Development of ERP System for Outsourcing Company using Internet of Things and Blockchain Technology

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Abstract - Enterprise Resource Planning (ERP) systems are pivotal in optimizing operations within outsourcing industries, providing a unified platform for managing business processes. However, the current generation of ERP platforms exhibits significant limitations in seamlessly integrating with emerging technologies such as the Internet of Things (IoT) and blockchain. the paper highlights the transformative potential of effective integration with IoT can offer real-time visibility and operational efficiency such as attendance of the worker, while blockchain can provide robust security and transparency of worker activity through smart contracts. The implementation of an ERP system compared to the traditional manual method to quantify the efficiency gained through this technological advancement. In this analysis, we collected attendance data for 20 employees, documenting the time taken for both manual and ERP-based attendance in seconds. The result of ERP system significantly reduces attendance time. Efficiency is calculated as the percentage reduction in time achieved by using the ERP system compared to the manual method. An average efficiency of 69.05% shows that, overall, the use of ERP is nearly 70% more efficient than the manual method with IoT data transfer using MQTT to blockchain result is 100% retention rate.

Keywords: Enterprise Resource Planning, efficiency, Internet of Things, blockchain, outsourcing company

I. INTRODUCTION

Enterprise Resource Planning (ERP) systems have become indispensable tools in the outsourcing industry, where efficiency, accuracy, and streamlined operations are paramount. These systems integrate various business functions such as finance, human resources, supply chain management, and customer relationship management into a single cohesive platform. This integration enables organizations to automate processes, improve data accuracy, and enhance decision-making capabilities[1]. The Sustainable Development Goals (SDGs) are goals set by all countries that join the United Nations to end poverty, protect the earth, and ensure that everyone has a chance to live a good life [2], [3]. Indonesia has established a program to achieve the SDGs by 2030, dividing the 17 international goals into four pillars: social development, economic development, environmental sustainability, and legal reform [4], [5]. The industrial sector plays a significant role in reducing unemployment and improving the welfare of the population. Data from the Ministry of Industry indicates that approximately 60% of employment opportunities for the unemployed come from the industrial sector. To enhance operational efficiency and optimize processes, the ERP platform is utilized for supply chain management in industries.

ERP is a platform designed to manage an enterprise's operational processes, encompassing supply management, production, sales, and more[6]. By leveraging ERP, companies can improve their performance through increased efficiency, automated administration, and streamlined business processes [7], [8]. Outsourcing companies handle complex operations involving multiple processes such as project management, human resources, finance, procurement, and customer relationship management. ERPs integrate these functions into a single system, facilitating smooth and efficient workflows. This integration eliminates data silos, reduces redundant tasks, and ensures that all departments have access to real-time information, enhancing overall productivity and efficiency.

The current weakness of ERP platforms lies in their inability to seamlessly integrate with various emerging technologies such as IoT and blockchain. This limitation hampers the adaptability of ERP systems to the evolving technological landscape. The lack of integration with these cutting-edge technologies restricts the potential for leveraging real-time data from IoT devices and the enhanced security features offered by blockchain. One of the most interesting implementations of the Internet of Things (IoT) is LoRa (Long Range Wide Area Network) [9], [10], [11]. LoRa is a wireless communication technology specifically designed to connect low-power IoT devices over a wide network. LoRa technology is well-suited for systems that support the Sustainable Development Goals (SDGs) [12]. LoRa supports wide-ranging IoT networks, which can be used to support various applications that align with the SDGs, such as agricultural monitoring, healthcare monitoring, and more [13]. To improve the security of the ERP system blockchain technology holds substantial potential for enhancing the capabilities and security of the ERP systems. Blockchain's inherent security features, such as immutability and cryptographic hashing, make it an ideal solution for protecting sensitive ERP data [14]. All s and records are securely and transparently recorded, minimizing the risk of data tampering and fraud. Blockchain operates on a decentralized network, meaning that data is not stored in a single, vulnerable location. This reduces the risk of data loss due to a single point of failure and enhances data resilience [15], [16]. Blockchain offers transparent and auditable records of all s [17]. This transparency is invaluable for supply chain management, auditing, and compliance, which are crucial aspects of many ERP systems. Every recorded data on the blockchain can be audited and traced back to its origin. This is essential for compliance and auditing, which are core components of ERP functionality.

