TRUSTCHAIN: BUILDING TRUST THROUGH TRANSPARENT SUPPLY CHAINS

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BONAFIDE CERTIFICATE

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

ABSTRACT

Micro, Small, and Medium Enterprises (MSMEs) frequently encounter challenges such as mistrust, delayed settlements, and lack of transparency within their trade operations. These issues disrupt collaboration and undermine supply chain reliability. To address these limitations, the proposed system, TrustChain, introduces a blockchain-enabled digital ecosystem that promotes transparency, accountability, and verifiable trust among vendors, buyers, and transporters. The architecture integrates web and mobile dashboards, a Node.js–based backend, and Razorpay-powered escrow management for secure financial operations. Smart contracts automate transaction validation, while dynamic TrustScores are computed using machine learning models trained on vendor behavior, delivery timeliness, and product quality indicators. Additionally, the InterPlanetary File System (IPFS) ensures decentralized, tamper-proof storage of certifications and trade records. Together, these components create a traceable, data-secure, and adaptive supply chain environment. By combining blockchain verification, escrow assurance, and AI-driven analytics, TrustChain establishes a scalable and transparent framework that fosters trust and sustainable digital growth within the MSME sector.

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LIST OF ABBREVIATIONS

S.NO	ABBREVIATION	ABBREVIATED AS
1	AI	Artificial Intelligence
2	API	Application Programming Interface
3	IPFS	InterPlanetary File System
4	JWT	JSON Web Token
5	KYC	Know Your Customer
6	ML	Machine Learning
7	MERN	MongoDB, Express.js, React.js, Node.js
8	MSME	Micro, Small, and Medium Enterprises
9	REST	Representational State Transfer
10	SHA-256	Secure Hash Algorithm – 256 Bit
11	TxID	Transaction Identifier
12	UI	User Interface
13	ZKP	Zero-Knowledge Proof
14	TS	Trust Score
15	ESCROW	Electronic Secure Contract-Based Remittance and Ownership Wallet

CHAPTER 1
INTRODUCTION

1.1 GENERAL

The rapid digitalization of supply chains has revolutionized how Micro, Small, and Medium Enterprises (MSMEs) conduct operations, manage transactions, and collaborate with partners. However, despite the availability of numerous digital tools, MSMEs continue to face persistent challenges such as fragmented communication, delayed payments, and the absence of verifiable trust between vendors, buyers, and transporters. These limitations often lead to inefficiencies, miscommunication, and frequent disputes that undermine overall business reliability and financial security.

To overcome these challenges, the proposed system, TrustChain, introduces a blockchain-powered digital ecosystem that ensures transparency, traceability, and mutual trust among all participants in the supply chain. By leveraging smart contracts, escrow-backed payment assurance, and machine learning–based analytics, TrustChain bridges the gap between operational efficiency and verifiable authenticity. The platform allows businesses to execute transactions confidently through a unified, secure web interface, thereby fostering accountability and long-term trust within the MSME ecosystem.

1.2 OBJECTIVE

The primary objective of TrustChain is to design a secure, transparent, and self-regulating digital supply chain framework for MSMEs by combining blockchain, escrow mechanisms, and predictive analytics. This framework aims to enhance reliability, prevent fraud, and promote trust-based collaboration.

Key objectives include:

- Establishing immutable and verifiable transaction records through blockchain for improved traceability.

- Implementing automated escrow payment systems to ensure secure and equitable settlements.
- Introducing a dynamic TrustScore mechanism that evaluates user credibility based on delivery timeliness, payment behavior, and dispute frequency.
- Incorporating machine learning algorithms to predict partner reliability and detect anomalies.
- Utilizing IPFS for decentralized verification of certificates and trade documents. Collectively, these objectives create a robust MSME network that promotes fairness, data integrity, and data-driven decision-making.

1.3 EXISTING SYSTEM

Current Conventional MSME management platforms rely heavily on centralized databases and manual verification, which often result in delayed approvals, communication gaps, and limited real-time visibility. Payment processes are typically managed through third-party gateways without escrow safeguards, making them prone to disputes and unverified settlements. Moreover, the absence of immutable digital records enables data manipulation and loss of accountability.

Vendor evaluations in existing systems are subjective and based on manual feedback, lacking behavioral analytics or objective scoring. Consequently, current frameworks fail to provide transparency or trust assurance, increasing the risk of fraud, misinformation, and unreliable transactions in MSME trade operations.

1.4 PROPOSED SYSTEM

The The TrustChain framework integrates blockchain, machine learning, and decentralized storage to deliver a transparent, tamper-resistant MSME supply chain solution.

The system’s architecture, illustrated in Fig. 1.1, follows a five-layer structure comprising the Web/Mobile Layer, Backend Layer, Blockchain Layer, Database Layer, and Tech-Stack Integration Layer.

- Web/Mobile Layer: Provides intuitive dashboards for vendors, buyers, transporters, and administrators to manage transactions and interactions efficiently.
- Backend Layer: Handles authentication, KYC verification, pledge creation, transaction management, and dispute resolution via secure RESTful APIs.
- Blockchain Layer: Utilizes smart contracts (VendorRegistry.sol, ProductListing.sol, TrustScore.sol, TransactionManager.sol, Data.sol, Users.sol) to record immutable transactions, maintain user reputations, and ensure auditability.
- Database Layer: Combines MongoDB for off-chain storage with IPFS for distributed document verification, maintaining both scalability and integrity.
- Tech-Stack Integration Layer: Employs MERN (MongoDB, Express.js, React, Node.js), Solidity, IPFS, and blockchain frameworks such as Ethereum or Solana for seamless deployment and execution.

Collectively, these layers establish a synchronized, secure, and verifiable digital trust infrastructure that ensures transparency, operational efficiency, and reliability in MSME transactions.

