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Enterprise Architecture Design and Implementation for IoT Integration in Manufacturing Electrical Panels

Djarot Hindarto[1)]*, Ferial Hendrata[2)], Mohammad Iwan Wahyuddin[3)], Sigit Wijanarko[4)]
[1,3,4)] Prodi Informatika, Fakultas Teknologi Komunikasi dan Informatika, Universitas Nasional Jakarta
[2)]Prodi Sistem Informasi, Universitas Narotama, Surabaya, Indonesia
[1)]djarot.hindarto@civitas.unas.ac.id, [2)]ferial.hendrata@narotama.ac.id,
[3)]iwan.wahyuddi@civitas.unas.ac.id, [4)]sigit.wijanarko@civitas.unas.ac.id

ABSTRACT

Internet of Things technology has transformed manufacturing efficiency and optimization. Electrical panel manufacturing benefits from Internet of Things for better functionality, predictive maintenance, and smoother operations. This study examines the design and implementation of an Enterprise Architecture strategy for seamless Internet of Things integration in electrical panel manufacturing. This research aims to explain Enterprise Architecture and use it as a framework for Internet of Things integration in electrical panel manufacturing. This study examines the complex relationships between Internet of Things components, their connectivity, and a broad Enterprise Architecture framework needed to organize their functionality. This integration uses Enterprise Architecture principles to optimize resource use, reduce downtime, and improve manufacturing efficiency. This effort involves analyzing existing infrastructure, identifying Internet of Things deployment points, and creating an Enterprise Architecture plan that meets business goals. This research emphasizes the need for close IT-operations collaboration to achieve a unified vision and smooth Internet of Things integration. This research addresses Internet of Things implementation challenges in manufacturing, including security, data interoperability, and scalability. Strong governance and adaptable architecture are stressed to address these challenges within an Enterprise Architecture framework. This research aims to help electrical panel manufacturers harness the transformative power of the Internet of Things. Strategic Enterprise Architecture helps businesses navigate complexity, leverage Internet of Things, and create a more agile, connected, and optimized manufacturing landscape.

Keywords: Data Interoperability; Enterprise Architecture; Electrical Panel Manufacturing; Internet of Things; Optimized Manufacturing Landscape

INTRODUCTION

With respect to the manufacturing sector, the Fourth Industrial Revolution has emerged as the principal catalyst for industry transformation. During this wave of transformation, Internet of Things (IoT) (Mishra, 2023) technology has become the foundation that fundamentally changes the paradigm of electrical panel manufacturing. This not only enhances functionality, but the presence of IoT in industrial power panels also opens the door to unforeseen potential. The implementation of IoT has brought about a revolutionary change by introducing the concept of predictive maintenance that was previously difficult to achieve. Intelligently integrated sensors enable electrical panels to autonomously maintain their condition, predict maintenance needs, and even perform repairs before any damage occurs. This not only saves time and costs but also minimizes the potential disruptions in operations. The utilization of IoT has optimized the overall operation of electrical panels. Dengan adanya konektivitas yang terus-menerus, kinerja dapat terintegrasi dengan baik sehingga penyesuaian otomatis dapat dilakukan untuk mencapai efisiensi yang optimal. This creates a more

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seamless and adaptable operational environment, where electrical panels are not only static but can also adapt to the dynamics of demand and the surrounding environment. The Internet of Things not only brings technological advancements in the production of electrical panels but also has a significant impact in addressing future challenges in this industry, making it more efficient, reliable, and adaptable to evolving industrial needs.

