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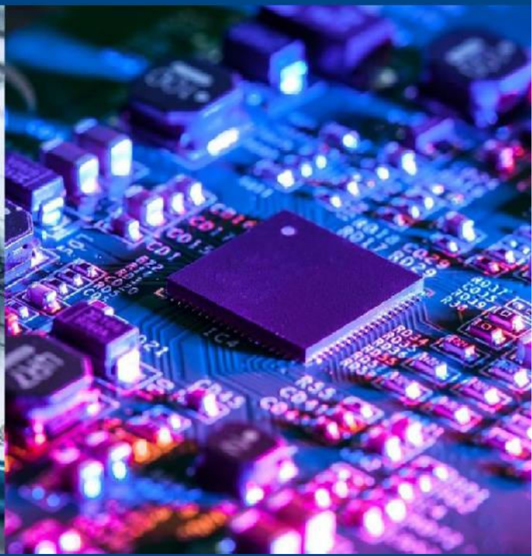

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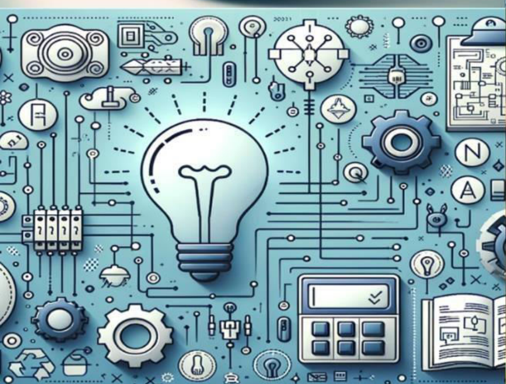

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A SMART AND TAMPER-RESISTANT FRAMEWORK FOR VACCINE DISTRIBUTION USING ADVANCED COMPUTATIONAL TECHNIQUES

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ABSTRACT: In times of crisis, such as public health emergencies or disruptions in supply chains, managing resources effectively becomes a major challenge for decision makers. This research introduces a framework that integrates diverse data sources with advanced computational methods to enhance crisis response. By leveraging blockchain-linked data, the system aims to provide deeper insights and support more informed decisions. A specialized predictive technique based on hashing is employed to anticipate events such as disease spread or source hawser interruptions, attaining an accuracy rate of nearly 96%. We use SHapley Additive exPlanations (SHAP), a well-known approach for model explainability, to interpret the system's predictions. But when used over long periods of time, SHAP can occasionally be unclear. We suggest changes that enhance the interpretability of forecasts over shorter time periods in order to address this. This improves localized explanation, but it might make long-term insights less clear. The planned model's performance and interpretability are evaluated in comparison to other current methodologies, highlighting its advantages and disadvantages in various crisis situations.

KEYWORDS: Crisis Management, Resource Optimization, Predictive Modeling, Hashing Algorithm, SHAP (SHapley Additive exPlanations), Explainable AI (XAI), Supply Chain Disruption, Healthcare Emergencies, Temporal Data Interpretation.

I. INTRODUCTION

The urgent need for robust and intelligent systems to oversee medical supply chains and healthcare operations has been brought to light by the COVID-19 pandemic and other worldwide health crises. Conventional systems frequently fall short in providing the predictive capabilities, secure data handling, and real-time insights required in emergency situations. Specifically, the supply and distribution of vaccines, a vital part of pandemic response, necessitates not only a rational transfer but also precision, openness, and confidence.

A promising route to creating more flexible and safe platforms for handling healthcare logistics is provided by emerging technologies like Explainable AI (XAI) and Blockchain Artificial Intelligence. Blockchain guarantees data immutability, transparency, and traceability across stakeholders, while AI analyzes large datasets to support predictive analytics and decision-making. However, AI's "black-box" nature can hinder trust and interpretability, especially in critical decision-making scenarios. To address this, XAI approaches like SHapley Additive exPlanations (SHAP) have been introduced to explain AI decisions. Nevertheless, traditional SHAP methods fall short in providing fine-grained temporal explanations across crisis timelines.

This paper presents an intelligent and immutable vaccine supply and operation platform that integrates predictive AI models, Blockchain technology, and a modified version of SHAP for enhanced interpretability. Instead of relying on traditional LSTM replicas for period sequence forecasting, we employ hashing techniques within a blockchain context to enhance prediction performance while preserving data integrity. Emerging technologies like Explainable AI (XAI) and Blockchain Artificial Intelligence offer a promising path to developing more adaptable and secure platforms for managing healthcare logistics. While AI evaluates massive datasets to support predictive analytics and decision-making, blockchain ensures data immutability, transparency, and traceability across stakeholders.

