

Blockchain Based Incentive and Penalty Mechanism for Service Providers

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Abstract

Blockchain is considered one of the most secure systems due to the use of cryptography. Here, the goal is to identify key factors that are essential for successfully implementing reward and penalty systems. The article talks about how to apply penalties and rewards based on different factors to keep the quality of service for the end customer. The article also shows that there is a lot of potential for new ideas and ways to apply them. The results show that blockchain technology can change the service processes through improved data integrity, trust development and efficiency. The potential of this technology is mainly related to immutable ledger and smart contract features. Automated transactions reduce administrative costs and manipulations. Blockchain improves traceability and response to safety incidents. Blockchain also promotes environmental sustainability by tracking resources. It helps in humanitarian initiatives by ensuring efficient and transparent supply chain management. In addition, blockchain optimizes resource allocation by minimizing waste within inventory and distribution networks. The present report further identifies avenues for subsequent investigation, emphasizing under-researched dimensions of sustainable supply chain management.

Keywords: Blockchain, Smart Contracts, Service Quality Management, Incentive Mechanism, Ethereum, Performance Evaluation, Decentralization

1. Introduction

1.1 Background

As the economy grows, consumption of services increases but the service sector is not able to match its credibility of quality. Service provider ecosystems such as logistics, manufacturing networks and digital service platforms require strong mechanisms to maintain the quality of service. Service Level Agreements (SLAs) typically define the expected performance metrics, but enforcement often depends on centralized monitoring systems. These centralized systems have such issues: lack of transparency, risk of data manipulation, frequent disputes between service providers and clients, and delays in enforcing rewards or penalties. Blockchain technology is a decentralized, transparent and tamper-proof way of recording transactions. Smart contracts can automate the enforcement of rules by eliminating intermediaries. The integration of decentralized storage and blockchain smart contracts allows trustworthy documentation of service data and automated quality evaluation. In this paper, we propose a blockchain-based quality management system with automatic incentive and penalty mechanisms for

service providers. One of the main characteristics of blockchain technology is smart contracts, self-executing programs that operate when predetermined conditions are satisfied[1]. These contracts automatically deal with the SLAs and thus reduce the need of continuous human supervision and allow trust between the stakeholders. Also, the immutability of data on a blockchain improves data integrity, enhances the transparency of the system and increases the trustworthiness of the system. Service provider environments such as logistics, manufacturing, and digital platforms usually have several participants. The quality of service can't be guaranteed since each party can have different responsibilities. Service Level Agreements (SLAs) describe the expected results, e.g. delivery times, reliability and quality standards. In most traditional systems, these agreements are still controlled and enforced by centralized platforms. These centralized systems typically have multiple problems. For example, transparency is often limited and some data are inaccessible to stakeholders. There is also a risk that data alteration or selective reports, which can reduce trust between stakeholders. Many times, there are disputes between service provider and client regarding vague performance records. Another common problem is that rewards and penalties aren't applied immediately. This is because the process usually requires manual checks and approvals, which can take a long time. By employing a distributed ledger, each transaction and service-related detail is securely recorded and accessible to all involved parties[1,2]. The quality management system using blockchain technology uses automated reward and punishment mechanisms for the service providers. In the suggested system, smart contracts will assess the performance of the services against the set standards and reward or punish the services accordingly. This will ensure that the outcome is directly dependent on the performance and hence encourage the service providers to offer quality services.

1.2 Problem Statement

Maintaining consistent service quality for any service-based systems like logistics, digital platforms etc. is still a major challenge. Despite of Service Level Agreements (SLAs) usage to define expected outcome, their monitoring and enforcement are usually handled by centralized systems. Such systems are usually not transparent, and the stakeholders do not get the performance data. Such system creates trust issues between the service providers and the clients. Delay in rewards and non-application of penalties for poor performance impacts fairness. There is always a possibility of data manipulation or biased reporting, which makes it difficult to verify whether the service was delivered as agreed. Disputes between stakeholders are common because they are time-consuming and costly to solve. Blockchain technology and smart contracts have the potential to solve the problem in a decentralized way for carrying out agreements. This approach is tamper-proof and automatic. However, the actual application of the incentive and penalty mechanisms via blockchain is still in a nascent stage of study.

