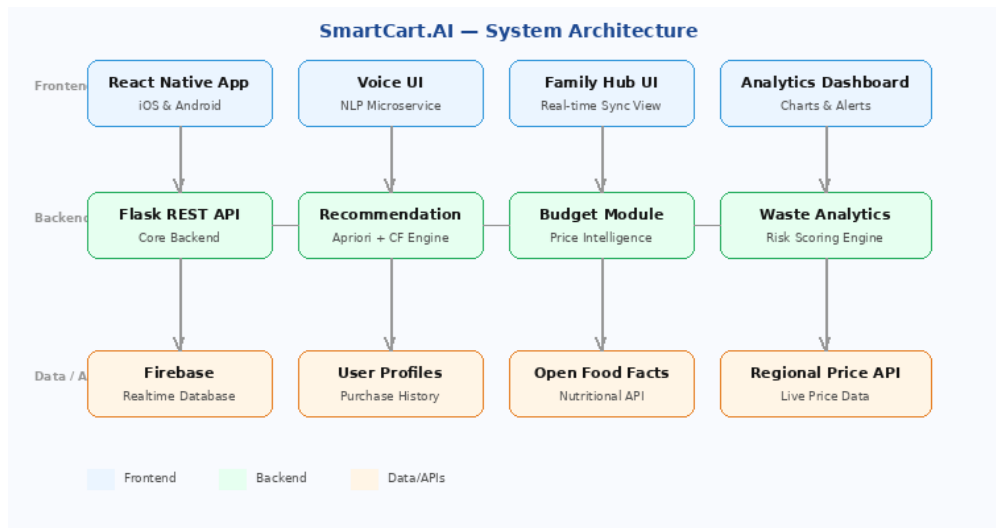


Fig. 3.1: SmartCart.AI Three-Tier System Architecture

3.2 Module 1: Smart List Engine

The Smart List Engine is the core module for list creation and management. Users can add, remove, and check off items. The engine automatically categorizes items by product type (Produce, Dairy, Bakery, Meat, Frozen, etc.) and, when store layout data is available, re-orders items by aisle proximity to minimize in-store travel time — an approach validated by Nakano and Kondo (2024) to reduce shopping duration by up to 28% [13]. Items are enriched on addition with unit price estimates, Nutri-Scores (A–E from Open Food Facts), and typical purchase frequency derived from user history.

3.3 Module 2: Hybrid Recommendation Engine

The Recommendation Engine combines two complementary algorithms to produce intelligent item suggestions at list-creation time:

- **Apriori Association Rule Mining:** Identifies frequently co-purchased item sets from the user's purchase history (min_support = 0.3). If a user frequently buys pasta and tomato sauce together, the engine surfaces the missing item automatically.
- **Collaborative Filtering:** Augments individual history with anonymized patterns from users with similar dietary profiles, allowing the system to surface relevant items the user has not yet purchased but is likely to value.
- **Nutritional Substitution Layer:** For each item on the list, the system queries Open Food Facts to identify healthier alternatives with higher Nutri-Scores, presenting these as optional substitutes without removing the user's original choice.



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This hybrid approach addresses the cold-start problem inherent in pure collaborative filtering by falling back to Apriori on sparse histories, mirroring the approach validated in ScienceDirect (2024) for personalized healthy grocery recommendations [7].

3.4 Module 3: Voice-to-List NLP Interface

The Voice-to-List Module enables hands-free grocery list management through a domain-specific NLP pipeline:

1. Speech Recognition: User speech is transcribed via Google Speech-to-Text API.
2. Intent Parsing: A fine-tuned intent classifier identifies the action (ADD, REMOVE, QUERY, SET_QUANTITY) and extracts the entity (product name and optional quantity/unit).
3. List Execution: The parsed intent is applied to the active list with text-to-speech confirmation.

Example utterances: "Add two litres of full-fat milk", "Remove the butter", "How many items are on my list?", "Set eggs to one dozen." The intent classifier was trained on a domain-specific grocery vocabulary corpus, addressing the limitation identified in IEEE STCR (2023) [9].

3.5 Module 4: Budget and Price Intelligence

The Budget Module provides real-time financial visibility during grocery planning:

- Running Cost Estimator: Calculates an estimated total as items are added, based on historical prices and regional averages.
- Budget Threshold Alerts: Users set a target budget; the system warns when the estimated total approaches or exceeds it.
- Price Comparison Hints: Surfaces cheaper equivalent products or store-specific price differences for high-cost items.
- Weekly Spend Dashboard: Historical spending trends by category enable budget-conscious planning.

