An Enhanced CoD System Leveraging Blockchain, Smart Contracts, and NFTs: A New Approach for Trustless Transactions

Phuc N. T. (*)[1], Khanh H. V.[1], Khoa T. D.[1], Khiem H. G.[1], Huong H. L.[1], Ngan N. T. K.[2],
Triet N. M.[1], Kha N. H.[1], Anh N. T.[1], Trong. V. C. P.[1], Bang L. K.[1], Hieu D. M.[1], and Quy L. T.(*)[1]

[1]FPT University, Can Tho City, Vietnam
[1]FPT Polytechnic, Can Tho City, Vietnam

***Abstract*—The global transportation of goods has evolved in response to varied economic demands. The rapid progression of modern scientific and technological innovations offers a shift from traditional shipping paradigms. Current systems, whether domestic like Cash-on-Delivery (CoD) or international such as Letter-of-Credit, necessitate trust-building through an intermediary—be it a carrier or a financial institution. While these conventional systems provide certain benefits, they inherently present several challenges and potential vulnerabilities, affecting both sellers and buyers. The introduction of blockchain technology and smart contracts has been explored as a viable alternative to bypass these intermediaries. However, simply removing the shipping intermediary presents its own set of issues, particularly when disputes arise. Notably, the shipper remains unaffected in situations of contention. Consequently, some models are now incorporating the shipper's role, either as a singular entity or in collaboration with others. Yet, a considerable number of these models still depend on an external trusted party for conflict resolution. Our study introduces a unique framework, blending the robustness of blockchain, the enforceability of smart contracts, and the authenticity assurance of NFTs. This system creates a streamlined CoD operation encompassing the seller, shipper, and buyer, using NFTs to produce digital receipts, guaranteeing both proof-of-purchase and a security deposit. Furthermore, our system provides an inherent mechanism for dispute resolution. Key contributions of our work including i) The design of a novel CoD system anchored on blockchain and smart contract capabilities; ii) The incorporation of Ethereum-based NFT (specifically, ERC721) for securely logging package information; iii) The development of smart contracts that facilitate NFT generation and transfer between transactional entities; and iv) Performance evaluation and deployment of these contracts across multiple EVM-compatible platforms such as BNB Smartchain, Fantom, Celo, and Polygon, establishing the optimal environment for our innovative system.**

Keywords*—*Letter-of-credit; cash-on-delivery; blockchain; smart contract; NFT; Ethereum; Fantom; polygon; binance smart chain

I. Introduction

The intricate world of shipping and logistics has always revolved around trust and verifiability, historically hinging on the foundational rapport either between buyer and seller or embedded within the trust framework of a shipping entity, notably the shipper [1]. Regrettably, within these traditional paradigms, numerous challenges have surfaced, casting a shadow on the reliability of transactions, especially in the context of international trade.

For instance, consider the Letter-of-Credit (LoC) model, a time-tested mechanism used in international trade. To elucidate, let's sketch a scenario involving a Vietnamese exporter, specializing in cashew nuts, and an importing entity situated in Italy. While seemingly straightforward, the mechanics of their transaction heavily rely on a neutral third party, conventionally a bank, to validate and authenticate the dealings.[1] The fragile nature of this process becomes glaringly evident when crucial documents, say the LoC, go missing. The consequences can be dire, as evidenced by a 2021 event involving potential financial losses in a Vietnamese cashew shipment to Italy, all precipitated by the unavailability of requisite documents.[2] Fortunately, swift diplomatic intervention averted a crisis. Yet, the incident remains a poignant testimony to inherent systemic frailties.

On the domestic front, where the Cash-on-Delivery (CoD) model reigns supreme, sellers are ensnared in a web of dependency on shipping companies. Under this system, profits from goods sold are typically remitted to the sellers either periodically or upon hitting predetermined financial ceilings. However, this trust-dependent system has shown its flaws. A poignant case from Vietnam during 2017-2018 involving GNN Express highlighted the vulnerability, as funds intended for sellers were misused by the shipping entity.[3]

Such systemic vulnerabilities have instigated an earnest quest for robust, technology-driven mechanisms in the shipping sector. The genesis of Bitcoin in 2009 marked a paradigm shift, championing a decentralized, transparent Peer-to-Peer transactional ecosystem reinforced by the Proof-of-Work (PoW) consensus mechanism [2].

Building on this momentum, Ethereum entered the scene, revolutionizing the landscape with the introduction of smart contracts—autonomous, self-regulating contracts, where contractual terms and conditions transmute into programmable code lines.[4] This technological marvel birthed transactional frameworks such as localEthereum in 2017, advocating for

[1]For reasons aligned with information security and confidentiality, we have intentionally refrained from naming the specific companies involved in these transactions from Vietnam and Italy.

[2]https://vietnamnet.vn/en/100-containers-of-cashew-nuts-exported-to-italy-suspected-of-being-scammed-821553.html

[3]https://vir.com.vn/gnn-scandal-rocks-delivery-segment-62710.html

[4]https://ethereum.org/en/whitepaper/

payment paradigms rooted in the Solidity language.[5] While several innovative models sprouted, Ethereum's technological acumen found resonance in other platforms, leading to the creation of EVM-integrated platforms, heralding a new era of smart contract adaptability.

Yet, the path is not devoid of hurdles. A recurring critique of many frameworks has been their apparent sidelining of a crucial player in the shipping process: the shipper. Excluding them could muddle dispute resolution processes between sellers and buyers [3]. Recognizing this gap, subsequent studies championed the seamless incorporation of shippers via blockchain and smart contracts [4]. However, integrating shippers isn't the panacea; challenges like potential package damages during transit loom large [5].

Addressing this multifaceted issue is our primary research impetus. We harness the potential of NFT technology to meticulously encapsulate package particulars, ensuring a transparent and accountable transfer process from sellers to buyers, with shippers playing a pivotal role. The cornerstones of our research are: (a) architecting a holistic shipping framework anchored in blockchain technology and enriched with smart contracts; (b) engineering a meticulous Ethereum-based NFT mechanism (specifically ERC721) for comprehensive package information cataloging; (c) the meticulous design and deployment of NFT-empowered smart contracts, enabling seamless transactional experiences between stakeholders; and (d) rigorously assessing the performance of these smart contracts across a spectrum of EVM platforms - specifically, we install a recommendation system on four popular blockchain platforms today, supporting Ethereum Virtual Machine (EVM), including Binance Smart Chain (BNB Smart Chain)[6]; Polygon [7]; Fantom [8]; and Celo [9]. [10]

II. Preliminaries

A. Understanding Blockchain

Blockchain gained prominence with Bitcoin's debut in 2008, presented by Nakamoto [2]. It serves as a distributed, credible, and transparent ledger. Within a peer-to-peer network, a blockchain system distributes transaction information across multiple computing devices. This facilitates a robust link between transaction participants, eliminating traditional intermediaries like banks [6].

Presently, blockchains are categorized into Public, Private, and Consortium. Public blockchains, like Bitcoin and Ethereum, are open for all, even anonymous participants, to validate transactions, introduce new ones, and ensure the authenticity of existing data. In contrast, private blockchains like GemOS, MultiChain, Ripple, and Eris restrict participation to authorized members. Consortium blockchains merge attributes from both types. They are designed for business needs, balancing openness with security. Examples include Hyperledger Fabric [7] and the private configurations of Ethereum [8].

[5]https://docs.soliditylang.org/en/v0.8.17/
[6]https://github.com/bnb-chain/whitepaper/blob/master/WHITEPAPER.md
[7]https://polygon.technology/lightpaper-polygon.pdf
[8]https://whitepaper.io/document/438/fantom-whitepaper
[9]https://celo.org/papers/whitepaper
[10]The ETH platform was consciously excluded due to the prohibitive costs associated with smart contract operations.

B. Key Blockchain Platforms

1) Ethereum: Ethereum, as described in [9], is a distributed platform that facilitates the execution of smart contracts using the Solidity language. Powered by the Ethereum Virtual Machine (EVM), Ethereum extends its capabilities to decentralized finance (DeFi), establishing protocol-bound conditions.

2) Hyperledger fabric: Hyperledger Fabric, an open-source solution [7], is tailored for enterprise requirements. With its distinct architecture, it supports dual modes—public and private blockchains. Unlike Ethereum's reliance on EVM, Fabric employs Docker containers termed "ChainCode" for smart contract execution, offering compatibility with Java and Go, which simplifies development and lowers operational costs.

