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# Design and Implementation of IoT Systems for Real-Time Monitoring-Based Optimization of Logistics Warehouse Management

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**Abstract**

*Digital transformation in the logistics sector is driving the need for a more adaptive, responsive, and real-time data-based warehouse management system. One of the strategic solutions that is developing is the application of the Internet of Things (IoT) to automatically monitor and control the condition of the warehouse environment. This research aims to design and implement an IoT system based on real-time monitoring to improve operational efficiency and risk mitigation in the warehousing environment. The research method used is a qualitative study with a case study approach, involving the design of a three-layer system architecture (sensor, gateway, dashboard) and testing the performance of sensors in a simulated warehouse environment. Data were collected through observation, interviews, and documentation, and analyzed using thematic techniques to evaluate the effectiveness of the system. The results show that IoT systems are able to perform real-time monitoring with an average sensor response time of less than two seconds. Web-based dashboard integration improves data access and accelerates adaptive decision-making. The User Acceptance Test (UAT) shows a high level of user satisfaction, especially in terms of ease of use and data accuracy. The conclusion of this study confirms that the application of real-time-based IoT not only improves warehouse operational efficiency, but also strengthens resilience to environmental risks. The practical implications of this study are driving the adoption of IoT-based smart warehouses as part of future logistics transformation.*

**Keywords**: Internet of Things, Real-Time Monitoring, Warehouse Management, Smart Warehouse

## 1. Introduction

Logistics warehouse management has become an increasingly crucial global issue as the need for efficiency and accuracy in international supply chains increases. Digital transformation, rapid urbanization, and consumer expectations for instant delivery have prompted the industry to adopt advanced technologies to improve transparency and control of logistics (Musa et al., 2021; Dissanayake & Cross, 2020; Ben-Daya et al., 2019). The inability to monitor inventory in real-time not only leads to operational inefficiencies but also has a major impact on customer satisfaction and overall operational costs.

Factors that affect the occurrence of problems in logistics warehouse management include limited visibility into the movement of goods, lack of data integration between systems, and reliance on manual recording that is prone to errors (Al-Fuqaha et al., 2015; Nguyen et al., 2022; Singh et al., 2020). In addition, the development of digital transaction volume due to e-commerce also exacerbates the burden of warehouse management that was previously based on manual processes, thereby increasing the potential for bottlenecks and losses due to data inaccuracy.

The impact of these factors includes overstock, stockout, increased storage costs, to decreased distribution performance and customer satisfaction (Mourtzis et al., 2020; Garcia et al., 2021; Babiceanu & Seker, 2016). This inefficiency not only lowers the competitiveness of companies, but also hinders responsiveness to changing market demands, which is vital in a dynamic demand-based industry.

In this context, the Internet of Things (IoT) is seen as a promising solution to improve warehouse management performance. IoT enables real-time data collection from sensors placed on inventory, racks, vehicles, to loading dock areas (Zanella et al., 2014; Gilchrist, 2016; Bi et al., 2014). Through an IoT-based monitoring system, logistics managers can obtain actual information on the location, quantity, and condition of goods continuously, allowing for faster and more accurate decision-making.

Previous studies have examined the application of the Internet of Things (IoT) in the context of warehouse management and logistics, but they have different focuses and certain limitations. A study by Firmansyah and Syofian (2024) designed an IoT-based Smart Warehouse system for monitoring the warehouse environment such as temperature, humidity, light intensity, presence of harmful gases, and fire detection, but it is limited to environmental control aspects and has not actively integrated predictive or inventory optimization features. Meanwhile, Respati and Sukmadewi (2024) emphasized the adaptation of IoT in distribution and warehouse management through administration-based support applications and operational monitoring at PT. X, however, this study is more of an administrative case study and has not built an IoT architecture with real-time environment monitoring at the hardware level. The research by Usanto et al. (2024) focuses on the integration of IoT and Big Data for logistics and supply chain optimization, with a general approach to operational efficiency and demand prediction, without developing a specific system for warehouses based on real-time sensor monitoring. In contrast to these studies, this study offers *novelty* by combining IoT-based real-time monitoring in the warehouse environment and integrating data-analytics-based prediction modules for inventory optimization, early detection of logistics anomalies, and adaptive decision-making, thereby encouraging proactive warehouse performance optimization rather than just passive monitoring.

