

Intelligent Hybrid Smart Shopping Trolley for Shopping Malls: RFID-Based Automated Billing with Edge–Cloud Analytics and Autonomous Assistance

Gundal Kirti Sandip¹, Prof. Bangar Abhishek¹

¹Department of Computer Engineering, Jaihind College of Engineering, Kuran, Pune, India

Abstract- Long checkout queues, manual barcode scanning, billing errors and the physical effort of pushing a trolley through a crowded mall remain persistent problems in organised retail. Existing smart-trolley research addresses these problems in isolation: RFID-based systems automate billing, AI-driven carts add tracking and demand forecasting, IoT and fog-computing architectures reduce latency, and sensor-driven carts add autonomous following. This paper reviews four representative studies and proposes an integrated, low-cost Hybrid Smart Shopping Trolley for shopping malls. The proposed system combines an RFID reader and microcontroller for real-time item identification and billing, an ultrasonic and infrared sensor layer for obstacle-aware assistance, a fog/edge layer for time-critical processing, and a cloud layer for inventory forecasting and customer analytics. A layered architecture, working flow, component design, security model and evaluation methodology are presented. Based on results reported in the reviewed literature, the approach is expected to cut checkout time by roughly 70%, reach about 98% product-identification accuracy, and keep system latency below 200 ms, while remaining cheaper than camera-based cashierless stores. Limitations and future directions are also discussed.

Keywords— Smart Shopping Trolley, RFID, Automated Billing, Internet of Things, Edge–Cloud Computing, Inventory Forecasting, Retail Automation

I. INTRODUCTION

Shopping malls and supermarkets are among the most crowded retail environments. Customers typically pick items, queue at a counter, wait while each item is scanned manually, and then pay. This process is slow, labour intensive and error-prone, and it reduces customer satisfaction, especially at peak hours. For retailers, manual billing and manual stock counting lead to discrepancies, stock-outs and overstocking.

The Internet of Things (IoT) and Radio Frequency Identification (RFID) offer a practical way to automate these tasks. Unlike barcodes, RFID tags can be read without line of sight and in fractions of a second, so items can be detected automatically as they enter or leave a trolley. A display on the trolley can show a running bill, giving customers control over spending, and payment can be completed digitally without queuing.

A review of the literature shows that most proposals focus on one aspect only: billing automation, AI-based tracking and forecasting, cloud/fog architecture, or autonomous movement. The objective of this paper is to analyse four such studies and to combine their strengths into a single practical design suited to shopping malls, particularly in developing markets where cost and infrastructure are constraints.

Contributions of this paper:

- A comparative analysis of four recent smart-trolley studies covering RFID auto-billing, AI-driven carts, IoT with cloud/fog computing, and RFID-based customer identification with autonomous navigation.
- A proposed hybrid architecture that integrates RFID billing, sensor-based assistance, edge/fog processing and cloud analytics.
- A working flow, component specification and security model for the proposed trolley.

- An evaluation methodology and expected performance drawn from the reviewed literature, along with limitations and future work.

II. LITERATURE REVIEW

1. RFID-Based Smart Trolley with Auto Billing [1]

Kavitha et al. present an RFID-enabled trolley with a microcontroller, digital display and web-based billing application, evaluated with 200 subjects. The study reports that automated billing reduces checkout time by about 70% while minimising human error in invoicing. Real-time bill display improved customer control and transparency. The authors also note practical challenges: proper tag placement is essential because hidden or badly oriented tags cause missed detections, small stores face high upfront investment, older customers may be slower to accept self-service, and reliable power is required.

2. AI-Driven Smart Shopping Carts [2]

Zulfiqar et al. propose a three-layer architecture (hardware, data processing and application layers). RGB-D cameras, Kalman filtering and re-identification with cosine similarity provide person-specific tracking; reinforcement learning (Q-learning) optimises navigation; a CNN generates personalised recommendations; and an LSTM network forecasts demand for inventory management. Reported results include a tracking F1-score of 0.93, a navigation success rate of 96% in dense and dynamic settings, Precision@5 of 0.88 for recommendations, a forecasting MSE of 0.034 (versus 0.062 for ARIMA), 85% user satisfaction, and latency below 200 ms with up to 50 concurrent carts. Communication uses MQTT and HTTPS, with AES-256 encryption and role-based access control. The authors acknowledge that experiments were done in controlled settings and that real stores may behave differently.

3. IoT-Enabled Smart Carts with Cloud and Fog Computing [3]

Wang explores low-cost RFID tags and smart carts that bill directly from the cart, and compares cloud and fog computing architectures. Cloud computing offers high computational and storage capability but suffers higher latency and energy consumption, whereas fog computing offers low latency, mobility support, location awareness and lower energy use. A neuro-fuzzy model, with customer clustering based on an LRFMP (length, recency, frequency, monetary, periodicity) model, is evaluated using the correlation coefficient and mean squared error, with data split 65% training, 15% validation and 20% testing. The study concludes that combining IoT with cloud and fog layers improves efficiency, reduces congestion and minimises energy waste. Its reported regression values ($R \approx 0.79$ in later iterations) indicate moderate rather than strong correlation, which suggests room for improvement.