3) Celo: Celo is a decentralized platform prioritizing mobile access and stability of value. While it is EVM-compatible, it differentiates itself with a mobile-first approach. The platform incorporates stable-value tokens, ensuring that transaction fees are predictable.

4) Fantom: Fantom is a high-performance, scalable, and secure smart contract platform. Leveraging its unique Lachesis Protocol, it guarantees low time-to-finality. Being EVM-compatible means developers familiar with Ethereum can easily transition to Fantom.

5) Matic (Polygon): Polygon, formerly known as Matic, offers a scalable and interoperable framework. While it started as an Ethereum sidechain, it has evolved to support multiple chains. Its EVM compatibility and commitment to scalability make it a preferred choice for many decentralized applications.

C. Decentralized Logic: Smart Contracts

Smart contracts, known as chaincode in Hyperledger Fabric, digitally facilitate, verify, or enforce credible transactions. These self-executing contracts embed the terms directly within the code. In decentralized applications, they serve as algorithmic agents, functioning like traditional contracts.

1) Distinctive features: Smart contracts exhibit several traits:

- Decentralization: Stored across the Ethereum network, contrasting centralized solutions.
- Predictability: Act only under stipulated conditions, maintaining consistent outcomes.
- Autonomy: Automate tasks, staying dormant until activated.
- Immutable Nature: Once deployed, they're unchangeable. However, they can be rendered inactive if preprogrammed.
- Versatility: Programmable before deployment, they cater to diverse decentralized applications.
- Trustless Operations: Enable interactions without mutual trust, as blockchain validates data accuracy.
- Openness: Being on a public ledger, their code is visible to all but remains unalterable.

2) Functionality overview: A smart contract's functionality parallels that of a vending machine. It awaits the right conditions, then executes. Assets and terms are encrypted into a blockchain block. Upon activation, the contract follows the encoded logic, autonomously ensuring term adherence.

3) Advantages:

- Efficient Cost Structures: Smart contracts streamline processes that conventionally demand intermediaries. By eliminating middlemen, like banks or notaries, there's a direct reduction in associated costs and fees. Transactions are executed automatically when predetermined conditions are met, ensuring that users only bear the essential costs of the contract's execution.
- Adaptive Terms for User Convenience: Smart contracts are designed to be programmable, granting them a degree of flexibility unparalleled by traditional contracts. This adaptability allows parties to customize terms according to their specific needs. Whether it's payment schedules, compliance criteria, or conditional operations, smart contracts can be tailored to handle diverse scenarios, enhancing user experience and satisfaction.
- Complete Transparency and Clarity in Transactions: Being on a blockchain, every smart contract's terms and transactions are transparent to all involved parties. This ensures that every stakeholder can verify transaction details, reducing ambiguities and mistrust. The open nature of public blockchains further enhances transparency, as any external observer can validate the contract's operation, fostering trust and collaboration.
- Unwavering Reliability and Minimal External Interference: Once deployed on the blockchain, a smart contract is immutable. This means that without the consensus of network participants, it cannot be altered, ensuring its credibility. The decentralized nature of blockchains also ensures that no single entity has control over the contract, making it resistant to censorship, fraud, and undue interference.
- Speedy, Straightforward Deployment and Execution: Traditional contracts can be time-consuming due to manual processes, verifications, and approvals. In contrast, smart contracts automatically execute when their conditions are met. This automation, combined with the power of blockchain technology, leads to faster transactions and contract completions. Tools like Remix simplify the development and deployment, further accelerating the entire process.

4) Solidity and related tools: Solidity, inspired by languages like JavaScript, C++, and Python, caters to smart contract creation for the EVM. It supports complex types, inheritance, and libraries.

Web3.js serves as a bridge for Ethereum interactions, akin to how jQuery interacts with web servers. It facilitates Ether transfers, smart contract interactions, and more, relying on JSON RPC to communicate with Ethereum nodes.

Remix, a development environment for Solidity, assists in contract drafting, compilation, and debugging. It provides tools for contract deployment and transaction simulations.

D. Chosen Platforms for Implementation

Our research showcases the Letter-of-credit Chain's proof-of-concept on Ethereum, Binance Smart Chain, and Fantom.

1) Binance Smart Chain: Binance Smart Chain (BSC) is an evolution of the original Binance Chain, designed to run parallelly. Like Ethereum, BSC extends its capabilities to DApps and can be deployed on EVM-compatible platforms. BSC employs the Proof of Staked Authority (PoSA) model, a combination of Proof of Authority and Proof of Stake. Validators stake BNB tokens and earn rewards for validations. The seamless integration between Binance Chain and BSC ensures asset interoperability, benefiting from fast transactions and EVM's capabilities.

2) Celo: Celo emphasizes on financial tools accessible via mobile phones. Supporting EVM-compatible smart contracts, its primary aim is to diminish financial barriers and simplify access.

3) Fantom: Prioritizing speed and security, Fantom provides a scalable smart contract platform. It ensures swift transaction confirmations using its Lachesis Protocol, making it a viable option for various decentralized applications.

4) Matic (Polygon): Polygon provides a framework for building and linking Ethereum-compatible blockchain networks. Its primary focus lies in scalability and instant blockchain transactions, catering to a multitude of DApps.

III. Related Work

Blockchain technology has increasingly found applications in domains requiring secure and transparent interactions among multiple stakeholders. This section provides an overview of these applications, culminating in the emergence of blockchain-based freight models that incorporate Non-Fungible Tokens (NFTs).

A. Blockchain in Delivery and Transactional Systems

Historically, blockchain has been explored as a solution to problems in various delivery systems. Some notable examples include:

- *Cash-on-Delivery*: Blockchain has been employed to address challenges in cash-on-delivery systems, ensuring both payment security and delivery assurance [10], [11].
- *Letter-of-Credit*: Blockchain's immutability and transparency features make it suitable for modernizing Letter-of-Credit mechanisms, enhancing trust among parties [12], [13].
- *Traditional Delivery*: The technology also aids in streamlining traditional delivery processes by creating clear, tamper-proof records [5], [14].

B. Blockchain in Healthcare

Beyond delivery systems, the need for transparency and security has made blockchain a favorite for healthcare applications:

- Traditional healthcare systems leverage blockchain for securely storing and accessing patient records, ensuring both patient privacy and data integrity [15], [16].
- Blockchain's transparent and immutable nature has led to its use in the supply chain management for blood and related products, ensuring traceability and accountability [17], [18].
- There are also systems in place that give patients control over their information, promoting a patient-centric approach to healthcare [19].

C. Bitcoin and its Limitations

Introduced in 2009, Bitcoin was a pioneering system that facilitated trust-less peer-to-peer payments [20]. However, Bitcoin's reliance on the Proof-of-Work (PoW) consensus algorithm led to significant operational costs, both monetary and environmental [21]. The system's constraints, particularly its limited throughput and associated high fees for transaction validations, led to the search for alternative blockchain solutions.

D. Emergence of Ethereum and Smart Contracts

In response to Bitcoin's limitations, Ethereum emerged as a versatile platform, introducing the concept of smart contracts. These self-executing contracts, with terms directly written into code, enabled more sophisticated and customizable transactions. Ethereum's introduction of the Solidity programming language further empowered developers to create advanced applications on the blockchain. Additionally, Ethereum showcased improved system performance compared to Bitcoin [4].

E. Decentralized Exchange Platforms

Platforms like Local Ethereum [22] and Open Bazaar [23] aimed to facilitate trust-less exchanges between buyers and sellers. While Local Ethereum focused on a direct barter system, Open Bazaar introduced a third-party, the moderator, enhancing transactional trust. These platforms emphasized transparency, ensuring all members could monitor ongoing transactions, even if not directly involved.

However, these systems' reliance on predefined smart contracts meant inflexibility in the transaction process. Any dispute would require an external trusted party for resolution. This limitation prompted the exploration of adaptable smart contract solutions like the "middleman" [24], offering dynamic contracts with penalties for breaches.

F. Broadening the Scope: Beyond Traditional Buyer-Seller Models

Ethereum's decentralized applications (Dapps) started considering more participants in transactional models, like shippers or shipping companies [25]. This shift in perspective highlighted the pivotal role of shippers in the transactional ecosystem. However, these models also introduced complexities in arbitration, requiring parties to post deposits as assurance against potential disputes [3], [26].

G. Our Contribution

In light of the aforementioned challenges and developments, we propose a novel blockchain-based freight model integrating NFT certificates. In our model, unique NFTs are generated upon item shipment, creating a secure, transparent, and traceable record of each transaction.