1.3 Research Objective

We analyze the improvement of service quality by using reward and penalty systems based on smart contracts on blockchain. Paper also considers the use of these contracts to design incentive systems. It considers how automated penalty enforcement can make people more accountable. It also discusses the main problems of implementing such systems and proposes improvements and ideas for future research.

2. Methodology

2.1 System Design

The system design phase started with a description of the components and interactions with them. The proposed framework explained by modular approach for scalability and adaptability[3,4]. This phase

was essential in order to synchronize the system objectives with the stakeholder demands. It creates a definitive framework for implementation. In this phase, each system component was meticulously designed to execute specified functions while ensuring seamless interaction with other components. The modular architecture permits the independent development, testing, and updating of system components. The components are the blockchain layer, smart contracts and application interfaces.

2.1.1 Requirement Analysis

Some big problems found include lack of openness, delay in issuing rewards and punishments, and reliance on centralized monitoring systems. Stakeholders in the proposed system are service providers, clients (people who ask for services), and system administrators. Everyone who has a stake in the system has a different idea of what it should do. Clients want service providers to be fair and give them rewards on time. Service providers want clients to trust the service's quality. The system must also ensure the safety of data and prevent any alterations to service records. Another important requirement is that Service Level Agreements (SLAs) can be automatically enforced without any help from a person. Cost-effectiveness and scalability were important in real world uses. The requirement analysis helps to figure out the main features required in proposed blockchain-based framework.

2.1.2 System Architecture Design

Based on the identified requirements, system architecture is designed to ensure scalability, flexibility, and efficient interaction between system components. The proposed system follows a layered architecture with four main layers:

1. Blockchain Layer: It is responsible for maintaining the distributed ledger, recording all transactions, and ensuring data immutability.
2. Smart Contract Layer: It contains the core logic of the system. It defines the rules for service agreements, performance evaluation, reward distribution, and penalty enforcement.
3. Application Layer: It acts as the interface between users and the blockchain network.
4. User Roles Layer: It defines the roles and interactions of different stakeholders, including service providers, clients, and administrators. Each role has specific permissions and responsibilities within the system.

A clear separation of responsibilities and efficient system design are supported by layered architecture. It also ensures that the system can be extended or modified in the future without affecting the entire framework.

2.1.3 Workflow Design

The proposed system has a step-by-step process to manage the quality of service. The process begins when a client submits a request, performance expectations are set. These details are then recorded in a smart contract as part of the Service Level Agreement (SLA). Upon receipt of a request, a service provider acknowledges it and consents to the given terms. Important performance data such as delivery times, quality assessments or user ratings are collected during or after the execution of the service. Even if the provider retains this data off-chain, they record a secure hash of it on the blockchain to ensure its immutability. After the service is completed, the collected performance data is sent to the smart contract for evaluation. The contract itself checks automatically that the service is provided with the agreed standards and conditions. If everything is fine, the provider gets an incentive[5]; otherwise a penalty is applied. The last step is that the smart contract does the right thing (release payment, add a bonus, deduct a penalty). Each step is stored on the blockchain, which makes the whole process transparent, safe and easy to track for all parties.