The uniqueness of this research is to integrate IoT and blockchain technologies into the ERP system. While both IoT and blockchain have individually shown their value in enhancing data security, transparency, and automation, the combined integration of these technologies within an ERP framework is relatively uncharted territory. This research seeks to bridge the gap between these technologies to create secure, transparent, and scalable system. The synergies of IoT and blockchain, offering a transformative solution for businesses seeking to optimize their operations and data management in a secure and environmentally conscious manner. Section II explains the conceptual design and method the system used. Section III explains the environment implementation of the system and result. The conclusion of this research will be described in section IV.

II. METHOD

In this section, we will outline our initial research design system for the ERP integrated with blockchain and IoT technology shown in Fig. 1. There are several section for proposed system related to IoT System, ERP System, and blockchain that will be described below with the experimental environment presented in Table I, II, and III.

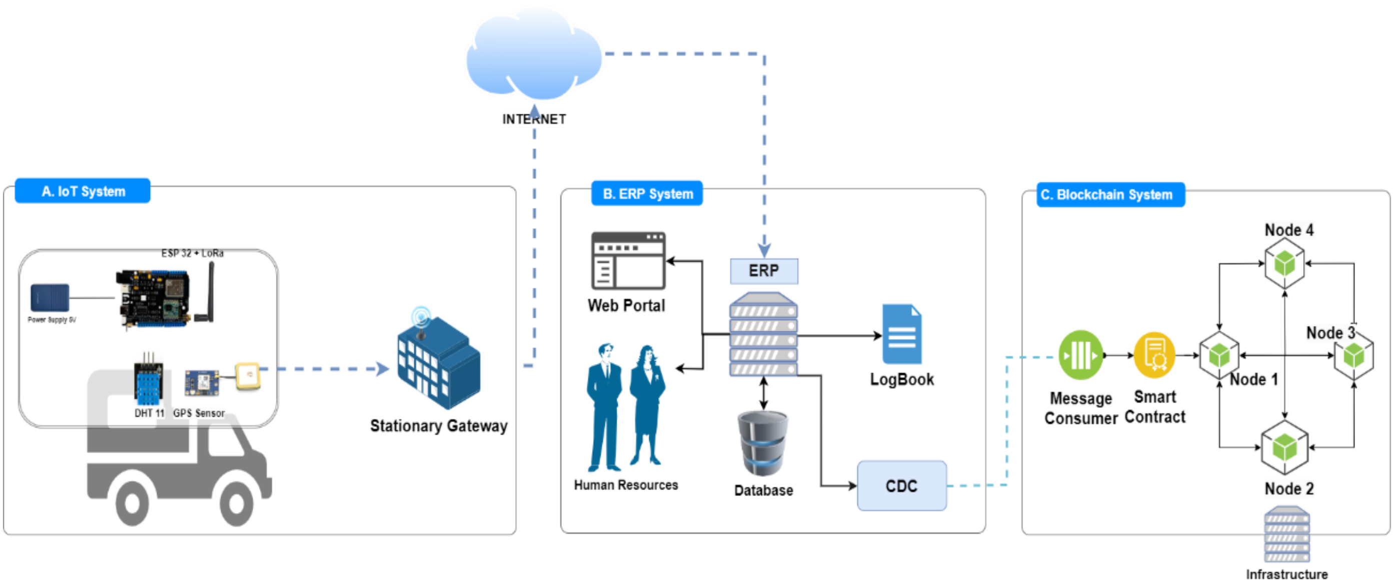

Fig. 1 System design

TABLE I
IoT DEVICE SPECIFICATION

No	Module	Specification
1	Transmitter (LoRa Aurora)	• ESP32 • LoRaWAN RFM95W • Antenna 915 Mhz • Cable Connector • Breadboard • Base Frequency 915 MHz • LoRaWAN Frequency Range 902 – 928 MHZ
2	Receiver (LoRa Aurora)	• ESP32 • LoRaWAN RFM95W • Antenna 915 Mhz • Cable Connector • Breadboard • Base Frequency 915 MHz • LoRaWAN Frequency Range 902 – 928 MHZ
3	GPS Hardware (uBlox GPS NEO M8N)	• Voltage Operating 5 V • -161 dBm Sensitivity • Clock Speed Frequency: 16MHz

TABLE II
ERP SERVER SPESIFICATION

No	Server Requirement	
	Item	Spesification
1	Processor	CPU intel core i7
2	RAM	16 GB
3	Memory	500 GB
4	Database	MariaDB
5	Programming	HTML, CSS, Javascript

TABLE III
BLOCKCHAIN SERVER NODE SPECIFICATIONS

Component	Specification
RAM	8 GB
ROM	150 GB
Virtual Machine	4 CPU(s), 1382 MHz used
Software Version	Hyperledger Besu 22.7.4

A. IoT System

An IoT system for ERP to monitor supply chains is efficiently designed by integrating a microcontroller, specifically the ESP32, with LoRa communication capabilities. This system incorporates various sensors to gather several data, including the DHT11 for temperature and humidity readings and a GPS sensor to acquire precise longitude and latitude coordinates. The ESP32 serves as the central processing unit, collecting, and transmitting real-time data from these sensors. The temperature and humidity data from the DHT11 sensor offer insights into the environmental conditions affecting the supply, while the GPS data ensures precise tracking of the location throughout the entire logistics process. The LoRa communication technology facilitates long-range data transmission with JSON format to stationary gateway and will be deliver to ERP website.