IV. Approach

A. Preliminary: Traditional Freight Transport Modalities

In specific regions, the logistics and shipment processes are overseen and authorized by specialized transport entities. These entities may perform diverse roles—either solely ensuring product delivery or overseeing the financial exchange from the consumer to the vendor. In the model depicted in Fig. 1, the consumer commits the entire invoice payment upfront. This model signifies that the transportation company's primary responsibility is the physical delivery, devoid of any financial intermediation. The outlined process seamlessly moves from invoice consolidation to packaging, and finally, product distribution to the end consumer.

Conversely, the Cash-on-Delivery (CoD) model, prevalent in several regions, is more vendor-centric. Here, transportation companies play a pivotal role in not just delivering but also managing payment collections, as illustrated in Fig. 2. Although the CoD model ensures payment upon successful delivery, it brings forth specific risks for the merchants.

As delineated in the preceding sections, traditional freight systems possess inherent challenges. Our novel contribution aims at an intricate blend of blockchain, NFTs, and smart contracts to modernize and secure the transportation model, safeguarding against potential discrepancies among stakeholders (e.g., vendor, consumer, courier).

B. Revolutionizing Freight: The Blockchain, NFT, and Smart Contract Fusion

Our proposal, visualized in Fig. 3, hinges on three pivotal technologies: blockchain for transparent and immutable transaction recording, NFTs as digital certificates vouching for consensual agreements, and smart contracts automating contractual obligations. This amalgamation targets the eradication of reliance on central trust entities, even in conflict scenarios.

The process initiates with the vendor, who is mandated to deposit a security amount. This ensures that the product aligns with the information and quality delineated in the smart contract. The logistics company, responsible for managing couriers, deposits a fee to safeguard against potential risks like misplacement, product damage, or insolvency. The consumer's deposit encompasses the logistics fee and a partial product deposit, the latter serving as a safeguard against arbitrary purchase cancellations.

As Fig. 3 suggests, the vendor initiates the process by cataloging the product's specifics (e.g. weight, unit price,

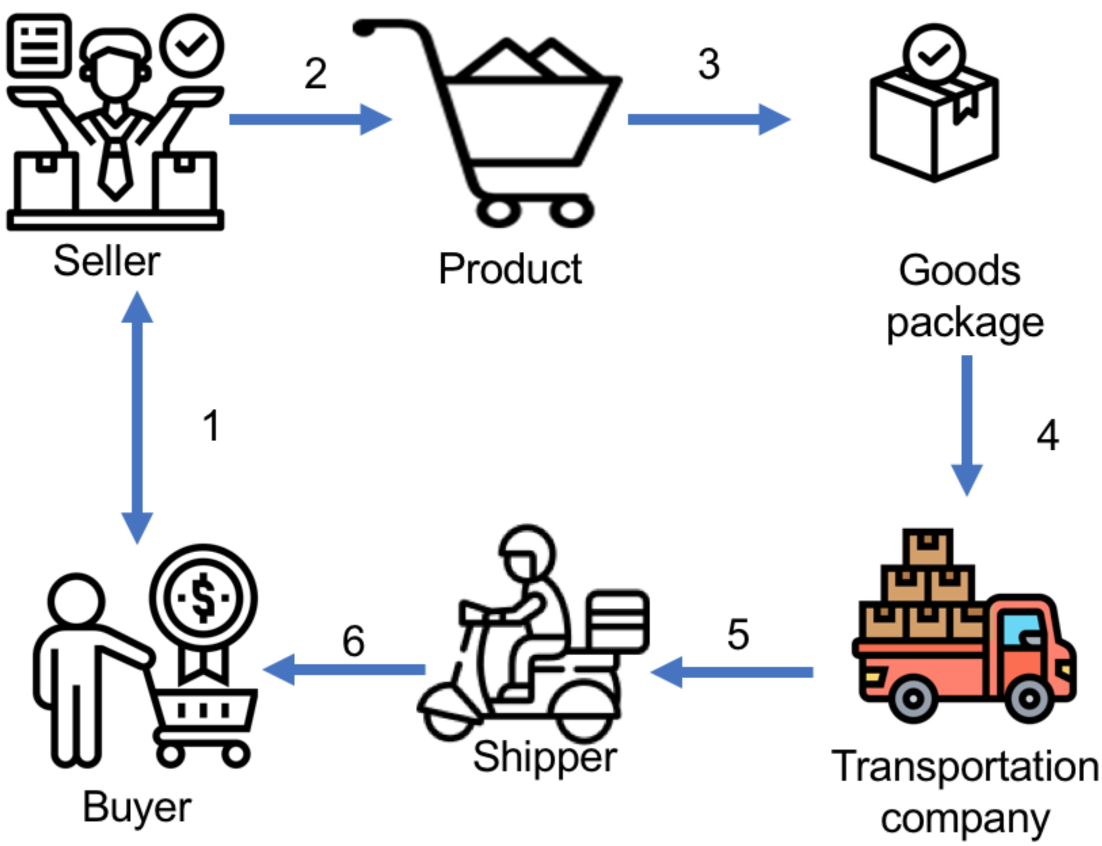


Fig. 1. Traditional framework involving a transportation entity in freight movement.

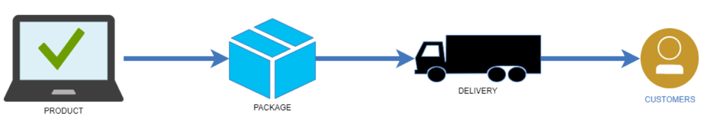


Fig. 2. Conventional Cash-on-Delivery (CoD) mechanism in freight transport.

type) into the system. Leveraging these details, the system's underlying smart contract crafts a shipment contract. Once this agreement is in place, an appropriate logistics partner is chosen. All agreements and stipulations are meticulously recorded within an NFT, consented upon by all involved entities (i.e. vendor, consumer, logistics entity).

The physical shipment process, potentially involving multiple couriers, is orchestrated by the logistics company. Upon reaching the consumer and obtaining an affirmation of product integrity, the NFT records this validation. The final transactional phase sees the consumer settle any outstanding product payments, the logistics entity obtaining their fees and security deposits, and the vendor procuring the product sales revenue. Any discrepancies or contractual breaches get resolved based on the smart contract's predefined conditions, ensuring transparency and fairness.

In culmination, all transactions get appended to the distributed ledger, making them immutable and transparent, and the system resets, readying for the next shipment cycle.

V. Implementation Process for Advanced Patient-Centric Medical Test Record Management

The core objective of our research paper is to leverage the innate capabilities of the blockchain, especially in the realm of Non-Fungible Tokens (NFTs), to provide a seamless experience for patients managing and sharing their medical test results. The very design of our proposed model, which emphasizes intuitive patient-centric management of test results, coupled with the ease of sharing these results with any desired entity, underscores the need to opt for EVM-enabled blockchain platforms, eschewing the Hyperledger ecosystem, to enable broader accessibility.

In this vein, our efforts have been directed towards discerning the most apt platform that can seamlessly host our model. Our search and subsequent evaluations led us to focus on four of the contemporary leading blockchain platforms, each supporting the Ethereum Virtual Machine (EVM) - Binance Smart Chain (BNB Smart Chain)[11], Polygon[12], Fantom[13], and Celo[14].

Our contributions to this domain have been further enriched by sharing the implementation details on these platforms, thus, fostering a transparent discourse around transaction costs asso-

[11] https://github.com/bnb-chain/whitepaper/blob/master/WHITEPAPER.md
[12] https://polygon.technology/lightpaper-polygon.pdf
[13] https://whitepaper.io/document/438/fantom-whitepaper
[14] https://celo.org/papers/whitepaper