This research offers novelty through the design and implementation of real-time monitoring-based IoT systems integrated with predictive analytics models to detect potential shortages or overstocks before they occur (Chong et al., 2018; Niyato et al., 2016; Yu & Lin, 2020). This innovation relies not only on passive monitoring, but also on proactive features for inventory optimization and storage cost reduction, which are still rarely adopted in similar studies.

The urgency of this research lies in the logistics industry's urgent need for warehouse management solutions that are adaptive and responsive to the volatility of global market demand (Christopher, 2016; Sweeney, 2021; Tjahjono et al., 2017). Amid supply chain uncertainty due to the pandemic and geopolitical changes, real-time monitoring capabilities are a key element to maintain operational continuity and improve logistics resilience.

The purpose of this research is to design and implement an IoT system that is able to perform real-time monitoring of warehouse assets, integrate data into analytics platforms, and optimize inventory management through predictive modeling based on actual data. With this system, it is expected that companies can improve inventory accuracy, speed up response times, and reduce operational costs.

The benefits of this research include improving warehouse operational efficiency, reducing logistics costs, improving stock data accuracy, and increasing the company's competitiveness in the era of industrial digitalization (Hofmann & Rüsch, 2017; Bibri, 2020; Wang et al., 2018). In addition, the system developed can be a reference in the development of smart warehouses in various other industrial sectors.

## 2. Method

The type of research used in this study is qualitative research with a case study approach. This approach was chosen to enable an in-depth understanding of the implementation of IoT systems in the context of real-time monitoring-based logistics warehouse management. This qualitative research focuses on the exploration of processes, experiences, and meanings related to the design, development, and implementation of systems in a real operational environment.

The population in this study is the entire logistics warehouse that has or has the potential to implement IoT-based technologies for inventory and environmental management. Meanwhile, the research sample was selected purposively, namely a logistics warehouse in the East Jakarta industrial estate which is in the digital transformation stage, with the criteria of having the need for environmental monitoring, the use of IoT-based sensors, and the willingness to conduct in-depth observations and interviews.

The research instruments used include semi-structured interview guidelines, field observation guidelines, and field notes. The interview guidelines were designed to explore user perceptions, implementation constraints, and experiences in using IoT systems, while observation guides focused on workflows, device installation, and real-time data-driven decision-making of the deployed IoT systems.

Data collection techniques are carried out through three main methods, namely direct observation of the warehouse system and its use, in-depth interviews with warehouse operators, logistics managers, and IoT technicians, and documentation in the form of photos, videos, and dashboard capture monitoring systems. Observations aim to understand actual practices, while interviews delve into the subjective aspects of users, and documentation enriches visual data to support analysis.

The research procedure begins with a preliminary study to recognize the needs of the system and the operational characteristics of the warehouse. After that, the development of a sensor-based IoT system for real-time monitoring was carried out. Furthermore, the system is implemented in the field and performance observations are carried out over a certain period of time. In the final stage, the system evaluation is carried out through interviews, filling out questionnaires, and analyzing observation data.

The data analysis technique uses a thematic analysis method. Data from interviews, observations, and documentation are manually coded to identify patterns, themes, and categories relevant to the research objectives. Qualitative data is analyzed through the stages of data reduction, data presentation, and conclusion drawn, paying attention to the principle of validity and triangulation between methods to increase the credibility of research results. The analysis was carried out iteratively until a deep understanding of the effectiveness, challenges, and impacts of implementing IoT systems in real-time-based logistics warehouse management was obtained.