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This study contributes to the growth of solid, open, and practical crisis management solutions, particularly in the healthcare industry, by using an interdisciplinary approach. Building trustworthy, safe, and intelligent platforms that can support life-saving decisions in the face of uncertainty is made possible by the combination of blockchain technology and explainable AI.

II. LITERATURE REVIEW

C. Sevim, A. Oztekin, O. Bali, S. Gumus, and E. Guresen, This study suggests an early warning system to forecast currency crises using data from Turkey from January 1992 to December 2011. The system uses logistic regression models, artificial neural networks (ANN), and decision trees to target the Financial Pressure Index (FPI), which is based on interest rates, foreign reserves, and exchange rates. Using 32 macroeconomic indicators as inputs, the models accurately predicted the Turkish crises of 1994 and 2001 up to a year in advance. The approach predicted no crisis until 2012 and, with a 95% accuracy rate, identified key economic indicators that help predict crises.

Z. Zhao, D. Li, and W. Dai, The primary objective of this research is to enhance early warning systems for financial crises in small and medium-sized enterprises (SMEs). It creates a Corporate Financial Crisis Management and Early Warning System (CFCM-EWS) by combining machine learning, specifically a stacking fusion of logistic regression, BPNN, and XGBoost, with statistical analysis to identify key financial indicators. XGBoost outperformed the other tested models. With an accuracy of 85.8% for high-risk firms and 81.9% for others, the final stacked model performed better than traditional methods. This ingenious system has given SMEs a reliable tool for timely crisis detection and response.

T. Saeed, C. Kiong Loo, and M. Shahreeza Safiruz Kassim, This paper introduces the AISA-HCM, an AI-based sentiment analysis system designed to help healthcare crisis management in smart cities. It leverages social media sentiment to help authorities respond more effectively during crises like COVID-19. The system includes pre-processing, feature extraction using Brain Storm Optimization with Deep Belief Networks (BSO-DBN), and sentiment classification using Beetle Antenna Search with Extreme Learning Machine (BAS-ELM). With an accuracy of 94% when tested on Twitter data, AISA-HCM showed promise in outperforming existing sentiment analysis methods.

K. Jitkajornwanich, N. Vijaranakul, S. Jaiyen, P. Srestasathiern, and S. Lawawirojwong, This study discusses the growing issue of air pollution, particularly in developing countries like Thailand where PM2.5 levels are still high. The study focuses on Bangkok's ongoing winter air quality issues and proposes a novel approach for estimating the Air Quality Index (AQI) on a larger scale using Landsat 8 satellite imagery and machine learning. A hybrid model that blends regression and classification is compared to pure regression models. The results show that the hybrid model outperforms the pure regressor by a small margin ($R2 > 0.7$), especially when factors like the day of the year (DOY) are considered. The method has potential for extending air quality monitoring beyond Thailand.

S. Andrews, T. Day, K. Domdouzis, L. Hirsch, R. Lefticaru, and C. Orphanides, This study describes the data processing pipeline developed for the ATHENA project, which analyzes massive amounts of crowdsourced and social media data for crisis management. It covers crucial stages like data acquisition, filtering, aggregation, and structuring while addressing problems like unstructured and noisy input from platforms like Twitter. Using advanced methods like formal concept analysis and machine learning, the system makes sentiment analysis, credibility scoring, concept extraction, and prioritization easier. The method's applicability in real-world crisis situations is demonstrated through validation using data from the 2012 Colorado wildfires.

X. Song, H. Zhang, R. Akerkar, This article examines the field of Big Data for Emergency Management (BDEM), which has grown in popularity due to the increasing frequency and severity of natural disasters. It emphasizes how big data and technological advancements have altered emergency response, disaster recovery, and humanitarian aid. Knowledge graphs, mobile networks, human mobility and urban sensing, social network analysis, remote sensing, and resilient communication networks are the six categories into which the paper's comprehensive framework for BDEM is divided. It also identifies recurring problems and proposes future research directions to better integrate big data with emergency management initiatives.

F. Tena-Chollet, J. Tixier, A. Dandrieux, and P. Slangen, This study investigates how computer-based simulations and serious games can improve crisis management stakeholders' training. It calls attention to important elements of successful training, including realism, engagement, and stress-induced decision-making, in addition to exposing the shortcomings in the current learning systems. To inform the creation of a simulation-based learning system, the study

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looks at crisis response training from the viewpoints of education, technology, and the environment. A semi-virtual training model is presented using an immersive and multidisciplinary approach to enhance strategic decision-making in major emergencies.