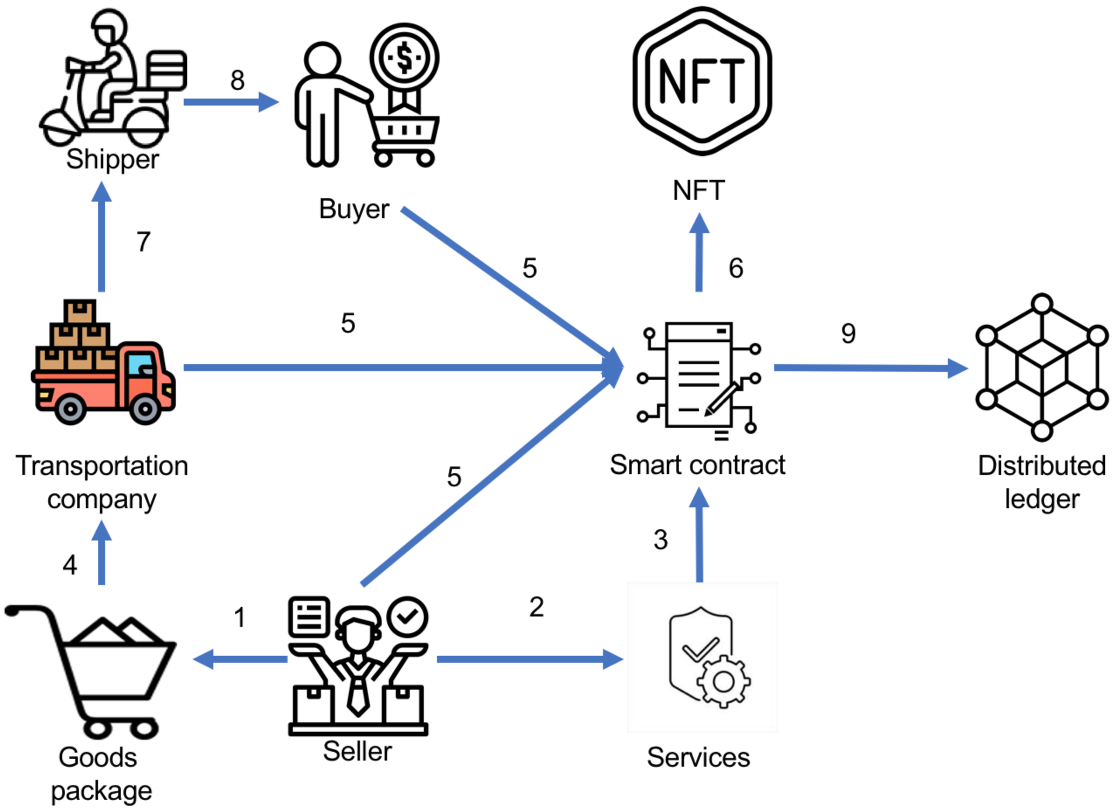


Fig. 3. Innovative freight model harnessing Blockchain, Smart Contracts, and NFTs.

ciated with these platforms' native tokens[15], namely, BNB[16], MATIC[17], FTM[18], and CELO[19].

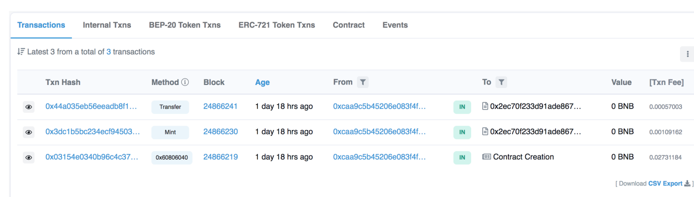
The culmination of our assessments was directed towards ascertaining the cost-effectiveness of executing smart contracts, designed leveraging the Solidity language, on the testnet environments of these platforms. This would be instrumental in guiding our decision on the optimal platform for deployment.

A. *Deployment on EVM-compatible Platforms with a Spotlight on BNB*

The blockchain realm, especially platforms compatible with the Ethereum Virtual Machine (EVM), offers versatility that serves a range of applications. In discussing a tripartite model involving sellers, shippers, and buyers and bolstered with an integrated consensus protocol for payments, the superiority of EVM-compatible platforms is evident.

This section provides an intricate look at our model's integration on these platforms, emphasizing its deployment on the Binance Smart Chain (BNB) - Fig. 4.

[15]Our models were released on 11/24/2022, 8:44:53 AM UTC
[16]https://testnet.bscscan.com/address/0xafa3888d1dfbfe957\\b1cd68c36ede4991e104a53
[17]https://mumbai.polygonscan.com/address/0xd9ee80d850ef3c4978dd0b099a45a559fd7c5ef4
[18]https://testnet.ftmscan.com/address/0x4a2573478c67a894e32d806\\c8dd23ee8e26f7847
[19]https://explorer.celo.org/alfajores/address/0x4a2573478C67a894E32D806c8Dd23EE8E26f7847/transactions


Transactions | Internal Txns | BEP-20 Token Txns | ERC-721 Token Txns | Contract | Events

Latest 3 from a total of 3 transactions

Txn Hash	Method	Block	Age	From		To	Value	[Txn Fee]
0x44a035eb56eeadb8f1...	Transfer	24866241	1 day 18 hrs ago	0xcaa9c5b45206e083f4f...	IN	0x2ec70f233d91ade867...	0 BNB	0.00057003
0x3dc1b5bc234ecf94503...	Mint	24866230	1 day 18 hrs ago	0xcaa9c5b45206e083f4f...	IN	0x2ec70f233d91ade867...	0 BNB	0.00109162
0x03154e0340b96c4c37...	0x60806040	24866219	1 day 18 hrs ago	0xcaa9c5b45206e083f4f...	IN	Contract Creation	0 BNB	0.02731184

[Download CSV Export]

Fig. 4. Snapshot of transaction details, specifically from BNB smart chain.

This figure is a snapshot highlighting transaction details on the Binance Smart Chain (BNB). Within this image, users would observe an interface displaying transaction IDs, timestamps of transactions, sender and receiver addresses, and the amount transferred. Furthermore, it likely showcases the transaction's status (whether it's pending, failed, or successful), gas fees associated, and possibly even a link to the block where this transaction is recorded. By analyzing this snapshot, one can discern the efficiency and speed of transactions on the BNB Smart Chain and understand its user-friendly interface.

In Fig. 5, the visualization concentrates on the non-fungible token (NFT) creation process. This graphical representation likely delineates the steps involved in minting an NFT, from selecting the digital asset, inputting metadata, determining rarity or attributes, to finally issuing or minting it on the blockchain. The figure may also exhibit the interaction with smart contracts during the NFT creation and any gas fees or computational resources required. The graphical elements emphasize the uniqueness and immutable nature of NFTs and

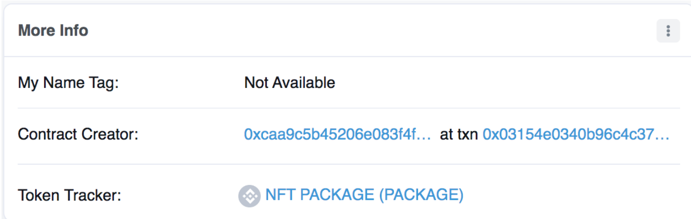


Fig. 5. Visualization of the NFT creation process.

the efficiency of the BNB Smart Chain in facilitating their creation.

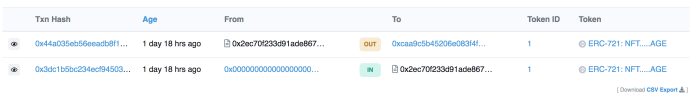


Fig. 6. Demonstration of NFT transfer mechanics.

The focus of Fig. 6 is on the intricacies of NFT transfers, especially concerning the ERC-721 token standard. This diagram likely presents an NFT's journey from one digital wallet to another, illustrating the security protocols, verification processes, and blockchain confirmations involved. An integral aspect might also include the interaction with the underlying ERC-721 smart contract, ensuring the asset's authenticity and ownership transfer. This figure aims to highlight the seamlessness and secure nature of transferring unique digital assets on platforms that adhere to the ERC-721 standard.

Continuing from earlier, our goal is to benchmark our system against four premier EVM-compatible platforms. By sharing our insights on these platforms, we aim to enlighten the community and gather actionable data. Through a meticulous analysis of smart contract execution costs in these testnet environments, we seek the platform that blends optimal cost-efficiency with performance for tangible deployments.

Our implementation model focuses on two main purposes i) data manipulation (i.e. package) - initialization, query and update - on blockchain platform and ii) generation of NFTs for each order goods for easy retrieval by sellers and buyers (i.e. product reviews before and after delivery).

B. Data and NFT Initialization Procedure

The intricacies of initializing package data, from its inception to the eventual registration on the blockchain, are portrayed in Figure 7. This diagram offers an overview of the process and helps comprehend the significance of each step.

Package data is a conglomerate of multiple parameters:

- Sender's Details: This pertains to the individual or entity dispatching the goods. It includes crucial aspects such as the sender's address, the weight of the package, and specifics about the item being sent.
- Recipient's Details: It's essential to ascertain where the package is headed. Data includes the recipient's address and an estimated time of arrival.
- Security Deposits: The financial security mechanisms are indispensable in maintaining the integrity of the system. Each of the three key participants - sender, recipient, and shipper - deposits an amount that acts as a safeguard, facilitating automatic resolution of potential disputes via the smart contract.
- Metadata of the Package: Further granular details about the package are recorded, such as which shipping company is responsible, when and where it's to be delivered or picked up, etc. This becomes exceedingly crucial in scenarios involving multiple shippers, which could either belong to the same logistics company or different entities.