B. Enterprise Resources Planning System

The ERP system equipped with a web portal, human resources, logbook, and database management. This ERP system used open-source ERP solution called ERPNext, ERPNext allowing for customization and designed to be deployed on a server. The web portal serves as a gateway to access and manage several components such as human resources, logbook, and database management. The utilization of widely recognized web development languages, including HTML, CSS, and JavaScript to facilitate user to modification and manage. The details of system described as follows:

1) Web Portal: ERPNext is an open-source ERP system that is built on top of the Frappe framework. To customizing the web portal in ERPNext, we use HTML and CSS for structuring and styling the user interface to advertise the industry trough ERP Platform to make responsive and friendly use for user.

2) Human Resources Management: The Human Resources module in ERPNext encompasses a comprehensive set of functionalities for employee information management, onboarding processes, attendance tracking, leave management, performance evaluations, training and development programs, employee self-service through website portal. It shows graphical data and historical attendance of the employee in the industry.

3) Database: ERPNext utilizes MariaDB as its underlying database system to store data in structured formats, facilitating organized and efficient data management. This relational database, based on the entity-relationship model, ensures that data relationships are maintained and can be easily navigated through the user interface.

4) Logbook: *The logbook's* integration with monitoring tools provides real-time alerts for events requiring immediate attention, and access controls ensure that only authorized personnel can access and manage this crucial repository of historical data. It will capture details such as logins, data entries, updates, and other system operations. Each entry is meticulously timestamped to establish a chronological sequence of events, enabling a clear understanding of the timing of specific activities. User identification is a key component, ensuring accountability as administrators can trace actions back to specific users.

