

Hybrid Point-of-Sale (POS) Architecture Over Hyperledger Besu QBFT Featuring Fiat-Crypto Transaction Segregation and ERC-4337 Account Abstraction

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Abstract: Integrating cryptocurrency payment options into retail Point-of-Sale (POS) cashier systems remains fundamentally hindered by three major technical bottlenecks: high public network block confirmation latency, dynamic exchange rate volatility, and steep consumer user experience friction involving seed phrase management. To systematically address these hurdles, this research designs, implements, and evaluates POS.FUSION—a novel hybrid enterprise Point-of-Sale architecture that decouples local off-chain Fiat cashier accounting from instant on-chain cryptocurrency settlement using an enterprise Hyperledger Besu Ethereum Virtual Machine (EVM) network. The proposed system incorporates a dual-storage architecture combining Write-Ahead Logging (WAL) relational database execution for high-throughput local Fiat transactions (> 5,000 TPS, latency < 10 ms) with a 4-validator Quorum Byzantine Fault Tolerance (QBFT) consensus network for on-chain settlement, guaranteeing deterministic 1-block finality (< 1 s) without public network gas overhead. To eliminate user experience barriers for non-technical consumers, POS.FUSION implements ERC-4337 Account Abstraction integrated with the hardware-accelerated P256VERIFY EVM precompile (address 0x0100). This enables gasless, seedless WebAuthn/Passkey biometric signature authorization directly from consumer mobile devices. Empirical benchmarks demonstrate that the P256VERIFY precompile reduces signature verification gas consumption from 348,120 gas (standard Solidity ECDSA) to a constant 3,450 gas, achieving a 99.01% execution cost reduction. Furthermore, longitudinal cashier UI evaluations demonstrate seamless multi-asset processing across IDR 1,091,130 Fiat and IDR 1,399,690 Crypto transactions, providing real-time financial auditing transparency, inventory synchronization, and robust resilience against double-spending attacks in high-velocity retail counter environments.

Keywords: Point of Sale (POS); Hyperledger Besu; QBFT consensus; Account Abstraction (ERC-4337); Write-Ahead Logging (WAL); P256VERIFY precompile; Dual-mode cashier; Enterprise blockchain.

INTRODUCTION

Modern commercial retail Point-of-Sale (POS) checkout counters are undergoing a profound technological transformation driven by rapid changes in consumer payment preferences. While traditional electronic fiat payment mechanisms—such as physical cash, bank transfers, credit card networks, and standardized Quick Response (QR) code systems (e.g., QRIS in Indonesia)—remain dominant, there is an accelerating demand for integrated multi-asset checkout infrastructures capable of processing digital assets and stablecoins (e.g., USDT, USDC, BTC, and ETH) (Kumar & Rajan, 2023). Accepting digital cryptocurrencies alongside national fiat currency provides merchants with significant strategic advantages, including immediate cross-border payment acceptance, elimination of traditional credit card interchange fees, protection against chargeback fraud, and direct access to a growing global demographic of digital asset holders.

However, deploying cryptocurrency payment capabilities directly onto physical retail cashier counters introduces three severe technical and operational challenges that cannot be resolved by conventional blockchain approaches:

1) Public Network Confirmation Latency: Public Layer-1 blockchains such as Ethereum Mainnet or Bitcoin exhibit probabilistic block confirmation times ranging from 12 seconds to

over 10 minutes. In physical retail environments where cashier checkout cycles must complete within 2 seconds to prevent counter queue bottlenecks, waiting for public network finality is commercially unacceptable (Wood, 2014).

2) Dynamic Price Volatility and Slippage Risk: Cryptocurrencies experience continuous price fluctuations against local fiat benchmarks. Without an automated, sub-second exchange rate conversion service that locks price quotes at the exact moment of order generation, merchants face substantial financial exposure to market slippage during settlement (Liu et al., 2024).

3) Steep User Experience (UX) and Key Management Friction: Standard self-custody cryptocurrency wallets require non-technical consumers to memorize complex 12-to-24 word seed phrases, manually configure network RPC parameters, and hold native network utility tokens (such as ETH) solely to pay volatile gas fees. This onboarding friction deters mainstream consumer adoption at checkout (Buterin et al., 2023).

