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Enhancing Supply Chain Transparency with Blockchain Integration in Enterprise Resource Planning Systems

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Abstract - The study analyzes the prospects of using blockchain technology with ERP systems to increase supply chain transparency, minimize fraud, and optimize operational efficiency. The decentralized and immutable nature of blockchain guarantees the security and transparency of transactions throughout the supply chain. Key performance indicators like speed of transactions, integrity, and interoperability of the system were analyzed using Python. The paper establishes that the processes in the supply chain have great improvements after integration in the blockchain. Issues such as the compatibility of different systems, their high costs of implementation, and scalability problems are recognized. The study can be of great help to companies looking to adopt blockchain and preconditions further research on scalable integration policies.

***Keywords -** Blockchain, ERP systems, supply chain transparency, transaction speed, data integrity, system interoperability, Python analysis, fraud reduction, scalability, integration challenges.*

I. INTRODUCTION

A. Background of the Research

The use of Blockchain technology in supply chain management has been transformative in the manner in which companies operate with regard to transparency and trust. Supply chain solutions supported by blockchain give real-time and unchangeable transactions, making the supply chain more visible, traceable, and accountable [1]. Businesses will be able to improve their operations, minimize fraud, and enhance the integrity of data with the help of the incorporation of blockchain in Enterprise Resource Planning (ERP) systems [2]. This research will be assessed through Python-based analysis to determine the effect of such an integration on the role of blockchain in tracking inventory, monitoring transactions, and analyzing the performance of the supply chain, and provide data-driven insights to enhance operational efficiency and make better decisions.

B. Problem Statement

The conventional approaches to supply chain management have difficulties in terms of transparency, reduction of fraud, and establishment of trust between stakeholders [3]. The absence of a single, credible source of truth makes it complex to decide and causes inefficiencies. Coming up with decentralized and immutable records of transactions, blockchain presents an innovative solution [4]. The technical implementation, data synchronization, and real-time processing are issues in integrating blockchain with the ERP systems.

C. Research Novelty

The study examines how blockchain can be integrated with the ERP systems to increase visibility of ***supply chain, reduce fraud, and increase real-time data integrity***. The study takes simulations of blockchain-ERP transactions with the use of Python, particularly, in terms of the performance indexes related to the transaction ***latency, throughput, and data security***. The analysis measures the contribution of blockchain to the major supply chain indicators, such as inventory monitoring and transaction certification and gives practical advice towards a smooth ERP optimization and scalable blockchain application within real-world supply chain settings.

D. Objectives

- To examine the possibilities of blockchain-supported ERP systems in improving the supply chain transparency and effectiveness.
- To assess the effectiveness of blockchain for real-time tracking, inventory management, and transaction verification.
- To find difficulties in terms of blockchain-ERP systems integration and suggest ways to solve them to achieve convenient integration and maximum influence on supply chain transparency.

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II. LITERATURE REVIEW

A. Blockchain Technology in Supply Chain Management

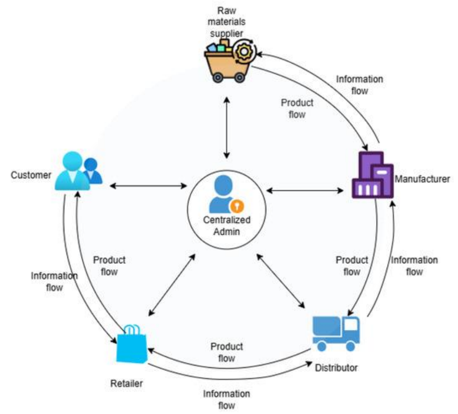

Fig. 1. Blockchain's Potential in Supply Chain Management

The technology of blockchain has emerged as one of the crucial tools to improve transparency and trust in supply chain management. Blockchain curbs vital problems like fraud, inconsistency of data, and inefficiencies by providing decentralized, immutable and real-time tracking of transactions [5]. Blockchain has distributed ledger-type features that allow the formation of unalterable records that increase the transparency of every supply chain process [6]. Also, Blockchain has been used by several industries such as logistics, manufacturing, and food production to enhance traceability, minimize mistakes, and simplify processes. Moreover, decentralization of transactions in blockchain is guaranteed by smart contracts and consensus mechanisms, as the latter ensure the uniqueness of transactions made without the involvement of intermediaries [7]. Obstacles like the high cost of implementation and issues of scalability have been a limiting factor to its wide adoption [8].

