Towards a Medical Waste Classification System Based on Blockchain, Smart Contracts, and NFT Technologies

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Abstract. The end of the covid-19 epidemic has revealed many weaknesses in the health system and the medical waste treatment process. In particular, the ineffective treatment of medical waste has also contributed to the explosion in the number of infections in some countries (i.e., India, Brazil, and Vietnam). Several studies have found that even developed countries (i.e., with better infrastructure and health services than the world average) have to face emergencies during this time. epidemic. Therefore, the amount of medical waste dumped into the environment is extremely terrible. The waste generated suddenly during this period includes protective gear, masks, and vaccines that burden the waste treatment process. There are several approaches to exploiting Blockchain technologies to solve the problem of direct contact between the stages: medical staff - transportation staff - waste disposal staff to minimize unintended spread. However, to thoroughly solve the current waste classification and treatment processes, a more reward/punishment solution is needed. Specifically, we propose a model to assess the compliance/violation level of waste sorting and treatment in medical centers and isolation areas based on current popular technologies: blockchain, smart contracts, and NFTs.

Keywords: Medical waste treatment · Blockchain · Smart contracts · NFT · Ethereum · Fantom · Polygon · Binance Smart Chain

1 Introduction

The passing of the Covid epidemic has revealed inadequacies in the treatment of medical waste. Studies conducted by [10] have shown that medical waste directly contributes to the spread of Covid disease. Other studies have also shown that upgrading medical facilities (i.e., waste disposal processes) is not enough to

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ensure a safe, closed process in a healthcare environment. Therefore, a series of approaches have been born [1,17] to speed up the processing process to support medical doctors and e-medical staff, where direct contact is minimized (ie., face-to-face). These solutions also support the doctor/nurse-patient visit process. Specifically, patients will report information online about their symptoms. The doctors will give the corresponding advice to help the patient have an effective treatment plan.

However, for the medical waste treatment process, where there is a need for interaction between many stakeholders (i.e., nurses, doctors, patients, staff in medical center departments, as well as employees of waste transportation/disposal companies). Indeed, 99% of items (including medical equipment and supplies) become junk after use within the first six months of first use [13]. Therefore, many approaches [3,5] have presented processes based on central processing in the waste treatment process before the time of the Covid epidemic. However, these solutions do not take into account the risk reduction of direct contact between stakeholders (eg, health workers - transportation companies or transport companies - waste treatment companies). In addition, the approach based on traditional centralized data storage faces many risks, such as a lack of transparency between information transfer stages [9]. Centralized storage also prevents information authentication between the parties involved in the traditional waste treatment process [6,7]. In addition, information is easily hacked or stolen by malicious users [20] because all information is stored centrally and is difficult to recover when attacked by hackers or natural disasters (eg, fire or flood).

Because of the above risks, many approaches exploit Blockchain technology as an alternative to centralized storage, and lack of transparency [14]. In the matter of waste treatment, the majority of systems deployed on two main platforms, Ethereum [8] and Hyperledger [12] offer solutions medical waste treatment (see Related work for details). However, these approaches have not yet provided a specific definition for reward behaviors and violations for individuals and organizations for their waste sorting behavior.

Therefore, in this article, we propose a medical waste classification model based on the combination of a series of current advanced technologies including: Blockchain, smart contract, and NFT (see Approach section for more details). In addition, to demonstrate the effectiveness of the proposed model we implemented a proof-of-concept based on the Ethereum platform (i.e., see 2 section for reasons to use this platform instead of other platforms) combined with ERC 721 (i.e., Ethereum's NFT issuance certificate). We also install smart contracts on three EVM (Ethereum Virtual Machine) enabled platforms including BNB smart chain, Fantom, Polygon and Celo (i.e., see Evaluation for more details).

