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INVENTORY MANAGEMENT SYSTEM USING BLOCKCHAIN TECHNOLOGY

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Abstract

Warehouse Management Systems (WMS) automate handling and control operations for stored materials and are a fundamental part of most companies, as movements of the most diverse types of materials and products occur at all times. Among several subsystems, Inventory Management is a fundamental part of the WMS. However, it may suffer from inaccuracy due to theft and unreported damage to materials. These inaccuracy problems can get worse if a hacker tampers the product quantities. To mitigate this problem, we propose blockchain technology to increase security. In Blockchain technology, the data stored becomes immutable and, therefore, cannot be tampered with. In this work, we developed and tested a prototype of an inventory management system, specifically the storage space allocation subsystem, using a blockchain Ethereum smart contract to register the aisle, shelf, and bin of the product location. Proving that blockchain is a real possibility to provide a good choice for a security inventory management system.

Keywords: Aisle; Ethereum; Shelf; Smart Contract; Storage Space Allocation; Warehouse Management Systems

1. Introduction

The Warehouse Management System (WMS) streamlines the handling and oversight of stored materials, serving as a critical component in the operations of most companies. Various types of materials and products are consistently in motion, whether for an industry's supply chain and final products, or for the storage of goods intended for wholesalers and retailers. Distribution centers often strategically position themselves in easily reachable locations to cater to transformation industries, wholesalers and retailers extensively utilize WMS (Machado and Sellito, 2012:46).

WMS seamlessly integrates with Enterprise Resource Planning (ERP) systems, providing crucial information regarding the receipt, storage, sorting, and inspection of supplies and finished products. This integrated data is then communicated to other systems for recording and decision-making purposes. The agility and precision of WMS play a pivotal role in reducing customer service times, fulfilling production requirements, and augmenting operational productivity (Naciri et al., 2011:1203; Nazário, 2009:284). Information technology significantly contributes to this sphere, given the increasingly intricate systems and the emergence of technological resources that mitigate costs and time in operations. Technologies such as barcodes, QR codes, RFID, and other similar innovations have revolutionized this domain (Novaes, 2016:1).

The Warehouse Management System (WMS) consolidates various interconnected subsystems or modules that collectively oversee and optimize warehouse and distribution center operations. Notable among these subsystems are (Khan et al., 2022:150; Kamali, 2019:9):

Inventory Management: This module facilitates the tracking of warehouse items, monitoring stock levels, storing details about products, and their historical movements. It also manages information regarding product status, occurrences, and available space.

Order Management: Tasked with processing customer orders, this subsystem encompasses order entry, picking, packaging, and shipping. Its primary goal is to ensure accurate and timely order fulfillment.

Receiving and Storage: Responsible for accepting incoming shipments, inspecting and verifying contents, and determining the appropriate storage locations within the warehouse for the received items.

Picking and Packing: This module governs the selection of items from their storage spots to assemble customer orders, optimizing routes and selection methods to enhance efficiency.

Shipping: Handles the preparation of items for shipping, including labeling, packaging, and generating shipping documents. It can integrate carrier services for real-time shipping rate quotes and tracking.

Inventory Management stands out as a foundational element within the WMS (GAO and LU, 2022). Nevertheless, it can be vulnerable to inaccuracies caused by theft and unreported material damage (Paulino Pinto et al., 2018:7; Silva, 2019:27). To address potential issues of manipulated product quantities recorded in the WMS inventory subsystem, employing Blockchain Technology to store these values emerges as a possible solution. In Blockchain Technology, stored data becomes immutable, impervious to tampering. Instances of theft or damage to physical stock items might result in discrepancies between recorded quantities in the system and the actual inventory. Auditing becomes crucial to investigate the root cause of these disparities.