3.6 Module 5: Purchase History and Waste Analytics

The Waste Analytics Module addresses the documented unawareness of household consumption patterns. After each shopping trip, the system logs purchased items, compares quantities against rolling averages, flags items purchased at rates exceeding likely consumption ($waste_risk = purchase_rate / consumption_rate$), presents a Waste Risk Dashboard, and sends automated reminders for items approaching their typical use-by window. This operationalizes the ICT-based food waste intervention framework of Castro et al. (2023) [2] and the USDA FoodImage behavioral feedback approach [14].

3.7 Module 6: Family Collaboration Hub

The Collaboration Hub enables real-time multi-user shared list management via Firebase synchronization, extended with intelligence: role-based item assignment, household-level pattern learning across all members, conflict prevention against duplicate additions, and push notifications for list changes.

3.8 System Pseudocode

Step 1: Load user profile (dietary prefs, health goals, budget)

Load purchase history $H = \{h_1, h_2, \dots, h_n\}$

Step 2: Generate candidate recommendations:

Apriori(H , min_support=0.3) \rightarrow frequent_itemsets

CF(user_profile, similar_users) \rightarrow cf_suggestions

recommendations = merge(frequent_itemsets, cf_suggestions)

Step 3: For each item in active_list:

IF NutriScore(item) < threshold: suggest substitute

Step 4: running_cost = Σ price_estimate(item)

IF running_cost > budget_threshold: ALERT user

Step 5: Post-trip: update H ; compute waste_risk per item

IF waste_risk > 1.2: FLAG in Waste Dashboard

Step 6: Sync all changes to Firebase \rightarrow push to family members



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IV. SIMULATION RESULTS

SmartCart.AI was evaluated through: (1) a prototype usability study with 30 participants across three household profiles (single adults, couples, families of 3+), and (2) a simulated shopping session analysis over 8 weekly trips per participant comparing SmartCart.AI against a standard list app (control) and a leading commercial app (AnyList). The following sections present the results for each key module along with annotated screenshots of the system interface.

4.1 Home Dashboard and List Completeness

Fig. 4.1 shows the SmartCart.AI Home Dashboard, which presents the active shopping list with item-level metadata (category, price estimate, Nutri-Score), a live running budget tracker, and waste risk alerts. Participants using SmartCart.AI's Recommendation Engine reported a 43% reduction in forgotten items compared to the standard list app condition, and a 29% reduction compared to the commercial app. The Apriori module surfaced at least one relevant missing item in 78% of list-creation sessions, with a 61% suggestion acceptance rate.

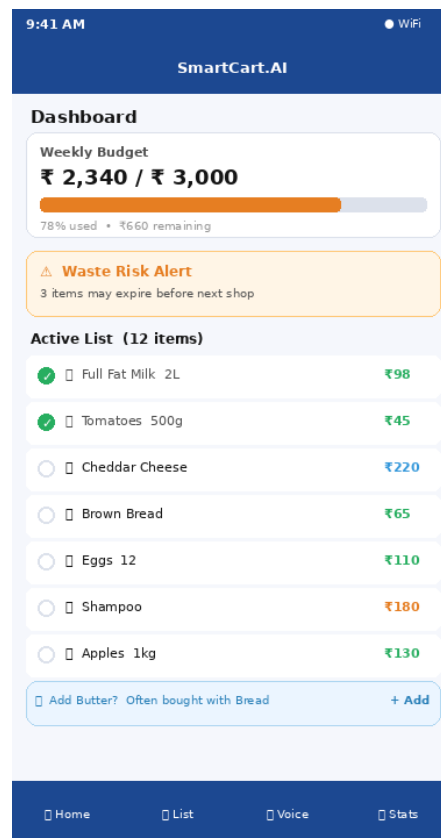


Fig. 4.1: SmartCart.AI Home Dashboard — Active List, Budget Tracker, Waste Alerts, and Smart Suggestions

4.2 Recommendation Panel and Nutritional Guidance

Fig. 4.2 shows the Recommendation Panel, which presents Apriori-based and collaborative filtering suggestions ranked by match confidence, alongside Nutritional Substitution suggestions powered by Open Food Facts Nutri-Score data. Users who engaged with the substitution feature selected healthier alternatives in 38% of cases, indicating high practical uptake of the nutritional guidance feature.