Therefore, our work contributes on four aspects. (a) Propose a mechanism for classification and treatment of medical waste based on blockchain technology and smart contract; (b) propose a model to create reward/punishment decisions for individuals/organizations based on NFT technology; (c) implement the proposed model based on smart contracts and the proposed model (i.e., proof-of-concept);

and (d) deploying proof-of-concept on 4 supporting platforms (ERC721 - NFT of ETH) and EVM (deploying smart contract implemented in solidity language) including BNB Smart Chain, Fantom, Polygon, and Celo.[1]

2 Related Work

2.1 Ethereum-Based Waste Treatment System

Two popular examples in applying the Ethereum platform in building a supply chain management model for waste treatment in the healthcare environment are [8]. For electronic medical devices (eg, CT scanner, X-Ray machine, pacemaker, etc) that are no longer in use (e.g., damaged, expired) at the centers healthcare is called e-waste, Gupta et al. [8] proposes a system to treat the above types of waste based on Blockchain technology (i.e., Ethereum). To develop processing policies that comply with strict requirements at medical centers, the authors have built a system of smart contracts. In order to raise awareness among users about waste disposal, each user will receive a reward if they complete the sorting before sending them for disposal. However, these solutions only apply smart contracts to distribute reward points instead of storing evidence of reward receipts or violations in the waste disposal process - as we have applied (i.e., based on NFT).

Another model was introduced by Laura et al. [11], which is implemented on the Ethereum platform. This system helps observers in assessing violations in solid waste segregation (computers and smartphones). The difference between this paper and other approaches is that it proposes a remote management model based on QR code (i.e., generated from classification to processing). For cross-border processes (i.e., between countries rather than within the same country) Schmelz et al. [16] introduces an Ethereum-based system, privacy protection model, for garbage disposal. Information that is not related to the waste treatment process will be stored offchain instead of putting them on-chain. This approach is similar to our NFT-based certificate and metadata storage model. However, our focus is on encouraging standard behavior in waste sorting as well as violations of the above procedure.

2.2 Waste Treatment System Based on Hyperledger Fabric

In this section, we show three case studies in applying the Hyperledger platform to propose a medical waste treatment model. Most waste products during the Covid 19 pandemic are listed as hazardous waste to health (i.e., 99% of items after use are medical waste [13]). So they combine blockchain and smart contracts to classify and dispose of garbage instead of just centralized local storage. For example, Trieu et al. [12] proposes a waste treatment model called MedicalWastChain. This proposed model is aimed at the treatment of medical waste from

[1] We do not deploy smart contracts on ETH because the execution fee of smart contracts is too high.

medical centers, reuse of tools, the process of transferring medical supplies waste (i.e., protective gear, gloves, masks, etc.) and waste treatment processes in factories. They aim for a solution to help parties trace the source of waste and toxic levels during the pandemic. Similar to the above approach, Ahmad et al. [2] aims at the traceability model of personal protective equipment for healthcare workers (i.e., doctors, nurses, testers) during the pandemic. To assist with validation of waste treatment processes (i.e., stakeholder interactions), Dasaklis et al. [4] proposed a blockchain-based system set up on smartphones.

However, the above approaches do not pay too much attention to the regeneration/refurbishment process. Neither of the above approaches offers a reasonable solution for handling (i.e., reward and handling of violations). Specifically, the above solutions (for both Hyperledger Eco-system and Ethereum platforms) only focus on the management model of the waste treatment chain from the place of origin (i.e., medical centers) to factories. In this paper, we not only offer a model to manage the waste sorting process, but also provide a solution for rewarding and handling user violations based on NFT technology.

3 Approach

3.1 The Traditional Model of Medical Waste Treatment

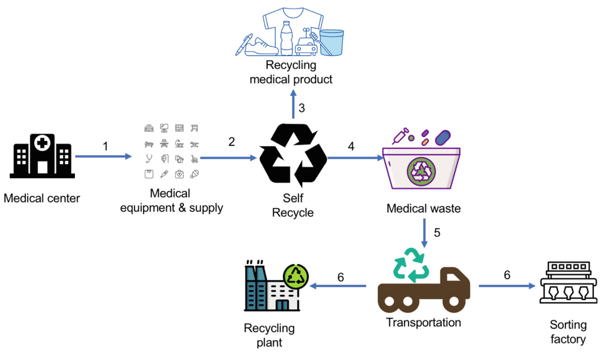

Fig. 1. The traditional model of treatment and classification of medical waste

To build a model of treatment and classification of medical waste that is commonly applied today, we refer to the process of classifying and treating medical waste during the Covid-19 pandemic. In the documents that can be downloaded and referenced from CDCs in different parts of the world, we choose Vietnam for two reasons: i) Vietnam has successfully controlled through the first two waves of Covid-19 in 2019 and early 2020; ii) is a developing country - undeveloped waste treatment infrastructure can be applied in other countries around the world. Specifically, in contrast to complicated waste treatment processes