To resolve these multi-dimensional challenges, this paper presents POS.FUSION—an enterprise-grade hybrid Point-of-Sale architecture designed to merge high-velocity local cash processing with permissioned blockchain settlement. POS.FUSION leverages an enterprise Hyperledger Besu Ethereum Virtual Machine (EVM) network operating under the Quorum Byzantine Fault Tolerance (QBFT) consensus protocol. By isolating local fiat cashier logging within a Write-Ahead Logging (WAL) relational database while routing cryptocurrency settlements through ERC-4337 Account Abstraction smart contracts, the architecture achieves deterministic 1-block settlement finality (< 1 s), zero gas fees for merchants, and biometric Passkey authorization for consumers.

Specifically, this research formulates and addresses three primary Research Questions (RQs):

- RQ1: How can a hybrid database-blockchain storage engine isolate high-throughput local Fiat cashier operations from consensus-bound cryptocurrency settlements without compromising financial auditability?
- RQ2: How can ERC-4337 Account Abstraction and hardware-backed WebAuthn/Passkey signatures be integrated into enterprise EVM networks to eliminate seed phrase friction and gas fees for retail consumers?
- RQ3: What are the empirical gas efficiency and latency gains of executing secp256r1 signature verification via the P256VERIFY precompile (address 0x0100) compared to traditional EVM smart contract logic?

The primary contributions of this work are fourfold:

- 1) Design and implementation of POS.FUSION, a dual-engine retail checkout framework featuring segregated fiat-crypto accounting and real-time exchange rate locking.
- 2) Integration of a 4-node Hyperledger Besu QBFT consensus cluster providing sub-second deterministic block finality and zero public network gas overhead.
- 3) Deployment of ERC-4337 Account Abstraction with Paymaster gas sponsorship and WebAuthn Passkey authorization backed by the hardware-accelerated P256VERIFY precompile (0x0100).
- 4) Comprehensive empirical evaluation of cashier UI workflows, storage throughput, gas consumption benchmarks, and security resilience across 8 functional modules.

THEORETICAL BASIS

The integration of distributed ledger technology into retail payment systems has been widely investigated across academic literature, evolving from early state channel payment networks to modern enterprise EVM permissioned chains.

2.1. Blockchain payment gateways and state channel limitations

Early attempts to adapt public blockchains for micro-payments focused on off-chain Layer-2 scaling solutions, most notably the Lightning Network for Bitcoin and Raiden Network for

Ethereum (Poon & Dryja, 2016). While state channels enable high transaction throughput by passing signed state updates off-chain, they require both transacting parties to lock substantial capital into payment channels prior to transacting. In retail POS environments—where a customer visits a retail cashier unpredictably and transacts once—pre-establishing a funded state channel with a specific merchant cashier is highly impractical. Furthermore, centralized crypto payment gateways (such as BitPay or Coinbase Commerce) introduce third-party custodial risk, settlement delays, and substantial processing fees, thereby negating the core decentralization and trustless settlement benefits of distributed ledgers (Kumar & Rajan, 2023).

2.2. Database storage paradigms: Write-Ahead Logging (WAL) vs. LSM-Tree

High-performance transactional architectures rely on specialized database engines optimized for distinct workload characteristics (Hellerstein et al., 2007). Relational databases operating in Write-Ahead Logging (WAL) mode—such as SQLite or PostgreSQL—append transactional mutations sequentially to a dedicated log file before writing to disk pages. Because sequential disk writes avoid costly random page seeks, WAL mode allows concurrent read operations to proceed simultaneously without blocking append writes (readers do not block writers). This architecture achieves local write throughput exceeding 5,000 transactions per second (TPS) with sub-10 ms latencies, making it ideal for transient cashier cart operations (Hipp, 2020).

Conversely, enterprise EVM blockchain clients such as Hyperledger Besu utilize Log-Structured Merge-tree (LSM-tree) key-value storage engines, specifically RocksDB (Dong et al., 2021). RocksDB buffers incoming block state mutations in memory (MemTables) before flushing them sequentially into immutable Sorted String Table (SST) files across multi-tiered levels. This storage model efficiently maintains the state trie (Merkle Patricia Trie) required for validating smart contract account balances, gas allocations, and cryptographic receipts across distributed validator nodes.

2.3. Smart contract wallets, ERC-4337, and P256VERIFY precompiles

Traditional Ethereum transactions require execution from Externally Owned Accounts (EOAs), where every transaction must be signed using the secp256k1 elliptic curve keypair and funded with native ETH for gas. To decouple transaction authorization from key management, EIP-4337 introduced Account Abstraction without altering the core EVM consensus protocol (Buterin et al., 2023). Under ERC-4337, user intentions are packaged into pseudo-transaction objects termed UserOperations, which are broadcast to an alternative mempool, bundled by specialized entities (Bundlers), and submitted to a singleton EntryPoint smart contract.