2.1.4 Incentive & Penalty Model Design

An incentive and penalty model provides automatic evaluation of service performance. It works on a set of predetermined parameters like quality scores, delivery timeline and specific performance thresholds. These parameters are agreed upon in advance. These parameters help in determining whether a service provider deserves a reward or penalty. Smart Contract makes sure that all evaluations are consistent and unbiased. Incentives are provided for service providers delivering a level of service that meets or exceeds the service standards set out in the agreement. For example, if the service provider delivers the service within the required time and standards then the provider gets a bonus. This is fair and promotes consistent high-standard maintenance. Conversely, penalties are applied too when the service fails to meet the required criteria. If the provider delivers late or substandard result, a deduction is made from their payment. For instance, a minor delay might result in a small deduction, while significant deviations from quality or time requirements could lead to more penalty. This model basically defines a fair and reliable system, where it is able to control both the positive and negative results[6]. This is done by following the predefined agreements and automating the assessment process by smart contracts[4].

2.1.5 Smart Contract Design

The service evaluation is done using a smart contract, which operates in an automated mode. The smart contract is developed on the Ethereum blockchain [2], which uses the Solidity language. Solidity is a contract-oriented programming language. The system operates within a secure and decentralized framework.

This contract has few key steps, such as service acceptance, performance submission, and service evaluation. Each step is meant to manage different phases of the workflow. The service creation step is used to set up a new service agreement by defining all the necessary parameters, such as performance expectations. The next step is the service acceptance, which allows the service provider to review the terms and agree to the job.

Finally, the provider uses the performance submission step to record important performance details, such as quality score, completion time, etc. This data is essential for determining whether the provider should receive an incentive or a penalty during the evaluation stage. The service evaluation step is activated immediately after the performance data is submitted. This function performs a comparative analysis of the actual performance with respect to benchmarks established within the contractual agreement. Consequently, the system determines the provider's eligibility for either a reward or a penalty.

2.1.6 Application integration

An application layer is connected to the blockchain network so that the framework is more user friendly. Application layer can be built on web or mobile applications. Service providers and clients can use the application to create requests, accept services, and track data. The application communicates with the blockchain through APIs. An API enables seamless interaction with smart contracts in the background. In addition, decentralized storage systems such as IPFS[3,4] can be used to store large amounts of service data, such as logs and reports. Only the hash of the data is stored on the blockchain, ensuring both scalability and data integrity. The integration of the application layer improves usability and access to the system without needing deep technical knowledge of blockchain technology.