4. RFID Customer Identification and Autonomous Smart Cart [4]

Kulkarni et al. describe an Arduino-based cart using an EM18 RFID reader to identify both customers and products, an LCD for the live bill, an HC-SR04 ultrasonic sensor for forward/backward control, IR sensors for turning, and L293D drivers with four DC motors. The prototype achieved 98% identification accuracy over 500 scans, 92% collision-avoidance success, 85% autonomous-navigation accuracy in a 60 m² area, and an average transaction time of about 12 seconds versus 3–5 minutes at conventional counters. Estimated labour savings were 40–60%, compared with 70–80% for Amazon Go, but at much lower infrastructure cost. Limitations include battery life of 2–3 hours, 68% navigation accuracy in extreme crowds, and sequential (non-simultaneous) tag reading.

5. Comparative Summary

Table 1. Comparison of the reviewed studies

Aspect	RFID Auto-Billing (Kavitha et al.)	AI-Driven Cart (Zulfiqar et al.)	IoT Cloud/Fog Cart (Wang)	RFID + Autonomous Cart (Kulkarni et al.)
Main focus	Automated billing, adoption	Tracking, navigation, forecasting	Architecture, neuro- fuzzy analytics	Customer ID, billing, movement

Core technology	RFID, MCU, display	RGB-D, RL, LSTM, CNN	RFID, cloud/fog, neuro-fuzzy	EM18 RFID, Arduino, ultrasonic, IR
Key result	~70% faster checkout	F1 0.93; 96% navigation success	Lower latency and energy waste	98% ID accuracy; ~12 s billing
Cost level	Moderate	High (cameras, cloud AI)	Moderate	Low to moderate
Main limitation	Tag placement, upfront cost	Controlled-lab testing	Moderate regression values	Battery, crowds, sequential scans

6. Research Gap

No single reviewed system provides low-cost RFID billing, practical obstacle-aware assistance, latency-aware edge/fog processing and demand forecasting together. High-end AI carts depend on costly cameras and cloud services, while low-cost RFID carts lack analytics and scalable architecture. This paper addresses that gap with a tiered hybrid design in which expensive intelligence is optional and cloud-based rather than mandatory on every trolley.

III. PROBLEM STATEMENT AND OBJECTIVES

Problem statement: To design a cost-effective smart shopping trolley for shopping malls that automates item detection and billing, eliminates checkout queues, assists navigation, and supplies retailers with real-time inventory and customer insights.

Objectives

- Automate product identification and billing using RFID without manual scanning.
- Display a live bill and allow item addition and removal with instant bill updates.
- Provide obstacle-aware movement assistance using low-cost sensors.
- Use edge/fog processing for real-time response and cloud processing for analytics.
- Support contactless digital payment and secure handling of customer data.
- Give retailers real-time stock visibility and demand forecasts.

IV. PROPOSED SYSTEM

1. System Architecture

The proposed Hybrid Smart Shopping Trolley follows a four-layer architecture.

- Perception layer (trolley hardware): RFID reader, ultrasonic and IR sensors, motor driver and motors, display and optional load cell.
- Edge/fog layer: a microcontroller (Arduino) coordinating sensors and display, optionally paired with a Raspberry Pi or in-store fog node for time-critical tasks such as billing updates, obstacle avoidance and tag de-duplication.
- Cloud layer: product database, billing and payment services, LSTM-based demand forecasting, customer clustering and recommendation analytics.
- Application layer: customer interface (trolley display or mobile app) showing items, running total, offers and receipt; administrator dashboard showing stock levels, alerts, sales trends and trolley status.

Data moves from the perception layer to the edge layer for immediate decisions, and summarised transaction data is forwarded to the cloud for storage and analytics. This keeps the trolley responsive even when network quality is poor.

2. Hardware Components

Table 2. Hardware components and their roles

Component	Role
RFID reader and passive tags	Detect products added to or removed from the trolley; identify customer card

Microcontroller (Arduino Uno / Nano)	Reads RFID data, runs billing logic, drives display and motors
Raspberry Pi / fog node (optional)	Local processing, database caching, communication with cloud
LCD/OLED display	Shows item name, price and running total
HC-SR04 ultrasonic sensor	Distance measurement for safe forward/reverse movement
IR sensors	Obstacle detection and left/right turning
L293D motor driver and 12 V DC motors	Controlled movement of the trolley
Load cell (optional)	Weight verification to detect theft or untagged items
Battery and power management	12 V supply, with future solar assistance
Wi-Fi/MQTT module	Link to the store network and cloud

3. Software Components

- Billing software: looks up price by tag ID in the central database, applies discounts and loyalty rules, and updates the total.
- Payment module: supports UPI, mobile wallets and cards for contactless payment, followed by a digital receipt by email or mobile.
- Product information module: shows details such as ingredients and allergens on the display.
- Inventory module: decrements stock on each completed sale and triggers replenishment alerts.
- Analytics module (cloud): LSTM demand forecasting and customer clustering for offers.