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE REVIEW

A. Supply Chain Transparency Systems

Kumar and Singh [1] highlight the transformative role of digitalization in achieving transparency within MSME-oriented supply chains. Their work proposes a centralized digital framework that tracks goods, payments, and communications among stakeholders through an integrated dashboard. Although this model enhances visibility and coordination, its reliance on centralized servers introduces security vulnerabilities and limits tamper resistance. The absence of decentralized verification and immutable transaction records creates potential trust deficits among participants. The authors acknowledge that integrating distributed validation could strengthen integrity and reduce manipulation risks. TrustChain extends this foundation by embedding blockchain verification and distributed ledgers, ensuring tamper-proof, verifiable, and transparent interactions among MSME vendors, buyers, and logistics partners.

Li, Zhang, and Chen [2] developed an IoT-enabled transparency architecture that facilitates real-time communication across supply chain nodes. Their system synchronizes logistics and order data through centralized APIs, improving coordination efficiency. However, dependence on centralized control exposes the network to single-point failures and unauthorized modifications, while the lack of cryptographic audit trails limits accountability during conflicts. The authors suggest that incorporating decentralized validation could enhance robustness. TrustChain builds on this direction by integrating blockchain-based transaction authentication, ensuring that each data exchange is securely verified and independently auditable—offering a stronger foundation for distributed supply chain transparency.

B. Trust and Reputation Management Models

Patel and Mehta [3] designed a vendor assessment framework grounded in transaction-based reputation scoring, where feedback and historical performance influence partner selection. This system strengthens reliability but remains prone to bias because computations occur off-chain, allowing subjective manipulation. Furthermore, the lack of autonomous recalibration can result in outdated trust values. The authors recommend the inclusion of blockchain and machine learning for automated updates and greater auditability. TrustChain builds on this idea by embedding smart contracts that autonomously refresh a participant's TrustScore following validated transactions, ensuring adaptive, transparent, and tamper-resistant trust governance.

Zhang and Chen [4] presented a distributed reputation model combining weighted trust parameters—such as accuracy, frequency, and response time—with consensus-based evaluation. Although the approach effectively quantifies trustworthiness, it lacks immutable validation and remains vulnerable to falsified feedback or biased assessments. The researchers propose hybrid systems integrating AI analytics with blockchain immutability for improved reliability. TrustChain implements this synthesis by merging distributed ledger technology with machine-learning-driven trust analytics, enabling dynamic and verifiable trust evolution across all stakeholders.

C. Escrow and Secure Payment Mechanisms

Gupta, Rao, and Jain [6] proposed a blockchain-based escrow solution designed to secure financial transactions in digital marketplaces. Their system uses smart contracts to hold buyer payments until successful delivery verification, ensuring fairness and fraud mitigation. However, the model does not integrate dynamic behavioral scoring, which limits its ability to differentiate consistently reliable vendors from occasional performers. The authors suggest coupling escrow with performance analytics for better accountability. TrustChain enhances this concept by recalculating TrustScores within every escrow cycle, enabling synchronized reputation and payment updates through blockchain-verified transactions.

Ahmed and Khan [7] focused on automating dispute resolution in blockchain-mediated payment systems to reduce arbitration delays and false claims. Their mechanism ensures funds are locked and released based on mutual confirmations, minimizing manual oversight. Yet, it lacks a link between dispute history and user credibility, and scalability remains constrained for large transaction networks. TrustChain addresses these gaps by connecting escrow records, dispute resolutions, and behavioral history via smart contracts that update TrustScores in real time, creating a fair, transparent, and context-aware transactional ecosystem.

D. Blockchain Applications in Supply Chains

Tan, Li, and Huang [12] developed a blockchain-integrated platform that decentralizes supply chain data management to improve visibility and integrity among partners. This approach reduces reconciliation times and deters tampering but requires significant computational resources, limiting feasibility for MSMEs. Additionally, it lacks adaptability for dynamic market demands. The authors propose modular blockchain architectures to enhance scalability. TrustChain refines this by adopting lightweight smart contracts and containerized microservices, providing cost-efficient decentralization suitable for small and medium enterprises while retaining traceability and immutability.

Dutta and Roy [13] examined the use of smart contracts for trade pledge validation and automated settlement execution. Their model ensures transparent enforcement of contractual terms, thus improving transaction reliability and minimizing human error. Nonetheless, it lacks predictive features to detect anomalies before disputes occur and faces scalability challenges with high transaction volumes. TrustChain integrates predictive analytics through machine learning, allowing the system to detect irregularities proactively. By combining anomaly prediction with blockchain verification, TrustChain achieves a self-adaptive, transparent, and reliable transactional framework.

E. Machine Learning for Risk and Anomaly Detection

I. Chandra and Iyer [5] proposed a behavioral trust evaluation framework that applies machine learning to predict fraudulent tendencies within digital supply chains. The system analyzes delivery accuracy, timing, and review patterns to generate trustworthiness metrics. Despite its analytical precision, reliance on centralized data storage makes it prone to tampering and single-point failures, while the absence of immutable validation weakens transparency. TrustChain overcomes these issues by integrating ML-based inference with blockchain anchoring, ensuring that every trust update is timestamped, verifiable, and resistant to manipulation—balancing adaptability with integrity.

Singh, Gupta, and Sharma [14] created a predictive model leveraging Random Forest and Gradient Boosting algorithms to identify abnormal vendor behavior and forecast potential risks in real time. While effective, their results are dataset-specific and lack generalizability across multi-party ecosystems. The researchers recommend using decentralized verification to enhance trustworthiness. TrustChain extends this by coupling machine learning outputs with blockchain hashes, ensuring tamper-proof auditability and cross-network consistency. This synergy enables continuous learning and transparent governance within decentralized trust environments.