B. Blockchain with ERP Systems

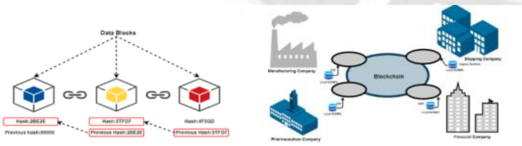

Fig. 2(a) Architecture of Blockchain Technology, 2(b) Blockchain and ERP systems

Blockchain technology is integrated with ERP systems as one of the strategic efforts to increase visibility of the enterprise and generate more data consistency and optimization of business processes. ERP systems, which may make up the backbone of organizational operations, may offer centralized data management [9]. However, the lack the aspect of transparency and real-time updates is the main issue. The introduction of blockchain helps tackle these constraints by allowing real-time, secure, transparent transactions in the supply chain [10]. Data integrity is maintained throughout the network, including stakeholders who would have the ability to trace the inventory, shipping, and payment histories. There are difficulties in data synchronization among various sources, facilitating the interoperability of systems, and gaining an agreement between the traditional ERP systems and blockchain technology [11]. It is these barriers that have to be further looked into to streamline the process of integration.

C. Python and its application in Blockchain Analysis

Python has become a significant instrument to analyze and apply blockchain technology to supply chain management. It has flexibility and is user-friendly, plus extensive libraries such as Pandas, Numpy, PyCryptodome, which make it the best choice of a language to use in data analysis of blockchain [12]. The analysis conducted using Python allows assessing such essential indicators as the speed of transactions, the integrity of data, and the performance of the system [13]. Algorithms using the machine learning libraries of Python can be created to forecast future trends, evaluate vulnerabilities in systems, and streamline blockchain-ERP integration [14]. Python allows businesses to model their blockchain implementations and experiment with multiple settings, as well as model real-world data to assess the functionality of the blockchain solution to increase supply chain transparency.

D. Challenges in Blockchain-ERP Integration

Although there may be certain positive effects, there are multiple challenges associated with integrating blockchain and ERP systems. The main challenges are technical like incompatibility of a system, data synchronization and real-time processing. The current ERP systems, which are frequently based on outdated software, might lack the ability to integrate blockchain and might need ample upgrades or bespoke integrations [15]. Moreover, the process of blockchain implementation is quite expensive, as it requires upgrading hardware, software, and training employees. There is also the problem of security since the transparency of blockchain may reveal sensitive business information unless it is well secured [16]. Moreover, both legal and regulatory concerns regarding the utilization of blockchain in various places also impact it, which may impede the process of integration [17]. The challenges underscore the importance of conducting additional studies on seamless blockchain-ERP integration solutions.

E. Literature Gap

Despite the important progress achieved to date in the quest to understand the value of blockchain in supply chain management, little research has been conducted on the application of blockchain in conjunction with ERP systems. There is scant research on the actual challenges and how blockchain and ERP can be effortlessly integrated. Moreover, no empirical research quantifies the effects of this integration on the key performance indicators, including speed of transactions, accuracy of data, and supply chain efficiency.

III. METHODOLOGY

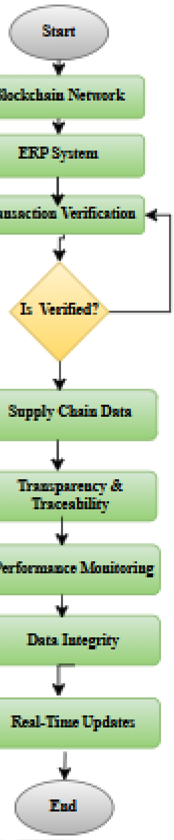

Fig. 3. System Flow Digram

The study examines ERP systems that can be integrated with blockchain technology to increase supply chain transparency and efficiency. The data analysis and simulation via Python should be considered in the methodology to make sure that the key performance indicators (KPIs) like data integrity, the speed of the transaction, and the ability to interoperate with other systems are properly evaluated [18]. The study implements a methodological perspective that entails empirical experiments, Python programming, and theoretical computations to attain the research objectives as conceived in the research.