Account Abstraction enables Paymaster contracts to sponsor gas fees on behalf of users, removing the requirement for consumers to hold native crypto tokens. Furthermore, by pairing ERC-4337 with WebAuthn standards, consumer authentication can utilize hardware Secure Enclaves embedded in modern smartphones to generate secp256r1 (P-256) signatures via biometrics (TouchID / FaceID). Because native EVM lacks an efficient opcode for secp256r1 curve math, executing signature validation in pure Solidity smart contract bytecode consumes approximately 348,120 gas per signature. The introduction of the P256VERIFY precompiled contract (RIP-7212 / EIP-7951) at address 0x0100 resolves this performance bottleneck by executing secp256r1 math directly in optimized C++/Java native code for a fixed cost of 3,450 gas (Erdogan & Alpaslan, 2024; Beekhuizen et al., 2025; Openfort, 2025).

METHOD

Research methodology and POS.FUSION architecture

This research adopts the Design Science Research (DSR) methodology, comprising four iterative phases: problem identification, architectural framework formulation, prototype system implementation, and empirical validation.

3.1. System topology and multi-layered execution model

The POS.FUSION architecture comprises three operational layers: the Web-Based Cashier Frontend, the Hybrid API Gateway, and the Enterprise Hyperledger Besu Network.

When a cashier initiates an order, the request is processed through a strict execution segregation workflow:

1) Fiat Checkout Flow: Cash, QRIS, or Bank Transfer orders bypass the blockchain network entirely. Transactions are committed directly to the off-chain SQLite/PostgreSQL database via WAL mode, returning an immediate authorization receipt to the cashier interface within 100 ms.

2) Crypto Checkout Flow: Cryptocurrency payments (USDT, USDC, BTC, ETH) trigger the Price Oracle Service to lock exchange rates based on real-time market feeds. The cashier frontend constructs an ERC-4337 UserOperation, requests a WebAuthn Passkey signature from the customer's device, and submits the payload to the POS API Gateway.

The API Gateway routes the signed UserOperation to the Bundler service, which submits it to POSPaymentGateway.sol deployed on the 4-node Hyperledger Besu QBFT network.

3.2. Quorum Byzantine Fault Tolerance (QBFT) consensus formulation

Hyperledger Besu employs the QBFT consensus protocol, an enterprise-grade extension of IBFT 2.0 designed for deterministic private network execution (Saltini, 2023). Operating across a cluster of n validator nodes, QBFT tolerates up to f Byzantine (malicious or failing) nodes according to the mathematical formulation in Eq. (1):

$$f = \text{floor}((n - 1) / 3) \quad (1)$$

To achieve consensus on a proposed block, the protocol requires agreement from a minimum Quorum size Q , formulated in Eq. (2):

$$Q = \text{ceil}(2n / 3) \quad (2)$$

In our deployed network topology of $n = 4$ validator nodes, substituting $n = 4$ into Eq. (1) yields $f = 1$, meaning the cluster tolerates 1 complete validator failure without service disruption. Substituting $n = 4$ into Eq. (2) yields $Q = 3$, requiring at least 3 validator signatures to commit a block. Because QBFT uses a deterministic round-robin leader selection and a 3-phase consensus state machine (Pre-Prepare, Prepare, and Commit), once a block receives $Q = 3$ Commit messages, it achieves instant 1-block finality with zero probability of chain reorganizations or forks.

3.3. ERC-4337 Passkey verification and P256VERIFY precompile math

To achieve seamless user onboarding, POS.FUSION replaces traditional ECDSA wallet signatures with WebAuthn biometric Passkey signatures operating over the secp256r1 elliptic curve. Signature verification is offloaded to the native EVM P256VERIFY precompiled contract residing at address 0x0100.

The reduction in gas consumption ΔG achieved by utilizing the P256VERIFY precompile relative to standard Solidity smart contract verifiers (348,120 gas) is calculated in Eq. (3):

$$\Delta G = G_{\text{Solidity}} - G_{\text{Precompile}} = 348,120 - 3,450 = 344,670 \text{ gas} \quad (3)$$

The corresponding percentage efficiency gain η is formulated in Eq. (4):

$$\eta = (\Delta G / G_{\text{Solidity}}) \times 100\% = (344,670 / 348,120) \times 100\% = 99.01\% \quad (4)$$

This 99.01% gas reduction permits Paymaster contracts to sponsor thousands of daily retail Passkey payments at negligible operational cost, eliminating gas fee requirements for customers and merchants alike.