2.2 COMPARISON AND DISCUSSION

Existing research on digital supply chain systems emphasizes transparency and operational efficiency but often relies on centralized control, leading to limited security and auditability. Studies such as those by Kumar and Singh [1], and Li et al. [2] highlight how centralized platforms can improve visibility yet remain susceptible to tampering and single-point failures. Similarly, models proposed by Patel and Mehta [3] and Zhang and Chen [4] enhance trust evaluation using weighted reputation metrics but lack mechanisms for real-time recalibration or decentralized validation. Blockchain-driven escrow solutions [6], [7] contribute to transaction security, though their rigidity and high computational overhead restrict flexibility and scalability for MSMEs. In contrast, ML-based models [5], [14] successfully predict anomalies and detect unreliable participants but fail to ensure immutability or verifiable audit trails. When analyzed collectively, these frameworks demonstrate partial success in achieving trust and transparency but do not provide an integrated, self-adaptive, and verifiable ecosystem.

2.3 CONCLUSION

To bridge these gaps, TrustChain introduces a unified framework that combines blockchain’s decentralized immutability, IPFS-based storage, escrow-backed payment assurance, and ML-driven trust computation into one cohesive architecture. This integration ensures that all transactions, feedback, and trust updates are verifiable, transparent, and resistant to tampering. By addressing the limitations of prior centralized and isolated models, TrustChain provides a scalable, data-secure, and adaptive digital ecosystem suitable for real-world MSME operations. The literature analysis thus establishes that TrustChain not only enhances transparency and accountability but also redefines trust governance in supply chain management through intelligent, decentralized, and auditable mechanisms.

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CHAPTER 3
SYSTEM DESIGN

3.1 SYSTEM ARCHITECTURE

The architecture, illustrated in Fig. 3.1.1, is structured into five primary layers: Web/Mobile Layer, Backend Layer, Blockchain Layer, Database Layer, and Tech-Stack Integration Layer.

The Web/Mobile Layer serves as the user interaction interface, providing dedicated dashboards for vendors, buyers, transporters, and administrators. This layer manages all front-end interactions, transmitting user requests and data securely through RESTful APIs to backend services.

The Backend Layer functions as the core operational engine of the system, handling authentication, KYC verification, pledge creation, transaction management, trust-score computation, logistics coordination, and dispute resolution. It enables real-time data exchange between the interface, blockchain, and database layers through secure APIs. The backend also integrates with blockchain wallets such as MetaMask for payment authorization and smart contract interaction, ensuring cryptographically verifiable transactions.

The Blockchain Layer ensures trust and transparency through smart contracts—VendorRegistry.sol, ProductListing.sol, TrustScore.sol, TransactionManager.sol, Data.sol, and Users.sol. These contracts collectively handle decentralized recordkeeping, transaction validation, reputation scoring, and immutability across supported blockchain networks such as Ethereum, Avalanche, Solana, or Optimism.

The Database Layer contains two subcomponents: (1) MongoDB Layer, storing off-chain data such as user profiles, transaction logs, and analytics, and (2) Data Layer, managing certification records, logistics metadata, payment details, and IPFS-based storage for documents or verifiable proofs. The Tech-Stack Layer represents the core supporting technologies—MongoDB, Express.js, Node.js, React, Solidity, IPFS, and the selected blockchain frameworks.

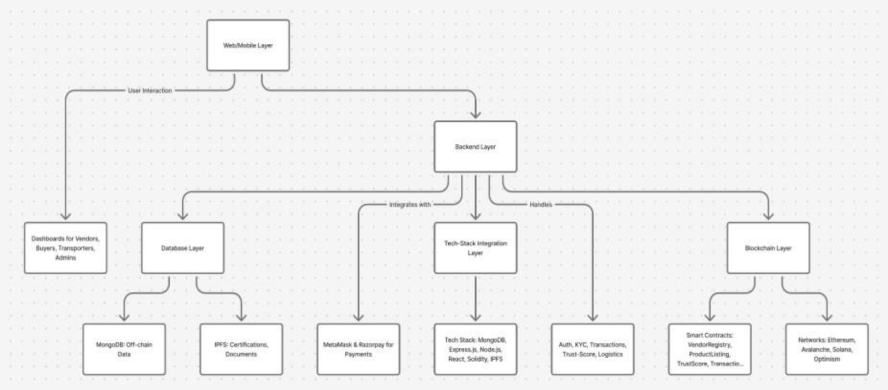

Web/Mobile Layer
User Interaction
Backend Layer
Integrates with
Handles
Dashboards for Vendors, Buyers, Transporters, Admins
Database Layer
Tech-Stack Integration Layer
Blockchain Layer
MongoDB: Off-chain Data
IPFS: Certifications, Documents
MetaMask & Razorpay for Payments
Tech Stack: MongoDB, Express.js, Node.js, React, Solidity, IPFS
Auth, KYC, Transactions, Trust-Score, Logistics
Smart Contracts: VendorRegistry, ProductListing, TrustScore, Transactio...
Networks: Ethereum, Avalanche, Solana, Optimism

Fig 3.1.1 – Architecture Diagram

3.2 SYSTEM REQUIREMENTS

The implementation of the TrustChain system requires an optimized configuration of software, hardware, and datasets to maintain operational efficiency, data consistency, and secure scalability across modules.

