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TOWARDS DECENTRALIZED RESOURCE MANAGEMENT FOR DISASTERS: NGO-RMSD

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Abstract. *The necessity for an efficient resource management system during and post-disaster is underscored by the prevalent coordination and resource management challenges faced by various organizations, including non-governmental organizations (NGOs) and government units. To address these problems, our system proposal introduces NGO-RMSD, a blockchain-based decentralized system designed to enhance collaborative efforts during and after disasters. Utilizing the Quorum framework for its energy efficiency, NGO-RMSD enables seamless transactions and updates across parties, eliminating intermediaries and fostering a trusted environment for resource management. This paper details the development of this decentralized system, incorporating smart contracts for autonomous operation. Decentralized systems provide superior security, transparency, and immutability, making them fundamentally more robust and efficient than centralized systems for managing complex, multi-stakeholder scenarios like dis-aster response. This decentralized model ensures transparency, eliminates intermediaries, and enables all parties to conduct transactions and updates reliably. These contracts effectively assess and prioritize the needs of affected individuals, ensuring timely and accurate resource allocation. A proof of concept has been implemented, demonstrating the practicality and potential impact of NGO-RMSD. Designed in alignment with NGO's field requirements and distributed under a free software license, this system promises to significantly improve coordination for disaster resource management. Possible improvements and future work for a more sustainable system is discussed. Looking forward, we aim to enhance the efficiency and effectiveness of disaster relief efforts by providing assistance to a larger number of affected individuals in a more organized and expeditious manner.*

Key words: *Disaster, Non-Governmental Organizations, Crisis Management, Organization, Blockchain, sustainability*

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1. INTRODUCTION

Predicting the outcomes of disasters with high precision is a complex task, due to the variability in regional characteristics, severity, type, and the specific climatic and geographical conditions prevalent at the time of the disaster's occurrence [23]. Due to these situations in pre-disaster forecasting, which preclude absolute precision, the effectiveness of the preventative measures adopted is consequently relative and variable. For this reason, the importance of first and early intervention in disaster situations is critical. Even in developed nations like the United States and Japan, disaster preparedness measures remain inadequate [1].

Although disaster management is primarily the responsibility of local governments, numerous non-governmental organizations (NGOs) actively participate in crisis management during such periods. Given the extensive societal damage caused by disasters, ranging from human and animal welfare to natural and production resources, NGOs specializing in various domains play pivotal roles in post-disaster recovery processes. Additionally, NGOs and volunteers significantly contribute to disaster relief efforts. However, critical coordination challenges persist among these stakeholders in post-disaster crisis management.

Today, NGOs are extensively involved in various aspects of disaster management. They contribute to community preparedness, mitigate pre-disaster risks and post-disaster losses, and engage in short-term interventions and long-term recovery initiatives. Without the assistance of voluntary organizations, it is unlikely that local governments and states can adequately address the needs of disaster victims. Effective dis-aster management requires collaborative efforts, involving voluntary organizations at all stages of disaster response and fostering coordination among stakeholders [2]. NGOs operate to support local governments and the public during crises, aligning with their mission objectives [3]. An example of such NGO involvement is Ahbap, a Turkish organization that actively participated in post-disaster recovery following the 2020 Elazig Sivrice and the 2023 Kahramanmaraş earthquakes in Turkey. A member of our team actively engaged as a volunteer with Ahbap, contributing substantially to post-disaster recovery endeavors. Our assessments highlight inefficiencies in resource allocation and challenges in providing assistance to the most vulnerable individuals, with NGOs often operating independently of one another.

Upon analyzing NGOs, it becomes evident that they vary in missions, visions, and resources, each possessing unique strengths. The most significant challenge discerned in post-disaster management pertains to the coordination deficit between NGOs and governmental bodies, resulting in suboptimal utilization of resources. This circumstance engenders deficiencies in resource allocation, consequently impeding the pace of post-disaster recovery endeavors. Hence, the research question in this study is “Can block-chain be used to address these resource management problems in the post-disaster process?”

Subsequent sections of the paper delve into discussions on resource management during disasters, followed by an exploration of decentralization. Related works in the field are presented, leading to the detailed proposal of the NGO-RMSD system in Section 5. The implementation of the proof of concept for this system is outlined in Section 6, while the conclusion and avenues for future research are provided in the concluding section.