Regardless of the considerable potential of the Internet of Things (Sakr & Sadhu, 2023) to enhance operational effectiveness within the electrical panel manufacturing industry, its integration frequently encounters intricate obstacles. The complexity of integrating Internet of Things technology into pre-existing manufacturing structures stands as a primary obstacle. Security constitutes a primary concern. Complexity increases in the realm of data and infrastructure security risks within an extensively interconnected ecosystem such as IoT. Electrical panels that are interconnected with a vast area network present potential susceptibilities to cyber-attacks and hacking, which can disrupt system operations and compromise security. Additionally, data interoperability represents a significant obstacle. The use of diverse communication protocols by IoT devices frequently complicates the exchange and analysis of data. This necessitates meticulous integration and standardization to guarantee that data produced by a variety of devices can be appropriately processed and comprehended. Additionally, a structured framework is an immediate necessity. In addition to hardware, data collection, analysis, and implementation into existing production processes must be meticulously planned for to achieve IoT integration. To ensure uninterrupted operations during the integration of IoT into the manufacturing environment, a methodical and coordinated strategy is necessary. Significant advantages can be derived from IoT integration in the electrical panel industry by surmounting these obstacles. Nonetheless, a comprehensive approach is required, which entails prioritizing security, ensuring data interoperability, and constructing a structured framework to guarantee a fruitful execution.

Considering the inherent complexity, it is critical to prioritize Enterprise Architecture (Afarini & Hindarto, 2023), (Hindarto, 2023b) strategy as the primary underpinning for integrating the Internet of Things into the manufacturing of electrical panels. EA encompasses much more than merely technical design. Implementing IoT integrations into the pre-existing infrastructure frameworks is a technology transformation that can be systematically managed with EA. Mapping the necessary changes to facilitate the integration of IoT technology is a critical function of Enterprise Architecture (Wedha & Hindarto, 2023) within the realm of electrical panel manufacturing. Critical aspects such as integration, interoperability, security, and data management are considered in the formulation of EA-assisted strategies. When considering the integration of new technology into an existing infrastructure, it is not sufficient to add more of it. With the aim of reducing interference with continuous operations, the EA framework offers explicit direction regarding the organization, management, and integration of IoT devices with pre-existing equipment and systems. Electronic architecture facilitates the detection of supplementary hardware and software infrastructure prerequisites that might be necessary to streamline the implementation of the IoT. Enhanced comprehension of the optimal integration of IoT technology can be obtained by organizations engaged in the manufacturing of electrical panels through the implementation of an Enterprise Architecture (Hindarto, 2023a), (Prawira et al., 2023) methodology. Such developments facilitate the development of enduring approaches that enhance the utilization of the Internet of Things, optimize operational efficiency, fortify security measures, and provide efficient predictive maintenance. EA (Amanda et al., 2023) serves as a transformative foundation for the entire electrical panel manufacturing industry, constituting more than a mere technical framework.

Advancements in the incorporation of the Internet of Things into the manufacturing process of electrical panels have led to substantial modifications in a multitude of operational facets. With the ability of systems to autonomously monitor, regulate, and adjust to boost productivity without requiring constant human intervention, operational efficiency has increased dramatically. The implementation of predictive

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maintenance has materialized, enabling electrical panels to proactively identify impending issues, thereby mitigating unforeseen periods of inactivity and operational setbacks. Although these advancements are promising, the burgeoning obstacles are likewise becoming more intricate. Due to the proliferation of potential infrastructure attacks facilitated by the increasing connectivity between devices, data security continues to be a significant concern. System interoperability, encompassing the integration of diverse Internet of Things devices with pre-existing infrastructure, necessitates meticulous standardization to guarantee the seamless and efficient exchange of information. Scalability continues to be a concern, as the future expansion and development of IoT infrastructure must be accounted for. The most recent methodology advocated via the Enterprise Architecture (Hindarto, 2023c) strategy materializes as a methodical resolution to tackle this obstacle. EA facilitates a comprehensive method for strategizing, overseeing, and integrating Internet of Things technologies, emphasizing interoperability, scalability, and security. Organizations can utilize EA to design adaptive infrastructure, ensure that IoT integration is not only effective in the present but also prepared for future growth and development, and overcome security challenges with encrypted systems. Therefore, the IoT integration approach implemented via EA emerges as the cutting-edge methodology in this field, establishing a robust framework for an industrial revolution in electrical panel production that is characterized by enhanced efficiency, adaptability, and safety.