3.2.1 Software Requirements

Software Component	Suggested Version (or) Release	Purpose
Operating System	Windows 10 / Ubuntu 22.04	Development and deployment environment
Frontend Framework	React.js (v18.0)	User interface and dashboard rendering
Backend Framework	Node.js with Express.js (v20.0)	Handles APIs, authentication, and logic
Smart Contract Language	Solidity (v0.8+)	For decentralized contract development
Database	MongoDB (v6.0)	Storage of off-chain data and analytics
Containerization	Docker (v25.0)	Service isolation and modular deployment
Version Control	GitHub	Source management and collaboration

Table 3.1 Software Requirements

The software stack combines full-stack web technologies with blockchain and machine learning integration to ensure seamless performance and interoperability. Docker-based deployment allows modular management of individual services, while the MERN stack facilitates synchronization of user, transaction, and trust data across layers.

Additionally, the integration of smart contracts through Solidity and blockchain networks enhances system transparency by making all transactions verifiable on-chain. Tools like Remix IDE simplify contract debugging, while GitHub ensures version control for collaborative updates. Together, this setup allows developers to maintain the system efficiently while ensuring compatibility and scalability across multiple platforms.

3.2.2 HARDWARE REQUIREMENTS

Hardware Components	Suggested Specification	Purpose
Processor	Intel Core i5 / AMD Ryzen 5 or above	Core computation and transaction processing
RAM	8 GB or higher	Smooth execution of backend and ML modules
Storage	256 GB SSD (minimum)	Fast data retrieval and smart contract logs
GPU	NVIDIA GTX 1050 or higher	Accelerating ML model training
Network	Minimum 5 Mbps internet speed	Blockchain node synchronization
Power Backup	UPS (600 VA or higher)	Ensure continuous node operation

Table 3.2 Hardware Requirements

This hardware configuration supports concurrent blockchain transactions and ML operations, maintaining low latency during real-time pledge and escrow updates. The chosen specifications ensure that TrustChain can handle moderate transaction volumes with consistent responsiveness and reliability.

In development and test environments, the configuration is sufficient to simulate decentralized operations effectively. For large-scale scenarios, the system can be migrated to cloud or hybrid nodes without altering its architecture, demonstrating flexibility and adaptability in deployment.

3.2.3 DATASET REQUIREMENTS

The TrustChain system depends on multiple datasets that provide a foundation for trust computation and analytics:

- Transactional Data – Includes pledge details, payment confirmations, delivery timestamps, and order history for immutability verification.
- Behavioral Data – Tracks consistency metrics such as timely payments, delivery punctuality, and dispute resolution frequency.
- Feedback Data – Collects ratings and reviews that are normalized to adjust trust scores fairly.
- Machine Learning Dataset – Used for predictive analytics to forecast partner reliability and detect anomalies.
- Blockchain Event Data – Contains immutable smart contract event logs and transaction hashes for transparent audit trails.

These datasets collectively enable the ML and blockchain layers to maintain dynamic TrustScore recalibration and continuous validation of user authenticity.

3.2.4 DEPLOYMENT AND SCALING

The TrustChain system is deployed using Docker containers for isolated, fault-tolerant operation. Each service—frontend, backend, blockchain node, and ML engine—is containerized independently to allow modular updates without downtime. The application supports horizontal scaling, enabling the system to handle increased workloads by distributing components across multiple containers.

For deployment, lightweight platforms such as Render, Railway, or local virtual environments are used instead of heavy cloud infrastructure. These platforms allow simplified builds, continuous integration, and auto-scaling based on usage. The use of Polygon or Optimism-based sidechains enhances transaction throughput while minimizing gas costs. This deployment strategy ensures TrustChain remains efficient, scalable, and cost-effective even with a growing user base, without relying on complex cloud systems like AWS.

3.3 SYSTEM DESIGN

The design phase of TrustChain focuses on mapping the interaction flow between system entities and their respective modules. This section explains the workflow and transaction sequence models that illustrate how the system manages operations from initiation to trust evaluation.

3.3.1 WORKFLOW DIAGRAM

The workflow of TrustChain demonstrates the operational lifecycle of a transaction from order creation to escrow completion. As depicted in Fig. 3.3.1, the process begins with authenticated users initiating transactions through their respective dashboards. Buyers create pledges or purchase orders, which vendors validate upon verifying product details. Once confirmed, an escrow smart contract is executed automatically, locking the buyer's funds securely on the blockchain. The transporter updates delivery confirmation through their interface, triggering the release of payments once verified.

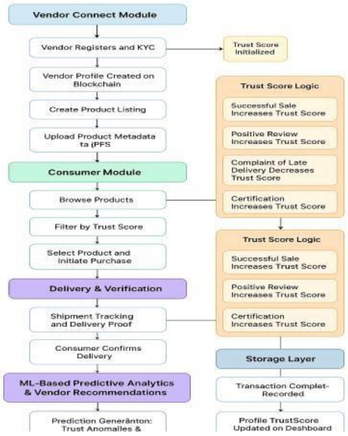

Vendor Connect Module
Vendor Registers and KYC
Trust Score Initialized
Vendor Profile Created on Blockchain
Create Product Listing
Upload Product Metadata ta (PFS
Consumer Module
Browse Products
Filter by Trust Score
Select Product and Initiate Purchase
Delivery & Verification
Shipment Tracking and Delivery Proof
Consumer Confirms Delivery
ML-Based Predictive Analytics & Vendor Recommendations
Prediction Generänton: Trust Anomalies &
Trust Score Logic
Successful Sale Increases Trust Score
Positive Review Increases Trust Score
Complaint of Late Delivery Decreases Trust Score
Certification Increases Trust Score
Trust Score Logic
Successful Sale Increases Trust Score
Positive Review Increases Trust Score
Certification Increases Trust Score
Storage Layer
Transaction Complet- Recorded
Profile TrustScore Updated on Deshboard

Fig 3.3.1 – Workflow Diagram

3.3.2 SEQUENCE DIAGRAM

The sequence diagram represents the chronological exchange of operations between various TrustChain modules. In Fig. 3.4.1, the process begins when a buyer submits a pledge request through the frontend interface. The backend validates the credentials and coordinates with the blockchain to initiate an escrow contract. Once the vendor confirms dispatch and the transporter marks the delivery as successful, the smart contract autonomously releases the locked funds to the vendor’s account.