C. Blockchain

Through the utilization of Hyperledger Besu to establishing a private network hosted on our server. Hyperledger Besu use QBFT Proof of Authority (PoA) consensus protocol that implemented in the system where the consensus of the majority of validators (equal to or greater than 2/3) is required to add a block to the chain. Validators, responsible for validating s, must reach consensus, and QBFT ensures Byzantine fault tolerance by mandating at least four validators to achieve agreement, even in scenarios where specific nodes encounter difficulties in propagating data to their peers. The entire blockchain infrastructure using smart contract to store the data and several blockchain infrastructure. The details of blockchain system described as follows:

1) Message Consumer: *The integration* of a Change Data Capture (CDC) mechanism, enabling the ERP system to capture real-time data changes from IoT devices. At the core of this integration, a Message Consumer component serves as the connecting link, seamlessly linking the CDC module with the blockchain layer. This strategic connection guarantees the swift and accurate transmission of every modification made within the ERP system to the blockchain network. It's noteworthy that the data to be captured is in JSON format, encompassing information such as temperature, humidity, and the location of the goods.

2) Smart Contract: Smart contracts written in Solidity bring the ability to execute code on the Ethereum blockchain, enabling decentralized and trust lessness execution of predefined logic. Solidity is a high-level programming language designed specifically for creating smart contracts on the Ethereum Virtual Machine (EVM). Here's how you might structure a Solidity smart contract to handle and store IoT data like temperature, humidity, longitude, and latitude data.

3) Node Validator: The Blockchain Server Node in the Hyperledger Besu network boasts robust specifications designed to support the intricacies of blockchain operations. Each node needs minimum 8 GB of RAM and 150 GB of ROM. To ensure the decentralization system, the minimum node equipped is 4 nodes. Additionally, the presence of Quorum Block Explorer enhances transparency and visibility into the blockchain's history from each node. This comprehensive setup reflects a commitment to optimal performance, security, decentralization, and management capabilities within the blockchain infrastructure.

III. RESULT AND DISCUSSION

In this section, the results of the system will be implemented with outsourcing company in integrating the ERP platform with IoT and blockchain technologies. The discussion will delve into the environment specifications, the methodology utilized for experimentation, and a comprehensive analysis of the implementation results, cantering on the performance of this integrated system.

A. Evaluation of Attendance Efficiency Time Reduction Using ERP System

This section will describe the analysis of the efficiency improvements achieved by outsourcing company employee's attendance process through the implementation of an ERP system compared to the traditional manual method. Our goal was to evaluate how the transition to an ERP system has impacted the time required for attendance and to quantify the efficiency gained through this technological advancement. In this analysis, we collected attendance data for 20 employees, documenting the time taken for both manual and ERP-based attendance in seconds. By comparing these times, we calculated the efficiency percentage for each employee, providing a clear picture of the improvements brought about by the ERP system Table IV.

Based on the provided data, The analysis of the employee's attendance using both manual and ERP systems This indicates that the average time taken for manual attendance is 129.75 seconds, whereas with the ERP system, it is only 40.5 seconds. Thus, the ERP system significantly reduces attendance time. Efficiency is calculated as the percentage reduction in time achieved by using the ERP system compared to the manual method. An average efficiency of 69.05% shows that, overall, the use of ERP is nearly 70% more efficient than the manual method. From the table, efficiency for each employee varies, with the lowest being 62.5% and the highest at 77.27%. This demonstrates that all employees experience significant efficiency improvements when switching to the ERP system.

TABLE IV
COMPARISON OF ATTENDANCE TIME AND EFFICIENCY BETWEEN MANUAL AND ERP SYSTEMS

No	Name	Occupation	Manual Absence Time (Seconds)	Absence using ERP (Seconds)	Efficiency (%)
1	Employee 1	Worker	120	45	62.50
2	Employee 2	Worker	150	50	66.67
3	Employee 3	Worker	135	40	70.37
4	Employee 4	Worker	110	30	72.73
5	Employee 5	Worker	125	35	72.00
6	Employee 6	Worker	140	50	64.29
7	Employee 7	Worker	130	40	69.23
8	Employee 8	Worker	115	30	73.91
9	Employee 9	Worker	145	50	65.52
10	Employee 10	Worker	135	45	66.67
11	Employee 11	Worker	120	35	70.83
12	Employee 12	Worker	110	25	77.27
13	Employee 13	Worker	125	35	72.00
14	Employee 14	Worker	140	50	64.29
15	Employee 15	Worker	130	40	69.23
16	Employee 16	Worker	115	30	73.91
17	Employee 17	Worker	150	50	66.67
18	Employee 18	Worker	135	45	66.67
19	Employee 19	Worker	120	35	70.83
20	Employee 20	Worker	145	50	65.52
Average			**129.75**	**40.5**	**69.05**