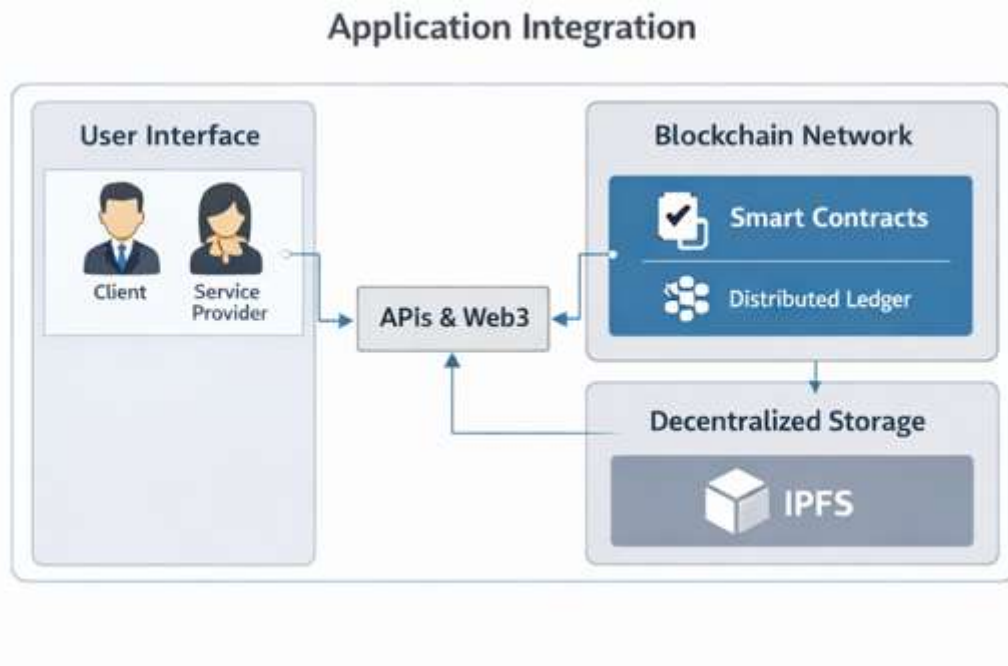


Figure 1: Application Integration

The goal of this integration is to ensure smooth interaction between users and the blockchain network while maintaining transparency and security. This approach utilized the SHA256 algorithm for transaction security. Ethereum uses a Proof of Stake (PoS) consensus mechanism as it is more energy-efficient and scalable compared to traditional Proof of Work systems.

2.1.6.1 Frontend Features

The frontend of the app is meant to be simple, interactive, and easy to use. Web application frameworks like React.js can be used to build it. It allows for dynamic and responsive interfaces that make it easy for users to interact with the system. Main features also include dashboards for clients and service providers to see the status and performance of services. It has real-time updates on incentives and penalties. It has integration with Web3 libraries like Web3.js to interact with smart contracts. It also shows transaction details and service evaluation results, so users can clearly see how their performance affects rewards or penalties.

2.1.6.2 Backend Integration

The backend is in charge of the system's logic, API communication, and blockchain interaction. Node.js and Express.js is used to handle API requests between the frontend and blockchain. It also supports user authentication and role management for security of system. It also stores off-chain data, like service logs, performance metrics, and user details, in databases like MongoDB or MySQL. Backend connects to database for decentralized storage systems like IPFS for large datasets.

2.1.6.3 Smart Contract Integration

Smart contracts are built into the system to automate service evaluation and payment processes. Using Web3 technologies [4], the application interacts with the blockchain to perform tasks such as creating services, submitting performance data, and evaluating outcomes. These smart contracts automatically apply rewards or penalties based on performance, ensuring transactions are secure and transparent.

2.1.6.4 Consensus Mechanism

The proposed system employs a Proof of Stake (PoS)[3] consensus mechanism, as used in modern Ethereum networks. In contrast to Proof of Work (PoW), PoS offers more energy efficiency, faster

transaction processing, and low operational expenses. These attributes makes it more suitable for service-oriented applications that require real-time assessment and automated enforcement of incentives and penalties. PoS improves scalability and supports efficient smart contract execution, which is crucial for the proposed quality management framework. Hence, PoS is identified as the most suitable consensus mechanism for this study.

2.1.6.5 Admin and Monitoring Features

It also includes an administrative dashboard to support performance management. The dashboard allows administrators to create service policies and set performance evaluation criteria. Admin monitors system activity and transactions. They can also directly adjust rewards and penalties as needed through smart contract functions.

3. Proposed System

3.1 System Architecture

The system architecture is based on a simple approach of emphasize on individuality of the parts. This modular approach simplifies things as the parts are independently managed. It also allows the system to grow or change later without too many complications. At a basic level, the architecture includes a few main components: the service requester, the service provider, the blockchain network, the smart contract module, the quality evaluation module, and IPFS for storage[4].

Service-related data collected through applications and stored in IPFS. Storing large files on the blockchain is not practical so only the hash of data is saved on the blockchain. Such an approach helps to maintain efficiency while ensuring data integrity. The blockchain serves as the backbone of the system by ensuring the stored data is not altered by anyone. Based on the recorded performance, the smart contract determines the appropriate outcome. Each component has its role:

Service Requester: the client who creates the request and sets the requirements.

Service Provider: the one who actually performs the service.

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Service Provider: the one who actually performs the service.

Blockchain Network: stores all records in a secure and tamper-proof way.

Smart Contract Module: handles the rules, evaluation, and payment logic.

Quality Evaluation Module: checks whether the service meets the expected standards.