To fortify data consistency and system efficiency, the platform employs a distributed ledger model. This supports concurrent storage, mimicking a peer-to-peer network structure, enabling multiple users to store data simultaneously, thereby diminishing system latency.

The structure of package data can be understood by examining the following data representation:

```
goodsObject = {
"goodsID": goodsID,
"deliveryCompanyID": deliveryCompanyID,
"shipperID": shipperID,
"type": type of goods,
"buyerID": buyerID,
"sellerID": sellerID,
"quantity": quantity,
"unit": unit,
"packageID": packageID,
"addressReceived": received address,
"addressDelivery": delivery address,
"time": time,
"location": location,
"state": Null
};
```

Within this structure:

- The "state" parameter is a dynamic attribute, commencing as a Null value. A change to 1 signifies the shipping company has taken possession of the goods, whereas a 0 implies it's awaiting collection by the shipper.
- The "unit" denotes the order's quantity. An adjunct "packageID" helps in tracking the particular package associated with the order.

Post the collection of packages from sellers, the onus falls on shippers to ensure the items are consistent with the listed details. Post verification, they're held in a temporary digital storage before getting committed to the blockchain.

The verification process is paramount, for any discrepancies or damages can directly impact the shipping procedure. Furthermore, it establishes a foundation for resolving conflicts that might arise during the transportation of goods.

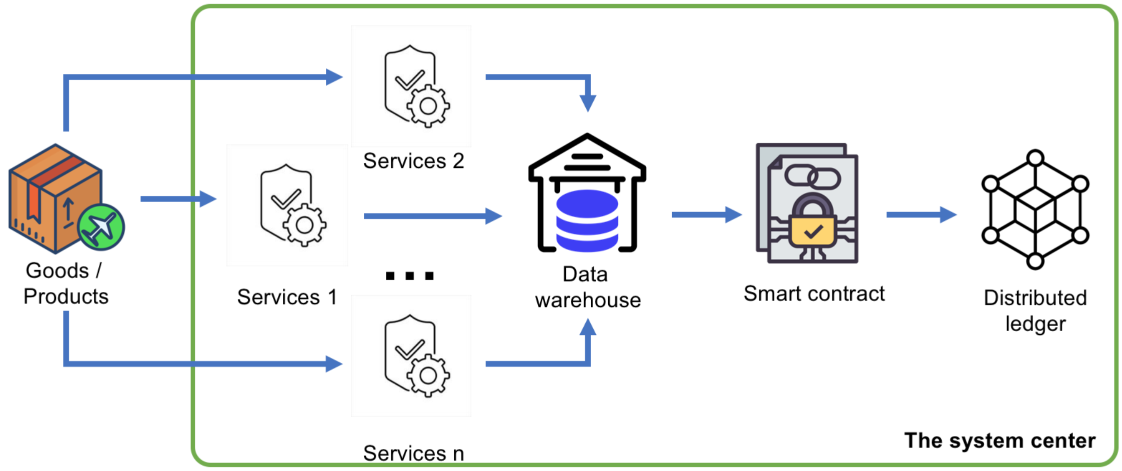


Fig. 7. Procedure to initialize data and NFT for goods.

NFTs, in this context, encapsulate distinct attributes of each order. Beyond the conventional details, they also record financial commitments in the form of deposits from each party involved. The NFT structure is as such:

```
NFT PACKAGE = {
"shipperID": shipperID,
"sellerID": sellerID,
"buyerID": buyerID,
"packageID": packageID,
"type": type of goods,
"quantity": quantity,
"addressReceived": received address,
"addressDelivery": delivery address,
"depositShipper": deposit of shipper,
"depositSeller": deposit of seller,
"depositBuyer": deposit of buyer,
"time": estimated delivery time
};
```

NFTs offer a transparent mechanism to track goods and ensure accountability. For instance, in cases of delivery delays, the embedded information within the NFT provides a clear path for conflict resolution.

For more nuanced interpretations of stakeholder deposits and related topics, our preceding research works and articles offer a comprehensive discussion.

C. In-depth Examination of Data Query Process

The data query process, depicted in Fig. 8, is as intricate as the data initialization phase, and its operations are molded to accommodate multiple simultaneous participants. The overarching principle is the distributed model, which caters to an environment where several users can query data concurrently, ensuring the system's scalability and flexibility.

Different stakeholders have distinct query requirements:

1) Shippers: Their primary focus is on logistical details. They query data to obtain specifics like the consignee's particulars and their corresponding addresses. Such information is pivotal to ensure the seamless delivery of goods to the right destinations.
2) Sellers/Buyers: Their queries are more customer-centric. Sellers and buyers are keen on tracking the status of their orders, particularly post-dispatch and receipt. Furthermore, if any discrepancies or issues arise—be it delays or damages—they would resort to this system to glean insights and possibly initiate conflict resolution processes.

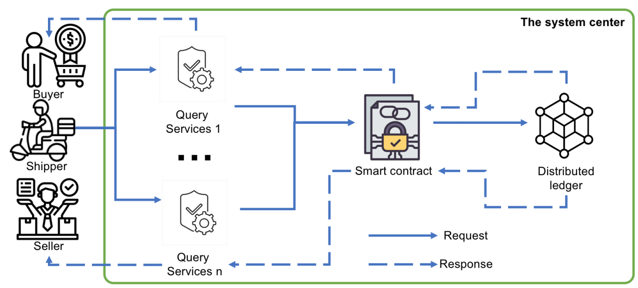


Fig. 8. Illustration of the data query process.

The data retrieval mechanism can be delineated as follows:

- Users, be it shippers or sellers/buyers, initiate their query through a predefined service, often implemented as an API call. These calls are essentially instructions directed at smart contracts present in the blockchain system. Each smart contract has specific functions tailored to handle a variety of tasks, and in this context, it deals with fetching the requisite data from the distributed ledger.
- Every query isn't just a fleeting transaction; it's logged within the system. This implies that all retrieval requests metamorphose into a query history, which is associated with the respective individual or organization. Such a chronicle can be instrumental for audit trails or to understand behavioral patterns of users over time.

A point of intrigue in this system is the handling of more complex shipping processes. When a package's journey isn't a straightforward 'A to B' route, but rather involves multiple intermediary stops with various shippers handling the goods, the complexity grows. In such multi-hop scenarios, where several shippers—either from the same or different logistics companies—are involved, NFTs play a crucial role. They act as verifiable digital tokens at each handover point, ensuring transparency and traceability.

However, the system is designed to be robust but not infallible. Instances might arise where queries return no results, possibly due to erroneous inputs like an incorrect ID. In such scenarios, the system is intuitive enough to relay a 'not found' message, ensuring users are promptly informed.

Lastly, when it comes to NFT-based queries, they are seamlessly integrated with the overarching system. All necessary services to handle NFT inquiries are provided as APIs, facilitating easy and efficient interactions for users.

D. An In-depth Exploration of the Data Update Mechanism

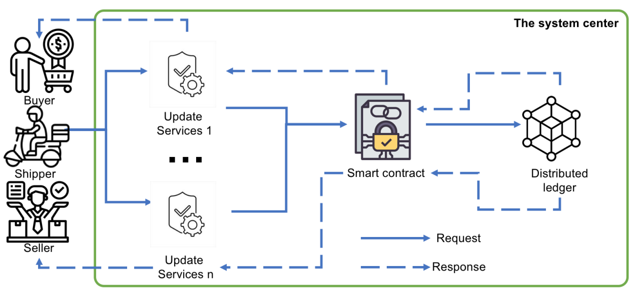


Fig. 9. Illustration of the data update mechanism.

Updating data within the blockchain requires utmost precision, given the immutability of records once entered. This process is not simply about making amendments; it's about ensuring the integrity of the entire system.

Before any data can be updated, there's a prerequisite: the data in question must exist. This might sound simple, but it's a crucial step. This is ensured by invoking the data query procedure beforehand. In simpler terms, before attempting any changes, the system checks if the data entry to be updated is actually present. If it isn't, the user is promptly notified with a message, as detailed in the previous Section V-C.