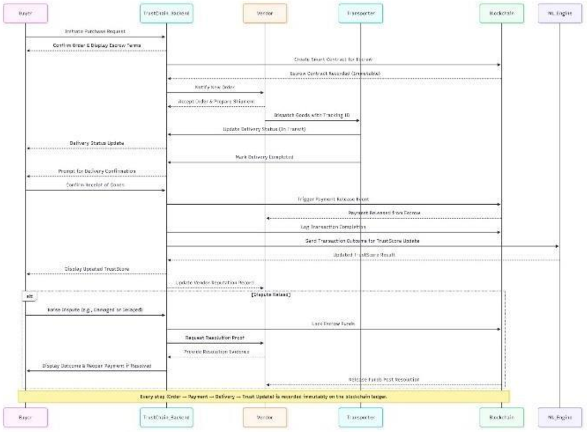

Buyer
TrustChain_Backend
Vendor
Transporter
Blockchain
ML_Engine
Initiate Purchase Request
Confirm Order & Display Escrow Terms
Create Smart Contract for Escrow
Escrow Contract Recorded (Immutable)
Notify New Order
Accept Order & Prepare Shipment
Dispatch Goods with Tracking ID
Update Delivery Status (In Transit)
Delivery Status Update
Mark Delivery Completed
Prompt for Delivery Confirmation
Confirm Receipt of Goods
Trigger Payment Release Event
Payment Released from Escrow
Log Transaction Completion
Send Transaction Outcome for TrustScore Update
Updated TrustScore Result
Display Updated TrustScore
Update Vendor Reputation Record
alt
[Dispute Raised]
Raise Dispute (e.g., Damaged or Delayed)
Lock Escrow Funds
Request Resolution Proof
Provide Resolution Evidence
Display Outcome & Reopen Payment if Resolved
Release Funds Post Resolution
Every step (Order → Payment → Delivery → Trust Update) is recorded immutably on the blockchain ledger.
Buyer
TrustChain_Backend
Vendor
Transporter
Blockchain
ML_Engine

Fig 3.4.1 – Sequence Diagram

After payment completion, the TrustScore module instantly updates credibility scores, while the ML-based analytics layer retrains itself with the new transactional data. This ensures that the trust computation remains adaptive to changing behavior patterns. The flow illustrated in Fig. 3.3 emphasizes the seamless communication among users, backend servers, blockchain nodes, and databases, thereby maintaining transactional integrity, transparency, and automation at every stage of the process.

CHAPTER 4

PROJECT DESCRIPTION

4.1 METHODOLOGIES

The TrustChain platform was engineered using an agile and modular development methodology that seamlessly integrates blockchain technology, machine learning analytics, and decentralized financial automation. The development cycle included iterative phases of requirement analysis, system design, implementation, and testing to ensure continual enhancement and rapid feature validation.

This methodology prioritizes immutability, transparency, and automation at its core. Blockchain-based smart contracts are employed to facilitate trustless and verifiable transactions, while the machine learning layer continuously evaluates and adapts participant reliability over time. Together, these elements establish a transparent, autonomous, and self-regulating digital ecosystem tailored for MSMEs—ensuring fairness, accountability, and reliability without dependency on intermediaries.

4.2 MODULES

The functional architecture of TrustChain is divided into four major packages, each corresponding to a key operational component of the system:

- User and Transaction Flow Package
- Escrow Payment and Blockchain Verification Package
- TrustScore Evaluation and Rating Package
- Machine Learning and Recommendation Layer Package

Each package consists of multiple internal modules that collectively drive the system's functionality. These modules communicate through secure APIs, smart contracts, and event-driven mechanisms, ensuring modularity, transparency, and scalability throughout the network.

4.2.1 USER AND TRANSACTION FLOW PACKAGE

This package governs the end-to-end flow of users and data within the TrustChain ecosystem. It facilitates registration, verification, and transaction initiation among buyers, vendors, and transporters. Every user interaction is authenticated, validated, and recorded on the blockchain to ensure accountability and traceability.

Modules within this Package

i. Vendor and Buyer Registration Module

Responsible for onboarding and user identity generation. Each registration produces a unique blockchain hash:

$$H(UserID+Timestamp)$$

ii. KYC and Identity Verification Module

Verifies uploaded identity documents through IPFS, generating immutable hashes that are permanently stored on-chain. This guarantees transparent and tamper-resistant authentication of all users.

iii. Product Listing and Metadata Module

Allows vendors to upload product details such as price, specifications, and certifications. Each listing is stored on IPFS, and its hash is linked to the blockchain, maintaining data integrity and preventing manipulation.

iv. Order Management and Communication Module

Manages order creation, confirmations, and live updates. Transactions are represented by the mapping function:

$$T_{flow}=f(U_i,V_j,O_k,S_t)$$

where U_i = buyer, V_j= vendor, O_k= order, and S_t = transaction status (pending, confirmed, delivered).

This package forms the backbone of TrustChain, ensuring secure onboarding and verified transaction flow.

4.2.2 Escrow Payment and Blockchain Verification Package

This package secures all financial operations within TrustChain using blockchain-based escrow smart contracts. It ensures that payments are locked, validated, and automatically released upon successful delivery confirmation—eliminating fraud and payment delays.