2. RESOURCE MANAGEMENT NEED DURING DISASTERS

In this study, Türkiye serves as a case owing to the high frequency of natural disasters it has encountered in recent years. While Türkiye has witnessed a range of disasters, including forest fires and floods, this research primarily focuses on earthquakes, which have been the most devastating in terms of destruction. The data and examples within the study are specifically tailored to illustrate the impact and management of earth-quake disasters in Türkiye. According to earthquake statistics; earthquake rates in Türkiye are increasing every year. According to Boğaziçi University Kandilli Observatory data, 20,095 earthquakes greater than 3.5 magnitude have occurred in Türkiye in the last 100 years [21]. Additionally, according to AFAD's (Disaster and Emergency Management Presidency) data, hundreds of thousands of citizens were killed and more than one million houses were destroyed or damaged in these earthquakes [7].

In our ongoing engagement with NGOs active in disaster response, we have observed significant challenges in resource management and coordination during crises. Following the development of our NGO-RMSD proposal [27], Türkiye has experienced numerous large-scale natural disasters, including earthquakes, floods, and fires. Research con-ducted in the aftermath of these events has highlighted that NGOs' efforts to establish internal coordination networks often fall short in effectively managing these disasters [22]. A primary contributing factor to this inefficiency is the lack of robust technological systems.

Presently, resource management and coordination during disasters continue to face critical challenges. The nature and scale of the disaster, along with varying climatic and geographical conditions, lead to diverse and complex needs. The first 48 hours post-disaster are crucial for effective intervention, underscoring the urgency for developing comprehensive systems that address not only the gaps in resource management and co-ordination but also cater to the broader spectrum of needs arising in such emergency situations.

The primary challenges manifest in monitoring of the post-disaster essential needs and resource administration, spanning logistical operations, storage facilities, and distribution processes. Post-disaster necessity tracking encompasses the initial validation of requirements, subsequent monitoring of aid provisions, and the prevention of any misuse of resources or support, thereby facilitating effective management of assistance efforts. Moreover, challenges arise in human resource management, as NGOs involved in voluntary endeavors amid disasters possess access to diverse resources, encompassing aid provisions and workforce capabilities. Ensuring proper coordination among NGOs is essential for effective resource management and enhancing post-disaster recovery efforts while maintaining trust in NGOs. Autonomous systems present an opportunity to efficiently and promptly manage these resources, leveraging technology to simplify resource management and ensure coordination.

3. Decentralization

In many sectors and usage scenarios, there is a movement away from centralized systems and towards decentralized models. The intermediaries in the centralized systems slow down the operation and sometimes may not function as intended. Blockchain technology enabled us to develop decentralized systems where we can make transactions between peers without using any intermediary [19].

Blockchain technology operates as a distributed ledger system, facilitating trust among users directly, eliminating the need for intermediaries. This trust is established through interconnected records, referred to as transactions, which are organized into blocks by the computers (nodes) managing the blockchain system [4]. These transactions are stored securely in an immutable ledger. Given the decentralized nature of the blockchain system, it necessitates a mechanism for nodes to reach consensus on transactions, blocks, etc. Consensus protocols fulfill this function within blockchain networks, with the specific protocol chosen based on the characteristics of the blockchain in question.

Diverse types of blockchain networks exist, distinguished by factors such as node reliability, anonymity, and ledger accessibility. Public networks like Bitcoin [4] permit unrestricted access to transaction records, whereas private networks like Quorum [5] and R3 Corda [6] limit access to authorized users. The degree of decentralization, ranging from partial to complete, is contingent upon various hardware and software considerations, including network structure, node dispersion, consensus mechanisms, and developer expertise [19, 20]. While Bitcoin serves as a prime example of complete decentralization, enterprise solutions may exhibit limited decentralization, aiming to integrate essential stakeholders within specific ecosystems without monopolization. Hybrid architectures, which integrate blockchain solutions and centralized servers, offer increased flexibility in system design [19].