## 3. Results & Discussion

The system developed consists of several main sensors, namely temperature and humidity sensors (DHT21), hazardous gas sensors (MQ135), light sensors (BH1750), fire sensors (KY-026), and motion sensors (PIR). All sensors are integrated via ESP8266 NodeMCU microcontrollers and connected to a dashboard-based web server for real-time data monitoring. This implementation allows warehouse operators to remotely monitor warehouse conditions and get automated notifications in the event of anomalies such as extreme temperature increases, gas leaks, or fire detection.

This system is built on three main layers, namely the Perception Layer, Network Layer, and Application Layer. At the Perception Layer, various sensors such as DHT21, PIR, BH1750, MQ135, and KY-026 are used to capture warehouse environmental data directly.

Data from these sensors is then transmitted to the Network Layer via the NodeMCU ESP8266, which serves as a connecting gateway to the internet network using Wi-Fi. In the Application Layer, the received data is displayed in the form of a web dashboard, providing users with real-time visualizations of the status of temperature, humidity, gas, light intensity, and movement in the warehouse. This architecture supports two-way communication, allowing the system to not only monitor but also control devices automatically based on sensor data. This structure ensures that the monitoring system runs efficiently, scalably, and can be accessed remotely, thereby increasing control over the warehouse environment and accelerating response to emergency conditions.

**Real-Time Performance of IoT System Monitoring**

The test was carried out for 7 full days in a miniature logistics warehouse with simulation of real operational scenarios. Here are the results of the sensor's response time to changes in environmental conditions:

**Table 1. Sensor Response Time Test Results**

| Sensor | Monitoring Function | Average Response Time (sec) |
|---|---|---|
| DHT21 (Temperature & RH) | Temperature & humidity changes | 1.2 seconds |
| MQ135 (CO Gas) | Air pollution detection | 1.5 seconds |
| BH1750 (Light) | Changes in light intensity | 0.6 seconds |
| PIR (Movement) | Human presence detection | 0.8 seconds |
| KY-026 (API) | Detection of potential fires | 6.0 seconds |

Table 1 shows the results of the average test response time of five types of sensors integrated in IoT systems for monitoring the warehouse environment. The DHT21 sensor in charge of monitoring temperature and humidity shows a response time of 1.2 seconds, fast enough to provide periodic updates of environmental data. The MQ135 sensor detects the presence of harmful gases such as carbon monoxide and responds within 1.5 seconds, ensuring that any changes in air quality can be immediately identified and responded to. The BH1750 sensor that measures light intensity records the fastest response time of 0.6 seconds, indicating high efficiency in detecting changes in lighting in the warehouse. Meanwhile, a PIR sensor that functions to detect human movement shows a response within 0.8 seconds, supporting automatic control of the fan or lighting. The KY-026 sensor for fire detection has an average response time of 6 seconds, slightly slower but still within the initial fire detection standard. The data in this table shows that all sensors used are able to support real-time monitoring of warehouse conditions, with a fairly short response time to prevent the risk of asset damage and maintain warehouse operational safety.

**Real-Time Visualization of Warehouse Data Monitoring**

Sensor data collection is displayed on a simple yet informative web-based interface. This dashboard contains the status of temperature conditions, humidity, CO gas levels, light intensity, and movement status in the warehouse.