- difficult to apply to other countries due to budget constraints and modern equipment - the application model in Vietnam can be applied. in other countries around the world. The process of classification and treatment of medical waste during the Covid-19 epidemic was signed by the Ministry of Health in 2019 [15]. The steps are shown in Fig. 2. Specifically, Fig. 2 shows five sources of medical waste classification and five treatment steps. Sources of medical waste include treatment place (i.e., hospital, military barracks), testing, vaccination, and the personal place under quarantine (eg,household, apartment). For medical waste classification, the first three steps are carried out at healthcare centers (i.e., classification, separation, and collection) where all hazardous waste is sent to factories for treatment disposal (i.e., destruction) including transportation and treatment.

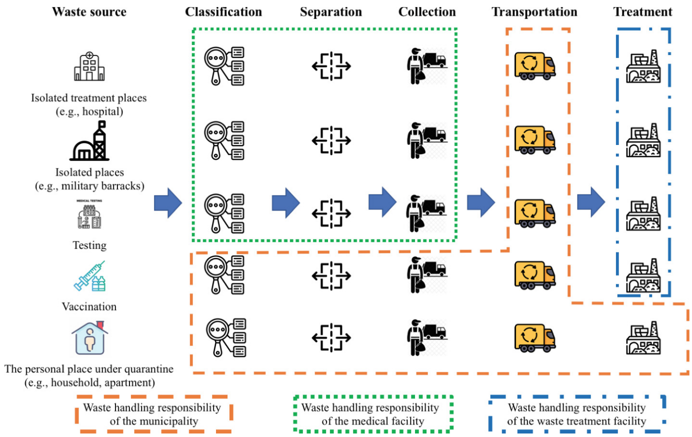

Fig. 2. The Covide-19 pandemic-related medical waste treatment sample in Vietnam

Figure 1 shows the steps of traditional garbage classification and treatment. Step 1 presents the waste collection process in departments in medical facilities (e.g., hospitals). These types of waste include medical equipment and supply. Step 2 presents the process of self-segmentation and reuse in the medical environment. At the end of this process, products belonging to the recycling medical product group are reused (step 3) while medical waste is disposed of (step 4). All medical waste is sent to the waste treatment area (step 5). Here, depending on the treatment requirements, the medical waste is classified into the corresponding treatment processes (i.e., recycling plant and sorting factory - step 6).

The risks in the traditional medical waste treatment process have been summarized and presented in the Introduction and Related work sections. However, in order to improve people's sense of self-segregation and treatment of medical waste, we propose a model that combines blockchain, smart contract, and NFT technologies to create certificates in classification at medical centers thereby identifying compliance/violation.

3.2 Model of Treatment and Classification of Medical Waste Based on Blockchain Technology, Smart Contract and NFT

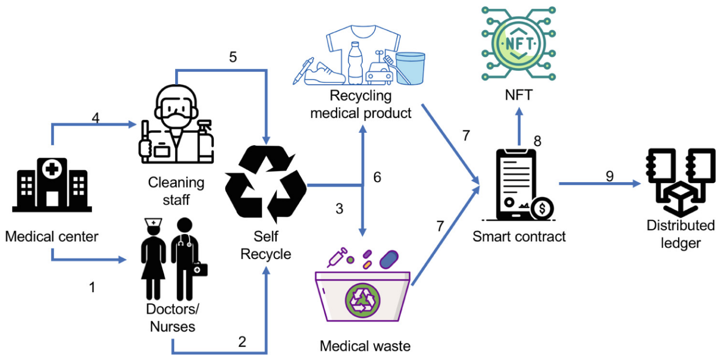

Fig. 3. Model of treatment and classification of medical waste based on blockchain technology, smart contract and NFT