4. Related Works

Limited research exists on disaster management, with some attention given to the utilization of decision support systems [8] and the application of digital twins, as evidenced in a recent study [9]. Notably, there are comprehensive open-source solutions like Sahana EDEN (https://sahanafoundation.org/) that offer multiple functions, yet their adoption remains limited. Insights gathered from our expert interviews and NGO consultations shed light on potential reasons for this, primarily stemming from a lack of alignment with end-users' needs and concerns regarding transparency and trust in existing systems. Blockchain technology presents a promising avenue for addressing these challenges by eliminating intermediaries and establishing trust. While initially associated with cryptocurrency and criticized for its high energy consumption, advances in enterprise blockchain frameworks offer the possibility of creating trusted environments with reduced energy consumption. Furthermore, blockchain holds potential across various domains such as supply chain management, medical data sharing, AI marketplaces, and initiatives with social impact [10].

Existing literature includes few proposals for decentralized systems, particularly focused on fundraising efforts [11] and aid distribution in disaster or refugee scenarios [12]. One noteworthy study [13] explores the integration of IoT and blockchain within supply chains to enhance the efficiency of humanitarian aid delivery. However, these proposals often lack technical depth and fail to engage NGOs directly. Another theoretical model [14] challenges the feasibility of establishing a trusted supply chain for humanitarian aid, raising important considerations for future research.

To our knowledge, there exists no resource management system dedicated to disasters that specifically emphasizes collaboration among NGOs. Consequently, this system proposal is concentrated on developing a prototype aimed at creating significant social impact through enhanced NGO coordination in disaster management scenarios.

5. System Proposal

The NGO-RMSD model, depicted in Figure 1, involves the addition of nodes to the blockchain network by NGOs using blockchain technology. All transactions within the system will be securely encrypted and stored in an immutable manner. The distributed application, facilitated by smart contracts on the blockchain, will involve participation from NGOs, individuals in need, and supporters. NGOs, sanctioned by the ministry, serve as voluntary platforms aiding local governments and ministries during disasters. Individuals in need refer to those adversely affected by disasters, both materially and emotionally. Supporters encompass individuals, institutions, or organizations willing to provide tangible or monetary assistance to disaster victims [27].

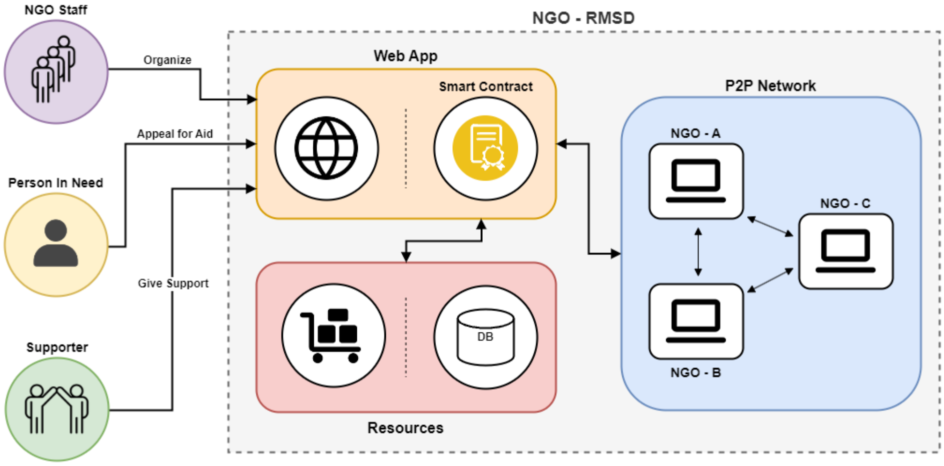

Fig. 1 NGO-RMSD Model

Underscoring the importance of privacy, the design of the system adheres to regulations such as the Turkish Law on the Protection of Personal Data (KVKK) [15] and the EU General Data Protection Rules (GDPR) [16]. Given the immutability of transaction records within the blockchain, they will not contain any personal information. Instead, such data will be stored exclusively in separate databases managed by individual NGOs. It is the responsibility of these NGOs to uphold the privacy of this information and ensure compliance with relevant legal requirements. While the utilization of non-interactive zero-knowledge proof (NIZK) based autonomous codes has the potential to enhance privacy further [17], this aspect is not within the scope of our current study.