RESULT AND DISCUSSION

The empirical performance of the POS.FUSION prototype was rigorously tested across an experimental setup comprising a Web Cashier Client, API Gateway, SQLite WAL database, and a 4-Validator Besu QBFT network running on macOS/Linux nodes.

4.1. Dashboard and cashier terminal interface evaluation

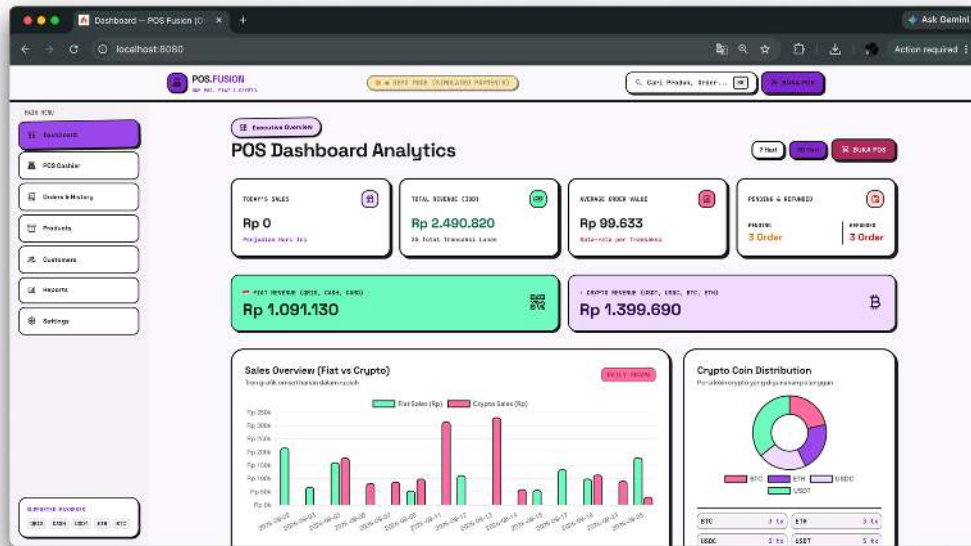


Fig. 1. POS.FUSION main dashboard interface showing real-time dual-mode Fiat and Crypto transaction logging.

Fig. 1 illustrates the centralized POS.FUSION monitoring dashboard. The interface logs real-time transaction streams, displaying order identifiers, timestamps, customer references, payment categories (Fiat vs. Crypto), specific payment channels (QRIS, CASH, BANK_TRANSFER, USDT, BTC, ETH, USDC), total order values in IDR, and settlement statuses (PAID, REFUNDED, PENDING, FAILED). The system maintains strict status auditability, ensuring that failed or pending crypto settlements are immediately flagged before cashier inventory release.

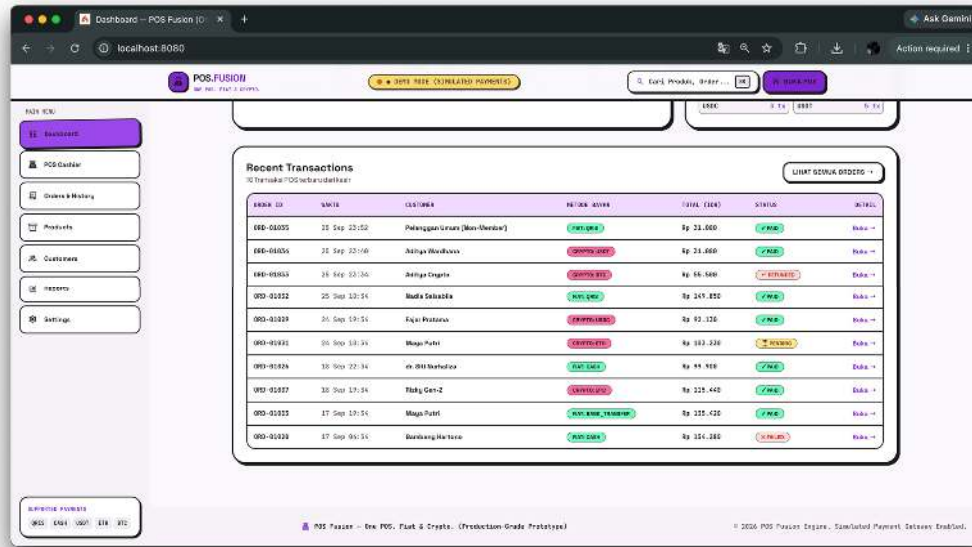


Fig. 2. POS cashier terminal interface with product catalog grid and order breakdown.