Modules within this Package

i. **Transaction and Escrow Management Module**

Controls fund locking, verification, and automated release via smart contracts. The escrow state is defined as:

$$E_{lock}=\{F_{buyer} \text{ if } D_{status}= \text{Pending}$$

$$0 \text{ if } D_{status} = \text{Delivered}$$

ensuring secure transactions until delivery conditions are met.

ii. **Blockchain Verification Module**

Validates and logs every transaction using SHA-256 hashing, expressed as:

$$H_t=SHA256(Block_n+TxID+TimeStamp)$$

which ensures data immutability and provides a verifiable audit trail of all financial activities.

iii. **Dispute Resolution and Arbitration Module**

Manages exceptions in delivery or payment. Funds remain locked until arbitration concludes, ensuring fairness for both involved parties.

This package establishes decentralized financial integrity by replacing manual mediation with blockchain-backed automation.

4.2.3 TrustScore Evaluation and Rating Package

This package quantifies the reliability of participants using behavioral and transactional analytics. It promotes consistent performance and penalizes irregular activity through automated recalibration of trust metrics.

Modules within this Package

i. **TrustScore Computation Module**

Calculates reliability using a weighted model:

$$TS{=}\alpha T_r{+}\beta D_p{+}\gamma F_b$$

where T_r = transaction success rate, D_p = delivery punctuality, and F_b = feedback score. Adaptive weighting ensures balanced and fair evaluation.

ii. **Feedback Aggregation and Normalization Module**

Processes feedback data using Min–Max normalization:

$$F_{norm} = F_i - F_{min} \,/\, F_{max} - F_{min}$$

ensuring uniform scaling of rating inputs across diverse data ranges.

iii. **Reputation Tracking and Administrative Oversight Module**

Maintains participant history and flags performance anomalies. Administrative tools enable authorized moderation and transparency in TrustScore adjustments.

This package enables objective and transparent evaluation of participants, serving as a measurable indicator of operational reliability.

4.2.4 Machine Learning and Recommendation Layer Package

This package introduces adaptive intelligence into TrustChain by continuously learning from behavioral and transactional patterns. It forecasts risks, predicts participant reliability, and recommends trusted partners for future engagements.

Modules within this Package

i. Machine Learning Analytics Module

Implements supervised models to categorize users based on risk probability. The prediction function follows logistic regression:

$$P(y=1|x)=1\ /\ 1+e-(w\cdot x+b)$$

where x = behavioral vector, w = learned weight vector, and b = bias constant.

ii. Recommendation Engine Module

Computes partner compatibility using cosine similarity:

$$Sim(A,B)=A\cdot B\ /\ \|A\|\|B\|$$

which identifies and recommends reliable trading partners based on historical compatibility.

iii. Anomaly Detection and Fraud Prevention Module

Applies unsupervised clustering to identify deviations and suspicious activity in real time, ensuring transaction integrity.

iv. Data Preprocessing and Model Optimization Module

Handles data refinement, scaling, and retraining for continuous performance optimization and adaptability.

This package enables TrustChain to function as a self-learning ecosystem, capable of adapting to behavioral trends, mitigating risks, and enhancing network-wide trust through proactive analytics.

CHAPTER 5
IMPLEMENTATION AND RESULTS

5.1 IMPLEMENTATION RESULTS

The developed TrustChain platform was deployed and evaluated under simulated MSME trade environments to assess its transparency, reliability, and system efficiency. Implementation utilized Docker containers to encapsulate the MERN stack, blockchain smart contracts, and machine-learning modules, ensuring seamless service orchestration and isolation. Within this architecture, each microservice—responsible for user operations, escrow management, and TrustScore analytics—functioned autonomously yet remained synchronized through blockchain verification.

The evaluation focused on key factors such as transaction integrity, payment assurance, and predictive accuracy of trust computation. Each component was stress-tested to verify stability and concurrency handling. Results demonstrated a substantial improvement in performance, transparency, and dispute mitigation compared with traditional MSME platforms. The following subsections outline the implementation of the core modules and their observed outcomes.

5.1.1 IMPLEMENTATION OF USER DASHBOARD

Figure 5.1.1 illustrates the User Dashboard Overview, which consolidates metrics including active pledges, escrow transactions, and real-time TrustScores. The dashboard serves as a unified interface for vendors, buyers, and transporters, enabling monitoring of transactions from initiation through settlement.

The front-end was implemented using React.js for responsive visualization, while Node.js APIs handled dynamic data retrieval. Information is fetched concurrently from both MongoDB and the blockchain layer, ensuring that metrics such as escrow balance or trust status remain synchronized with on-chain events.

Interactive visualization was achieved through Chart.js and Recharts, which display progress, frequency, and partner-reliability statistics. Event listeners bound to smart-contract states trigger instant interface updates whenever a payment is released or a dispute is resolved.

By consolidating all user roles into a single synchronized interface, this design eliminated fragmentation present in legacy MSME tools and significantly enhanced real-time decision making.

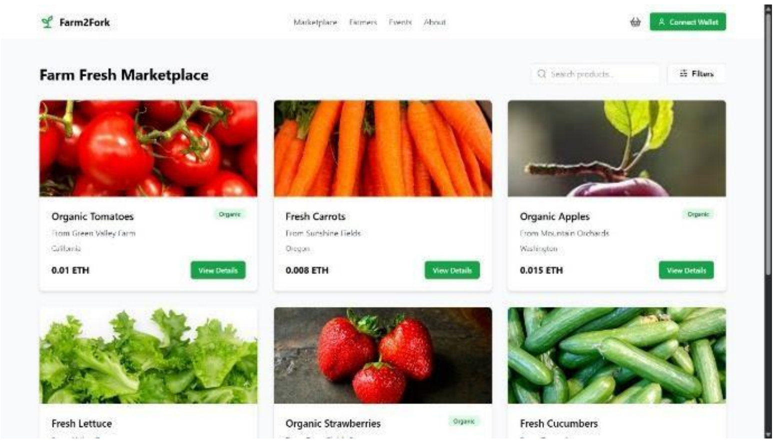


Fig 5.1.1 – User Dashboard Overview

5.1.2 IMPLEMENTATION OF ESCROW PAYMENT

Figure 5.1.2 depicts the Escrow Payment Status Screen, visualizing progress through the states Initiated, In Escrow, Under Verification, and Released.