5.1. Architecture

The system is formed of two main components, as illustrated in Figure 2; a blockchain (Quorum) network for NGO nodes and a web service. These components communicate through application programming interfaces (APIs), with the Web3JS library facilitating communication from node to JS Back-End. The front-end interface, developed using HTML and CSS, provides users across various platforms with a web page interface. Communication between the front-end and back-end is achieved through the ReactJS framework.

QBFT [24] is chosen as the consensus protocol of the proposed system as it is more stable, more efficient, and can support more nodes than the Istanbul Byzantine Fault Tolerance (IBFT) consensus protocol. Quorum and HyperLedger Besu recommended QBFT as the enterprise-grade consensus for production. Quorum developed QBFT to resolve the known problems of IBFT [26]. QBFT provides immediate finality, a dynamic feature set, optimal byzantine resilience, and O(n2) message complexity for n validators [24]. Validators are the approved accounts that can validate transactions and blocks. When a new block is proposed on the chain, this block is inserted into the ledger after a supermajority (greater than or equal to 2/3) number of validators sign the block.

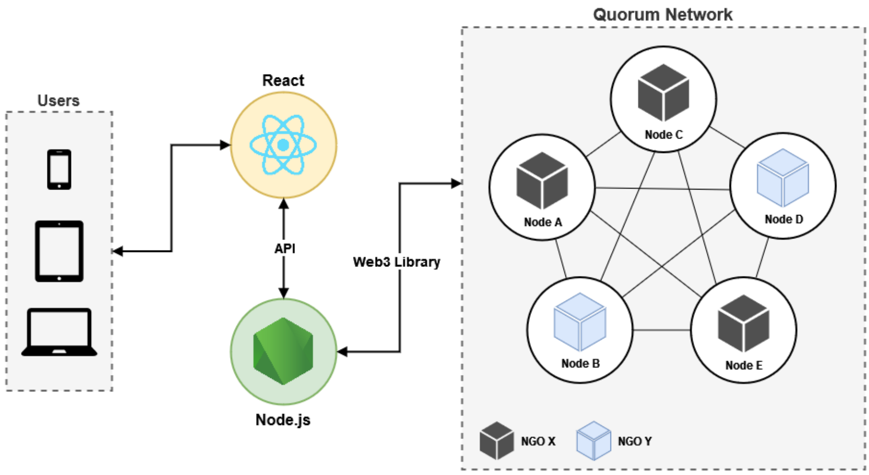

Fig. 2 NGO-RMSD System Architecture

We installed four initial (startup) nodes to initialize the blockchain network. QBFT and IBFT consensus protocols require four validators as a minimum number to be Byzantine fault tolerant [25]. It is desirable to add as many nodes as possible to the system for enhanced security and availability.

After system initialization, the first node account assumes an "admin" role, responsible for distributing admin privileges to predefined accounts on predetermined nodes following the community protocol. Each NGO participating in the blockchain network must have at least one node representing the institution. Since the system operates within a Docker image, there is no necessity to reserve a dedicated node machine solely for this purpose. This machine can still be utilized for general computing tasks by the NGO. Volunteers or NGO staff create their accounts through these nodes. These accounts will be used for reviewing support offers or requests and taking action. Efforts to automate this process are ongoing. Details are given on the Github repo page.

5.2. Smart Contracts

While blockchain technology is fundamentally oriented towards decentralization, certain implementations may also include centralized features. This is particularly evident in private or permissioned blockchain frameworks like Quorum, which delegate authority to specific entities for tasks such as adding nodes or users. The proposed system aims to prioritize trust and transparency. It assigns the ADMIN role to NGOs granting them to onboard new NGOs into the system and the authority to assign user roles such as CHECKER or CREATOR. Smart contracts allocate distinct roles to users, including

Admin, Checker, and Creator. The Admin role serves as the system administrator, while the Checker role is designated to NGOs to verify the accuracy of proposed support or requests. The Creator role, accessible to all system users, is crucial for initiating support offerings or requests.