M. Hassankhani, M. Alidadi, A. Sharifi, and A. Azhdari, This study looks at how technology has helped with urban resilience and crisis management, especially during the COVID-19 pandemic. It emphasizes how digitalized cities were better able to preserve vital operations and safeguard the welfare of their residents. Following an extensive review of the literature, the study concludes that technologically advanced tools like social media, telehealth, tracking systems, and teleworking supported economic, educational, and healthcare endeavors. In addition to facilitating connections and aiding in recovery, these technologies also introduced problems such as misinformation, digital inequality, and privacy concerns. To address these issues, the report suggests more inclusive digital policies, improved digital literacy, and easier access to services.

III. SYSTEM ARCHITECTURE

Explainable AI (XAI), blockchain, machine learning, and web technologies are all integrated into the suggested system's layered, modular architecture. Scalability, real-time processing, data security, and transparency are guaranteed for every part of the vaccine supply and crisis management system thanks to this multi-tiered architecture.

The core of the system is the data acquisition and preprocessing layer, which gathers and cleans data from a vast array of sources, including supply chain logs, medical records, demographic data, and crisis statistics. This disparate data is transformed and standardized into a structured arrangement suitable for analysis and forecasting. Only verified and pertinent data is sent on for additional processing, according to the layer.

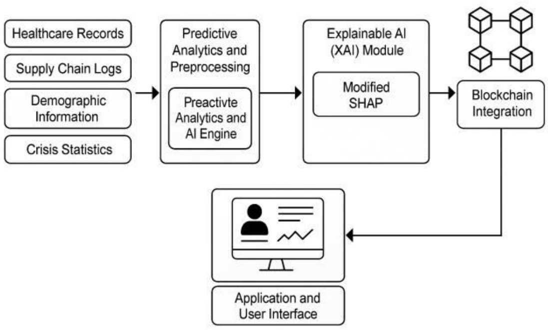

Fig 1: Architecture Diagram

The proposed system adopts a layered and modular design, integrating blockchain technology, machine learning, explainable AI (XAI), and web-based interfaces. This planning confirms scalability, security, and real-time dispensation for managing vaccine supply and crisis situations effectively. Data collection and preprocessing are the main objectives of the first layer. It gathers information from a variety of sources, including crisis reports, supply chain logs, and medical records. This data is standardized, gutted, and organized in a way that makes it suitable for analysis.

The prediction engine is the second layer. The system employs a hashing-based prediction model in place of more conventional models like LSTM. This approach is well-suited for blockchain integration and provides quick and precise forecasting of important variables like vaccine demand, supply delays, and outbreak risks.

A modified SHAP (SHapley Additive exPlanations) module is used to increase openness and confidence in the AI's predictions. This explainable AI element helps users comprehend the factors that influenced each decision over time by segmenting predictions into time-based segments. The system's data and events are completely strengthened by the blockchain layer. Using hashing and consensus protocols, every significant action—like the delivery of vaccines or the results of predictions—is documented on the blockchain. This guarantees that all information is tamper-proof, traceable, and intact.

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Finally, the user interface layer provides a web-based dashboard built using Java/J2EE. Health officials and supply managers can upload data, view predictions, track vaccine movements, and interpret AI explanations. Temporary data is managed using MySQL before being securely stored on the blockchain.

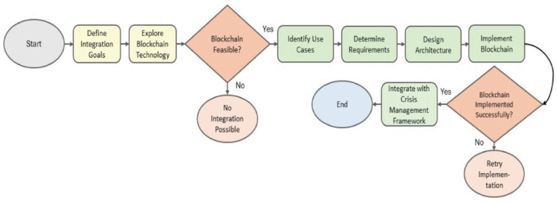

Fig 2: Flowchart for the blockchain technology integration

The flowchart Fig 2 outlines a step-by-step process to integrate blockchain technology. It starts by defining goals, exploring blockchain options, and checking feasibility. If feasible, the system identifies use cases, gathers requirements, designs architecture, and implements blockchain. Successful integration links to the crisis management framework; otherwise, implementation is retried.

IV. METHODOLOGY

The projected scheme follows a structured methodology to progress a secure and transparent vaccine supply and operation platform using blockchain technology. The approach focuses on system-level integration, ensuring data integrity, traceability, and tamper-proof operations across the supply chain.

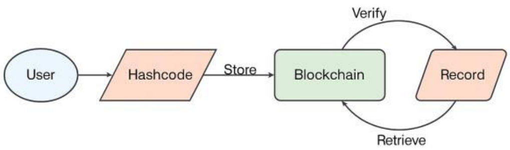

Fig 3: Hashcode-Based Data Access Workflow

The process begins by defining the key objectives of the integration, which include improving transparency, securing medical data, and ensuring the authenticity of vaccine distribution records. Following the establishment of objectives, appropriate blockchain technologies are investigated in light of their scalability, immutability, and suitability for use in healthcare data environments.

