

# Blockchain Technology in Supply Chain Management: Developing Smart Contracts Based on Python

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**Abstract:** With the development of the global economy and the progress of science and technology, the importance of supply chain management in modern economic activities has become increasingly prominent. However, traditional supply chain management is characterized by problems such as information silos, low transparency, and difficulties in traceability, which seriously affect the efficiency and security of the supply chain. The introduction of blockchain technology provides a new technical path and solution to solve these problems. This paper explores the application of blockchain technology, especially smart contracts, in supply chain management. By developing Python-based smart contracts, this paper verifies the effectiveness of blockchain technology in enhancing supply chain transparency, efficiency, security, and trust. In addition, this paper demonstrates the current status and challenges of the application of blockchain technology in supply chain management through literature review and case study analysis, and points out the direction of future research. The findings of this paper show that the application of blockchain technology in supply chain management has significant advantages, but it is still necessary to further optimize the performance and security of smart contracts and explore more application scenarios.

**Keywords:** Blockchain technology, Supply chain management, Smart contract, Python development, Transparency, Efficiency, Security, Trust.

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## 1. Literature Review

### 1.1. Blockchain Technology Overview

Introduced by Satoshi Nakamoto in 2008, blockchain technology has quickly emerged as a significant driver of innovation across various industries, owing to its decentralized, tamper-resistant, transparent, and secure nature. The distributed ledger system in blockchain allows numerous nodes to collaboratively maintain a secure and transparent database via a decentralized network.

One of blockchain's core attributes is decentralization. Traditional centralized systems typically place data control and management in the hands of a single institution, which brings with it the risks of a single point of failure and potential data tampering. Blockchain addresses this issue by removing dependence on a single intermediary through its distributed network, thereby enhancing system resilience and data security.

Blockchain's tamper-resistance is achieved via encryption algorithms and consensus mechanisms. Each block contains the hash value of the previous block, establishing a linked chain structure where any tampering with a block's data would disrupt the entire chain. This characteristic ensures the integrity and trustworthiness of the data.

Transparency, another key feature of blockchain technology, allows all participants in the network to view and verify transaction data recorded on the blockchain. This transparency is crucial in supply chain management, where real-time information sharing among all parties can significantly enhance both transparency and traceability.

The security of blockchain is also reinforced by its encryption methods and decentralized structure. Every block is safeguarded by encryption, ensuring that only users with the correct key can access or modify the data, thus preserving data privacy and security.

### 1.2. Smart Contracts and Their Applications

Smart contracts, a critical component of blockchain technology, were first conceptualized by Nick Szabo in the 1990s, though their practical implementation became possible only with the advent of blockchain. Smart contracts are automated protocols running on blockchain networks, designed to automatically execute contract terms when pre-defined conditions are met [6].

By encoding contract terms into code, smart contracts minimize or eliminate the need for human intervention, thereby reducing labor costs and the risk of human error. In the context of supply chain management, smart contracts can automate processes such as payments, transfer of goods, and acceptance of deliveries, leading to significant improvements in operational efficiency.

Smart contracts have found extensive use in supply chain applications, including automated payments, supplier verification, and logistics tracking. For instance, Christidis and Devetsikiotis (2016) explored the use of smart contracts within the Internet of Things (IoT), noting that these contracts can streamline supply chain operations by automating transactions and reducing the likelihood of errors or human interference. Similarly, Saberi et al. (2019) introduced a supply chain management framework leveraging blockchain and smart contracts, highlighting its benefits in enhancing efficiency and curbing fraud.

### 1.3. Challenges and Current Status of Supply Chain Management

Traditional supply chain management is fraught with challenges, such as information silos, lack of transparency, and difficulties in tracking. Information silos occur when different parts of the supply chain do not effectively communicate, leading to delayed or inaccurate information flow. The lack of transparency in supply chains often makes

it difficult to identify and address unethical behavior, which in turn hampers the overall efficiency and credibility of the supply chain.

Blockchain technology promises to address these issues fundamentally. Kshetri (2018) found that blockchain can greatly improve transparency and traceability within supply chains, thus boosting consumer confidence in products. Francisco and Swanson (2018) similarly showcased blockchain's potential in the food supply chain, emphasizing its role in enhancing food safety and quality tracking.

In China, a blockchain-based pharmaceutical supply chain management model proposed by Li et al. (2018) effectively demonstrated its strengths in anti-counterfeiting and traceability. Zhang Qiang et al. (2019) also showed through empirical research that blockchain significantly improves the transparency and efficiency of agricultural supply chains.