The present investigation explores the application of the Enterprise Architecture concept to the integration of the Internet of Things within the manufacturing process of electrical panels. This study aims to comprehensively examine the intricacies of the interconnections among Internet of Things (Vilas et al., 2023) components, the functioning of their connectivity, and the function of EA as a broad framework for arranging and enhancing its functionality. This investigation is predicated on an understanding of the circumstances surrounding the challenges encountered in the electrical panel manufacturing industry. Insists on scalability, data security, and system interoperability, among other complex obstacles that impede the seamless integration of the Internet of Things. The proposed solution method, EA, is highlighted as a structured approach capable of surmounting this complexity via the development of a methodical integration strategy. The primary aim of this research is to emphasize the crucial significance of EA in overseeing the integration of IoT within the electrical panel manufacturing industry. In addition to furnishing a technical framework, EA also offers strategic direction pertaining to the implementation and planning of the integration. A comprehensive comprehension of the significance of EA establishes a groundwork for delving into intricate facets of IoT integration related to security, interoperability, infrastructure design, and future adaptation. This research begins with an exhaustive comprehension of the function of EA in managing the complexity of IoT integration. The objective of this research is to conduct an in-depth investigation into the suitability of EA as a framework for effectively managing and optimizing the potential of IoT integration in the manufacturing of electrical panels.

LITERATURE REVIEW

The challenges, open issues, applications, architecture, and applications of IoT-based Enterprise Resource Planning (ERP) systems in competitive markets are investigated in this study. It emphasizes the distinctive characteristics of IoT and its influence on ERP, demonstrating that Internet-connected sensors and devices can autonomously manage data stored in the cloud and processed by ERP (Tavana et al., 2020). The challenges, unresolved matters, applications, and architecture of Internet of Things (IoT)-integrated enterprise resource planning (ERP) systems in competitive markets are investigated in this study. It emphasizes the distinctive characteristics of IoT and its influence on Enterprise Resource Planning (ERP), specifically how Internet-connected sensors and devices can autonomously oversee data stored and processed in the cloud via ERP (Lee, 2021). This research provides a thorough analysis of the present condition of microservices-based architecture for IoT systems, focusing on improving availability and reliability. The text emphasizes the merits, drawbacks, and prospects of this architectural design,

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showcasing its capacity to support Internet of Things systems while recommending additional investigation to rectify its deficiencies (Siddiqui et al., 2023). This study uses vibration sensors and bio-inspired control architecture for manufacturing systems to detect motor anomalies in real-time using IoT architecture. Latency and performance are evaluated (Aruquipa et al., 2022). Autonomous services that receive, process, communicate, and respond to real-time data are revolutionizing global manufacturing enterprises thanks to sensors, IoT, and communication technology (Jain, 2023). This paper examines Edge-Fog-Cloud architectural frameworks, their pros and cons, and their scientific value for Industrial IoT data analysis. It discusses current state-of-the-art and implementation challenges to improve network performance (Kumar & Agrawal, 2023). An integrated IoT-Operational Technology solution for dynamic scheduling and rescheduling in personalized production is proposed in the paper. It shows pharmaceutical analytical quality control lab implementation. Fog computing architectures with intelligent sensors and business events trigger online event rescheduling. The paper shows that moving computation closer to the cloud improves CPU run time for more significant instances but delays communication for more minor instances (Coito et al., 2022). Product Lifecycle Management (PLM) has changed product development and production engineering while IoT is growing. Due to cultural differences between PLM's engineering background and IoT's computer science background, PLM-IoT integration is complex. This research reviews the literature and proposes a manufacturing industry integration framework to close this gap (Barrios et al., 2022).

In a competitive market, this research delves into various intriguing aspects of ERP systems based on the Internet of Things. Product Lifecycle Management (PLM) and the Internet of Things are complex to combine because of differences in culture, which is one of the identified gaps. The research also emphasizes the effects of the Internet of Things on enterprise resource planning (ERP) systems and the usage of sensors and IoT-connected devices for autonomous cloud data management. The use of microservices in Internet of Things architectures to improve system availability and reliability is another area of emphasis. The use of vibration sensors and control architectures influenced by biosystems for the real-time detection of motor anomalies in manufacturing systems is also covered in this research. Additionally, the Edge-Fog-Cloud architectural framework is covered, and a solution that combines IoT and operational technology is proposed for the purpose of dynamically scheduling personalized production. Unfortunately, there is a lack of comprehensive knowledge regarding how to handle cultural differences when integrating PLM and the Internet of Things.