B. Internet of Things in ERP Platform

Data collection with IoT device is successfully deployed by connecting a transceiver module from Politeknik Elektronika Negeri Surabaya (PENS) to the transmitter located in Rungkut, Surabaya, to receive and process coordinate data. The transmitted data consists of latitude and longitude coordinates of the transmitter's position. These coordinates are then transmitted to the receiver and subsequently forwarded to the database for storage. The data is then displayed on the website. The transmitter's coordinate data is retrieved and transmitted to the database at regular intervals of every 10 seconds. Any changes in position are immediately reflected in the marker's position on the website display. This real-time updating mechanism ensures that the marker accurately represents the transmitter and receiver current location on the ERP website in Fig. 2.

The successful implementation of an IoT tracking system within an ERP platform in Fig. 3 can providing the user with real-time tracking and monitoring of goods and resources across the entire supply chain. The result tables of this IoT integration can be seen in TABLE V.

In the implementation of an ERP system integrated with IoT technology, the provided sample data plays a crucial role in facilitating various operational aspects. These data entries offer a snapshot of environmental conditions captured by IoT sensors, comprising parameters such as temperature, humidity, and location coordinates. For instance, Data 1 reveals a temperature of 28.1°C, a humidity level of 35%, and specific latitude and longitude coordinates, alongside a Received Signal Strength Indication (RSSI) value of -64 dBm. Such information enables the ERP system to monitor and analyse ambient conditions in real-time, aiding in the proactive management of environmental factors within relevant processes or facilities. Subsequent data entries (Data 2-7) provide a temporal sequence of environmental readings, allowing for trend analysis and anomaly detection. The variations in RSSI values across these entries indicate fluctuations in signal strength, which can be utilized to assess the reliability of data transmission between IoT devices and the ERP system. Furthermore, the higher temperature and humidity readings observed in Data 8-10, alongside fluctuating RSSI values, highlight instances that may require immediate action or further investigation within ERP-driven processes, such as climate-controlled facilities or supply chain logistics. Collectively, the sample data serves as a foundational component in the ERP-IoT integration, providing essential inputs for real-time monitoring, analysis, and decision-making across various operational domains. Through the synergy of ERP and IoT technologies, organizations can enhance efficiency, optimize resource utilization, and mitigate risks in their business processes.

C. Blockchain Performance Result

The Table VI presents the results of a blockchain performance test focusing on s per second (TPS) using Kafka under varying bandwidth conditions. This test involved 20 data samples to measure the system's performance across different bandwidth scenarios.