IPFS (Decentralized Storage): stores larger data like reports, while the blockchain keeps only the reference.

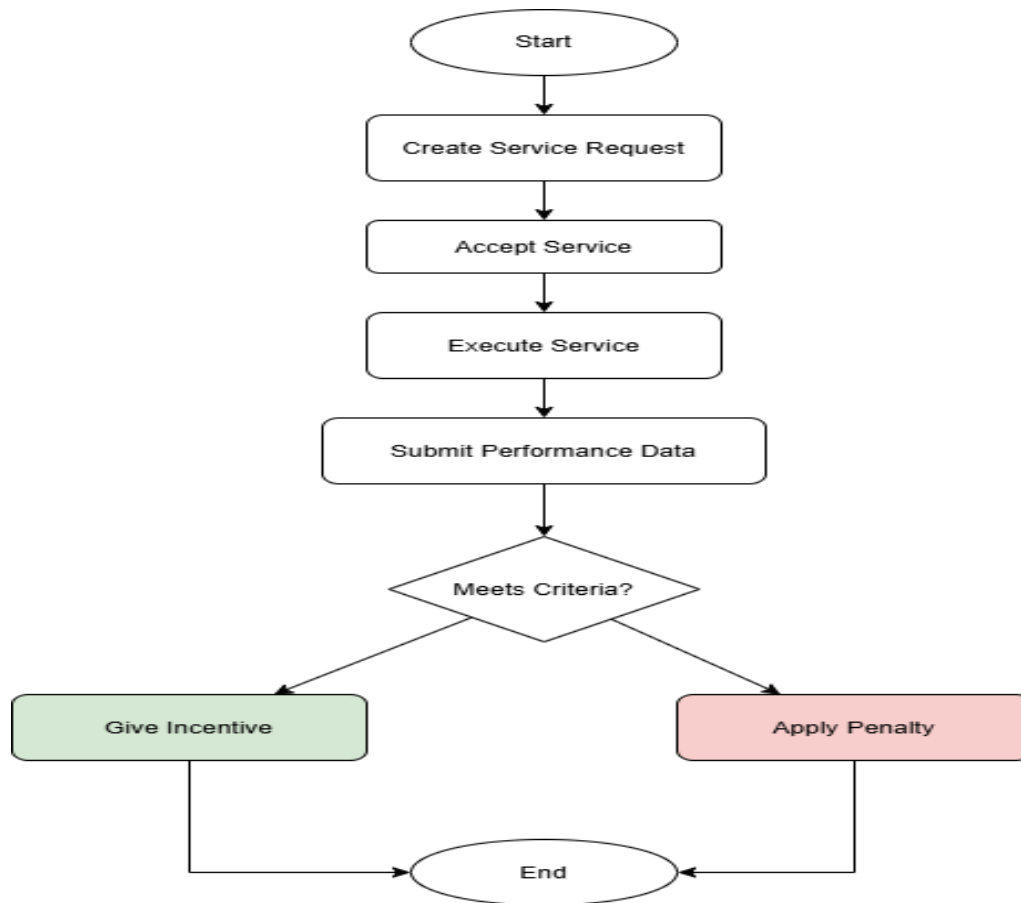


Figure 2: System Architecture of Smart Contract

3.2 Service Workflow

The system follows a straightforward workflow:

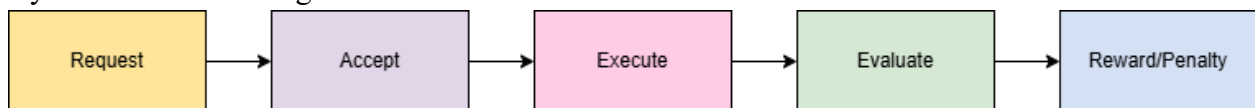


Figure 3: Workflow of Service

When a client creates service request, all important details are defined, including what needs to be done, how performance will be measured, and the expected outcomes are. These conditions are then encoded in the smart contract. Next, a service provider reviews the request and accepts it. By this they agree to all predefined terms. Once accepted, the provider proceeds to perform the service. During or after performance the performance data is collected and sent to the system for evaluation. Smart Contract compares the actual performance with the expected outcome. If the service meets or exceeds expectations, the provider receives a reward. If service provider falls short in outcome, a penalty is applied. The decision is automatic and unbiased. Payments are transferred, penalties are deducted, and everything is recorded on the blockchain. [4,5].