METHOD

Integrated Internet of Things research methods for industrial electrical panel manufacturing equipment may involve several methodical and comprehensive steps. Initially, the strategy will consist of a comprehensive analysis of the requirements of the electrical panel industry that desires IoT integration. This entails comprehending the utilized hardware, necessary interfaces, as well as functional and security prerequisites. Surveying to identify IoT technologies that are tailored to the manufacturing equipment requirements of the electrical panel industry is the subsequent course of action. Choosing the appropriate sensors, network devices, communications protocols, and cloud or edge infrastructure is required for this. During this stage, system availability, data security, and dependability will be prioritized. Following this, the detailed design of the system architecture becomes a crucial step. Creating data flow diagrams, integrating hardware, modeling applications, and establishing network infrastructure will comprise this procedure. In addition, simulation testing may be conducted during this phase to verify the performance of the system prior to its implementation. During the implementation phase, IoT is integrated with industrial manufacturing equipment used to produce electrical panels. This entails the installation of hardware, configuration of software, setup of the network, and testing of functionality. Throughout this phase, exhaustive documentation will be generated to streamline subsequent maintenance and repair processes. In conclusion, ongoing evaluation and monitoring of the system will be conducted after its complete

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implementation. This requires the manufacturing electrical panel industry to engage in data collection, performance analysis, problem identification, and continuous improvement of IoT integration systems to ensure their long-term effectiveness and dependability.

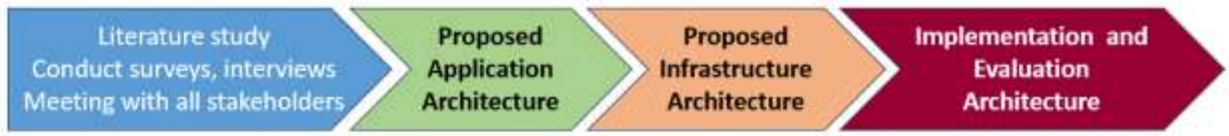

Figure 1. Proposed Research Methods
Source: Researcher Property

Literature Review

As part of our investigation into the integration of IoT with electrical panel manufacturing systems, we conduct a comprehensive literature review. The primary objective of this study is to conduct a comprehensive examination of the most recent research, scholarly articles, books, and other information sources that discuss IoT applications in the electrical panel manufacturing sector. The literature review serves as a crucial cornerstone as it facilitates a comprehensive comprehension of contemporary developments pertaining to the implementation of IoT within the realm of electrical panel production. This entails comprehending the underlying technology, encompassing the network systems that link the sensors installed on equipment to the overall operation of the integrated system. Moreover, by conducting literature reviews, one can discern obstacles that arise during the integration of IoT technology with electrical panel manufacturing systems. These encompass security concerns, interoperability of devices, management of big data, and additional facets pertinent to the intricacy of manufacturing systems. Furthermore, literature reviews offer valuable perspectives on the remedies suggested by scholars and professionals to surmount these obstacles. From the architectural concept to the technical implementation, potential integration with electrical panel manufacturing systems can be assessed and explored through the evaluation of diverse existing solutions. A comprehensive literature review helped researchers understand IoT implementation in electrical panel manufacturing. This will establish a robust groundwork for subsequent endeavors involving the design, development, and implementation of IoT integration in the industrial setting of electrical panels that are both effective and efficient.

Surveys are a crucial technique for gathering information from a variety of sources concerning the incorporation of IoT into electrical panel manufacturing systems. Professionals in the electrical panel industry, equipment users, technicians, and managers with hands-on experience implementing IoT technology in manufacturing settings may participate in this survey. The survey items will be meticulously crafted to delve into the perspectives and experiences of participants concerning the integration of the Internet of Things within the domain of electrical panels. The course will encompass various crucial elements, one of which is their hands-on expertise in the integration of IoT technology with equipment used in the fabrication of electrical panels. Additionally, participants will be queried regarding the challenges encountered throughout the integration procedure, encompassing both technical and managerial aspects.