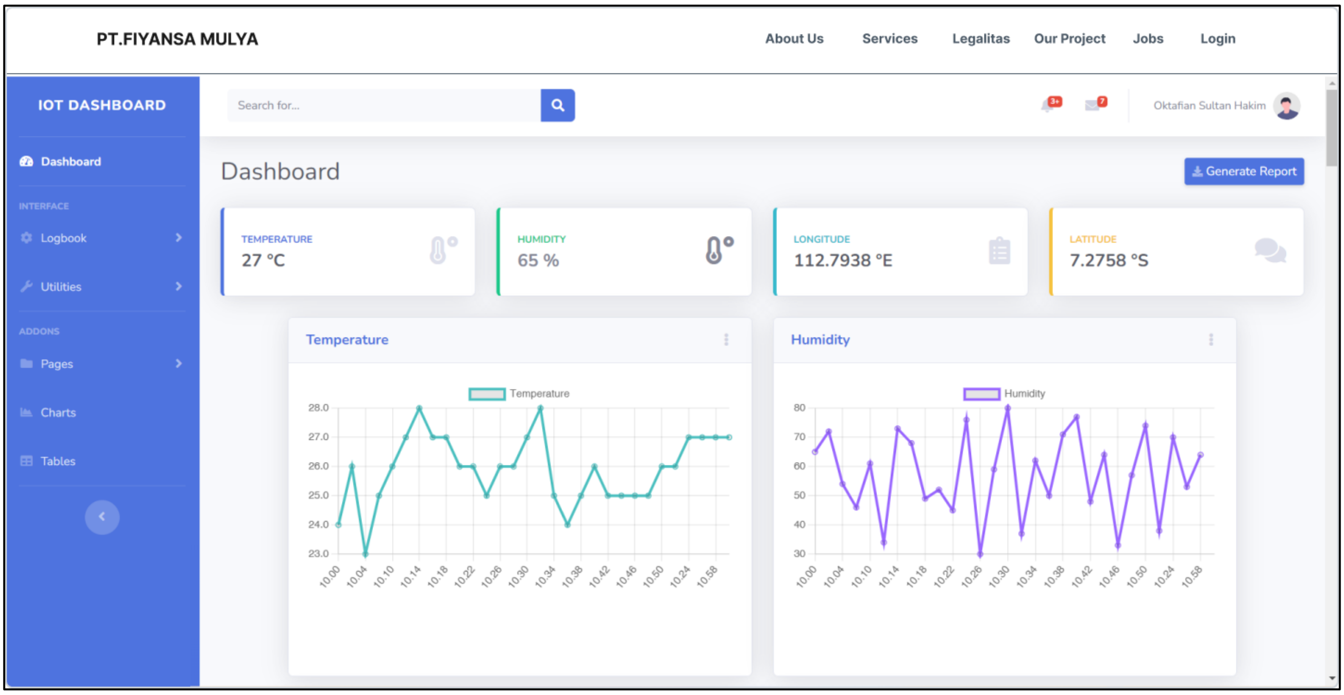

Fig. 2 Digital twin dashboard in IoT platform

TABLE V
INTERNET OF THINGS SENSOR DATA RESULT

Data	Temperature(°C)	Humidity (%)	Latitude	Longitude	RSSI (dBm)
1	28.1	35	-7.27626	112.795	-64
2	28.1	36	-7.3365	112.76	-95
3	28.1	36	-7.3361	112.763	-80
4	28	36	-7.3362	112.7632	-80
5	28	36	-7.33621	112.761	-84
6	28	36	-7.33632	112.762	-82
7	28	36	-7.33621	112.763	-74
8	29	47	-7.33631	112.766	-98
9	29	47	-7.33632	112.767	-94
10	29.6	52	-7.33643	112.768	-76

TABLE IVI
BLOCKCHAIN PERFORMANCE TEST

Variable	Bandwidth (Mbps)			
	6	2	1	0.5
Avg. Time(s)	1.284	1.379	1.448	1.554
TPS	0.666	0.624	0.599	0.543
Retention (%)	100	100	100	100

The average time increases as the bandwidth decreases. At a bandwidth of 6 Mbps, the average time was 1.284 seconds. As the bandwidth was reduced to 2 Mbps, 1 Mbps, and 0.5 Mbps, the average time increased to 1.379, 1.448, and 1.554 seconds, respectively. Correspondingly, the TPS also decreases with decreasing bandwidth. With a 6 Mbps bandwidth, the system achieved a TPS of 0.666. When the bandwidth was reduced to 2 Mbps, 1 Mbps, and 0.5 Mbps, the TPS decreased to 0.624, 0.599, and 0.543, respectively. Interestingly, the retention rate remained constant at 100% across all bandwidth scenarios, indicating that no data loss occurred during the tests. This consistency in retention demonstrates the reliability of the system in maintaining data integrity despite variations in bandwidth. The analysis reveals that higher bandwidth leads to better performance in terms of both average time and TPS. As the bandwidth decreases, the system's efficiency in processing s diminishes, leading to longer times and fewer s per second. Despite these performance variations, the constant retention rate is a positive indicator of the system's reliability. In conclusion, this performance test shows that while the blockchain system using Kafka can maintain data integrity across various bandwidths, its processing efficiency is significantly affected by the available bandwidth. Ensuring adequate bandwidth is crucial for optimizing speeds and maximizing TPS, highlighting the importance of network bandwidth considerations in blockchain deployments for optimal performance and scalability.