Figure 3 presents nine steps of classification and treatment of medical waste using blockchain technology, smart contract and NFT. In particular, doctors, nurses, and other medical center staff (eg, clinics, hospitals) must confirm constraints on waste segregation at the workplace (step 1). These requirements are presented in the form of guidelines and commitments (i.e., specify compliance/violations when sorting medical waste). Here, we only classify into two main groups including: recyclable waste at medical centers and hazardous waste. Step 2 presents healthcare workers with self-segregation of waste as required in step 1. Hazardous items must be isolated from the treatment and medical care area (i.e., waiting for the transporter to arrive at the centers). waste treatment center). In step 4, hospitals provide guidance documents to cleaning staff regarding the assessment of compliance/violation behaviors by doctors and nurses. Step 5, present the cleaning staff's monitoring process for all types of waste after being sorted (i.e., check the process for hazardous waste). Step 6 shows the cleaning staff to check the types of recyclable waste. These assertions are sent to the respective functions (i.e., name the functions in the smart contract) - step 7. Step 8 generates NFTs corresponding to compliance/violations based on cleaning's evaluation process. staff for individuals/organizations at medical centers. The entire process is stored in the distributed ledger (step 9).

4 Implementation

Our reality model focuses on two main purposes: i) data manipulation (i.e., medical waste) - initialization, query and update - on blockchain platform and ii) creation of NFTs for each user's (i.e., individual/organization) reward and violation behavior based on their behavior in waste sorting/disposal.

4.1 Initialize Data/NFT

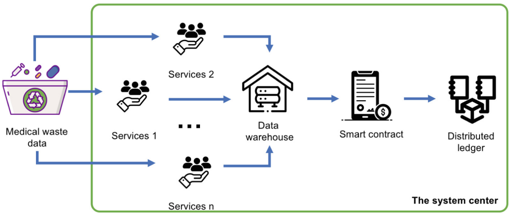

Fig. 4. Initialize data/NFT

Figure 4 shows the steps to initialize medical waste data. These types of waste include medical equipment (i.e., expired/damaged) or medical supplies (eg, masks, PPE, injections). These types of waste are required to be classified into different categories (i.e., discard, reuse) depending on their level of toxicity. Then descriptions of the type of waste are added to each specific garbage bag. Each trash bag has a unique address to separate them with the type of waste. In addition, information about the sorter as well as in which department, time, and location is also added to the metadata of the trash bag. As for the storage process, services support concurrent storage (i.e., distributed processing as a peer-to-peer network) on a distributed ledger - supporting more than one user for concurrent storage to reduce system latency. The medical waste data is organized as follows:

```
medicalWasteDataObject = {
"medicalWasteID": medicalWasteID,
"staffID": staffID,
"type": type of waste,
"apartmentID": apartmentID,
"quantity": quantiy,
"unit": unit,
"packageID": packageID,
"time": time,
"location": location,
"state": null,
"reUse": Null};
```

Specifically, in addition to the information to extract the content (i.e., place of origin, weight, type of waste, etc.), we also store information related to the status of the garbage bags at the hospital (ie. , “state” and “reUse” - defaults to Null). Specifically, “state” changes to 1 if the corresponding garbage bag has been shipped out of the medical center (i.e., for the type of waste to be treated); value

0 - pending. Meanwhile, "reUse" presents the value 1 when the type of waste (i.e., medical device) is reused (i.e., value 0 - pending). Non-hazardous wastes (i.e., non-toxic to the environment and user's health). After the waste sorting phase, the cleaning staff will check if they are in accordance with the process and wait for validation before synchronizing on the chain (i.e., temporarily stored on the data warehouse). Then the pre-designed constraints in the Smart Contract are called through the API (i.e., name of function) to sync them up the chain. This role of accreditation is extremely important because they directly affect the waste treatment process, as well as the premise for rewarding or sanctioning individuals and organizations.