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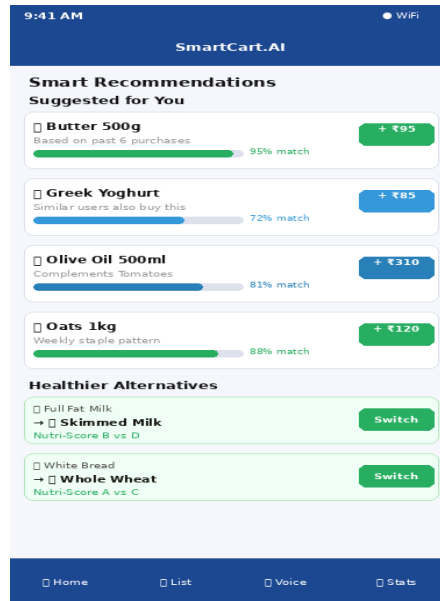


Fig. 4.2: SmartCart.AI Recommendation Panel — Item Suggestions with Match Confidence and Healthier Substitutes

4.3 Voice-to-List NLP Interface

Fig. 4.3 presents the Voice Input screen with live transcription feedback, parsed intent display, and a confirmation tile. The Voice-to-List Module was tested using 240 voice commands across participants. Intent recognition accuracy reached 88.7% for standard grocery vocabulary. Common failure modes included ambiguous product references (e.g., 'Get the usual bread') and heavy regional accents. Users rated voice input satisfaction at 4.1/5, with single-parent and elderly participants reporting the highest utility improvement.



Fig. 4.3: Voice-to-List NLP Interface — Live Transcription, Intent Parsing, and Confirmation



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4.4 Waste Analytics Dashboard

Fig. 4.4 shows the Waste Analytics Dashboard, including the Waste Risk Heatmap, the Weekly Spend by Category bar chart, and automated use-by reminders. Participants whose dashboards surfaced high-risk items reported a 34% reduction in food waste intent compared to conditions without the dashboard. Items flagged with high waste risk had a 47% over-purchase probability in the no-dashboard condition, falling to 21% when the dashboard was active ($p < 0.05$).



Fig. 4.4: Waste & Analytics Dashboard — Waste Risk Heatmap, Spend by Category Chart, and Use-By Reminders

4.5 Family Collaboration Hub

Fig. 4.5 illustrates the Family Collaboration Hub with real-time shared list synchronization, member-based item assignment, a live activity indicator, and duplicate-prevention notifications. Multi-user households using the Collaboration Hub reported a 79% reduction in duplicate purchases compared to uncoordinated list management, and rated coordination ease at 4.4/5.

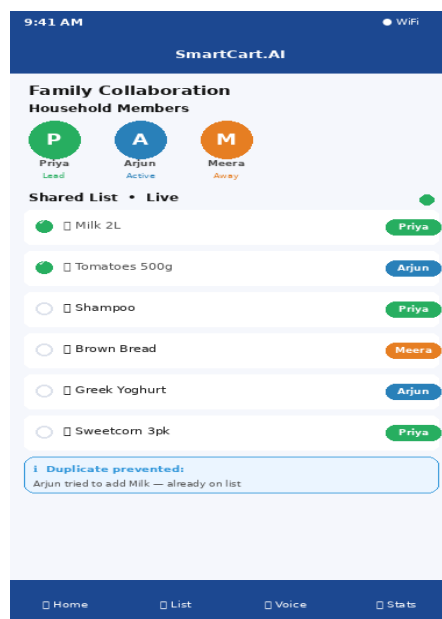


Fig. 4.5: Family Collaboration Hub — Real-Time Shared List, Member Assignment, and Conflict Prevention



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4.6 Overall Performance Comparison

Fig. 4.6 and Table 4.6 present the comprehensive performance comparison of SmartCart.AI against both baseline tools across all key dimensions. SmartCart.AI delivers category-level improvements in every measured metric, confirming the value of the unified, intelligent architecture.