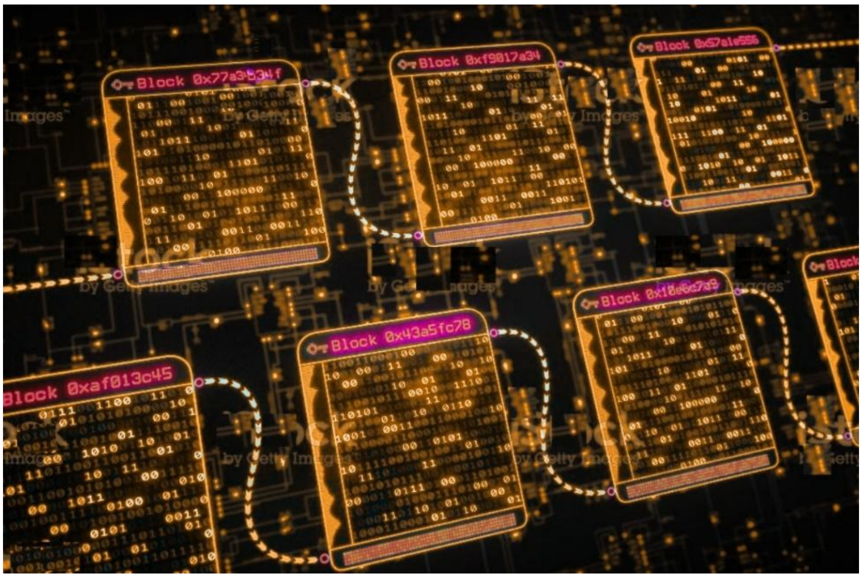
This initiative aims to introduce a prototype of an inventory subsystem designed to record material and product movements within warehouses and distribution centers. It leverages blockchain technology to track the specific locations of these items within the warehouse, employing a location system based on aisle, shelf, and bin.

2. Blockchain Technology

Blockchain Technology earned its name due to its structure resembling a chain of interconnected data blocks, as depicted in Figure 1. The concept was introduced in Nakamoto's work in 2008 (Nakamoto, 2008:1). Initially propelled into the spotlight alongside the emergence of Bitcoin Cryptocurrency, this technology gained recognition for its ability to securely store and transmit data. While its roots lie in supporting cryptocurrency systems, Blockchain Technology has since found diverse applications across various domains, including accounting systems, traceability, airline ticketing, supply chains, and numerous others.

The robust security inherent in blockchain technology stems from its decentralized and distributed nature for recording transactions. By eschewing a single centralized server, it circumvents the common vulnerability associated with such systems - the presence of a solitary point of failure (Yano et al., 2020:2). This decentralized approach ensures greater resilience and security, making it a compelling solution for a wide array of applications beyond cryptocurrency.

Figure 1 – Blockchain[1].



Source: Authors

Another pivotal security aspect lies in the immutability of data once it's recorded on the blockchain. This immutability is achieved through the aggregation of the previous block's hash code with the transaction data of the current block, solidifying the permanence of the blockchain data. The hash code functions as a condensed representation of data, producing a fixed-length hexadecimal output. In Ethereum's platform (Wood, 2017:1), the hexadecimal size amounts to 64 bytes.

The process of embedding the hash of the previous block into the current block occurs in the following steps:

Block Creation: When a new transaction needs recording on the blockchain, a new block is generated. Alongside the transaction details, this block encompasses additional

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1 Adapted from https://www.istockphoto.com/br/foto/blockchain-tecnologia-conceito-m%C3%BAltiplo-gm913016488-251338970

information for identifying the block, such as date, time, sequence number, and incorporates the hash code of the preceding block.

Hash Calculation: In calculating the hash for the current block, the system applies a hash algorithm to the block's entirety, encompassing transaction data, block identification information, and the hash of the prior block. The outcome is a singular hexadecimal value that serves as the identifier for the complete block content.

Inclusion of Previous Block's Hash: The current block integrates the hash of the previous block (i.e., the chain's last block). This recording process establishes the connection between blocks, with the current block "pointing" to the previous block, referencing its hash as a crucial link in the chain.

The aggregation of the previous block's hash ensures the immutability of recorded data within a blockchain network. Any attempt to modify the content of a block would necessitate altering subsequent blocks, rendering such alterations practically unfeasible without leaving noticeable traces. For instance, to manipulate transaction data within a blockchain network, a hacker would need to recalculate the hash code for all blocks succeeding the modified data, an undertaking that's essentially unattainable without detection.