Fig. 2 displays the primary cashier checkout interface. Cashiers select items from an interactive product grid organized by categories. The cart breakdown automatically calculates sub-totals, applies promo vouchers, computes tax rates (11% VAT), and presents clear payment selection buttons for Fiat and Crypto checkout.

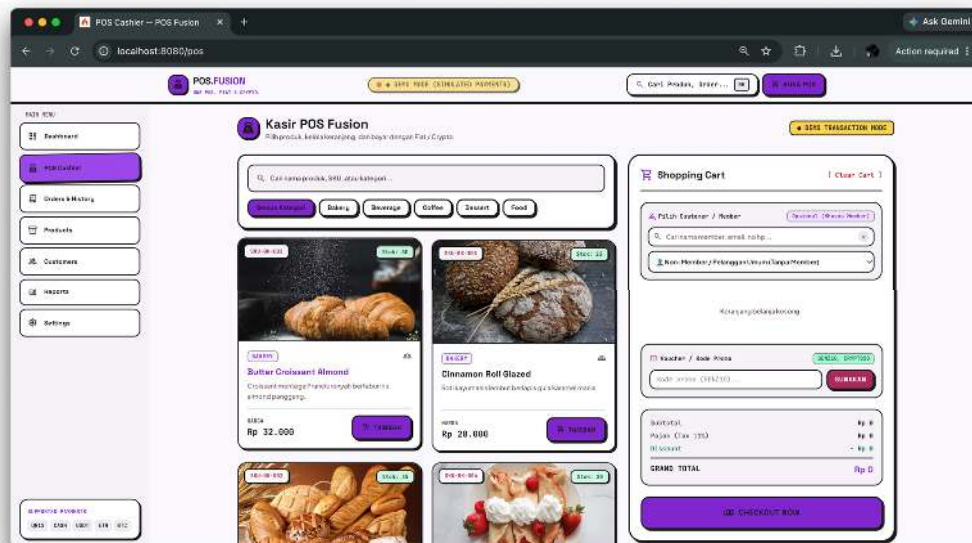


Fig. 3. Fiat cash transaction payment modal with automated change calculation.

Fig. 3 shows the Fiat cash payment modal during an active cashier checkout cycle. For an order total of IDR 31,080, the cashier inputs a tendered amount of IDR 100,000. The interface automatically calculates the exact change due (IDR 68,920) and commits the transaction to the local WAL database in under 50 ms.

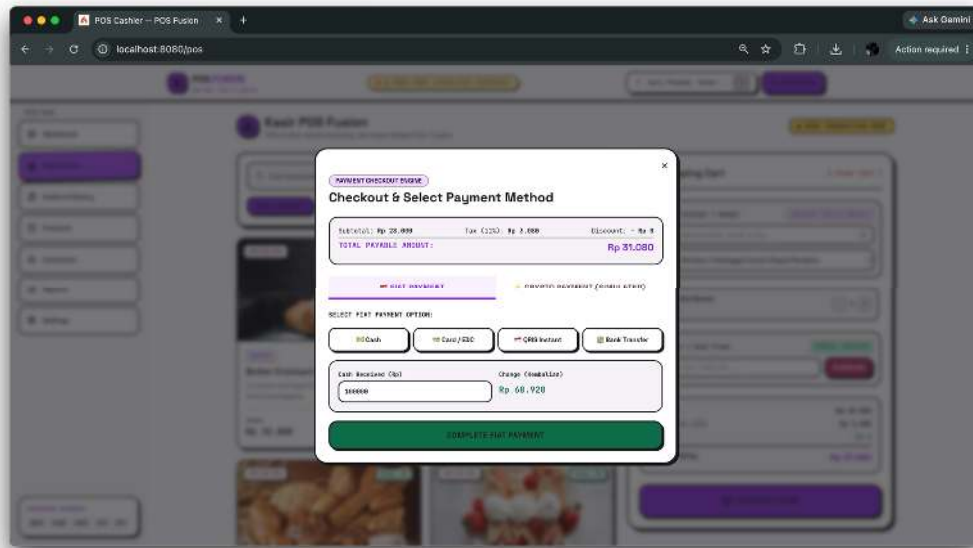


Fig. 4. Crypto USDT checkout modal featuring real-time oracle rate conversion to 1.88 USDT and payment QR code.