The architecture to support data updates is structured and methodical:

- API Integration: Similar to the mechanisms for data querying and initialization, the update services are provided through APIs. These Application Programming Interfaces act as gateways. They allow users to submit their update requests, which are then funneled to the appropriate part of the system for further action.
- Smart Contract Interaction: Once the API receives an update request, it communicates with a designated smart contract. Smart contracts are like automated intermediaries, each with specific functions to ensure that the processes within the blockchain are executed correctly. In this context, the smart contract handles the updating of data based on the request received.
- Purpose and Implications: The main objective of the update process is multifaceted. One primary role is to track and record the evolving status of packages as they move through various transit points. But it goes beyond mere tracking; it also addresses anomalies or issues. If something isn't right - maybe there's damage, or a package goes missing - the system can initiate conflict resolution mechanisms. This is achieved through a combination of smart contract logic and the attributes of Non-Fungible Tokens (NFTs).

Fig. 9 offers a visual representation of this intricate dance of data updates. When it comes to the realm of NFTs, the update dynamics take a slightly different hue. An NFT, by its very nature, is unique and cannot be replicated. Therefore, updating an NFT doesn't mean modifying its existing attributes. Instead, when details associated with an NFT need to be changed, the system creates a brand-new NFT to capture those updates. On the surface, this might seem like a mere transfer, like moving an NFT from one owner's address to another. But underneath, it ensures the veracity and traceability of each unique digital asset, as further explained in subsection V-B.

VI. In-depth Evaluation of Contract Operations

In our thorough evaluation, we scrutinize the intricacies of the expenses tied to blockchain operations, such as contract creation, NFT generation, and the dynamic transfer or retrieval of NFTs. These operations, illustrated in Fig. 5 and 6, bring with them costs. We categorize these costs under four main subsections: i) Transaction Fee; ii) Gas limit; iii) Gas Used by Transaction; and iv) Gas Price. Each of these sections offers a lens into the underlying costs and efficiencies of the blockchain processes.

Blockchain operations are often lauded for their immutable record-keeping and decentralized nature, but it's equally essential to understand the associated costs. Contract creation, NFT generation, and transfer each have their own set of expenses. These costs ensure the sustainability of the network, compensate for the computational effort, and can also act as a deterrent against frivolous or malicious activities. A closer examination of these costs can offer insights into the economic viability of blockchain-based systems.

A. Transaction Fee Analysis

The transaction fee is a fundamental aspect of our evaluation. It acts as a "price" for the computational and operational services provided by the blockchain. To showcase the relative costs across various platforms, we present a detailed breakdown in Table I.

From Table I, we can infer a few pivotal insights:

- Variability across Chains: There's a noticeable difference in transaction fees across different chains. For instance, the BNB Smart Chain's contract creation is significantly higher than that of Fantom or Polygon. Such variations can be attributed to the underlying architecture, consensus mechanism, network congestion, and other chain-specific factors.

TABLE I. TRANSACTION FEE

	Contract Creation	Create NFT	Transfer NFT
BNB Smart Chain	0.02731184 BNB ($8.32)	0.00109162 BNB ($0.33)	0.00057003 BNB ($0.17)
Fantom	0.009576994 FTM ($0.001850)	0.000405167 FTM ($0.000078)	0.0002380105 FTM ($0.000046)
Polygon	0.006840710032835408 MATIC($0.01)	0.000289405001852192 MATIC($0.00)	0.000170007501088048 MATIC($0.00)
Celo	0.0070974384 CELO ($0.004)	0.0002840812 CELO ($0.000)	0.0001554878 CELO ($0.000)

- Cost Gradient in Operations: Contract creation typically incurs a higher fee than other operations across all chains. This indicates the relative computational complexity and resources utilized during this process.
- Micro-transactions: Some fees, especially on chains like Polygon and Fantom, are incredibly minute, hinting at their potential suitability for high-frequency, low-value transactions.

Understanding these nuances is crucial for both developers and users, as it helps in making informed decisions about which chain to use, especially when balancing between operational costs and performance requirements.

B. Diving into Gas Limit Values

Gas limit refers to the maximum amount of units of gas the sender is willing to spend on a transaction or contract execution. It is a protective mechanism to ensure that a process doesn't run indefinitely, especially if something goes wrong. The Table II provides a clear breakdown of the gas limits set for three distinct operations across four blockchain platforms.

Table II distinguishes the gas limit values for three types of operations: Contract Creation, NFT Creation, and NFT Transfer across the BNB Smart Chain, Fantom, Polygon, and Celo blockchain platforms.

Detailed Insights:

BNB Smart Chain:

- The gas limit for contract creation stands at 2,731,184.
- For creating an NFT, the gas limit is considerably lower at 109,162.
- Interestingly, transferring an NFT requires a higher gas limit of 3,000,000, which is the highest among the three operations on this chain.

Fantom & Polygon:

- Both Fantom and Polygon have identical gas limits for the operations showcased.
- Contract creation requires a gas limit of 2,736,284.
- Creating an NFT comes in at 115,762.
- Transferring an NFT consumes the least gas limit, set at 72,803.

Celo:

- Celo has a distinctively higher gas limit for contract creation, which is 3,548,719, making it the highest among the platforms presented.
- The gas limit for NFT creation is 142,040.
- NFT transfer operations require 85,673 as the gas limit, which, similar to the trend in Fantom and Polygon, is less than the gas limit for NFT creation.

General Observations:

- Comparative Gas Limits: Across platforms, the gas limit for contract creation is consistently higher than that of creating an NFT, indicating the relative complexity of the contract creation process.
- NFT Transfers: The gas limits for NFT transfers differ significantly between chains. For instance, on the BNB Smart Chain, the limit is exceptionally high, whereas, on Fantom and Polygon, it's much lower. This suggests varying computational demands and efficiencies in the transfer process across these platforms
- Consistency between Fantom and Polygon: The identical gas limits for Fantom and Polygon for all three operations might indicate similarities in their underlying architecture or processing mechanisms for these specific operations.

In general, understanding the gas limit is essential for blockchain developers and users as it provides insights into transactional and operational costs. The values in Table II offer a comparative view of the efficiency and computational demands of different operations across various blockchain platforms.

C. Insight into Gas Consumption

Table III provides a comprehensive analysis of the gas utilized for various operations across four blockchain platforms. Unlike the gas limit which signifies the maximum gas units that could potentially be spent, "Gas Used by Transaction" indicates the actual gas consumed by an operation, thus giving a clearer picture of efficiency.

Table III showcases the gas consumed in units and as a percentage of the gas limit for three main operations: Contract Creation, NFT Creation, and NFT Transfer. These operations are evaluated across BNB Smart Chain, Fantom, Polygon, and Celo blockchain platforms.

Detailed Breakdown:

BNB Smart Chain:

- The contract creation operation uses all its gas limit, consuming 2,731,184 units, which equates to 100% utilization.
- Creating an NFT also exhausts its set gas limit, utilizing 109,162 units or 100

TABLE II. GAS LIMIT

	Contract Creation	Create NFT	Transfer NFT
BNB Smart Chain	2,731,184	109,162	3,000,000
Fantom	2,736,284	115,762	72,803
Polygon	2,736,284	115,762	72,803
Celo	3,548,719	142,040	85,673

TABLE III. GAS USED BY TRANSACTION

	Contract Creation	Create NFT	Transfer NFT
BNB Smart Chain	2,731,184 (100%)	109,162 (100%)	57,003 (1.9%)
Fantom	2,736,284 (100%)	115,762 (100%)	68,003 (93.41%)
Polygon	2,736,284 (100%)	115,762 (100%)	68,003 (93.41%)
Celo	2,729,784 (76.92%)	109,262 (76.92%)	59,803 (69.8%)

- In contrast, NFT transfer is highly efficient, consuming only 57,003 units, which is just 1.9% of its gas limit.

Fantom & Polygon:

- Both Fantom and Polygon have matching gas utilization statistics.
- Contract creation and NFT creation operations use up their entire gas limit, consuming 2,736,284 and 115,762 units respectively, which translates to 100% utilization for both.
- The NFT transfer operation, however, uses 68,003 units, or 93.41% of its gas limit, indicating a high efficiency but not as optimal as the previous two operations.

Celo:

- For contract creation, 2,729,784 units of gas are used, translating to 76.92% utilization of its gas limit.
- Creating an NFT follows the same pattern with 109,262 units consumed, equating to 76.92
- The NFT transfer operation on Celo uses 59,803 units, or 69.8% of its allocated gas limit.