4. Working Flow

- The customer enters the mall and activates a trolley by scanning a customer RFID card or logging in via the mobile app.
- When a tagged item is placed in the trolley, the reader detects the tag and the microcontroller reads the unique ID.

- The system checks whether the tag is valid. If not, an "Unknown Tag" message is shown and a rescan is requested.
- Product details are retrieved from the database and the price is added to the bill.
- The display updates the item list and running total in real time.
- If an item is removed, its tag is no longer detected (or a removal scan is made) and the bill is reduced automatically.
- During movement, ultrasonic and IR sensors keep a safe distance and steer around obstacles.
- When shopping is complete, the customer pays digitally from the trolley or the app; no cashier scan is needed.
- A digital receipt is generated, a gate or exit check verifies the paid items, and the sale is logged to the inventory database.

5. Control Logic for Assistance

Following the sensor logic reported in the reviewed prototype, the cart moves forward when the measured distance exceeds 40 cm, reverses when it is below 20 cm and stops in between, while IR sensors trigger left or right turns on obstacle detection. This simple threshold logic is inexpensive and predictable. More advanced person-following using vision and reinforcement learning is kept as an optional upgrade.

6. Analytics and Inventory Forecasting

Sales logs collected from all trolleys are used to train an LSTM network that predicts demand per product. The inventory relation $S(t+1) = S(t) - D(t) + R(t)$ is used, where S is stock, D is predicted demand and R is the replenishment quantity, and model quality is monitored with the mean squared error. Customer clustering based on recency, frequency and monetary value supports personalised offers shown on the trolley display.

7. Security and Privacy

- AES-256 encryption for data in transit and storage, with HTTPS/MQTT over TLS.
- Role-based access control for staff and administrators.
- Minimal collection of customer data and secure handling of payment information.

- Authentication of trolley devices to prevent cloned or spoofed units.
- Compliance with applicable data-protection regulations.

V. EVALUATION METHODOLOGY AND EXPECTED RESULTS

This paper is a design and review study. The metrics below define how the prototype should be evaluated, and the target values are taken from the reviewed literature rather than from new experiments.

1. Evaluation Metrics

- Product identification accuracy: correct reads over total scans.
- Checkout time: average time from end of shopping to receipt.
- Billing accuracy: bill errors per 1,000 transactions.
- Navigation reliability: collision-avoidance success rate and autonomous navigation accuracy.
- System latency and scalability: response time with increasing numbers of trolleys.
- Forecast accuracy: MSE, MAE and RMSE of the LSTM model against a baseline such as ARIMA.
- User satisfaction: survey of ease of use, transparency and overall experience.

2. Expected Performance from Reviewed Studies

Table 3. Performance values reported in the reviewed literature

Metric	Reported value	Source study
Checkout time reduction	About 70%	Kavitha et al.
Product identification accuracy	98% (500 scans)	Kulkarni et al.
Average transaction time	About 12 s vs 3–5 min	Kulkarni et al.
Collision-avoidance success	92%	Kulkarni et al.
System latency	Below 200 ms (50 carts)	Zulfiqar et al.

Forecast error (LSTM)	MSE 0.034 vs ARIMA 0.062	Zulfiqar et al.
User satisfaction	85%	Zulfiqar et al.
Labour cost reduction	40–60%	Kulkarni et al.

3. Comparison with Other Retail Models

Table 4. Traditional counter vs proposed trolley vs cashierless store

Feature	Traditional counter	Proposed hybrid trolley	Camera-based cashierless store
Checkout time	3–5 minutes	Seconds	Seconds
Billing accuracy	Prone to manual errors	High	High
Infrastructure cost	Low to moderate	Moderate	Very high
Labour saving	None	40–60%	70–80%
Scalability	High	High	Limited
Crowd performance	Human assisted	Moderate	Challenged by dense traffic

Advantages

- Eliminates checkout queues and reduces waiting time.
- Real-time billing gives customers control over spending.
- Reduces human error in billing and stock counting.
- Provides real-time inventory data, reducing stock-outs and overstocking.
- Supports contactless payment and digital receipts.
- Scalable and cheaper than camera-based cashierless systems.
- Edge/fog processing keeps the trolley responsive and energy efficient.