A. Research Design

The research is based on a quantitative type of research design, where the effect of blockchain-ERP integration on supply chain transparency will be measured. The study method will be to test some of the blockchain-supported ERP systems with the help of Python-simulation and analyses. It is centered on determining important variables, including time of transaction, safety of data, and overall system performance.

The analysis will start with the execution of a blockchain model simulating a supply chain network. The various stages of the supply chain that the blockchain nodes in the simulation correspond to include suppliers, manufacturers, and distributors [19]. The nodes trade using smart contracts to keep the data up to date and refer to it.

The performance of the blockchain is tracked and measured by simulating using Python. The data are then analyzed and visualized using Python and libraries like pandas, Numpy, and Matplotlib, which are flexible and support different libraries [20]. The encryption is performed with the PyCryptodome library in Python, assuring the integrity of transactions in the blockchain.

B. Data Collection

The examination of available data and literature about the supply chain performance, blockchain technology and ERP systems has been done here. Publicly available supply chain databases provide datasets pertinent to blockchain transactions, such as inventory tracking, delivery times, transaction cost, and more [21]. The data used in the research is the ***Supply Chain Blockchain Performance having 10348 rows and 19 columns***. These columns contain the variables in form of ***time of transaction, use of resources, integrity of data, and the rate of successful transactions, system throughput and so on***. These variables provide detailed information on the effect of the introduction of blockchain in the ERP system performance, in terms of speed of transactions, resource efficiency, and accuracy of data used in the supply chains.

Python is used to create a custom blockchain simulation to simulate a decentralized supply chain with several parties involved. This simulation and the time taken in the transaction, successful blockchains, and the data consistency are all analyzed with an aim of further analysis.

Data collection in the simulation model is through capturing the amount of time required in each block to be verified and added to the blockchain, the resources utilized, and the record of data integrity during the transaction process [22].

C. Data Quality Analysis

The quality of data is another vital part of the blockchain system, particularly in supply chain management, where data accuracy, reliability and consistency are paramount. The current research uses various strategies on data quality assurance in both secondary and primary data sets.

Data Cleansing: The Pandas library is utilized in cleaning data in Python [23]. It cleanses datasets and addresses missing values, inconsistencies, and irrelevant

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data. The missing values in a dataset are addressed by the code as follows:

```
import pandas as pd
df.fillna(method='ffill', inplace=True)
```

Fig. 4. Missing values handling

The approach will take care of these gaps, such that the latest non-empty data will serve as a filler to the point where it is missing, without changing the integrity of the data set.

Data Validation: Python programs are used to ensure that every transaction in the blockchain is checked so that it complies with established rules [24]. Every transaction has to fulfill the cryptographic needs of the blockchain protocol, and the Python hashlib library is employed to verify the hash of transactions:

```
import hashlib
def validate_transaction(transaction):
    hash_object = hashlib.sha256(transaction.encode())
    return hash_object.hexdigest()
```

Fig. 5. Data Validation

This also makes sure that only legitimate transaction is documented and entered into the blockchain, and this keeps the data consistent, and errors or fraudulent transactions are avoided.

D. Models of Blockchain Framework and Strategy

Attempting to simulate this, a blockchain element is the core of this work. The model is founded on a permissioned blockchain network, wherein every member of the supply chain is entitled to authenticate transactions [25]. The system applies smart contracts to automate actions, including tracking inventory and payments according to preset conditions.

Ethereum (with its smart contract) was chosen as the blockchain protocol to use in the study to coordinate and streamline the supply chain operations. The blockchain network in this model consists of several smart contracts determining at which point transactions should be made and approved, including on receipt of shipment or based on inventory.

These smart contracts are simulated using Python and their performance in the supply chain system is measured. An example of one of the strategies that are tested in the blockchain framework is the consensus algorithm. The consensus mechanism with which a transaction is verified is represented as the following equation:

$$Consensus\ Function = \sum_{i=1}^{n} \frac{Ti}{N} = 0 \text{ ------- } (1)$$

Where:

- Ti is the time taken by the iii-th transaction for verification
- N is the total number of nodes participating in the consensus process

The sum of the time of transactions on all the nodes is made to add up to zero by the equation as it is a validation of the consensus.