Smart contracts have been developed to serve various functions, categorized as role management, requirement and support creation, approval processes, and request support listing. Role Assignment and Listing Functions, initiated by the system administrator, aim to allocate roles to users using the setUser function and display user roles using the getUserAuth function. Authority-Role Control Modifier Functions are utilized by organizers to compare the hash of a user's role with the assigned role hash. The Requirement Creation Function allows users in the "Creator" role to generate new needs, specifying details such as type and quantity, which are then added to the need list with a "waiting for confirmation" label. Similarly, the Support Creation Function empowers "Creator" role users to create new support entries, detailing aspects like type, quantity, and transportation type, with the created support appended to the support list marked as "waiting for approval". Approve Functions are designed for users with the "Checker" role, enabling them to validate pending needs and supports labeled as "waiting for approval". Once validated, the labels transition to "approved", and the approved support is listed in the approved support list. Request-Support Listing Functions facilitate the display of all needs and supports, with functions like showSupport and showSupports listing known supports, while showAllApprovedSupports lists approved supports. showNeedOffers and showNeed functions list needed records and known need records, respectively. The last two functions, showNeedStatus and showSupportStatus, are accessible to "Checker" role users and are responsible for listing known requests and confirmation status [27].

5.3. System Application Flow

The system's application flow, depicted in Figure 3, begins with the user selecting their application type. This selection is transmitted to the Quorum node and recorded as an unapproved application. A transaction is then broadcasted to the network, updating the ledgers of nodes. Subsequently, any unapproved applications within the network are reviewed by an NGO staff member who communicates with the applicant to validate the application. Upon validation, indicating the legitimacy of the requirement or support, the applicant's information is documented in the local database, and the application is approved. Following validation, the approved application is stored, and another transaction is initiated to update the network's ledgers. If no unapproved applications remain, the application flow process concludes.

The initial system comprises three nodes, demonstrating a scenario involving two NGOs with at least one one, utilizing total five nodes. The NGO-RMSD prototype is implemented on the Quorum framework, offering a private/permissioned blockchain structure with low energy consumption. Docker container technology facilitates integration into any operating system without the need for specialized hardware. Web3JS facilitates communication between the Quorum network and the web interface backend, while smart contracts are written in Solidity. QBFT consensus protocol is employed, with NodeJS utilized in the backend for its asynchronous functionality.

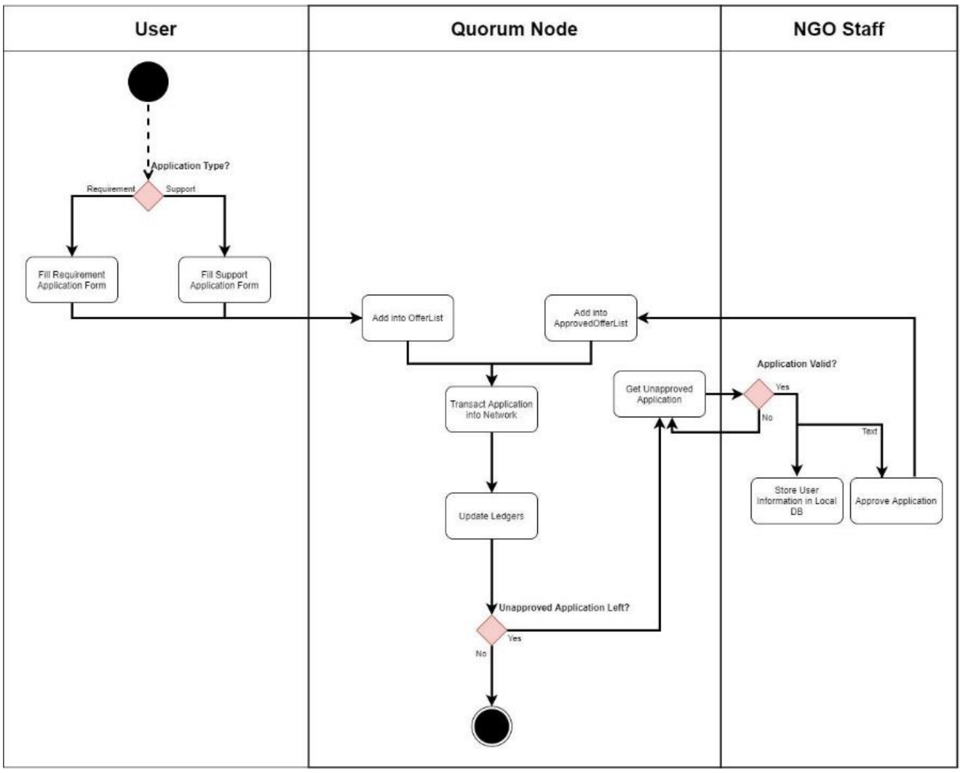

Fig. 3 System Activity Diagram [27]