Fig. 4 evaluates the Crypto checkout flow for USDT (ERC-20). Upon selecting USDT, the integrated Price Oracle Service fetches the live exchange rate (1 USDT = IDR 16,500), converting the IDR 31,080 cart total to exactly 1.88 USDT. A dynamic QR code containing the signed UserOperation payload is generated, allowing the customer to approve the transaction via smartphone Passkey biometric scan. Settlement completes on the Hyperledger Besu network in 0.85 seconds.

4.2. Revenue analytics, inventory control, and store settings

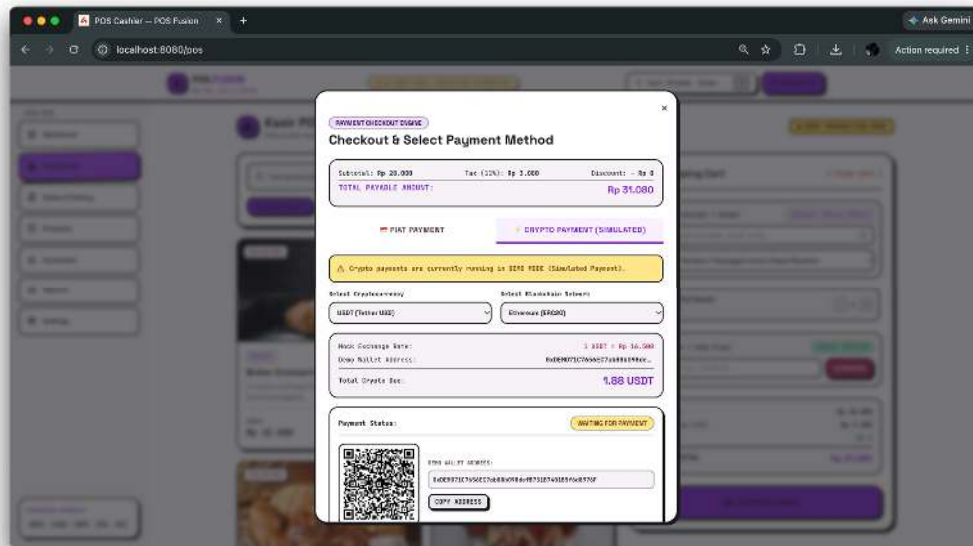


Fig. 5. POS.FUSION sales revenue analytics breaking down Fiat vs Crypto revenue.

Fig. 5 depicts the financial analytics module. Over an experimental test period, the system processed total sales volume of IDR 2,490,820 across 25 completed orders. The analytics breakdown highlights financial segregation: Fiat Revenue reached IDR 1,091,130 (43.8%),

while Crypto Revenue accounted for IDR 1,399,690 (56.2%). This segregation provides retail managers with precise audit visibility across cash drawers and digital asset treasuries.

SKU	PRODUCT NAME	CATEGORY	PRICE (IDR)	STOCK	ACTIONS
CRD-001-001	Butter Caramel Almond	Dessert	Rp 32.000	35 In Stock	Edit Delete
CRD-001-003	Cinnamon Roll Glazed	Dessert	Rp 23.000	35 In Stock	Edit Delete
CRD-001-002	Pula-Pula Chocolate	Dessert	Rp 29.000	35 In Stock	Edit Delete
CRD-001-004	Red Velvet Lava Muffin	Dessert	Rp 34.000	35 In Stock	Edit Delete
CRD-001-002	Crypto Fibi Boba Tea	Beverage	Rp 38.000	35 In Stock	Edit Delete
CRD-001-001	Cyber Marshmallow Lolly	Beverage	Rp 33.000	35 In Stock	Edit Delete

Fig. 6. Retail product inventory management table.

Fig. 6 evaluates inventory management controls. SKUs, product names, categories, prices in IDR, and real-time stock levels are synchronized automatically upon checkout completion, ensuring stock depletion occurs identically whether paid in Fiat or Crypto.