4.2 Data Query

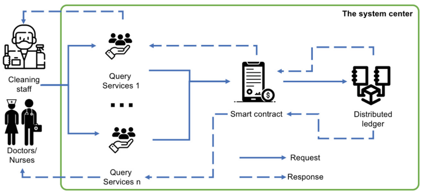

Fig. 5. Data query

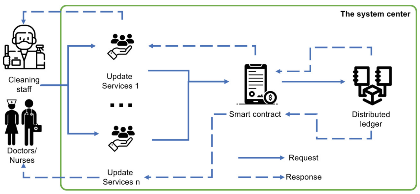

Fig. 6. Data updated

Similar to the data initialization steps, the data query process also supports many simultaneous participants in the system for access (i.e., distributed model). Support services receive requests from Cleaning staff or nurses/doctors to access data. Depending on the query object we have different access purposes. Specifically, Cleaning staff queries with the purpose of checking the classification process or transferring hazardous medical waste to the shipping company. In contrast, healthcare professionals can query data to find reusable medical tools (i.e., out of stock). Figure 5 shows the steps to query medical waste data. These requests are sent as requests (i.e., pre-designed services as API calls) from the user to the smart contracts available in the system (i.e., name of function) before retrieving the data. from the distributed ledger. All retrieval requests are also saved as query history for each individual or organization. In case the corresponding information is not found (eg, wrong ID), the system will send a message not found results. For the NFT query process, all support services are provided as APIs.

4.3 Data Updated

The data update routine is invoked only after verifying that the data exists on the thread (i.e., after executing the corresponding data query procedure). In this section, we assume that the search data exists on the string. Where none exists, the system sends the same message to the user (see Sect. 4.2 for details). Similar to the two processes of query and data initialization, we support update services in the form of APIs to receive requests from users before passing them to smart contracts (i.e., name of function) for processing. The purpose of this process is to update the time and location of the garbage bags during transportation and handling of medical waste. Thereby, the administrator can trace the status of medical waste treatment/transportation from medical centers to waste treatment companies. Figure 6 shows the procedure for updating medical waste data. For NFTs (i.e., available) the update process includes only moving from the owner's address to the new (i.e., new owner). If any information is updated on an existing NFT, it will be stored as a new NFT (see Sect. 4.1 for details).

5 Evaluation

Since the proposed model rewards/penalizes for compliance/violation of the medical waste classification process, we implement the recommendation model on EVM-enabled blockchain platforms instead of mining platforms under the Hyperledger eco-system. In addition, assessments based on system responsiveness (i.e., number of requests responded successfully/failed, system latency - min, max, average) have been evaluated by us in the previous research paper. Therefore, in this paper we determine the suitable platform for our proposed model. Specifically, we install a recommendation system on four popular blockchain platforms today, supporting Ethereum Virtual Machine (EVM), including Binance Smart Chain (BNB Smart Chain)[2]; Polygon[3]; Fantom[4]; and Celo[5]. Our implementations on these four platforms are also shared as a contribution to the article to collect transaction fees corresponding to the four platforms' supporting coins[6], ie, BNB[7]; MATIC[8]; FTM[9]; and CELO[10]. Our implementations to evaluate the execution cost of smart contracts (i.e., designed based on Solidity language) run on testnet environments of four platforms in order to choose the most cost-effective platform to deploy. Our detailed assessments focus on the cost of performing contract creation, NFT generation and NFT retrieval/transfer (i.e., updating NFT ownership address) presented in the respective subsections related to i) Transaction Fee; ii) Gas limit.

[2] https://github.com/bnb-chain/whitepaper/blob/master/WHITEPAPER.md.
[3] https://polygon.technology/lightpaper-polygon.pdf.
[4] https://whitepaper.io/document/438/fantom-whitepaper.
[5] https://celo.org/papers/whitepaper.
[6] Implementation of theme models our release at Nov-24-2022 04:19:05 AM +UTC.
[7] https://testnet.bscscan.com/address/0x94d93a5606bd3ac9ae8b80e334dfec74d0075ece.
[8] https://mumbai.polygonscan.com/address/0x48493a3bb4e7cb42269062957bd541d52afc0d7a.
[9] https://testnet.ftmscan.com/address/0x48493a3bb4e7cb42269062957bd541d52afc0d7a.
[10] https://explorer.celo.org/alfajores/address/0x48493A3bB4E7cB42269062957Bd541D52aFc0d7A/transactions.