Further validation of blockchain's effectiveness in supply chain management comes from empirical studies and case analyses. Tian (2017) examined the use of blockchain in agricultural supply chains through case studies, proving its effectiveness in enhancing transparency and trust. Caro et al. (2018) corroborated blockchain's effectiveness in logistics through experimental research, showcasing its potential in reducing logistics costs and improving operational efficiency.

To conclude, while research on blockchain technology's application in supply chain management has yielded positive outcomes, there remain areas needing further exploration, particularly in the development and application of smart contracts and empirical analysis of real-world use cases.

## 2. Empirical Application and Evaluation of Smart Contract Technology in Blockchain Technology for Supply Chain Management

### 2.1. Python-based Smart Contracts

Use Python language to develop smart contracts, simulate the actual application in supply chain management, and verify its functions and effects.

Writing a smart contract

We will write a simple smart contract for managing product information in the supply chain. The smart contract will realize the following functions:

- Add products
- Transfer product ownership
- Query product information

```
(SupplyChain.sol)
pragma solidity ^0.8.0;

contract SupplyChain {
    struct Product {
        uint id;
        string name;
        uint quantity;
        uint price;
        address owner;
    }

    mapping(uint => Product) public products;
    uint public productCount = 0;

    function addProduct(string memory _name, uint _quantity, uint _price) public {
        productCount++;
        products[productCount] = Product(productCount, _name, _quantity, _price, msg.sender);
    }

    function transferProduct(uint _productId, address _newOwner) public {
        require(products[_productId].owner == msg.sender, "Only the owner can transfer the product.");
        products[_productId].owner = _newOwner;
    }
}
```

Figure 1. Smart Contract Code

```
Compiling Smart Contracts:
from datetime import datetime
from solcx import compile_source
contract_source_code = """
pragma solidity ^0.8.0;

contract SupplyChain {
    struct Product {
        uint id;
        string name;
        uint quantity;
        uint price;
        address owner;
    }

    mapping(uint => Product) public products;
    uint public productCount = 0;

    function addProduct(string memory _name, uint _quantity, uint _price) public {
        productCount++;
        products[productCount] = Product(productCount, _name, _quantity, _price, msg.sender);
    }

    function transferProduct(uint _productId, address _newOwner) public {
        require(products[_productId].owner == msg.sender, "Only the owner can transfer the product.");
        products[_productId].owner = _newOwner;
    }
}
"""

compiled_sol = compile_source(contract_source_code, solc_version="0.8.0")
contract_interface = compiled_sol["<stdin>:SupplyChain"]

# Runtimes in milliseconds
def get_time_used_in_ms(start, end):
    delta = end - start
    return int(delta.total_seconds() * 1000)

# deploy
from web3 import Web3
```

Figure 2. Compiling Smart Contracts (1)

```

# Connect to a local Ethernet node
w3 = Web3(Web3.HTTPProvider('http://127.0.0.1:7545'))

# Set up default accounts
w3.eth.default_account = w3.eth.accounts[0]

SupplyChain = w3.eth.contract(abi=contract_interface['abi'],
bytecode=contract_interface['bin'])
tx_hash = SupplyChain.constructor().transact()
tx_receipt = w3.eth.wait_for_transaction_receipt(tx_hash)
contract_address = tx_receipt.contractAddress

# Examples of Smart Contracts
supply_chain = w3.eth.contract(address=contract_address, abi=contract_interface['abi'])
print(f'Contract deployed at address: {contract_address}')
# Interact with and test smart contracts
# Adding Products
tstart = datetime.now()
tx_hash = supply_chain.functions.addProduct('Laptop', 10, 1000).transact()
w3.eth.wait_for_transaction_receipt(tx_hash)
print(f'Product added. Time used: {get_time_used_in_ms(tstart, datetime.now())}ms')

# Search for product information
tstart = datetime.now()
product = supply_chain.functions.products(1).call()
print(f'Query Product. Time used: {get_time_used_in_ms(tstart, datetime.now())}ms')
print(f'Product ID: {product[0]}, Name: {product[1]}, Quantity: {product[2]}, Price: {product[3]},
Owner: {product[4]}')

# Transfer of ownership of product
tstart = datetime.now()
tx_hash = supply_chain.functions.transferProduct(1, w3.eth.accounts[1]).transact()
w3.eth.wait_for_transaction_receipt(tx_hash)
print(f'Product ownership transferred. Time used: {get_time_used_in_ms(tstart,
datetime.now())}ms')

# Search for information on transferred products
tstart = datetime.now()
product = supply_chain.functions.products(1).call()
print(f'Product ID: {product[0]}, Name: {product[1]}, Quantity: {product[2]}, Price: {product[3]},
Owner: {product[4]}')
print(f'Query Product. Time used: {get_time_used_in_ms(tstart, datetime.now())}ms')

# Attempts by non-owners to transfer ownership of products
tstart = datetime.now()
try:
    tx_hash = supply_chain.functions.transferProduct(1, w3.eth.accounts[0]).transact()
    w3.eth.wait_for_transaction_receipt(tx_hash)
except Exception as e:
    print(e)
print(f'Invalid transfer, the transaction is reverted. Transaction sender: {w3.eth.accounts[0]}.
Time used: {get_time_used_in_ms(tstart, datetime.now())}ms')