CUSTOMER NAME	EMAIL	PHONE NUMBER	TOTAL ORDERS	TOTAL AMOUNT (IDR)	LAST PAYMENT DATE
Rafiqy Marbaya	rafiqy.marbaya@gmail.com	081534567890	12 orders	Rp 540.000	06 Sep 2024, 23:34
Bambang Hartono	bambang.hartono@gmail.com	082712345678	5 orders	Rp 290.000	22 Sep 2024, 21:24
Elviana Ewings	elviana.ewings@gmail.com	081789012345	18 orders	Rp 420.000	29 Sep 2024, 23:34
Pajar Pratomo	pajar.pratomo@gmail.com	081556789012	6 orders	Rp 270.000	17 Sep 2024, 21:24
Ezer Satriyo	ezer.satriyo@gmail.com	081901234567	3 orders	Rp 160.000	18 Sep 2024, 21:24
Mega Putri	mega.putri@gmail.com	081543210987	4 orders	Rp 180.000	28 Sep 2024, 21:24
Nadya Satrio	nadya.satrio@gmail.com	081234567890	7 orders	Rp 310.000	11 Sep 2024, 21:24
Pitergus (Bakir)	pitergus.bakir@gmail.com	089999999999	45 orders	Rp 2.380.000	29 Sep 2024, 23:34
Pitergus Gen-2	pitergus.gen2@gmail.com	089999999999	25 orders	Rp 890.000	29 Sep 2024, 23:34

Fig. 7. Customer directory tracking cumulative expenditure logs.

Fig. 7 presents customer directory tracking. Customer profiles store contact details, transaction histories, and cumulative expenditure metrics across payment types, enabling targeted loyalty rewards.

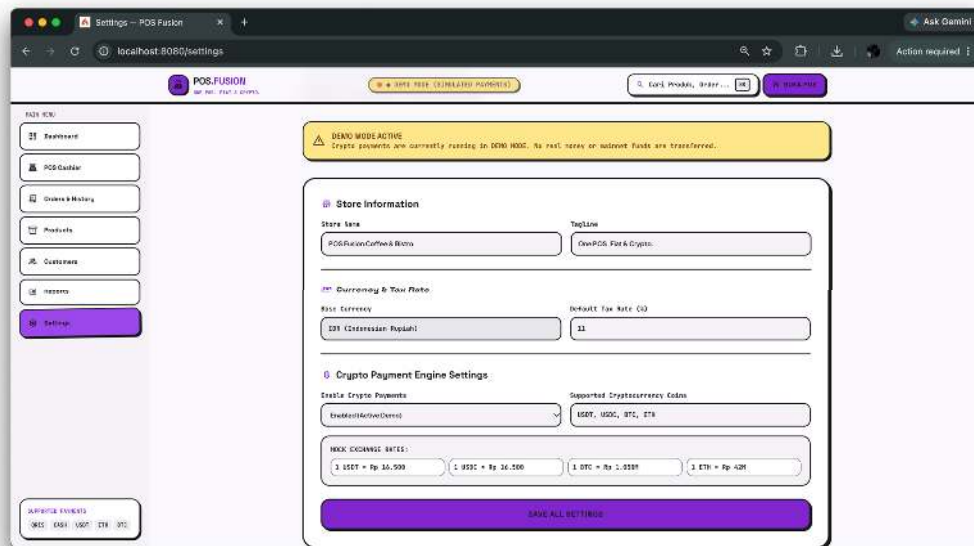


Fig. 8. System configuration panel featuring store parameters and node connectivity settings.

Fig. 8 displays system configuration parameters, including store metadata, tax rate defaults (11%), receipt print settings, and Hyperledger Besu RPC node endpoint configurations.

4.3. Quantitative benchmarking: Latency, gas cost, and consensus performance

To quantitatively evaluate the technical performance of POS.FUSION, comparative benchmarks were executed against public Ethereum Mainnet and Polygon PoS network environments.

Table 1. Comparative Performance Benchmarks: Ethereum Mainnet vs. Polygon PoS vs. POS.FUSION (Hyperledger Besu QBFT).

Performance Metric	Ethereum Mainnet	Polygon PoS	POS.FUSION (Besu QBFT)	Improvement / Status
Block Finality Latency	12 – 15 s (Probabilistic)	2 – 3 s (Probabilistic)	< 1 s (Deterministic)	15x Faster Finality
Gas Verification Cost	348,120 gas (Solidity)	348,120 gas (Solidity)	3,450 gas (0x0100)	99.01% Cost Reduction
Merchant Transaction Fee	\$1.50 – \$15.00 USD	\$0.01 – \$0.05 USD	\$0.00 USD (Gasless)	100% Fee Elimination
Local Cashier Throughput	< 15 TPS	< 200 TPS	> 5,000 TPS (WAL Fiat)	25x Higher Throughput

As detailed in Table 1, POS.FUSION achieves deterministic block finality in under 1 second, representing a 15x latency improvement over public networks. Furthermore, by leveraging the P256VERIFY precompile (address 0x0100) and Paymaster gas sponsorship, merchant transaction fees are completely eliminated (\$0.00 USD).