6. IMPLEMENTATION

This project utilizes open-source and freely licensed software, with minimal dependencies on proprietary products. The smart contracts are deployed on the DS4H blockchain research network [18], currently consisting of five Quorum nodes, and users access the system through the web interface, designed to enable disaster victims to submit requests or provide support through forms. All system operations are recorded on the blockchain as transactions, and users can track transaction statuses through the web interface.

The smart contracts developed in this project are open to improvement. The current version of the system is given and described on the public Github page (https://github.com/MSKU-BcRG/akys). We continue to improve the smart contracts and implement security testing. These smart contracts are deployed in the DS4H blockchain research network. The users will use this system through the web interface. Prototype web interfaces have been developed for the system, allowing disaster victims to submit requests or provide support using forms displayed in Figure 4. Every operation within the system is recorded on the blockchain as transactions. Users have the capability to monitor the status of these transactions via the web interface depicted in Figure 5.

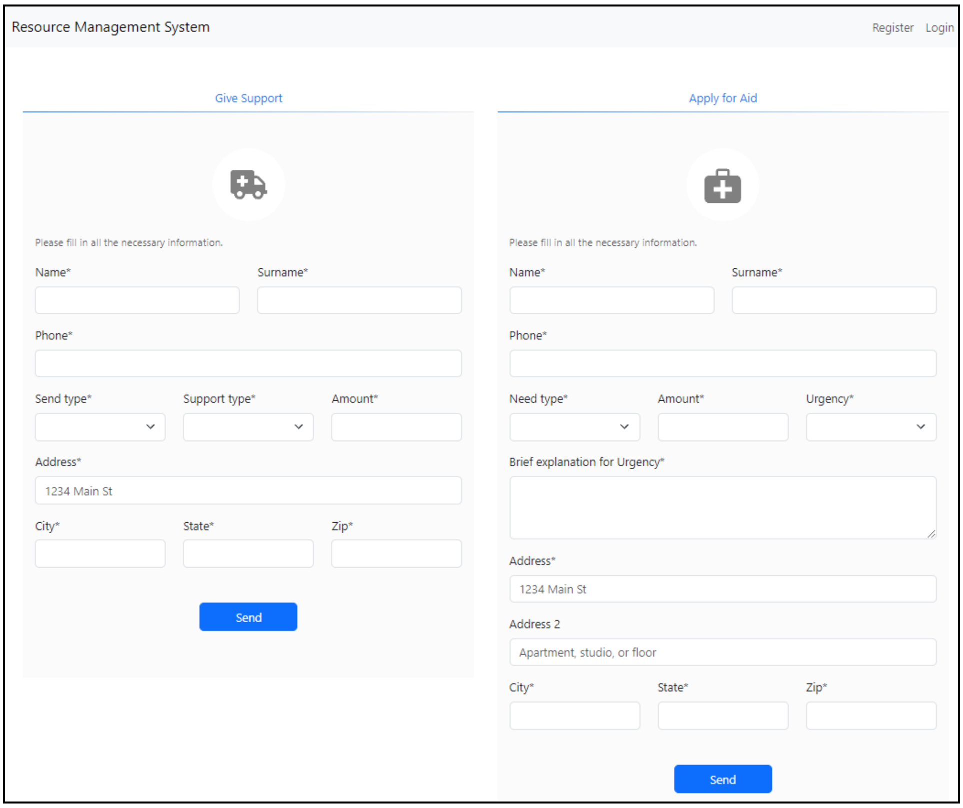

Fig. 4 User Forms of giving support and applying for aid

6.1. Performance Test

The test scenario was carried out with TUBU ArGe Company. We used two general-purpose AWS servers EC2 with 3.3 GHz Intel Xeon Scalable processors. Each instance has 2 GB Memory, 2 vCPUs, and 100 GiB SSD. Canonical, Ubuntu, 22.04 LTS operating system is used. Each instance has 3 nodes, 6 nodes are used in total. Quorum with QBFT consensus protocol is used. The block time interval is set to one second (default value was 5). The empty block interval value is used as 600 seconds (the default value was 60). The verbosity of logs is reduced from five to three, as this is enough to see the errors.