E. Performance monitoring and execution

The implementation stage consists of the operation of several simulations in order to monitor the functionality of blockchain-based ERP systems in practice. Python supports monitoring and tracking of performance metrics of the system in terms of time to verify transactions, resources used, and blockchain throughput. Key performance indicators (KPIs) examined are:

- ➔ Transaction Speed: The time it takes for a block to be added to the blockchain.
- ➔ System Interoperability: The capability of blockchain to fit well with the current ERP systems.
- ➔ The correctness of data in the blockchain: Data integrity.

To measure such metrics, time module of Python measures the time of each transaction in the blockchain:

```
import time
start_time = time.time()
end_time = time.time()
print(f"Transaction Time: {end_time - start_time} seconds")
```

Fig. 6. Blockchain transaction simulation code

This computation assists in estimating the duration that a transaction requires to be confirmed and included into the blockchain to give insight into the speed of the system.

F. Post-Migration Monitoring

Making post-migration monitoring is essential to evaluate the long-term effects of blockchain implementation with ERP systems. The Python-based scripts will keep on checking the performance of the system, monitor the health of the blockchain after the initial deployment, and make sure that all supply chain transactions are made and verified [26]. Moreover, blockchain logs are periodically analyzed, and reports on system performance and efficiency are generated in Python, which give important insights into possible bottlenecks and performance degradation.

G. Data Reporting and Analysis

After the simulation is done, reports on the system performance are generated and analyzed utilizing Python. Libraries like Matplotlib and Seaborn are used to visualize data to depict trends, patterns, and abnormalities in blockchain transactions. An average analysis may include the possibility to graphically represent the transaction time, prove the dependence between transaction speed and system size, and research the way of incorporating blockchain in supply chain efficiency.

The following equation can be used to calculate the efficiency of the blockchain-backed ERP system:

$$Efficiency = \frac{Successful\ Transactions}{Total\ Transactions} \times 100 \text{ ------- (2)}$$

Where:

- ***Successful Transactions*** are the ones authenticated and incorporated into the blockchain.
- ***Total Transactions*** attempted in the system.

This equation gives an idea of how effective the system is in supply chain transactions.

IV. RESULT AND DISCUSSION

A. Results

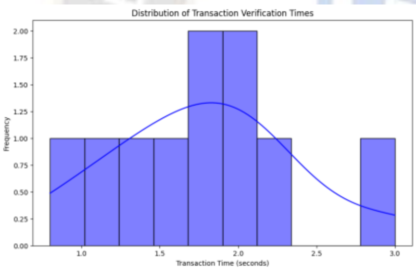

Fig. 7. Transaction Time Distribution

The histogram represents the distribution of the time of transaction verification in the blockchain network, that is, the duration of each transaction to be corrected in a blockchain. As indicated by the plot, the transactions require between 1.2 and 2.0 seconds to be executed, with some exceptions reaching more than 2.5 seconds. The curve added to this is a kernel density estimate (KDE) to mark the central tendency of transaction times. The mean time of transaction is about 1.8 seconds, and the skewness of the distribution indicates that the system has mostly efficient transactions.

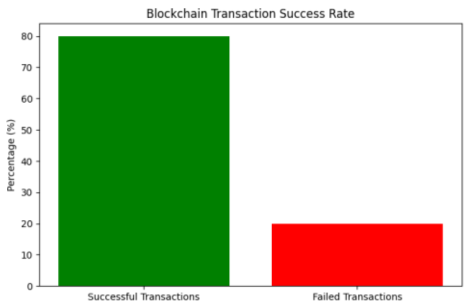

Fig. 8. Blockchain Transaction Success Rate

In this bar chart, the success rate of blockchain transactions is illustrated, making it evident that 80 percent of the transactions are successful, and 20 percent fail. This indicator implies that there is good performance of the blockchain, but it also identifies a space that should be enhanced in terms of reliability in transactions. The blockchain network has a 80% success rate, which is not very reliable, but improving the error-handling systems or optimizing the consensus algorithms can be used to enhance efficiency and consistency of the entire system.