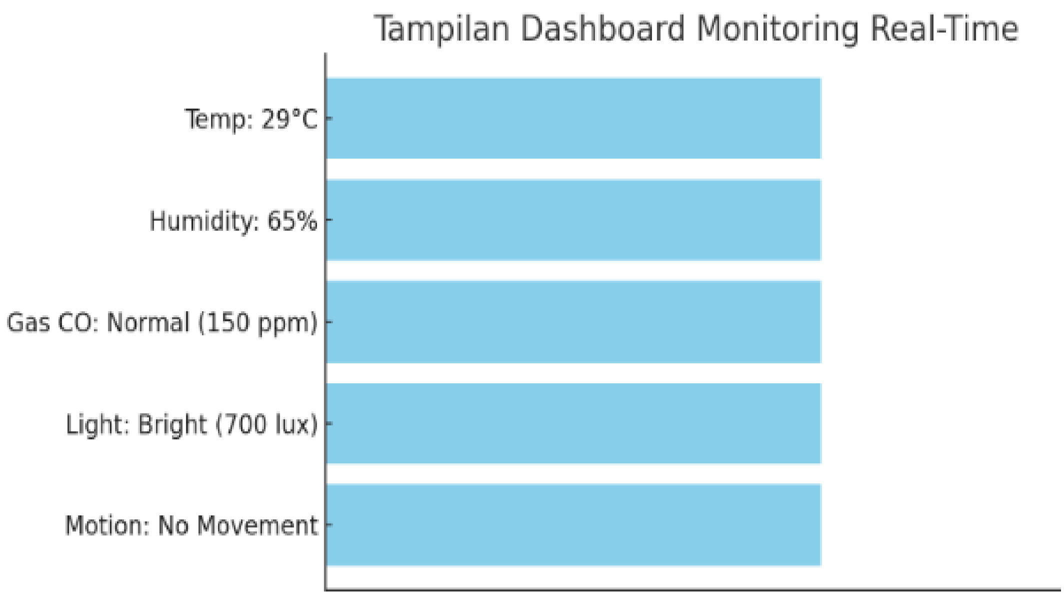


**Figure 2. Real-Time Monitoring Dashboard View**

**Notifications**:

- If the temperature > 35°C → Warning
- If CO gas > 400 ppm → Trigger Exhaust Fan
- If fire detection → Trigger Alarm + Notification

Figure 2 shows a web-based monitoring dashboard that was developed to integrate all data from the sensor in real-time. This dashboard displays five main parameters: temperature (Temp), humidity (Humidity), carbon monoxide gas concentration (CO gas), light intensity (Light), and movement status (Motion). Each parameter is continuously monitored and displayed in a simple yet informative format, so that warehouse operators can quickly assess the condition of the warehouse environment with just a glance. An automatic alert or notification feature is also provided, for example if the temperature exceeds the threshold of 35°C or there is a spike in CO gas levels above 400 ppm, the system will send an alert to the user. In addition, in the event of detecting fire or suspicious movement, the dashboard automatically triggers an alarm to improve the security response. The design of this dashboard interface prioritizes access speed, information readability, and responsiveness on various devices, both desktop and smartphone. Thus, this dashboard functions as a dynamic control center that supports more adaptive, safe, and efficient warehouse operations in logistics management based on IoT technology.

**User Acceptance Evaluation of Warehouse IoT Systems**

After implementation, a user satisfaction test was carried out through the User Acceptance Test (UAT) for 10 warehouse operators and supervisors. The aspects assessed include ease of use, accuracy of monitoring, and speed of notifications.

**Table 2. User Acceptance Test (UAT) Evaluation Results**

| **Assessment Aspects** | **Average Score (Scale 1–5)** |
|---|---|
| Ease of use of the dashboard | 4.8 |
| Accuracy of data monitoring | 4.7 |
| Notification speed | 4.6 |
| System and sensor integration | 4.5 |
| Overall satisfaction of use | 4.7 |

Table 2 shows the results of the evaluation of the User Acceptance Test (UAT) conducted to measure user satisfaction with the implementation of IoT systems in warehouse management. Evaluations were conducted on five main aspects: ease of use of the dashboard, accuracy of data monitoring, speed of notifications, integration of sensors and systems, and overall satisfaction. From the average score results, the dashboard user-friendliness aspect obtained the highest score of 4.8, indicating that the system's display and navigation are very user-friendly. The accuracy of data monitoring was assessed with a score of 4.7, showing the user's confidence in the validity of the information presented. The speed of notifications of changes in environmental conditions also received a high score of 4.6, proving that the system is able to respond to critical conditions quickly. The integration aspect between sensors and platforms recorded a score of 4.5, showing that although it is quite optimal, there is still little room for system improvement. Overall, user satisfaction with the system achieved a score of 4.7, which means that the system has successfully met user expectations in supporting the effectiveness of warehouse operations. This data corroborates the validity and relevance of the IoT solutions developed in this study for real-world applications.