One of the invaluable attributes of blockchain networks is the presence of smart contracts. These contracts are essentially codes imbued with predefined rules, akin to event-driven computer programs, operating autonomously—without human intervention—when specific events occur. Consider a purchase and sale scenario: before finalizing the transaction, the smart contract autonomously verifies the buyer's balance, the seller's inventory, and confirms whether the transaction value aligns with the purchased items' worth. Only upon successfully passing these checks does the smart contract execute the transaction, debiting the buyer's account, crediting the seller's account, and updating the seller's inventory. These actions occur automatically, streamlining the process while ensuring security.

Smart contracts find residence on the blockchain network, simplifying the enforcement of rules across a myriad of applications (Silva, 2019:5). Their presence not only ensures the integrity of transactions but also facilitates swift and secure execution of predefined actions, fostering efficiency across various domains.

3. Inventory Management System

A robust inventory management system stands as an essential tool for efficiently organizing and monitoring a company's array of products, materials, and assets, particularly those associated with physical goods. Its significance lies in enabling efficient inventory management, aiding decision-making processes, and optimizing overall business operations. The integration of automation and inventory management systems can notably enhance the precision and effectiveness of this vital process.

Given Blockchain Technology's potential to mitigate fraud in inventory management by safeguarding information against tampering, the prototype system's primary focus will center on the allocation of storage space within warehouses, stemming from the intake and outbound movement of items.

3.1 Receiving Items

3.1.1 Physical Receipt

Upon arrival at the receiving area (e.g., warehouse or distribution center), a warehouse receiver scrutinizes the items to ensure conformity with purchase order specifications and quantities. Any disparities are duly noted. Each item undergoes unique labeling and identification, facilitating traceability and precise recording within the inventory management system. This process often involves affixing barcode labels, serial numbers, or other identifiable markers.

3.1.2 Recording in the Inventory System

The warehouse receiver logs the received items into the inventory system, updating stock quantities and documenting pertinent details like batch numbers, manufacturing dates, and expiration dates.

3.1.3 Allocation of Storage Space

The warehouse receiver allocates items to designated storage locations in the inventory, considering variables such as product category, size, weight, and accessibility requirements. Typically, similar products are grouped together, enhancing accessibility and management. Organizing items within a stock control system using aisle, shelf, and bin numbers is a well-established practice in warehouses and distribution centers (Totuk, 2023:287). This practice streamlines item identification and expedites access to stored goods. The division aims to structure allocation spaces as follows:

Aisle:Aisles resemble streets within the warehouse or distribution center and are sequentially numbered or labeled with letters to aid navigation and reference.

Shelf: Within each aisle, multiple shelves exist, each also numbered or uniquely identified for ease of location.

Bin Number: Bins represent the smallest unit of space in a warehouse, subdividing shelves. Each bin is uniquely identified to facilitate quick and precise location of products or materials.

The amalgamation of aisle, shelf, and bin numbers generates a unique identifier for each storage location within the warehouse. For instance, the address of an item stored in aisle B, shelf 1, and the third bin would be labeled as “B1-3”. An Item Location System expedites the swift location of items in stock, reducing check-in and check-out times, minimizing errors, and mitigating storage challenges like overcrowded shelves or unused spaces.

3.2 Outgoing Items

3.2.1. Item Issue

The warehouse dispatcher locates items through the inventory system and groups, packs, and ships the items to the customer, recording any problem in the inventory system. This practice maintains the quantities in stock updated and records all the movements in the transaction history.

4. Materials and Methods

4.1 Inventory Management System

As highlighted in the preceding sections, blockchain technology was chosen for the Inventory Management System due to its robust security features. Conventional systems developed for Inventory Management can be susceptible to fraudulent activities, allowing the manipulation of recorded quantities to match physical stock quantities. While every system is vulnerable to hacking and manipulation, blockchain-based systems render tampering with data nearly impossible (Lei and Liu, 2019:55).