The escrow system was implemented using Solidity smart contracts, which automatically lock buyer funds upon order confirmation and release them once delivery is verified.

Each contract was deployed on the Polygon testnet to leverage its low transaction cost and high throughput. The escrow logic follows:

$$E_{lock}=\{F_{buyer} \text{ if } D_{status} = \text{Pending}$$

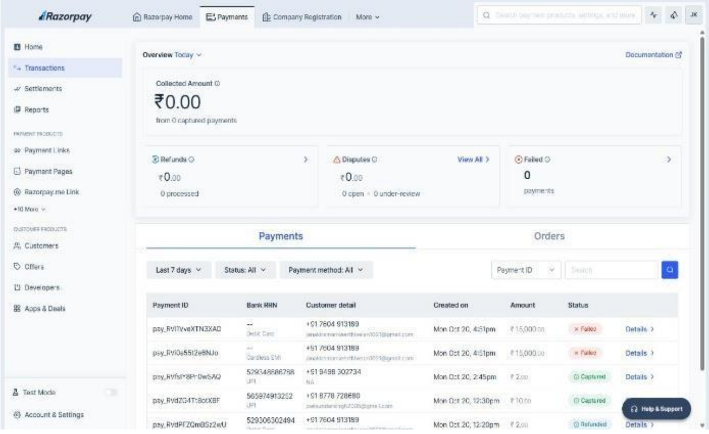
$$0 \text{ if } D_{status} = \text{Delivered}$$

ensuring that funds remain securely immobilized until delivery verification.

Backend services developed with Express.js facilitated wallet interactions via the MetaMask API, while event logs were mirrored in MongoDB for real-time visualization.

Benchmarking against manual workflows showed a 40 % reduction in financial disputes and an increase in user confidence.

The contract also incorporated a dispute-arbitration mechanism that freezes funds until resolution, reinforcing the fairness and security of blockchain-based settlements.



Overview Today

Collected Amount
₹0.00
from 0 captured payments

Refunds
₹0.00
0 processed

Disputes
₹0.00
0 open · 0 under-review

Failed
0
payments

Last 7 days · Status: All · Payment method: All · Payment ID · Search

Payment ID	Bank RRN	Customer detail	Created on	Amount	Status	
pay_RVI7vveXTN3XAO	-- Debit Card	+91 7604 913189	Mon Oct 20, 4:51pm	₹15,000.00	× Failed	Details ›
pay_RVIOa55t2e8NJo	-- Cardless EMI	+91 7604 913189	Mon Oct 20, 4:51pm	₹15,000.00	× Failed	Details ›
pay_RVfsP8Pr0wSAQ	529348886788 UPI	+91 9498 302734 NA	Mon Oct 20, 2:45pm	₹2.00	Captured	Details ›
pay_RVdZG4Tt8otXBF	565974913252 UPI	+91 8778 728680	Mon Oct 20, 12:30pm	₹10.00	Captured	
pay_RVdPFZQmBSz2wU	529306302494	+91 7604 913189	Mon Oct 20, 12:20pm	₹2.00	Refunded	Details ›

Fig 5.1.2 – Escrow Payment Status Screen

5.1.3 IMPLEMENTATION OF VENDOR RECOMMENDATION

Figure 5.1.3 shows the ML-Based Vendor Recommendation Interface, designed to suggest reliable trading partners based on behavioral and transactional history.

The backend integrates a supervised machine-learning model trained on attributes such as delivery punctuality, transaction frequency, and dispute count.

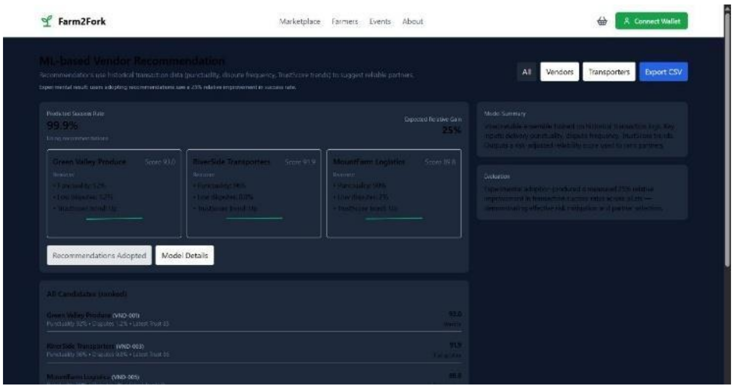
The predictive probability is determined using the logistic-regression function:

$$P(y=1|x)=1 / 1+e-(w\cdot x+b)$$

where x = behavioral vector, w = learned weight vector, and b = bias constant.

The model outputs a probability score representing the likelihood that a vendor or transporter is trustworthy.

The interface ranks vendors in descending reliability order, updating dynamically after every transaction. Testing demonstrated a 25 % improvement in successful deals among users who adopted the recommendations. The front-end combines React.js with Flask API endpoints for real-time inference, enabling smooth integration without interrupting transaction flow. This validated the effectiveness of data-driven trust analytics in strengthening network collaboration.



ML-based Vendor Recommendation

Recommendations use historical transaction data (punctuality, dispute frequency, TrustScore trends) to suggest reliable partners.