A test that is similar to normal daily blockchain usage was conducted. All transaction requests were made by incrementing the nonce value of a single user. Requests were sent to remote nodes. While calculating the average TPS, elapsed time and successful transactions were calculated. The successful transaction criterion is considered as getting a receipt. The receipt is available only for mined transactions.

In the first test, transactions were executed five times in total, at 5-second intervals, starting from 100 transactions and increasing up to 500 transactions. We reached up to 95.66 TPS max. In the second test, transactions were executed one time with 400 transactions. We reached up to 50.02 TPS max. A maximum of 374 transactions are fit into one block.

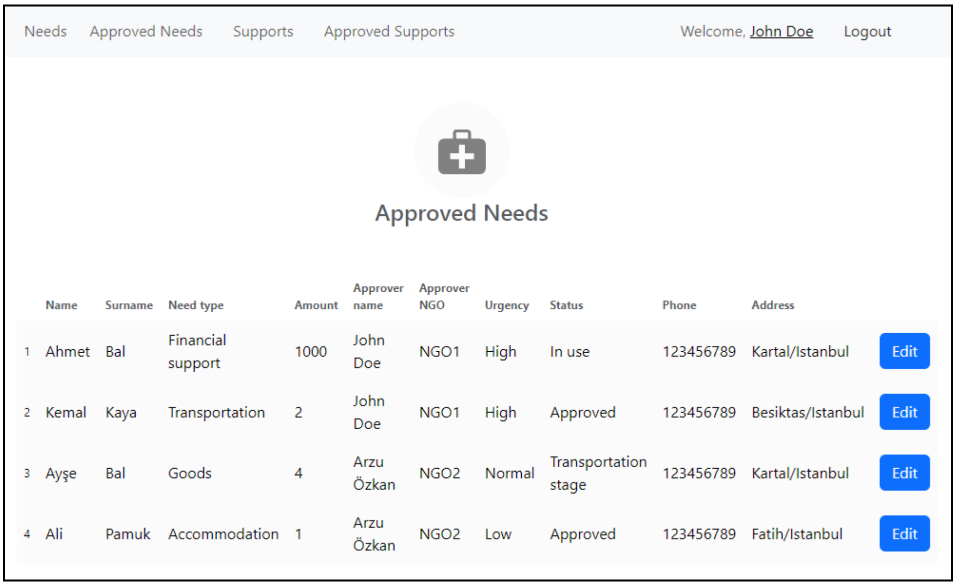

Fig. 5 Interface to track approved requests

6.2. Testing the Post-disaster Scenario

We tested the system as a simulation where a small earthquake damaged a village. There were needs like food, goods, accommodation, transportation and financial support. Ahbap NGO (https://ahbap.org/) is actively giving support during disasters. Arzu Özkan is an active volunteer in the Ahbap Organization. She checked if these needs were valid and then approved the needs on the system. Then the scenario continued as informing the parties.

7. Discussion and Findings

Our tests confirmed the decentralized system can be useful. We also want to emphasize the following possible improvements for a more sustainable system (See Fig. 6):

- Need categorization
- Regional need density analysis
- Logistics acceleration
- Warehouse assignment and prioritization
- Regional need density analysis
- Estimate real need
- Activity report
- Decentralized autonomous organization (DAO).

A highly advanced categorization can be made when communicating needs, and relevant need request categories can be automatically assigned to relevant NGOs. For example, all food needs are forwarded to NGO A, and shelter request needs are forwarded to NGO B.

Since those in need do not always have access to technology or may not use it because of electricity power outage or communication service outages; the real need is generally much greater than informed. We should also work on identifying a common pattern to provide support to people who cannot reach us.