IV. CONCLUSION

The successful integration of blockchain technology into ERP systems, augmented by the inclusion of IoT devices, introduces a pioneering synergy that reshapes the landscape of enterprise operations. This amalgamation of technologies represents a convergence of three transformative pillars, each contributing unique strengths to enhance the security, efficiency, and intelligence of traditional ERP ecosystems. At its core, the novelty of this integration lies in the seamless orchestration of blockchain's decentralized ledger, IoT's sensor-based data collection, and ERP's comprehensive management functionalities. By harnessing the collective power of these technologies, organizations can realize a spectrum of innovative applications that redefine the boundaries of ERP. One of the primary innovations introduced by this integration is the creation of a distributed and immutable record of IoT-generated data within the ERP environment. As IoT devices capture real-time data from various sources such as sensors, machines, and devices, blockchain technology ensures the secure and transparent storage of this data, preserving its integrity and authenticity. This decentralized ledger provides a tamper-proof audit trail of IoT data, enabling stakeholders to trust the accuracy and reliability of information stored within the ERP system. Moreover, the integration of IoT devices with blockchain-enabled ERP systems facilitates enhanced automation and efficiency across business processes. Through IoT-enabled sensors embedded in physical assets and environments, organizations can capture granular data insights in real-time, from supply chain logistics to manufacturing operations. These data streams can then be seamlessly integrated into ERP workflows, triggering automated actions, optimizing resource allocation, and driving predictive analytics-driven decision-making.

ACKNOWLEDGEMENT

We appreciate to the Ministry of Education, Culture, Research, and Technology (Kemdikbudristek) and Politeknik Elektronika Negeri Surabaya for their invaluable backing and financial support in underwriting our research. Their steadfast commitment to fostering scientific exploration and technological innovation has played a pivotal role in facilitating the successful execution of our study and the attainment of our research objectives. We express our sincere gratitude for their unwavering dedication to advancing research initiatives within our nation. Our research Endeavor was carried out under Bima Kemendikbudristek and outsourcing company which serve as collaborative partners from the corporate sector.

REFERENCES

[1] M. F. Acar, S. Zaim, M. Isik, and F. Calisir, “Relationships among ERP, supply chain orientation and operational performance: An analysis of structural equation modeling,” *Benchmarking*, vol. 24, no. 5, 2017, doi: 10.1108/BIJ-11-2015-0116.

[2] D. Firoiu, G. H. Ionescu, A. Bandoi, N. M. Florea, and E. Jianu, “Achieving sustainable development goals (SDG): Implementation of the 2030 Agenda in Romania,” *Sustainability (Switzerland)*, vol. 11, no. 7, 2019, doi: 10.3390/SU11072156.

[3] M. Wynn and P. Jones, "Industry approaches to the Sustainable Development Goals," *International Journal of Environmental Studies*, vol. 79, no. 1, 2022, doi: 10.1080/00207233.2021.1911101.

[4] K. Deniswara, A. Nathanael Mulyawan, J. Theodore Kesuma, and Veronica, "Sustainable Development Goals 2030: The Impact Of Sophisticated Technology Towards Green Accounting To Improve The Quality Of The Company," *European Journal of Molecular & Clinical Medicine*, vol. 07, no. 10, 2020.