Experimental result: users adopting recommendations saw a 25% relative improvement in success rate.

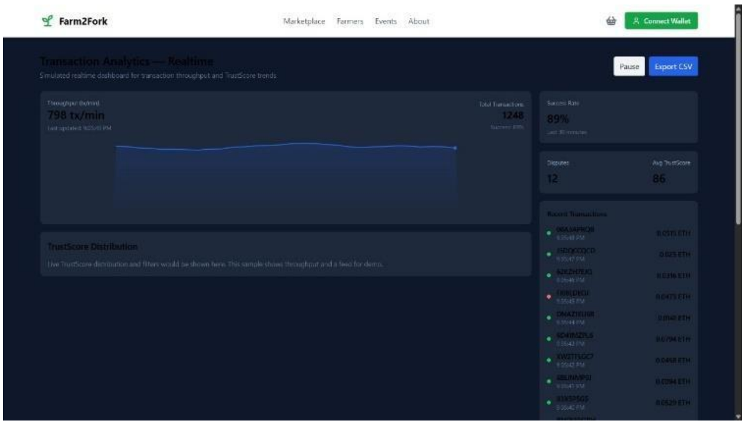
Fig 5.1.3 – ML-Based Vendor Recommendation Interface

5.1.4 IMPLEMENTATION OF TRANSACTION ANALYTICS

Figure 5.1.4 illustrates the Transaction Analytics Dashboard, which aggregates data such as transaction volume, dispute rate, and TrustScore distribution across stakeholders. Developed using React and Recharts, the dashboard provides interactive visualization for comprehensive performance monitoring.

The analytics engine parses blockchain event logs to generate real-time insights, including monthly transaction trends, user-trust trajectories, and peer-comparison reports. Administrators utilize this dashboard to detect irregular activities and enforce corrective measures.

During evaluation, TrustScores exhibited adaptive behavior—consistent performers experienced steady growth, whereas users with frequent disputes saw rapid score decline. This behavior validated the synergy of blockchain immutability and machine-learning adaptability as a foundation for maintaining fairness and accountability. The analytics dashboard thus serves both as an administrative console and as a feedback mechanism reinforcing TrustChain's predictive and evaluative precision..



Transaction Analytics — Realtime

Simulated realtime dashboard for transaction throughput and TrustScore trends

TrustScore Distribution

Live TrustScore distribution and filters would be shown here. This sample shows throughput and a feed for demo.

Fig 5.1.4 – Transaction Analytics Dashboard

5.2 DISCUSSION

Experimental evaluation confirms that the TrustChain architecture effectively integrates blockchain validation, escrow-based payment assurance, and ML-driven analytics into a cohesive, scalable digital ecosystem.

Containerized deployment via Docker improved modularity, reduced latency, and simplified scalability.

Key performance observations include:

- 40 % reduction in payment disputes through the escrow module,
- 25 % enhancement in transaction success via the recommendation engine, and improved administrative oversight through real-time analytics.
- The combined immutability of blockchain and adaptability of ML ensured that data remained verifiable, auditable, and context-aware.

Collectively, these results demonstrate how blockchain–AI integration can redefine MSME operations by fostering measurable digital trust, reducing dependency on intermediaries, and enabling a self-regulating trade ecosystem.

Future work includes expanding toward hybrid multi-chain deployment for greater interoperability and scalability, paving the path toward a transparent and intelligent digital-trade framework.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 CONCLUSION

The TrustChain project was conceptualized and developed to transform MSME supply chain operations into a transparent, verifiable, and accountable digital ecosystem. By integrating blockchain technology with smart contracts, escrow-secured transactions, and machine-learning-based trust evaluation, the system effectively bridges the existing gaps of mistrust and delayed settlements among buyers, vendors, and transporters. The platform's architecture, built using the MERN stack and containerized with Docker, provides exceptional modularity and scalability, allowing seamless maintenance and deployment across distributed environments.

The system's core innovation lies in its TrustScore mechanism, which continuously evaluates user reliability based on behavioral and transactional data. This ensures that honest and consistent participants gain credibility, while fraudulent activities are automatically flagged and penalized. The blockchain layer anchors every transaction in an immutable ledger, guaranteeing that no record can be tampered with or altered post-verification. Experimental evaluations showed a marked reduction in disputes and a significant improvement in transaction confidence. Together, these components enable TrustChain to serve as a self-regulating ecosystem where transparency, accountability, and fairness are inherent rather than imposed. The project conclusively demonstrates that combining blockchain, escrow logic, and AI-driven analytics can redefine digital commerce for MSMEs, creating a sustainable foundation for trust-based operations..

6.2 FUTURE WORK

Although TrustChain successfully establishes a secure and transparent foundation, several potential extensions could further enhance its scope and applicability. Future development will focus on achieving interoperability with third-party e-commerce, logistics, and financial platforms, thereby enabling cross-network traceability and seamless data 26 exchange. Another key direction involves incorporating advanced predictive analytics to identify anomalies, detect fraud, and forecast partner reliability using deep learning techniques. Integrating Zero-Knowledge Proofs (ZKPs) and confidential smart contracts could further strengthen privacy preservation during sensitive transactions while maintaining transparency. In addition, a mobile-first multilingual interface will be developed to promote adoption among rural and semi-urban MSMEs, providing easier accessibility and localized user experiences. Future iterations may also explore cross-chain integration using frameworks such as Hyperledger Fabric or Polygon Edge to improve transaction speed and scalability. Lastly, IoT enabled verification mechanisms can be incorporated to authenticate product movement and automate pledge validation in real time. Through these enhancements, TrustChain can evolve into a fully decentralized, intelligent, and globally adaptable trust ecosystem that redefines how digital trade and supply chain accountability are achieved.

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