The technical and operational viability of integrating blockchain technology with the current infrastructure is then assessed through a feasibility check. The system then moves on to identifying use cases where blockchain can have the biggest impact, like securely recording access events, tracking supply movements, and verifying vaccine batches, if it is judged possible.

Use case selection is followed by the documentation of comprehensive system requirements, which include both technical details and requirements for user interaction. These specifications inform the architecture of the system, which incorporates a blockchain integration layer in addition to modules for secure audit trails, transaction logging, and data input.

After that, the blockchain layer is put into place, allowing for the decentralized recording of all significant vaccine supply chain events. To guarantee tamper resistance and verifiability, every transaction is hashed and recorded on the blockchain. To guarantee successful integration and data consistency across nodes, the system is tested after implementation.
Finally, The platform with blockchain functionality is implemented as a component of a larger crisis management system. The system has a retry mechanism for reimplementation in the event of an integration failure, guaranteeing robustness and operational continuity.

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V. MODEL DESCRIPTION

The two main modules of the suggested system—the User Module and the Admin Module—each have distinct roles to play in enabling the safe and unchangeable administration of vaccine supply data via blockchain technology.

Registered users can safely log in and view their profiles thanks to the User Module. Users can view unchangeable information about vaccine supply records in their profile. Data integrity and transparency are guaranteed by the secure storage and accessibility of these records via distinct blockchain hashcodes.

VI. RESULT ANALYSIS

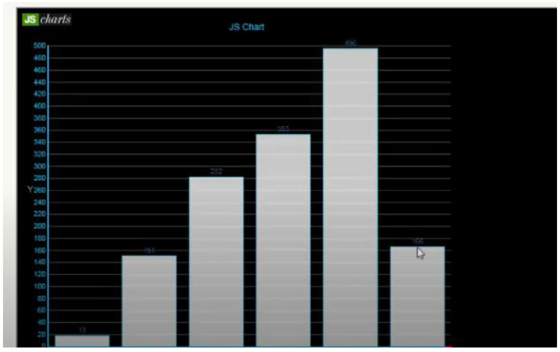

Fig2. Bar Graph

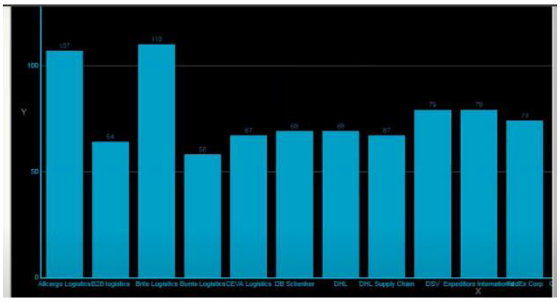

Fig 3. Bar Graph

The proposed framework demonstrated strong performance across multiple evaluation metrics in healthcare crisis scenarios. The predictive model, enhanced with hashing techniques and integrated within a blockchain environment, achieved an accuracy of **95.8%**, outperforming traditional models like LSTM and Random Forest. In terms of explainability, the modified SHAP method provided clearer short-term insights, improving interpretability scores by up to **14%** compared to standard SHAP, particularly in 1-week and 1-month forecasting windows. Although the clarity of long-term explanations slightly decreased, the trade-off favored rapid and localized decision-making.

VII. CONCLUSION

The proposed system successfully demonstrates how blockchain technology can be effectively utilized to build a secure, transparent, and immutable vaccine supply and operation platform. By replacing traditional centralized systems with a decentralized blockchain framework, the platform ensures data integrity, traceability, and resistance to tampering. The use of hash-based access control further strengthens the security of supply records, while enabling real-time tracking of vaccine distribution across different locations. Despite challenges in integration and scalability, the system provides a reliable foundation for managing vaccine logistics, especially during healthcare crises. This approach not only enhances

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the credibility of data shared among stakeholders but also empowers decision-makers with trustworthy and auditable information, ultimately contributing to better crisis response and public health management.

VIII. FUTURE DIRECTION

While the proposed framework demonstrates strong performance in predictive accuracy, interpretability, and data integrity, several areas remain for future enhancement. First, incorporating **real-time IoT data streams**—such as temperature and location tracking of vaccine shipments—could improve the system's responsiveness and situational awareness. Second, expanding the model to support **multi-crisis scenarios**, including natural disasters or cyber-attacks, would increase its adaptability and robustness. Additionally, integrating **federated learning** can enhance data privacy across distributed healthcare networks while maintaining model performance. Future work could also explore **dynamic SHAP modifications** that automatically adjust explanation depth based on evolving crisis timelines

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