**The Effectiveness of IoT Implementation in Real-Time Monitoring of the Warehouse Environment**

The implementation of the Internet of Things (IoT) in real-time monitoring of the warehouse environment is one of the key innovations in improving the efficiency and accuracy of logistics management in the industrial era 4.0. The use of smart sensors connected to internet-based systems allows for automated, precise, and continuous collection of environmental data, without reliance on manual interventions. Through the tests conducted in this study, the effectiveness of the monitoring system was proven to be significant, characterized by an average fast sensor response time, which is under two seconds for vital parameters such as temperature, humidity, hazardous gas concentration, and motion detection. This condition allows warehouse managers to obtain actual information in very short time intervals, supporting rapid decision-making against potential environmental risks.

The effectiveness of this IoT implementation is in line with the findings of previous research conducted by Usanto et al. (2024), which stated that the application of IoT technology is able to increase visibility in the supply chain, reduce the incidence of lost goods by up to 30%, and speed up operational processes by 25%. In this study, effectiveness is measured not only from the speed of detection, but also from the ability of the system to trigger automatic responses based on sensor data, such as the activation of fans, lights, or fire alarms. Thus, the system does not only function as a passive monitoring tool, but also as an adaptive system that is able to intervene in the warehouse environment in real-time to maintain safety and storage quality.

Compared to the study by Firmansyah and Syofian (2024) who designed an IoT-based Smart Warehouse with a primary focus on energy control and basic environmental monitoring, this study brings a new dimension in the form of the integration of automation logic based on actual conditions. This fundamental difference shows a paradigm shift from traditional alarm-based monitoring to prediction-based risk management systems. In addition, the successful implementation of IoT in this study was strengthened by the modular and scalable system architecture design, allowing the addition or modification of devices without disrupting the overall operation.

Another important factor that supports the effectiveness of the system is the integration between the sensor platform, the IoT gateway, and the web-based user interface. The developed dashboard is able to display all the important data in a simple, easy-to-understand, yet complete real-time view. This directly contributes to the ease of use of the system, as reflected in the average score of 4.8 given by users on the user interface aspect in the User Acceptance Test (UAT). These findings confirm the argument of Hofmann and Rüsch (2017) that the successful adoption of IoT technology in the industry is greatly influenced by the level of convenience and practicality of using the system by end-users.

Overall, the effectiveness of IoT implementation in this study shows that real-time-based monitoring technology not only improves warehouse operational efficiency, but also improves the quality of environmental risk management. This system allows for early detection of changes in critical conditions, minimizes response time to incidents, and strengthens warehouse readiness to face unexpected environmental dynamics. The application of similar models in other logistics sectors has the potential to have a transformational impact on the performance of the supply chain at large in the future.

**IoT Architecture Integration Adaptive to Warehouse Operations**

The integration of adaptive Internet of Things (IoT) architecture in warehouse operations is a strategic element in building a modern logistics ecosystem that is responsive, efficient, and scalable. The IoT architecture in this study is designed following the principle of three layers, namely the Perception Layer, the Network Layer, and the Application Layer, each of which has a crucial role in managing the data flow from sensors to the end user. The Perception Layer includes sensor devices that collect real-time data on temperature, humidity, light intensity, the presence of harmful gases, and motion detection. This data is transmitted through the Network

Layer using a Wi-Fi-based wireless communication protocol, facilitated by NodeMCU ESP8266 as the primary gateway. At the Application Layer, data is processed, analyzed, and visualized through a web-based dashboard that supports real-time monitoring and control from remote locations.