Implementing blockchain technology ensures the accuracy of recorded quantities within the inventory management system. Consequently, meticulous attention is essential during the reception and entry registration procedures. Through a user-friendly web interface, operators check in goods and specify their storage location within the Distribution Center. The standard practice for inventory items involves specifying their location using aisle, shelf, and bin numbers.

The System delineates three primary roles, as depicted in Figure 1:

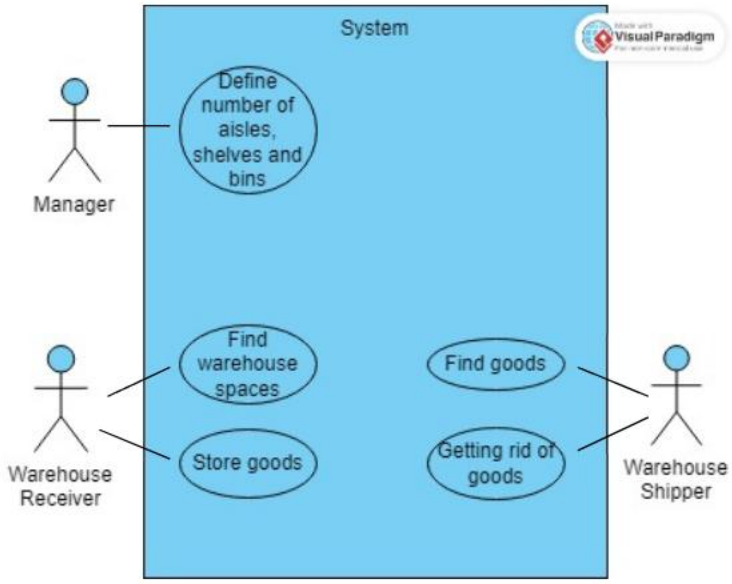
(i) Manager – Responsible for defining the distribution center's number of aisles, shelves, and bins and granting rights to other users.

(ii) Warehouse Receiver – Tasked with physically receiving merchandise and responsible for determining its allocation within the warehouse's available space. They record this location in the inventory system, specifying the aisle, shelf, and bin number for the newly received item.

(iii) Warehouse Shipper – This individual is responsible for shipping goods from the warehouse. Before shipment, they verify the goods and their respective stock locations, subsequently recording this information in the inventory system.

Given the system's foundation on blockchain technology, smart contracts will be utilized to manage vacancies. For efficiency, each location or aisle will possess its dedicated smart contract. These smart contracts will encompass the functions described in Figure 2 for effective management and control.

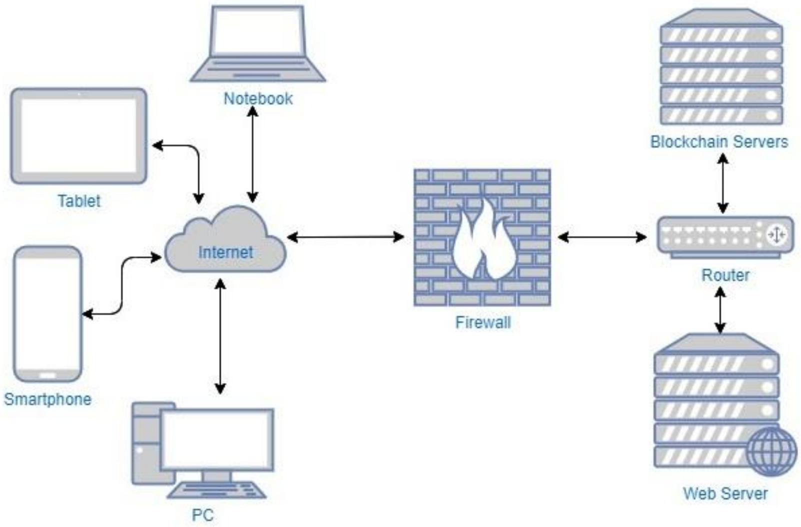
Figure 2 – Inventory Management System Use Case Diagram



Source: Authors

The functions of each agent (Figure 2) will be accessed via the Web Interface, as shown in Figure 3. Therefore, users, once connected to the Internet (PC, Smartphone, Tablet, and Notebook), will access smart contracts from different locations, whether in the office or own warehouse, monitoring storage and withdrawal operations.