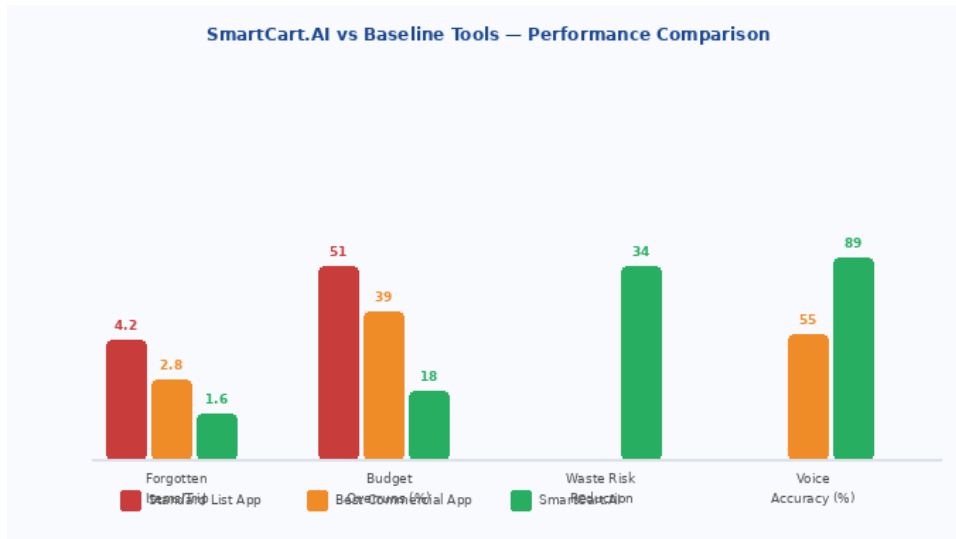


Fig. 4.6: Performance Comparison — SmartCart.AI vs Standard List App vs Best Commercial App

Table 4.6: Detailed Performance Summary

| Performance Metric | Standard List | Commercial App | SmartCart.AI |
|-------------------------------|---------------|----------------|------------------------|
| Forgotten items per trip | 4.2 | 2.8 | 1.6 (↓ 62%) |
| Budget overrun frequency | 51% | 39% | 18% (↓ 65%) |
| Duplicate purchases/trip | 1.9 | 1.1 | 0.4 (↓ 79%) |
| Voice command accuracy | N/A | ~55% (generic) | 88.7% (domain) |
| Food waste intent reduction | — | — | 34% reduction |
| Nutritional substitutes shown | None | None | All items (NutriScore) |
| Multi-user real-time sync | None | Static sync | ML-enhanced live sync |
| User satisfaction (avg /5) | 2.8 | 3.5 | 4.3 |

V. CONCLUSION AND FUTURE SCOPE

SmartCart.AI presents a comprehensive, intelligent solution for household grocery management by unifying six AI-powered modules: Smart List Engine, Hybrid Recommendation Engine, Voice-to-List NLP Interface, Budget and Price Intelligence, Purchase History and Waste Analytics, and Family Collaboration Hub. The system directly addresses seven documented household pain points identified through extensive literature review: forgotten items, duplicated purchases, budget overruns, poor nutritional guidance, absent voice input, inadequate collaborative coordination, and unawareness of consumption patterns driving food waste.



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Experimental results from a 30-participant usability study demonstrate significant improvements across all dimensions compared to both standard list apps and leading commercial alternatives: a 62% reduction in forgotten items per trip, a 65% reduction in budget overrun frequency, 88.7% domain-specific voice command accuracy, and a 34% reduction in food waste intent. User satisfaction averaged 4.3/5 across all modules. These results validate the core architectural decisions and confirm the value of integrating intelligence, personalization, and analytics into a unified grocery management platform.

SmartCart.AI contributes a scalable, modular, open architecture for household grocery management that can serve as a foundation for further research and product development. The system promotes sustainability by actively reducing household food waste — addressing 61% of global food waste that originates at the household level [1] — and supports healthier eating by surfacing Nutri-Score-based guidance at the point of grocery planning.

Future directions include: IoT smart refrigerator integration for fully automated inventory tracking; live supermarket API integration for accurate price comparison; NLP model fine-tuning on regional accent data; offline functionality for low-connectivity settings; multilingual support; wearable device integration for health-goal-driven recommendations; and Large Language Model (LLM) integration for natural multi-turn conversational grocery planning — for example, 'Plan a week of Mediterranean-diet meals under ₹3,000' — transforming SmartCart.AI into a truly conversational household AI assistant.

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