Challenges and Limitations

- Tag placement and cost: tags must be correctly placed and visible to the reader; tagging every item adds recurring cost, and metal or liquid products can interfere with reading.

- Simultaneous reads: low-frequency readers read tags sequentially; UHF readers with anti-collision support are needed for bulk reads.
- Battery life: reported at 2–3 hours of continuous use, so efficient power management or solar assistance is needed.
- Crowd handling: navigation accuracy falls in very dense crowds (68% in the reviewed prototype).
- Theft and fraud: removal of tags or items without scanning requires weight verification and exit checks.
- User adoption: older customers may need guidance and gradual rollout.
- Privacy: customer tracking and analytics must follow data-protection practice.
- Evidence limits: several reported results come from simulated or controlled environments and should be validated in real malls.

Future Scope

- UHF RFID readers with anti-collision for simultaneous multi-item scanning.
- Vision-based person following with reinforcement-learning navigation.
- Voice assistance and in-store product search with shelf-level guidance.
- OLED displays, a lighter chassis and solar or wireless charging.
- Mobile app integration across multiple stores with a single login.
- Federated learning and privacy-preserving analytics for customer data.
- Large-scale pilot testing in real shopping malls with a user study.

VI. CONCLUSION

This paper analysed four recent studies on smart shopping trolleys and proposed a Hybrid Smart Shopping Trolley that unites RFID automated billing, low-cost sensor assistance, edge/fog processing and cloud analytics. The design targets shorter checkout times, accurate billing, better stock visibility and a more comfortable shopping experience at moderate cost. The reviewed literature suggests that such a system can cut checkout time by about 70%, identify products with around 98% accuracy and operate with latency below 200 ms. Practical challenges

including tag cost, battery life, crowd performance and privacy must be addressed through staged deployment and real-world validation. The proposed approach offers a balanced path for malls, particularly in developing markets, to modernise retail without the heavy cost of fully cashierless infrastructure.

REFERENCES

1. T. Kavitha, B. Sasi Varun Kumar Reddy, E. Surendra Goud, G. Ramya Sree and B. Varun Kumar Reddy, "Smart Shopping Trolley with Auto Billing System Using RFID," in Proc. 1st Int. Conf. on Research and Development in Information, Communication, and Computing Technologies (ICRDICCT'25), vol. 4, pp. 581–587, SCITEPRESS, 2025. DOI: 10.5220/0013917200004919.
2. M. I. Zulfikar, A. Khalid, A. Siddig, M. J. Nawaz and S. Saay, "AI-Driven Smart Shopping Carts With Real-Time Tracking and Inventory Forecasting for Enhanced Retail Efficiency," IEEE Access, vol. 13, pp. 55576–55585, 2025. DOI: 10.1109/ACCESS.2025.3553854.
3. J. Wang, "Enhancing the e-commerce shopping experience with IoT-enabled smart carts in smart stores," Discover Internet of Things, vol. 5, art. 35, 2025. DOI: 10.1007/s43926-025-00128-2.
4. A. Kulkarni, A. K. Talele, M. M. Barhate, A. Dutta, A. Bora and M. Azmi, "Smart Shopping Cart with RFID Customer Identification and Smart Billing," Vishwakarma Institute of Technology, Pune, India.
5. M. Shahroz, M. F. Mushtaq, M. Ahmad, S. Ullah, A. Mehmood and G. S. Choi, "IoT-based smart shopping cart using radio frequency identification," IEEE Access, vol. 8, pp. 68426–68438, 2020.
6. M. Sanap, P. Chimurkar and N. Bhagat, "SMART - Smart Mobile Autonomous Robotic Trolley," in Proc. 4th Int. Conf. Intelligent Computing and Control Systems (ICICCS), 2020, pp. 430–437.
7. T. Hanooja et al., "Human Friendly Smart Trolley with Automatic Billing System," in Proc. 4th Int. Conf. Electronics, Communication and Aerospace Technology (ICECA), 2020, pp. 1614–1619.

8. J. L. He, "Development of intelligent management system for health combat readiness materials based on RFID technology," in Proc. ISCCN 2023, SPIE, vol. 12702, pp. 457–461.
9. R. T. Ocaña, S. A. M. Peñaranda and V. M. P. Falcon, "Smart shopping carts: reducing checkout queues with RFID and AWS facial recognition," in Proc. 2024 IEEE XXXI Int. Conf. Electronics, Electrical Engineering and Computing (INTERCON), 2024, pp. 1–7.
10. S. -R. Yan, S. Pirooznia, A. Heidari, N. J. Navimipour and M. Unal, "Implementation of a product-recommender system in an IoT-based smart shopping using fuzzy logic and apriori algorithm," IEEE Trans. Eng. Manage., vol. 71, pp. 4940–4954, 2022.