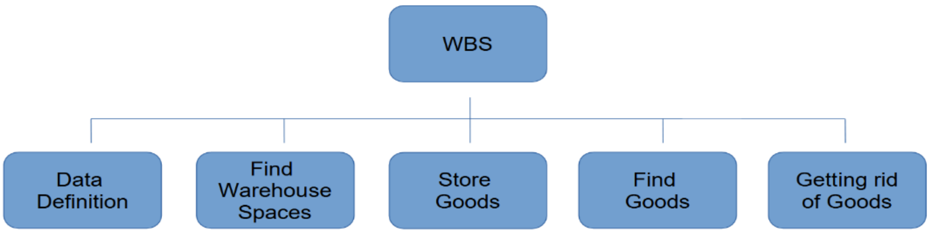
Figure 3 – Network Schematic



Source: Authors

4.2. Main Functions of the Inventory Management System

Figure 4 – Work Breakdown Structure (WBS)



Source: Authors

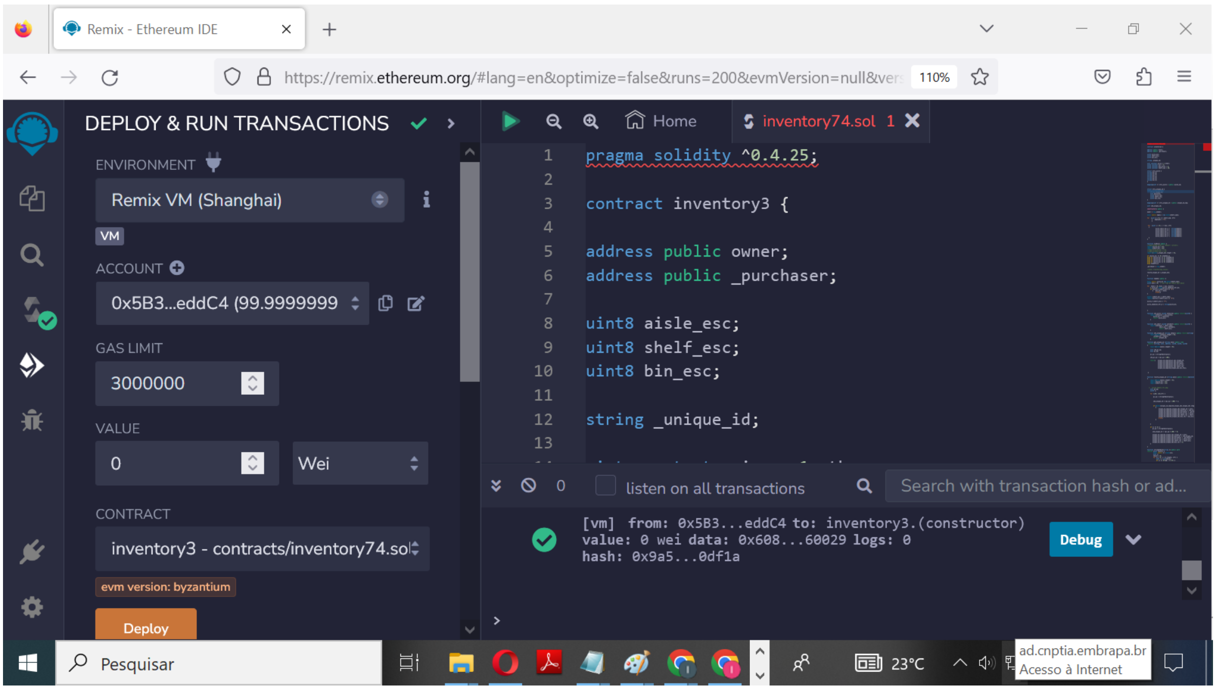
The first procedure of the smart contract presented in Figure 4 is the Data Definition process, where the quantities of aisles, shelves, and bins that the warehouse will have are defined. The following processes are:

- the system operations query operations for free shelves and bins;
- store goods received by the warehouse receiver;
- query for the location of goods already stored and;
- their removal, according to the service order by the warehouse shipper.