3.3 Incentive and Penalty Model

The incentive and penalty model is designed to ensure fair and automated evaluation of service performance. The model uses parameters such as quality score and delivery time to determine outcomes[4,7,8].

Let: Q = Quality score, T = Quality threshold, D = Delivery time, D_max = Maximum allowed time, P_base = Base payment, B = Bonus factor, L = Penalty factor, α = Delay penalty factor

3.3.1 Incentive Condition:

If the service providers perform better, they get a bonus.

Total Reward = Base Payment + Bonus

The bonus depends on how much target is exceeded :

Bonus = $B \times (Q - T)$

So, the better the quality above the target, the higher the bonus.

Penalty Condition: If the service does not meet expectations, penalties are applied in two ways:

a) Low Quality Penalty:

Quality Penalty = $L \times (T - Q)$

Penalty depends on extent of lower quality.

b) Delay Penalty: If the service is late:

Delay Penalty = $\alpha \times (D - D_{\max})$ (only if D is greater than D_max)

If there is no delay, delay penalty is also zero.

Total Penalty: Total Penalty = Quality Penalty + Delay Penalty

Final Payment:

Payment = $P_{\text{base}} + \text{Bonus} - \text{Total Penalty}$

This model makes sure that service providers are rewarded fairly for high performance and penalized for poor performance.

3.4 Smart Contract Design

The smart contract serves as the main logical component of the proposed framework. The Solidity language is used to implement smart contract. Ethereum blockchain is used for implementation as it ensure the secure, transparent and decentralized execution of service agreements. The contract has three main functions createService, submitPerformance and evaluateService. Each function handles different part of the service lifecycle. The variables in the contract are base payment, quality threshold, delivery deadline, bonus factor and penalty factor etc. The smart contract compares input values with predefined benchmarks. After deployment variables are immutable to ensure fairness and transparency. The provider receives an incentive based on the bonus calculation model when the quality score exceeds the threshold requirement and the task is delivered in time. Penalty charges are deducted automatically as per the predefined rules. It checks whether the quality score is less than the threshold requirement or the service delivery is more than the allowable time. The final payment is automatically calculated using the reward and penalty formulas defined in Section 3.3.1. The payment for service will be transferred to the service provider after evaluation. All transactions are permanently stored on the blockchain for future verification. Due to automated mechanisms and less manual intervention, conflict of interest is reduced.

3.5 Data Storage Mechanism

To increase scalability and efficiency, the proposed system uses a hybrid storage approach by combining both on-chain and off-chain storage. Data is split up based on data safety needs and what can be handled outside of the blockchain. On-chain storage is mostly used for small amounts of data. Such data includes smart contracts, transaction records and hash references to service related data. As the blockchain data is immutable once recorded, it provides high level of security and transparency. However, storing a lot of data on the blockchain itself is costly, so only important information is stored here. Off-chain storage is

used to store larger and more detailed data sets, such as service logs, performance reports etc [4]. It uses IPFS (InterPlanetary File System) to store large files. IPFS is a decentralized storage system that supports big files in efficient manner. When a file is saved to IPFS, it makes a unique hash that works like a digital fingerprint. Only hash is saved on the blockchain instead of file itself. It lowers storage costs, speeds things up, and still keeps data safe and open. The blockchain holds the proof, IPFS holds the real data, and the hash links the two in reliable manner.