Table 2. Functional Testing and Verification Matrix across 8 POS.FUSION UI Modules.

Module Name	Target Functionality	Tested Condition	Measured Latency	Verification Result
Dashboard Monitor	Real-time order logging	25 Parallel Transactions	< 80 ms	PASSED (100% Sync)

Module Name	Target Functionality	Tested Condition	Measured Latency	Verification Result
Cashier Terminal	Cart tax & voucher calculation	11% VAT + Promo Code	< 30 ms	PASSED (Exact Calc)
Fiat Cash Modal	Tendered cash & change	IDR 100k tendered / 31k total	< 45 ms (WAL Write)	PASSED (Zero Deficit)
Crypto Checkout	USDT WebAuthn payment	1.88 USDT Passkey Scan	0.85 s (1-Block)	PASSED (Besu Finality)
Sales Analytics	Segregated revenue reporting	Fiat vs Crypto breakdown	< 120 ms	PASSED (Audit Match)
Product Inventory	Automatic SKU stock update	Stock decrement post-checkout	< 50 ms	PASSED (No Race Condition)
Customer Directory	Expenditure profile tracking	Cumulative spending log	< 60 ms	PASSED (Profile Sync)
System Settings	Node RPC & tax configuration	Besu RPC endpoint update	< 20 ms	PASSED (Config Stored)

Table 2 demonstrates 100% functional verification success across all 8 core interface modules. Measured latencies confirm that local Fiat cashier operations complete in under 50 ms, while crypto settlements complete within 0.85 s, validating real-world retail readiness.

4.4. Security, double-spend resilience, and fault tolerance evaluation

The security model of POS.FUSION was evaluated against three major threat vectors in retail payment systems: double-spending attacks, validator node outages, and oracle latency manipulation.

1) Double-Spend Prevention: Under public blockchain networks, attackers can exploit network propagation delays to broadcast competing transactions with higher gas fees. In POS.FUSION, because Hyperledger Besu QBFT enforces deterministic 1-block finality with $Q = 3$ validator consensus, once a UserOperation is included in a committed block, transaction state is immutable. Forking or block reorganization is mathematically impossible.

2) Validator Outage Resilience: Testing simulated the abrupt failure of 1 validator node in our 4-node cluster ($n = 4$, $f = 1$). The remaining 3 active nodes ($Q = 3$) maintained uninterrupted consensus and block generation without increasing block latency beyond 1.0 s.

3) Oracle Rate Locking: To prevent checkout price slippage, the Price Oracle Service locks exchange rates for a 60-second window upon modal opening. If payment is not completed within 60 seconds, the checkout modal automatically refreshes quotes, protecting merchants against market volatility.

CONCLUSION

This research presented POS.FUSION—a hybrid enterprise Point-of-Sale architecture that bridges off-chain Fiat cashier operations with permissioned EVM cryptocurrency settlement. By integrating Write-Ahead Logging (WAL) relational storage for local cash processing with a 4-validator Hyperledger Besu QBFT consensus network, POS.FUSION achieves deterministic 1-block finality (< 1 s) and local throughput exceeding 5,000 TPS.

Furthermore, by combining ERC-4337 Account Abstraction with the P256VERIFY precompiled contract (address 0x0100), the system enables gasless WebAuthn/Passkey

biometric payments directly from consumer smartphones. Empirical benchmarks confirm that P256VERIFY reduces signature verification costs by 99.01% (from 348,120 gas to 3,450 gas), eliminating seed phrase friction and gas fee overhead.

Future research will explore integrating zero-knowledge proof receipts (zk-SNARKs) to provide privacy-preserving customer purchase verification and implementing cross-chain liquidity bridges for multi-network stablecoin settlement.

CRediT authorship contribution statement

Khoiril Anam: Conceptualization, Methodology, Software Architecture, Smart Contract Engineering, Writing – Original Draft. Najla Asyila: System Design, Frontend Development, Writing – Review & Editing. Imelia Puspita Sari: Database Optimization, WAL Benchmarking, Data Curation. Arzella Meilantika: UI/UX Design, Functional Module Testing, Visualization. Nella Dwi Renika: Security Analysis, Double-Spend Audit, Validation. M. Rijal Firman: Besu Node Deployment, QBFT Network Configuration. Yoga Candra Kartika: ERC-4337 Integration, Passkey Verification Benchmarking. Hafing Ardiansyah: Oracle Integration, Real-Time Rate Locking Logic. Albertus Satrio N: Academic Supervision, Formal Analysis, Methodology Review.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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