4.3. Development Environment and Simulations

The programming language used for the smart contract development was Solidity. In this work, we used the Remix platform development environment (REMIX IDE, 2021:1). The Remix Platform is an Integrated Development Environment (IDE) freely available with web access at https://remix.ethereum.org/, where developers can construct smart contracts for Ethereum Blockchain Networks. On this platform (Figure 5), it is also possible to carry out simulations, as it provides some user accounts and creates interfaces (buttons) for interaction with the smart contract functions. These buttons are blue for queries and orange for data updating in Remix: Revision 7c59a3fd; Last updated on Oct 23, 2023.

Figure 5 – Remix Platform



Source: Authors

5. Results

5.1 Query Available Bins

In the simulation test, six aisles were considered, each containing 48 shelves, and the shelves have each four bins to receive boxes or pallets. After receiving and labeling the product, the next step is to store the box or pallet. Before storage, the warehouse receiver must select a free bin for its allocation. To this end, the warehouse receiver can consult all aisles and check which shelves still have available bins. Figure 6 shows all shelves status of the six aisles. The letter "e" indicates shelves with free bins. Or the warehouse receiver can consult a specific aisle, as shown in Figure 7, in which they must fill in the aisle number, with 0 for aisle A, 1 for aisle B, 2 for aisle C, 3 for aisle D, 4 for aisle E, and 5 for aisle F. We can notice that aisle B, in the query presented in Figure 7, has shelf one full, represented by the letter f. Table 1 analytically shows the situation of the bins of the first seven shelves of aisle B, with the first shelf or shelf 0 being empty, i.e., with all the bins free and shelf one full, i.e., with all bins occupied.

Figure 6 – Situation of all six aisles in the system simulation

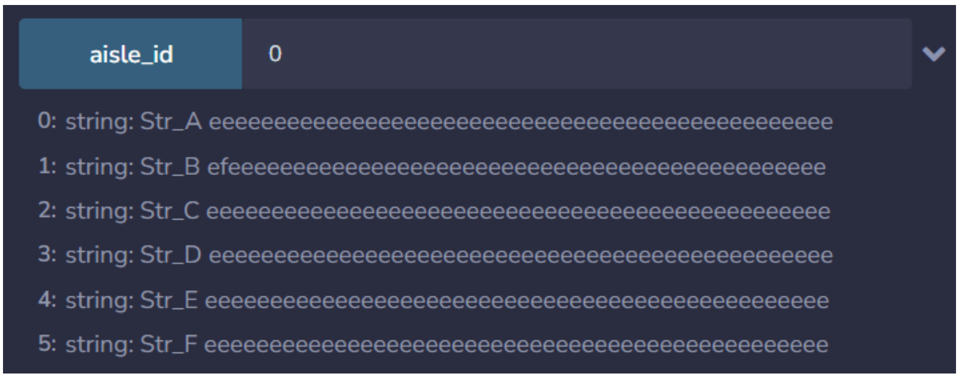


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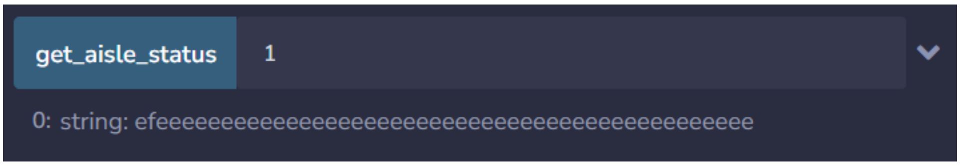
Figure 7 – Shelf situation in aisle B