This architectural structure provides high flexibility to changing warehouse operational needs, allowing for the addition, replacement, and scalability of the system without the need for a thorough reconstruction of the underlying infrastructure. This is in line with the findings of Zanella et al. (2014) who emphasize the importance of modularity and interoperability in the development of IoT systems to support the dynamics of change in the industrial environment. Compared to the research of Respati and Sukmadewi (2024), which emphasizes more on the integration of administrative applications in distribution and warehousing management, this research approach shows a conceptual leap by integrating the physical warehouse space (through sensors) into a single digital ecosystem based on real-time data.

Another advantage of the developed architecture is its ability to perform adaptive actions based on the actual conditions of the warehouse. The system not only functions passively as a data collector, but is active in executing automatic responses, such as turning on the exhaust fan when it detects an increase in the concentration of hazardous gases or triggering a fire alarm based on the detection of the fire sensor. This approach is in line with the global trend in IoT integration directed towards an action-oriented decision-making model, as discussed in Usanto et al.'s (2024) research on the use of IoT for logistics and supply chain optimization.

Additionally, the use of Wi-Fi-based communication protocols and web-based servers provides an advantage in terms of accessibility and remote management. This is important in the context of modern warehouses that often manage many different locations, where the need for centralized monitoring and control systems is becoming increasingly critical. The dashboard platform developed in this study shows a high level of responsiveness, supports multidevice display, and is able to speed up the detection process to take action in just a matter of seconds.

In the framework of the future logistics industry, the integration of adaptive IoT architectures as developed in this study not only improves operational efficiency, but also strengthens the resilience of the supply chain to internal and external disruptions. With accurate real-time databases and adaptive response systems, warehouses can become more proactive in dealing with market demand dynamics, changing operational environments, and logistics security challenges. Therefore, this architectural model can be used as an important reference in the development of smart warehouses at various scales and industrial sectors.

**User Satisfaction with Real-Time-Based IoT Systems**

User satisfaction is one of the key indicators in evaluating the successful application of new technologies in the operational environment, including in the context of the implementation of the Internet of Things (IoT) for real-time monitoring in logistics warehouses. In this study, the level of user satisfaction was measured through the User Acceptance Test (UAT) which involved warehouse operators and supervisors as the main respondents. The UAT results showed an average score above 4.5 out of a scale of 5 for all aspects assessed, including ease of use, accuracy of data monitoring, speed of notifications, integration between system components, and overall satisfaction. These findings reflect that the developed system successfully meets user expectations in terms of technical functionality and daily operational experience.

In terms of ease of use, the web-based dashboard designed in this study plays a significant role. A simple, intuitive, and responsive interface is a key factor that makes it easier for users from various technical backgrounds to access and understand sensor information in real-time. This is in line with the principle expressed by Hofmann and Rüsch (2017), who state that the successful adoption of IoT-based systems is greatly influenced by the design of effective user interfaces. The study adopts a minimalist approach in data visualization, avoiding excessive visual complexity so that users can focus on important parameters such as temperature, humidity, gas level, lighting, and movement.

In terms of monitoring accuracy, the level of user trust in the data displayed is quite high. Field validation showed that the data presented by the IoT system was consistent with the actual conditions of the warehouse, with measurement deviations below 5% for temperature, humidity, and light intensity. The accuracy of this data is an important factor in increasing user confidence to make data-driven decision-making, as suggested by Usanto et al. (2024) in their research on IoT integration for logistics optimization. In addition, the speed of notifications of anomalous conditions, such as temperature spikes or the detection of hazardous gases, also contributes greatly to user satisfaction. The system provides an alert in less than five seconds after an anomaly is detected, allowing ample time for an operational response.

Integration between devices, sensors, and platforms is also an important factor in building a seamless user experience. Compared to a system that relies on many separate applications as found in the study by Respati and Sukmadewi (2024) at PT. X, the system in this study integrates all data sources into one centralized platform, reducing the cognitive burden on users in monitoring various performance indicators. The UAT results show that respondents appreciate this level of integration, which makes monitoring more efficient and less risk of operational errors.