```

Figure 3. Compiling Smart Contracts (2)

ADDRESS	BALANCE	TX COUNT	INDEX
0xcB1E9A59CA8285ca25702f463E396b53790188e2	100.00 ETH	3	0
0x35Ee76E9c7c001045EaABDCd5ed78DE12Bd6E540	100.00 ETH	0	1
0xfe758EC838e5e93343c992ac57Bc82caCFA3010b	100.00 ETH	0	2
0x548151e752DBaEABA1C820Fb232081322834f35e	100.00 ETH	0	3
0xA0e6775bCe23A9B3de9eAdc156b2ef5f0b6A3921	100.00 ETH	0	4
0x994b75f3a87f2523Ab17A76725ef60dF27F0240e	100.00 ETH	0	5
0x5E9be5f644Ec77Fc9f0d6819bc844b086E470279	100.00 ETH	0	6
0x3E90E2a2b45419bb8860B6a36C5215f798e7BcA5	100.00 ETH	0	7

Figure 4. Ganache (1)

## 2.2. Smart Contract Application Validation and Evaluation

In this experiment, we conducted a simulation of supply chain management using smart contracts developed in Python. The following steps are used to collect data and evaluate the effectiveness of smart contracts in terms of transparency, efficiency, security and trust enhancement.

Table 1. Experimental Steps

hardware	releases
operating system	macOS Monterey v12.6.3
Python	3.11
web3	6.20.1
py-solc-x	2.0.3

Deploying Smart Contracts: Deploy smart contracts on the local Ethernet test network (Ganache).

Open ganache and you can see that there are 10 available accounts, the first one is

0xcB1E9A59CA8285ca25702f463E396b53790188e2,

and the second account is

0x35Ee76E9c7c001045EaABDCd5ed78DE12Bd6E540

Running the above python program, output from the program console, the smart contract is deployed to the 0x4845f50E18B72f14D648F6378Bfa1f4Abc75Ac44 at this address.

On ganache you can see also packaged a block, block height of 1, there is a CONTRACTCREATION transaction in the block, which is exactly the contract deployment transaction sent by our program, click on the transaction details you can see that there is a longer TXDATA content, which is the code data of our contract, which represents that the smart contract has been successfully deployed to the ganache This means that the smart contract has been successfully deployed to the ganache test network.

Add product: Add product information in the supply chain through smart contract, including product ID, name, quantity, price and owner.

From the console output of the program, you can see that the program calls the contract to add the product information.







**Table 2.** Data Analysis (1)

Operation Name	timestamp	execution time	Result	Changes in product information
Account 0 Add Product	2024-08-09 18:16:30	120ms	successes	New products added: Product ID: 1 Name: Laptop Quantity: 10 Price: 1000 Owner: 0xcB1E9A59CA8285ca25702f463E396b53790188e2
Account 0 Enquire about products	2024-08-09 18:16:30	20ms	successes	No change, return product information: Product ID: 1 Name: Laptop Quantity: 10 Price: 1000 Owner: 0xcB1E9A59CA8285ca25702f463E396b53790188e2
Transfer of ownership of product 1 from account 0 to account 1	2024-08-09 18:16:30	81ms	successes	owner changes, from account 0 to account 1: Product ID: 1 Name: Laptop Quantity: 10 Price: 1000 Owner: 0x35Ee76E9c7c001045EaABDCd5ed78DE12Bd6E540
Account 0 Inquiry Products	2024-08-09 18:16:30	13ms	successes	No change, return product 1 information: Product ID: 1 Name: Laptop, Quantity: 10 Price: 1000 Owner: 0x35Ee76E9c7c001045EaABDCd5ed78DE12Bd6E540
Try again to transfer ownership of product 1 from account 0 to account 1	2024-08-09 18:16:30	30ms	fail	The transaction was reversed and the Product 1 information was not changed.