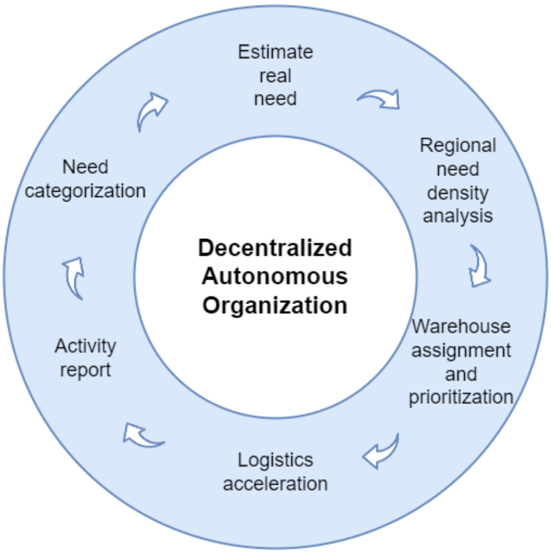

Fig. 6 Resource Management Improvements

Need density analysis should be conducted on a regional basis. For example, if the needs coming from region A are generally in a similar pattern (food, tent, shelter, etc.), early steps can be taken, such as having resources ready in that region. We experienced this in the Kahramanmaraş (Türkiye) earthquake in 2023. We created a location-based need density map by categorizing the incoming needs and creating a density-based map chart. Then, instead of wasting time by reaching out to each person in need in the same region one by one, NGOs identified the intensity of need in that region and delivered resources in the requested category to the associated locations. The logistics and distribution process of resources became much easier then.

Logistics is a problem during a disaster and requires intensive resource management. It can be very difficult to distribute the resources. Needs can be grouped from the same or nearby location to accelerate the confirmation and delivery processes to facilitate logistics operations. Then these can be delivered to nearby locations with a single truck or a group of coordinated trucks.

Warehouse assignment can be done by automatically matching incoming needs with the materials in the associated warehouse. It will require a system integrated with the warehouse inventory of NGOs. Prioritization should be done according to the warehouses in the nearest location when making matches.

The system can give an activity report of each NGO. A detailed listing of each NGOs activities on the system can be generated. These activities can be formed of which request's status was changed by which NGO member, and when, etc. These are very critical, especially for post-disaster inspections. A trusted reporting system will also relieve the legal pressure on the NGOs.

A decentralized autonomous organization (DAO) is needed to make such a system sustainable. It will ensure rapid decisions on managing the resources. NGOs will be active users of the system and decide together on new users and improvements to the system. Such a management system was proposed in a previous study [18] and is active in the DS4H blockchain research network.

8. RESULTS AND CONCLUSIONS

A decentralized resource management system (NGO-RMSD) for disasters is proposed and a prototype is implemented as a proof of concept. The proposed system will enable NGOs and government agencies to act in coordination. All transactions are transparent in this trusted system design.

The proof of concept implementation of the NGO-RMSD demonstrated promising outcomes, with smart contracts and project details publicly accessible on the project's Github page (https://github.com/MSKU-BcRG/akys). Live testing of the proposed system was implemented in the DS4H blockchain research network. The performance tests showed the system can handle 95 TPS which can be enough for several scenarios. We also tested the system on a scenario and confirmed the system is useful. Possible improvements for a more sustainable system are discussed on need categorization, estimate real need, regional need density analysis, warehouse assignment and prioritization, logistics acceleration, and activity report. DAO will enable the coordination between NGOs and make such a system sustainable as it will ensure rapid decisions on managing the resources.

Although the system has not yet undergone testing during an actual disaster event, ongoing communication with relevant NGOs indicates plans for further community-driven development. Future implementation of a DAO (Decentralized Autonomous Organization) is anticipated to enhance workforce and resource management, enabling NGOs to reach a broader spectrum of individuals in need and promptly address urgent requirements. Implementation of Zero Knowledge Proof (ZKP) based systems is envisioned to safeguard against unauthorized sharing of personal data, ensuring compliance with privacy regulations.

In upcoming efforts, focus will be placed on dynamically establishing new nodes and automating authentication processes, with detailed updates available on the project's Github repository. Integration of the system with new legislative frameworks will be prioritized, alongside continued emphasis on personal data privacy through ZKP algorithms. Furthermore, a dataset comprising collected data from disaster areas will be analyzed, facilitating the development of a decision support system using machine learning and Natural Language Processing (NLP). NLP will aid in matching requirement and support requests by analyzing textual data, while the integration of Large Language Models (LLM) with additional datasets and social media content, such as tweets, will further enhance system capabilities.

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