Observations:

- Full Utilization on BNB Smart Chain, Fantom, and Polygon: For the operations of contract creation and NFT creation, both the BNB Smart Chain and Fantom-Polygon duo show a 100% gas utilization, indicating that these operations are maximally optimized or perhaps the gas limits set are just adequate for these operations.
- Diversity in NFT Transfer Efficiency: The efficiency of the NFT transfer operation varies significantly across platforms. BNB Smart Chain is highly efficient, utilizing only a small fraction of its gas limit, while Fantom and Polygon use over 90%. Celo falls in between, using just under 70%.
- Celo's Consistent Utilization Pattern: Celo displays a consistent pattern of gas consumption across the operations, with both contract and NFT creation operations having identical utilization percentages. This could hint at a standard optimization mechanism or architectural decision inherent to the Celo platform.

In essence, Table III offers an in-depth perspective on the operational efficiency of various tasks across different blockchains. Such insights are invaluable for developers and users to understand the performance and optimization levels of each platform for specific operations.

D. Gas Price Analysis Across Blockchain Platforms

Table IV delves into the nuances of gas prices associated with specific blockchain transactions. Gas prices are critical as they are the cost per unit of gas, and thus dictate the transaction fee users will pay for their actions on a given blockchain network. By understanding these prices, users can gauge the economic feasibility of their operations on each platform. This table enumerates the gas prices for three primary blockchain operations: Contract Creation, NFT Creation, and NFT Transfer. These prices are examined across four prominent blockchain platforms: BNB Smart Chain, Fantom, Polygon, and Celo.

- BNB Smart Chain: Across all three operations, the gas price remains consistent at 0.00000001 BNB, equivalent to 10 Gwei. This uniformity suggests a standardized price point for transactions on this platform, regardless of the operation's nature.
- Fantom: Fantom too demonstrates a steady gas price for all operations at 0.0000000035 FTM, equating to 3.5 Gwei. This price is lower than BNB Smart Chain, hinting at more economical transactions on the Fantom network.
- Polygon: Polygon's gas prices for each operation are consistent at the microscopic level of 0.000000002500000012 MATIC and 0.000000002500000016 MATIC, which translate to 2.500000012 Gwei and 2.500000016 Gwei, respectively. While there are slight variations in the gas price between the operations, they are marginal and may result from intricate calculations or rounding mechanisms inherent to the Polygon platform.
- Celo: Celo's gas prices for all three operations are set at 0.0000000026 CELO. These prices correlate with a Max Fee per Gas of 2.7 Gwei. The "Max Fee per Gas" metric in Celo might indicate a pricing cap or standard set by the platform to ensure price stability.

TABLE IV. GAS PRICE

	Contract Creation	Create NFT	Transfer NFT
BNB Smart Chain	0.00000001 BNB (10 Gwei)	0.00000001 BNB (10 Gwei)	0.00000001 BNB (10 Gwei)
Fantom	0.0000000035 FTM (3.5 Gwei)	0.0000000035 FTM (3.5 Gwei)	0.0000000035 FTM (3.5 Gwei)
Polygon	0.000000002500000012 MATIC (2.500000012 Gwei)	0.000000002500000016 MATIC (2.500000016 Gwei)	0.000000002500000016 MATIC (2.500000016 Gwei)
Celo	0.0000000026 CELO (Max Fee per Gas: 2.7 Gwei)	0.0000000026 CELO (Max Fee per Gas: 2.7 Gwei)	0.0000000026 CELO (Max Fee per Gas: 2.7 Gwei)

Insights:

- Uniformity Across Platforms: Both BNB Smart Chain and Fantom showcase a uniform gas price across all operations, while Polygon and Celo exhibit minimal variations. Such consistency can help users predict their transaction costs with higher accuracy.
- Comparative Economy: When juxtaposing the platforms, Fantom and Polygon present themselves as the more economical options, with gas prices lower than BNB Smart Chain. Celo, while being slightly higher than Polygon, still offers a competitive rate, especially when compared to BNB Smart Chain.
- Gwei Representation: Representing gas prices in Gwei offers a standardized lens to compare across blockchains. Gwei is a common denomination used in the context of Ethereum-based blockchains, making it a familiar reference point for many users.

In conclusion, Table IV serves as a valuable resource for users to understand and compare the financial implications of their actions on different blockchain platforms. By staying informed on these gas prices, users can make more informed decisions about where and when to transact.

VII. DISCUSSION

A. Threats to Validity

Our study, while comprehensive in its approach, acknowledges potential threats to its validity. One prominent challenge is the dynamic nature of gas prices. They are known to fluctuate based on network congestion, overall demand, and blockchain-specific factors, meaning our analysis, which captures a specific moment in time, might not remain representative in the future. Furthermore, each blockchain platform has its unique mechanisms, such as gas auctions, that can introduce variations in gas prices and potentially lead to disparities in the actual transaction costs. External economic factors also play a pivotal role. The volatile nature of cryptocurrency valuations means the conversion of gas prices to traditional currency can vary greatly, impacting the real-world perception of operational costs. Lastly, our findings focus on a select group of operations and platforms, raising questions about the generalizability of our conclusions to other operations or nascent blockchain platforms.

B. Observations and Findings

Several key observations emerge from our analysis. Platforms like the BNB Smart Chain and Fantom exhibit a remarkable uniformity in their pricing structure across operations, which could potentially simplify cost predictions for users. There's also an evident economic disparity between platforms. For instance, when observing gas prices, Fantom and Polygon present themselves as more economical choices compared to the BNB Smart Chain. Notably, the consistent use of Gwei as a unit for expressing gas prices provides a standard frame of reference, which aids in drawing comparative conclusions across diverse blockchains.

C. Future Work

The future direction of our research aims to address some of the identified limitations and expand the horizons of our current findings. A temporal analysis could be beneficial, wherein tracking gas prices over extended periods might help identify patterns like peak congestion periods or times conducive to economical transactions. As the blockchain ecosystem grows, incorporating newer platforms into our analysis can offer a holistic view of the evolving landscape. A deeper dive into the economic models driving each blockchain platform might provide clarity on the reasons behind the observed gas prices. Furthermore, examining user behavior in response to fluctuating gas prices can offer invaluable insights into transaction patterns, platform preferences, and challenges hindering blockchain adoption.

The delineation of our subsequent directions in research is pivotal for contextual understanding. We are inclined to delve deeper into the introduction of *intricate methods and algorithms*, specifically those related to encryption and decryption. Such operations, foundational to preserving data integrity and security in blockchain platforms, offer a paradigm to examine the pecuniary ramifications of safeguarding transactional data on the blockchain [27], [28]. Parallel to this, the exploration of *complex data structures* presents a unique lens, offering insights into the interplay between data intricacies and transactional efficiency. The impetus to deploy our proposed model in a tangible, operational realm is palpable. The very act of *transposing our recommendation system onto the FTM mainnet* would be a leap from a sandboxed environment to a live ecosystem pulsating with real transactions. A discernible lacuna in our present analysis is our oversight of the multifaceted dimensions of user privacy policies. With citations underscoring the imperatives of access control and dynamic policy [29], [30], [31], [32], we're inclined to probe the nuances of how these privacy constructs shape transaction costs. Future vistas beckon us towards a slew of *infrastructure-centric methodologies*. The confluence of modernist paradigms like gRPC [33], [34], Microservices [35], [36], adaptive messaging systems, and broker-less architectures [37] presents a promising trajectory. A pivot towards an *API-call-centric* interface may very well be the linchpin, bridging users with a system that seamlessly obfuscates its underlying complexities while offering a user-centric experience.

VIII. Conclusion

Motivated by the pressing need to bridge this gap, our research ventured into the realm of NFTs, harnessing their potential to encapsulate package specifics. Our multi-pronged approach aimed at architecting a robust shipping paradigm anchored in blockchain, enriched with the finesse of smart contracts, and enhanced by NFTs. The meticulous design and deployment of NFT-empowered smart contracts have laid the groundwork for transparent, accountable, and seamless interactions among all stakeholders, including shippers. Our empirical assessment, spanning several leading EVM platforms, not only corroborates the viability of our proposed model but also underscores the transformative potential it holds for reshaping the shipping and logistics sector.

In conclusion, while blockchain technology and smart contracts herald a promising dawn, the path to holistic and inclusive transactional frameworks demands continuous innovation and introspection. Our endeavor stands testament to this, striving to chart a course where trust is not merely assumed but systematically engineered.

Acknowledgment

Deep thanks are owed to Engineer Le Thanh Tuan and Dr. Ha Xuan Son for their essential contributions during the conceptualization, realization, and appraisal of this study. The steadfast support from FPT University Cantho Campus, Vietnam, has also played a pivotal role in the advancement of this research.

References

[1] Y. Madhwal, Y. Borbon-Galvez, N. Etemadi, Y. Yanovich, and A. Creazza, "Proof of delivery smart contract for performance measurements," *IEEE Access*, vol. 10, pp. 69 147–69 159, 2022.