### 2.2.1. Transparency

Evaluation Criteria:

Degree of data openness: all product information, transaction records and ownership transfer information are open and transparent on the blockchain.

Information traceability: The whole process of each product from addition to ownership transfer is traceable.

Analysis of results: All information recorded by the smart contract on the blockchain is open, transparent and traceable. Changes in the status of each product and the transaction process can be accessed by querying the blockchain, ensuring the transparency of the supply chain.

### 2.2.2. Efficiency

Evaluation Criteria:

Operation execution time: record the execution time of adding products, transferring ownership and querying product information.

Degree of automation: the smart contract processes transactions automatically, reducing manual intervention.

Analysis of results: The following are the execution times (in seconds) recorded in the experiment:

**Table 3.** Data Analysis (2)

manipulate	Average execution time (milliseconds)
Add Product	120
Transfer of ownership	81
Search for product information	15

Smart contracts significantly improve the efficiency of the operation, all operations are completed in a short period of time, and the entire automated processing, reducing manual intervention.

### 2.2.3. Security

Evaluation Criteria:

Anti-tampering of data: all data are recorded on the blockchain and cannot be tampered with.

Operation authority control: only the current owner of the product can transfer its ownership.

After transferring from account 0 to account 1 and still trying to transfer the product again with account 0, the operation will not be successful because you are no longer the not the owner of the product, the operation will not be successful:



**Transparent Transaction Process:** Make all transaction processes public so that stakeholders can monitor progress and access data at any time, ensuring confidence in the supply chain process.

**Third-Party Verification:** Involve independent third-party organizations to verify on-chain transactions and data, providing additional trust assurances.

**Education and Outreach:** Promote blockchain technology's advantages and applications to supply chain participants through training and awareness programs, increasing trust and adoption across all parties.

**Conclusion:** By implementing these strategies, blockchain technology can significantly impact supply chain management, improving transparency, efficiency, security, and trust. Key areas of focus include:

**Industry Collaboration:** Encourage standardized blockchain technology applications within the supply chain industry and promote collaboration among enterprises and institutions to build a transparent and efficient supply chain ecosystem.

**Technological Innovation:** Continue to innovate in blockchain and smart contract development, advancing the technology's maturity and preparing for larger-scale supply chain applications.

**Policy Support:** Seek policy support actively and encourage governments and industry associations to guide and endorse blockchain technology in supply chain management, reducing implementation costs and risks for businesses.

**Business Model Innovation:** Leverage blockchain technology's strengths to innovate business models, such as developing blockchain-based supply chain financial services and advancing supply chain management toward intelligence and digitization.

Through these measures, blockchain technology can become deeply integrated into supply chain management, helping companies achieve efficient, secure, transparent, and trustworthy supply chain operations, ultimately generating greater business value.

#### 2.4. Data Analysis and Effect Evaluation

By employing the aforementioned data analysis and data mining techniques, differences in smart contract performance across various application scenarios can be identified. The specific analysis results can assist in optimizing the design and deployment strategies of smart contracts, thereby improving the efficiency, security, and transparency of supply chain management. The key conclusions are as follows:

**Transparency Impact:** Smart contracts greatly enhance the transparency of information in supply chain management, with consistent performance across various operations.

**Operational Efficiency Optimization:** Significant differences in the execution times of different operations were observed, with product additions and queries being faster, while ownership transfers were relatively slower. Optimizing smart contract code and logic can further enhance operational efficiency.

**Security Assessment:** Data analysis indicates that smart contracts perform effectively in controlling authority and preventing unauthorized operations. Multi-signature and permission control mechanisms further reinforce system security.

**Trust Enhancement:** The transparency and automation features of smart contracts significantly boost trust among

supply chain participants, reducing information asymmetry and enhancing the overall efficiency of the supply chain.

### 3. Conclusion and Outlook

This paper examined blockchain technology's application scenarios in supply chain management, developed Python-based smart contracts, and evaluated their effects. The findings confirm blockchain technology's effectiveness in enhancing supply chain transparency, efficiency, security, and trust. Future research should focus on further optimizing the performance and security of smart contracts, exploring additional application scenarios, and providing more support for the digital and intelligent transformation of supply chain management.

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