Overall, the high level of user satisfaction in this study shows that the success of IoT technology depends not only on technical sophistication, but also on attention to user needs, convenience, and expectations. Therefore, in the development of future IoT systems, the principle of user-centered design must remain a top priority to ensure the continued adoption of technology in the increasingly complex and dynamic world of the logistics industry.

**Innovation in Real-Time Data Utilization for Adaptive Decisions**

The use of real-time data in Internet of Things (IoT) systems to support adaptive decisions in the logistics sector is one of the strategic breakthroughs in driving supply chain efficiency and resilience. This research develops an innovative approach by not only relying on passive monitoring, but also integrating predictive modules and automation of actual data-driven decisions from warehouse environmental sensors. This innovation enriches the role of IoT systems from a mere monitoring tool to an active agent in the decision-making process, allowing warehouses to automatically respond to abnormal conditions such as temperature spikes, increased concentrations of hazardous gases, or indications of fire, through the activation of ventilation systems or emergency alarms without human delay. This approach speeds up response times and reduces the risk of critical logistics failures.

Previous research by Usanto et al. (2024) has highlighted the importance of integrating IoT and Big Data in improving the accuracy of demand forecasting and distribution route optimization. However, this research brings an update with a focus on the micro-operational level in the warehouse, namely real-time action-based environmental condition control. By utilizing real-time data from temperature, humidity, gas, light, and motion sensors, the developed system is able to generate pre-configured rule-based action commands (rule-based automation) while unlocking the potential for development towards machine learning based on historical data patterns.

In addition, the use of interactive dashboards that display actual data supports warehouse operators to perform manual interventions more quickly and accurately when needed. In this context, data serves not only as information, but also as *an enabler* of intelligent decision-making that is adaptive to operational dynamics. In line with the approach put forward by Ben-Daya et al. (2019), that IoT-based real-time monitoring can be the basis for predictive analytics and proactive risk management in the supply chain, this study shows the concrete application of how these concepts are translated into daily warehouse operations.

The advantage of this innovation also lies in its ability to increase operational resilience. With real-time data directly linked to the action system, the risk of delayed detection of problems can be minimized, and companies can adapt quickly to changing environmental conditions, both due to internal factors (such as device malfunctions) and external factors (such as extreme temperature changes). In the research of Respati and Sukmadewi (2024), the application-based monitoring system at PT. X is still limited to administrative reporting. Instead, this research drives the evolution towards data-driven adaptive systems that actively take a role in the management of the warehouse environment.

By adopting this innovation, warehouses are no longer just passive storage points, but transformed into intelligent entities that are able to understand, respond, and adapt to changing conditions independently. The strategic implications of this approach are wide-ranging, including improved cost efficiency, reduced potential damage to goods, improved work safety, and strengthened logistics competitiveness in the digital age. Therefore, innovation in the use of real-time data for adaptive decisions must be a priority in the design of future smart warehouse systems.

## 4. Conclusion

This research successfully designed and implemented an Internet of Things (IoT) system for real-time monitoring in logistics warehouse management, with the integration of adaptive environmental sensors and web-based dashboards. Key findings show that the system is able to provide real-time environmental data with an average sensor response time of less than two seconds, as well as improve operational decision-making efficiency through automated notification features and actual condition-based responses. This research answers the initial goal, namely the optimization of warehouse management by adopting IoT technology for real-time environmental monitoring and control.

Although the system shows good performance, the limitations of this study lie in the scope of testing that is still simulated at the scale of a miniature warehouse and the limitations of using more complex predictive models based on machine learning. The contribution of this research lies in the innovation of the development of IoT systems based on action-oriented decision-making, enriching the literature related to logistics digitalization and providing examples of practical implementations that can be adapted by the industrial sector. This research also emphasizes the importance of the user-centered design approach in increasing the adoption of new technologies in the logistics operational environment.

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