Source: Authors

Table 1 – Shelves status in aisle B

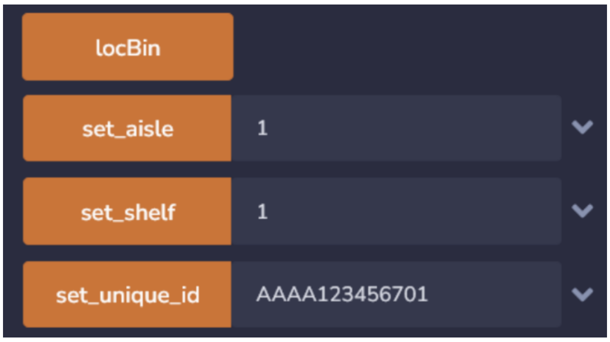
e				f				e				e				e				e				e				...	
bin1	bin2	bin3	bin4	bin1	bin2	bin3	bin4	bin1	bin2	bin3	bin4	bin1	bin2	bin3	bin4	bin1	bin2	bin3	bin4	bin1	bin2	bin3	bin4	bin1	bin2	bin3	bin4	bin1	...
				X	X	X	X																						

Source: Authors

5.2 Bin allocation

Once the warehouse receiver has consulted and found out which shelves can receive the new pallet or box, he must fill the aisle, the shelf, and the unique identifier data for the product already labeled at the receipt time. Figure 8 shows an example of a record for storage in aisle B (set_aisle = 1), on shelf 1 (set_shelf = 1), and unique product identifier (set_unique_id = “AAAA123456701”). After filling in all the data, click on locBin button to record the the product location in that bin.

Figure 8 – Box or pallet storage record in aisle B (“1”), shelf one and bin three

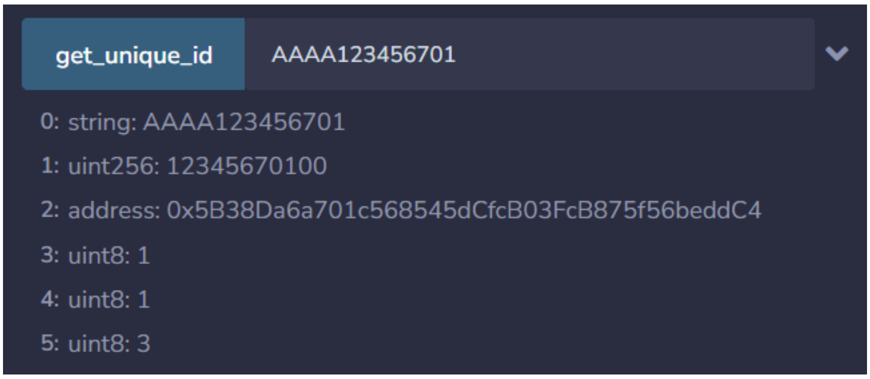


Source: Authors

5.3 Product Location Query

The warehouse shipper will use the get_unique_id function to find the product to be picked up. Figure 8 shows the product query with identifier AAAA123456701 (get_unique_id = “AAAA123456701”), which results in aisle B, identified by the number one, shelf one and bin three. This location identification is effective for quickly remove an item of the warehouse.

Figure 9 – Query product location data.



Source: Authors

6. Conclusion

As depicted in this study, blockchain technology stands as a viable solution to bolster the security of the inventory management system, mitigating potential fraud issues. The inherent data immutability of blockchain prevents any unauthorized alteration of values, instilling confidence in users who solely need to focus on monitoring the physical quantities of products and materials housed in warehouses or distribution centers.

The showcased system prototype demonstrates the feasibility of implementing an inventory management system utilizing this innovative form of data storage. The interfaces showcased in this study were sourced from the Remix platform, which automates the creation of buttons for querying and modifying data to facilitate the testing of smart contract functionalities. In forthcoming endeavors, our aim is to develop a web-based system featuring a more user-friendly interface employing HTML and JavaScript. This system will enable access to the smart contract on the blockchain server, enhancing usability and accessibility for users.

7.. Conflict of Interest Disclosure

The author declares that there is no conflict of interest.

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