Table 1. Transaction fee

	Contract Creation	Create NFT	Transfer NFT
BNB Smart Chain	0.02731376 BNB ($8.41)	0.00109162 BNB ($0.34)	0.00057003 BNB ($0.18)
Fantom	0.009577666 FTM ($0.001840)	0.000405167 FTM ($0.000078)	0.0002380105 FTM ($0.000046)
Polygon	0.006841190030101236 MATIC($0.01)	0.000289405001041858 MATIC($0.00)	0.000170007500612027 MATIC($0.00)
Celo	0.0070979376 CELO ($0.004)	0.0002840812 CELO ($0.000)	0.0001554878 CELO ($0.000)

5.1 Transaction Fee

Table 1 shows the cost of creating contracts for the four platforms. It is easy to see that the highest transaction fee of the three requirements is contract creation for all four platforms. In which, the cost of BNB Smart Chain is the highest with the highest cost when creating a contract is 0.02731376 BNB ($8.41); whereas, the lowest cost recorded by the Fantom platform with the highest cost for contract initiation is less than 0.009577666 FTM ($0.001840). Meanwhile, the cost to enforce Celo's contract initiation requirement is lower than Polygon's with only $0.004 compared to $0.01. For the remaining two requirements (Create NFT and Transfer NFT), we note that the cost of implementing them for all three platforms, Polygon, Celo, and Fantom is very low (i.e., negligible) given the cost. trades close to $0.00. However, this cost is still very high when deployed on BNB Smart Chain with 0.00109162 BNB ($0.34) and 0.00057003 BNB ($0.18) for Create NFT and Transfer NFT, respectively.

5.2 Gas Limit

Table 2. Gas limit

	Contract Creation	Create NFT	Transfer NFT
BNB Smart Chain	2,731,376	109,162	72,003
Fantom	2,736,476	115,762	72,803
Polygon	2,736,476	115,762	72,803
Celo	3,548,968	142,040	85,673

Table 2 shows the gas limit for each transaction. Our observations show that the gas limits of the three platforms (i.e., BNB, Polygon, and Fantom) are roughly equivalent - where Polygon and Fantom are similar in all three transactions. The remaining platform (i.e., Celo) has the highest gas limit with 3,548,968; 142,040; and 85,673 for all three transaction types.

5.3 Discussion

According to our observation, the transaction value depends on the market capitalization of the respective coin. The total market capitalization of the 4 platforms used in our review (i.e., BNB (Binance Smart Chain); MATIC (Polygon); FTM (Fantom); and CELO (Celo)) are $50,959,673,206; $7,652,386,190; $486,510,485; and $244,775,762.[11] This directly affects the coin value of that platform - although the number of coins issued at the time of system implementation also plays a huge role. The coin's value is conventionally based on the number of coins issued and the total market capitalization with a value of $314.98; $0.863099; $0.1909; and $0.528049 for BNB, MATIC, FTM, and CELO respectively. Based on the measurements and analysis, we have concluded that the proposed model deployed on Faltom brings many benefits related to system operating costs. In particular, generating and receiving NFTs has an almost zero (i.e., negligible) fee. Also, the cost of creating contracts with transaction execution value is also meager (i.e., less than $0.002).

In future work, we proceed to implement more complex methods/algorithms (i.e., encryption and decryption) as well as more complex data structures to observe the costs for the respective transactions. Deploying the proposed model in a real environment is also a possible approach (i.e., implementing the recommendation system on the FTM mainnet). Currently, we have not considered issues related to the privacy policy of users (i.e., access control [18], dynamic policy [19]) - a possible approach would be implemented in upcoming research activities.

6 Conclusion

Our work proposes a reward/punishment model for individual/organizational medical waste sorting behavior. Our proposal is based on blockchain technology, smart contracts (i.e., transparency, distributed storage, and processing), and NFT (i.e., immutable) to build waste separation and treatment processes. medical. We have implemented proof-of-concept on the Ethereum platform and smart contracts (i.e., contract creation, NFT create, NFT transfer) based on the Solidity language. We also tested smart contracts on four EVM-enabled platforms (i.e., BNB, MATIC, FTM, and CELO) to find the right platform (i.e., the lowest smart contract execution cost). Our analysis in the evaluation section demonstrated that implementations on Fantom offer more benefits than the other ones.

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