[5] S. Mbatha, "Roles of Practitioners in Industry-Government Research Collaborations of South African Clothing, Textiles, Leather, and Footwear Industry: Implications for SDGs and Agenda 2063," *Academic Journal of Interdisciplinary Studies*, vol. 11, no. 4, 2022, doi: 10.36941/ajis-2022-0103.

[6] M. Agus Zainuddin, O. Sultan Hakim, S. Sukaridhoto, H. Rante, and H. Rante Politeknik Elektronika Negeri Surabaya, "Implementation Internet of Things Using Linear Regression Method For Supply Chain Management System," vol. 7, no. 7, p. 12, 2022, doi: 10.36418/syntax-literate.v7i12.11369.

[7] B. Amade, A. C. Ogbonna, and E. I. Nkeleme, "An Investigation of the Factors Affecting Successful Enterprise Resource Planning (ERP) Implementation in Nigeria," *Journal of Construction in Developing Countries*, vol. 27, no. 1, 2022, doi: 10.21315/jcdc2022.27.1.3.

[8] F. Momani, A. G. Kanaan, M. H. Yusoff, S. I. A. Saany, A. Hatamleh, and Y. A. B. El-ebiary, "Erp Implementation Process Improvement : A Methodological Proposals," *Journal of Positive School Psychology*, vol. 6, no. 10, 2022.

[9] Y. Y. F. Panduman, S. Sukaridhoto, and A. Tjahjono, "A Survey of IoT Platform Comparison for Building Cyber-Physical System Architecture," in *2019 2nd International Seminar on Research of Information Technology and Intelligent Systems, ISRITI 2019*, 2019. doi: 10.1109/ISRITI48646.2019.9034650.

[10] Y. Y. F. Panduman, S. Sukaridhoto, A. Tjahjono, and R. P. N. Budiarti, "Implementation SEMAR-IoT-platform for vehicle as a mobile sensor network," *International Journal on Informatics Visualization*, vol. 4, no. 4, 2020, doi: 10.30630/joiv.4.4.425.

[11] Y. Y. Fridelin, M. R. Ulil Albaab, A. R. Anom Besari, S. Sukaridhoto, and A. Tjahjono, "Implementation of microservice architectures on SEMAR extension for air quality monitoring," in *International Electronics Symposium on Knowledge Creation and Intelligent Computing, IES-KCIC 2018 - Proceedings*, 2019. doi: 10.1109/KCIC.2018.8628575.

[12] Q. Zhou, K. Zheng, L. Hou, J. Xing, and R. Xu, "Design and implementation of open LORa for IoT," *IEEE Access*, vol. 7, 2019, doi: 10.1109/ACCESS.2019.2930243.

[13] A. M. C. Drăgulinescu, A. F. Manea, O. Fratu, and A. Drăgulinescu, "LoRa-Based Medical IoT System Architecture and Testbed," *Wirel Pers Commun*, vol. 126, no. 1, 2022, doi: 10.1007/s11277-020-07235-z.

[14] A. Faccia and P. Petratos, "Blockchain, enterprise resource planning (ERP) and accounting information systems (AIS): Research on e-procurement and system integration," *Applied Sciences (Switzerland)*, vol. 11, no. 15, 2021, doi: 10.3390/app11156792.

[15] T. M. Tan and S. Saraniemi, "Trust in blockchain-enabled exchanges: Future directions in blockchain marketing," *J Acad Mark Sci*, vol. 51, no. 4, 2023, doi: 10.1007/s11747-022-00889-0.

[16] G. Li, B. He, Z. Wang, X. Cheng, and J. Chen, "Blockchain-Enhanced Spatiotemporal Data Aggregation for UAV-Assisted Wireless Sensor Networks," *IEEE Trans Industr Inform*, vol. 18, no. 7, 2022, doi: 10.1109/TII.2021.3120973.

[17] I. Radeva and I. Popchev, "Blockchain-Enabled Supply-Chain in Crop Production Framework," *Cybernetics and Information Technologies*, vol. 22, no. 1, 2022, doi: 10.2478/cait-2022-0010.