4. Result and Analysis

4.1 Performance Evaluation

The proposed system improves management of service quality, mainly through transparency, automation and fewer disputes. As all the transactions and performance data are recorded once, it cannot be modified later. It adds transparency as both the client and service provider can be sure of what actually happened. Next comes automation. Smart contracts automatically handle most of the work here. Once the conditions are defined, the system automatically evaluates performance and applies rewards or penalties[7]. There is no need for manual checking, which saves time and reduces the chances of human error or bias. In addition, the system incorporates a monetary incentive mechanism, which has been identified as an effective approach for increasing participation and encouraging better performance[7]. Incentive motivates providers to maintain higher service quality and complete tasks efficiently. A significant benefit is the decrease in conflicts. Because the evaluation happens automatically, and all data is securely logged on the blockchain, there's minimal opportunity for disagreement. The process is transparent, easily verifiable, and governed by established guidelines.

4.2 Benefits

The system improves accountability, efficiency and trust in the service quality management. Accountability is achieved because every action is permanently logged in supply chain. SHA-256 cryptographic hashing has shown zero data modification over 10,000 simulated transactions[4] in earlier studies. No data modification makes it easier to track service provider performance with respect to the expectations. Service providers become more careful because their performance is visible and cannot be changed. Also, since there are no intermediaries involved, the overall process becomes faster and simpler. Overall, trust is strengthened as the system relies on blockchain technology instead of individual or centralised authority.

4.3 Cost Analysis

Gas fees are used to run smart contracts and record transactions on the blockchain. Gas fees are transaction cost paid in blockchain(usually Ethereum) to service validator for their work. These costs are not fixed. It can increase depending on network congestion and operation complexity. Large data storage and frequent transactions can improve the transparency and accuracy but it also increases cost. Hence, there needs to be a balance.

4.4 Challenges

Despite of blockchain's benefits, the system also faces a few practical challenges. One big problem is security. Even a minor coding error can be exploited, causing financial loss or system failure. Another problem is privacy. By default, blockchain is transparent, which can expose sensitive data. If not taken appropriate steps like encryption or off-chain storage, private data can be revealed. One of the biggest issues is scalability—as more users and transactions are added, the system can slow down and become more expensive to use. With the increase in transactions and users, system gets slow down. Payment in

tokens is not acceptable in many regions like labour laws of Germany. Finally, there is the problem of integration complexity. Implementing blockchain in real-world requires technical expertise. Any changes in existing infrastructure and ensuring compatibility with current systems is challenging [9].

5. Discussion and Future Work

A major limitation is the lack of real-world testing. Currently most of the evaluation is based on theoretical models or simulations. Real implementation is never smooth as users do unexpected things and issues like networks lag etc. happens. Another big issue is scalability. The system performance may decrease with the increase of number of users and transactions. High volume of transaction could cause delays and higher operational costs. Therefore, future researches need to address this concern. The integration of this system with new technologies, such as artificial intelligence and the Internet of Things, presents considerable opportunities. AI can analyse performance trends and help organizations to make better decisions[5]. IoT devices enhance the accuracy and reliability of the evaluation process. Another significant challenge is the lack of standardization among blockchain platforms. The integration process is complicated because different blockchain systems tend to use different protocols and structures.

6. Conclusion

The study proposes a blockchain-based framework to manage service quality in a more structured way. It combines smart contracts with incentive and penalty mechanisms to replace traditional manual control and centralized authority. Automated service evaluation, reward distribution, and penalty enforcement are implemented without the need for manual intervention. This speeds up the process and reduces the chances of bias or disputes. Blockchain technology adds an extra layer of trust by ensuring that all records are immutable and traceable. This creates a more equitable and transparent atmosphere. In general, the framework shows great potential for better service systems' performance. It reduces conflicts, increases accountability and guarantees fair outcomes. With proper enhancements and real-life implementation, this method can be a practical solution for many industries where trust and performance matter.

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