[2] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," *Decentralized Business Review*, p. 21260, 2008.

[3] D. Sinha and S. R. Chowdhury, "Blockchain-based smart contract for international business–a framework," *Journal of Global Operations and Strategic Sourcing*, 2021.

[4] V. Buterin *et al.*, "A next-generation smart contract and decentralized application platform," *white paper*, vol. 3, no. 37, pp. 2–1, 2014.

[5] H. X. Son *et al.*, "Towards a mechanism for protecting seller's interest of cash on delivery by using smart contract in hyperledger," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 4, pp. 45–50, 2019.

[6] M. A. Uddin, A. Stranieri, I. Gondal, and V. Balasubramanian, "A survey on the adoption of blockchain in iot: Challenges and solutions," *Blockchain: Research and Applications*, vol. 2, no. 2, p. 100006, 2021.

[7] E. Androulaki, A. Barger, V. Bortnikov, C. Cachin, K. Christidis, A. De Caro, D. Enyeart, C. Ferris, G. Laventman, Y. Manevich *et al.*, "Hyperledger fabric: a distributed operating system for permissioned blockchains," in *Proceedings of the thirteenth EuroSys conference*, 2018, pp. 1–15.

[8] S. Shi, D. He, L. Li, N. Kumar, M. K. Khan, and K.-K. R. Choo, "Applications of blockchain in ensuring the security and privacy of electronic health record systems: A survey," *Computers & security*, vol. 97, p. 101966, 2020.

[9] Z. Zheng, S. Xie, H.-N. Dai, W. Chen, X. Chen, J. Weng, and M. Imran, "An overview on smart contracts: Challenges, advances and platforms," *Future Generation Computer Systems*, vol. 105, pp. 475–491, 2020.

[10] X. S. Ha, T. H. Le, T. T. Phan, H. H. D. Nguyen, H. K. Vo, and N. Duong-Trung, "Scrutinizing trust and transparency in cash on delivery systems," in *International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage*. Springer, 2020, pp. 214–227.

[11] N. T. T. Le *et al.*, "Assuring non-fraudulent transactions in cash on delivery by introducing double smart contracts," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 5, pp. 677–684, 2019.

[12] K. L. Quoc, H. K. Vo, L. H. Huong, K. H. Gia, K. T. Dang, H. L. Van, N. H. Huu, T. N. Huyen, L. Van Cao Phu, D. N. T. Quoc *et al.*, "Sssb: An approach to insurance for cross-border exchange by using smart contracts," in *International Conference on Mobile Web and Intelligent Information Systems*. Springer, 2022, pp. 179–192.

[13] X. S. Ha, H. T. Le, N. Metoui, and N. Duong-Trung, "Dem-cod: Novel access-control-based cash on delivery mechanism for decentralized marketplace," in *2020 IEEE 19th International Conference on Trust, Security and Privacy in Computing and Communications (TrustCom)*. IEEE, 2020, pp. 71–78.

[14] H. T. Le, N. T. T. Le, N. N. Phien, and N. Duong-Trung, "Introducing multi shippers mechanism for decentralized cash on delivery system," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 6, 2019.

[15] N. Duong-Trung, H. X. Son, H. T. Le, and T. T. Phan, "On components of a patient-centered healthcare system using smart contract," in *Proceedings of the 2020 4th International Conference on Cryptography, Security and Privacy*, 2020, p. 31–35.

[16] ——, "Smart care: Integrating blockchain technology into the design of patient-centered healthcare systems," in *Proceedings of the 2020 4th International Conference on Cryptography, Security and Privacy*, ser. ICCSP 2020, 2020, p. 105–109.

[17] N. T. T. Quynh, H. X. Son, T. H. Le, H. N. D. Huy, K. H. Vo, H. H. Luong, K. N. H. Tuan, T. D. Anh, N. Duong-Trung *et al.*, "Toward a design of blood donation management by blockchain technologies," in *International Conference on Computational Science and Its Applications*. Springer, 2021, pp. 78–90.

[18] H. T. Le, T. T. L. Nguyen, T. A. Nguyen, X. S. Ha, and N. Duong-Trung, "Bloodchain: A blood donation network managed by blockchain technologies," *Network*, vol. 2, no. 1, pp. 21–35, 2022.

[19] H. T. Le, L. N. T. Thanh, H. K. Vo, H. H. Luong, K. N. H. Tuan, T. D. Anh, K. H. N. Vuong, H. X. Son *et al.*, "Patient-chain: Patient-centered healthcare system a blockchain-based technology in dealing with emergencies," in *International Conference on Parallel and Distributed Computing: Applications and Technologies*. Springer, 2022, pp. 576–583.

[20] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system bitcoin: A peer-to-peer electronic cash system," *Bitcoin. org. Disponible en https://bitcoin. org/en/bitcoin-paper*, 2009.

[21] G. Shang, N. Ilk, and S. Fan, "Need for speed, but how much does it cost? unpacking the fee-speed relationship in bitcoin transactions," *Journal of Operations Management*, 2022.

[22] Ethereum, "How our escrow smart contract works," 2022. [Online]. Available: https://www.thenational.ae/business/technology/cash-on-delivery-the-biggest-obstacle-\ \to-e-commerce-in-uae-and-region-1

[23] OpenBazaar, "Truly decentralized, peer-to-peer ecommerce features," 2022. [Online]. Available: https://openbazaar.org/features/

[24] N. Duong-Trung *et al.*, "Multi-sessions mechanism for decentralized cash on delivery system," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 9, 2020.

[25] "Two party contracts," 2022. [Online]. Available: https://dappsforbeginners.wordpress.com/tutorials/two-party-contracts/

[26] G. D. Marzo, F. Pandolfelli, and V. D. Servedio, "Modeling innovation in the cryptocurrency ecosystem," *Scientific Reports*, vol. 12, no. 1, pp. 1–12, 2022.

[27] H. X. Son, M. H. Nguyen, H. K. Vo *et al.*, "Toward an privacy protection based on access control model in hybrid cloud for healthcare systems," in *International Joint Conference: 12th International Conference on Computational Intelligence in Security for Information Systems (CISIS 2019) and 10th International Conference on EUropean Transnational Education (ICEUTE 2019)*. Springer, 2019, pp. 77–86.

[28] H. X. Son and N. M. Hoang, "A novel attribute-based access control system for fine-grained privacy protection," in *Proceedings of the 3rd International Conference on Cryptography, Security and Privacy*, 2019, pp. 76–80.

[29] S. H. Xuan *et al.*, "Rew-xac: an approach to rewriting request for elastic abac enforcement with dynamic policies," in *2016 International Conference on Advanced Computing and Applications (ACOMP)*. IEEE, 2016, pp. 25–31.

[30] H. X. Son, T. K. Dang, and F. Massacci, "Rew-smt: a new approach for rewriting xacml request with dynamic big data security policies," in *International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage*. Springer, 2017, pp. 501–515.

[31] Q. N. T. Thi, T. K. Dang, H. L. Van, and H. X. Son, "Using json to specify privacy preserving-enabled attribute-based access control policies," in *International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage*. Springer, 2017, pp. 561–570.

[32] N. M. Hoang and H. X. Son, "A dynamic solution for fine-grained policy conflict resolution," in *Proceedings of the 3rd International Conference on Cryptography, Security and Privacy*, 2019, pp. 116–120.

[33] L. T. T. Nguyen *et al.*, "Bmdd: a novel approach for iot platform (broker-less and microservice architecture, decentralized identity, and dynamic transmission messages)," *PeerJ Computer Science*, vol. 8, p. e950, 2022.

[34] L. N. T. Thanh *et al.*, "Toward a security iot platform with high rate transmission and low energy consumption," in *International Conference on Computational Science and its Applications*. Springer, 2021.

[35] ——, "Toward a unique iot network via single sign-on protocol and message queue," in *International Conference on Computer Information Systems and Industrial Management*. Springer, 2021.

[36] L. N. T. Thanh, N. N. Phien, T. A. Nguyen, H. K. Vo, H. H. Luong, T. D. Anh, K. N. H. Tuan, and H. X. Son, "Ioht-mba: An internet of healthcare things (ioht) platform based on microservice and brokerless architecture," *International Journal of Advanced Computer Science and Applications*, vol. 12, no. 7, 2021. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2021.0120768

[37] L. N. T. Thanh *et al.*, "Sip-mba: A secure iot platform with brokerless and micro-service architecture," *International Journal of Advanced Computer Science and Applications*, 2021.