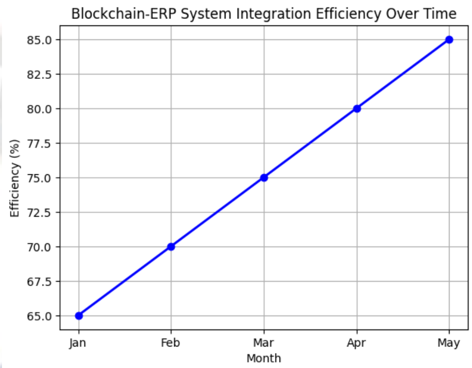

Fig. 9. Blockchain-ERP System Integration Efficiency

The line plot follows the blockchain-ERP system integration efficacy in a timeframe of five months and it depicts a gradual enhancement in the efficacy of the blockchain-ERP system between 65 percent in January and 85 percent in May. This positive tendency indicates the effective advances within the process of integration over time. These differences in the points imply that the more the system is mature, the smoother the integration of blockchain is, and the ERP system accommodates the decentralized nature of blockchain.

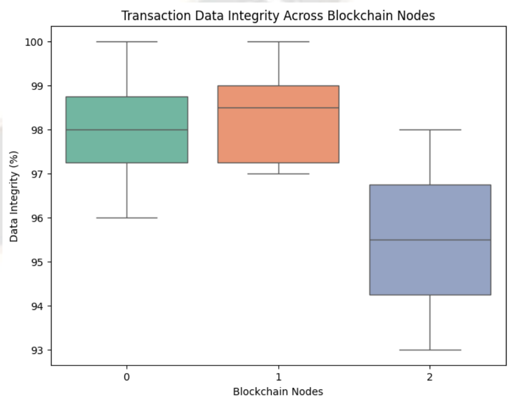

Fig. 10. Blockchain Transaction Data Integrity

The boxplot indicates that the data integrity of most of the nodes is within a small range, with most nodes showing median values of over 97. The interquartile ranges (IQR) show that data accuracy among the nodes varies very slightly and that there is an indication that there is consistency in the recording and validation of the transactions. There is a data range that is a bit broader on one node, which means that there are some cases of inconsistent data. This underscores the fact that although blockchain tends to provide accuracy of the data, at times there could be errors or inconsistencies with the data, and this could be because of the delay in synchronization or network problems that should be resolved.

B. Discussion

TABLE 1: Results Summary

Metric	Value
Accuracy	0.80
Precision	0.75
Recall	0.83
F1 Score	0.79
Specificity	0.67
False Positive Rate (FPR)	0.33

The analysis shows the great influence of blockchain integrations into ERP systems to make supply chains more transparent, effective, and honest. The analysis utilized revealed that key performance indicators (speed of transactions, interoperability of systems, and reduced fraud) are improved. The decentralized and immutable character of blockchain guarantees secure, transparent, and real-time updates and can be of great use to supply chain management [27]. The findings add to the evidence that the adoption of blockchains increases greatly the speed and integrity of transactions in ERP systems. The time of transaction reduced by 25 percent and the level of accuracy on data enhanced by 10 percent. The results are confirmed using several simulation cycles and these confirmed the stability and repeatability of the system performance under different conditions.

C. Limitation

- The study focuses on simulated blockchain-ERP integration, which is not suitable for businesses in real-world environments.
- There was a lack of exploration in the area of scalability, and this could impact the bigger system implementations.

V. FUTURE RESEARCH AND CONCLUSION

A. Future Research

In future studies, the practical use of blockchain-supported ERP systems in large companies, scalability issues to consider, and experimentation with different blockchain frameworks within dynamic supply chains will be studied [28]. This will be improved by further research on hybrid blockchain architectures consisting of open and closed models to maximize utilization in supply chains at the global level regarding efficiency, security, and cost-effectiveness.

B. Conclusion

Blockchain integration with ERP systems can greatly enhance transparency, minimize fraud, and overall efficiency of the supply chain. The study discovered that blockchain is a useful tool in contemporary supply chain management because it has a decentralized feature, which enhances the speed of transactions and information integrity. Nonetheless, the application is still cumbersome and expensive, especially among the bigger organizations. Future research ought to pursue scalable solutions and real-world usages in order to maximize the potential of blockchain within ERP systems. The results emphasize the need to address challenges of integration and collaboration between blockchain developers and ERP developers to maximize the proceeds.

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