Furthermore, the benefits component will be thoroughly examined in this survey. The participants will be requested to offer feedback regarding the advantages they have gained from the integration of the Internet of Things into the systems used to manufacture electrical panels. This may encompass various benefits such as enhanced operational efficiencies, heightened productivity, decreased expenditures, or even improved workplace safety. Moreover, in relation to electrical panels, the survey will inquire about suggestions participants may have concerning the future integration of the Internet of Things. Consulting individuals with practical expertise will offer valuable perspectives on the strategies that can be implemented to improve the effectiveness, productivity, and triumph of Internet of Things (Gopal et al., 2023) integration

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in the fabrication of electrical panels. A thorough and focused survey will be conducted to gather comprehensive insights from a diverse range of practitioners and stakeholders. Assembling the optimal strategy to integrate IoT with electrical panel manufacturing systems in support of the organization's technical and business objectives will be facilitated by this solid foundation.

To obtain a more comprehensive understanding of Internet of Things integration within the electrical panel manufacturing industry, it is imperative to conduct in-depth interviews with key stakeholders, including production managers, technicians, and owners of electrical panel companies. The primary considerations during this interview procedure will be the candidates' practical expertise in the implementation of IoT technology, the obstacles they encountered throughout the implementation process, the tactics they employed to surmount these challenges, and the advantages they have obtained. The valuable insights of respondents, including production managers, will illuminate the managerial implications of IoT integration on day-to-day operations. Since the introduction of the Internet of Things (Chandnani & Khairnar, 2022) in the manufacturing of electrical panels, they are capable of delineating alterations in work processes, efficiencies attained, and other noteworthy developments. Technician interviews will yield comprehensive technical knowledge. Their ability to provide comprehensive explanations of the technical obstacles encountered during the integration process includes hardware compatibility, system interoperability, and data security. They will also elaborate on the technical approaches they employed to surmount these challenges. Owners of electric panel manufacturers will give an overview of the long-term strategic benefits that have resulted from the incorporation of IoT into their operations. In addition to other potential benefits, they will emphasize the financial ramifications, enhanced product quality, and increased production efficiency that can be attributed to the implementation of the Internet of Things. By entirely conducting interviews, a multifaceted understanding of the IoT integration journey in electrical panel manufacturing can be obtained. By utilizing this information resource, one can not only gain insight into the accomplishments that have already been realized but also devise future strategic measures to enhance and broaden the integration of the Internet of Things in the manufacturing of electrical panels.

Proposed Application Architecture

To facilitate accurate monitoring of equipment, timely decision-making, and operational efficiency, the proposed application architecture for integrating the Internet of Things (Camatti et al., 2020) with manufacturing systems in electrical panel companies must be meticulously crafted. This architectural design will incorporate hardware components such as sensors that are linked to equipment used in the fabrication of electrical panels. The purpose of these sensors will be to gather vital information such as temperature, humidity, device performance, and operational data. Network connectivity will be utilized to transmit sensor data to the data processing platform. The primary hub for receiving, processing, and analyzing data from IoT sensors will be the data processing platform. Contingent to the requirements of the organization, these platforms may be edge-based or cloud-based. In this context, data processing technology that operates in real-time or near-real-time will be utilized to acquire timely and pertinent information. A subset of software applications will be developed in accordance with the data processing platform. Users, including production managers and technicians, will have the capability to analyze data, monitor equipment conditions in real-time, and optimize equipment operations using the information obtained through this application.

In this architecture, data privacy and security will be the primary concerns. To safeguard confidential information and deter unauthorized entry, stringent security protocols will be integrated across all tiers, encompassing sensors, cloud, and edge platforms. The architecture will possess the capacity for scalability and adaptation. In order to ensure the uninterrupted operation of the current system, it is imperative to accommodate the potential integration of supplementary equipment or the addition of new sensors.

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Utilizing IoT-obtained data, this architecture enables electrical panel manufacturers to optimize their operations. Utilizing intelligent data processing and sensors will facilitate prompt and accurate decision-making, increased productivity, enhanced maintenance, and enhanced product quality. This is a significant advancement toward the electrical panel industry's realization of intelligent, high-performance, and adaptive manufacturing systems.

Proposed Infrastructure Architecture

Precise considerations must be given to architectural infrastructure in the context of integrating the systems of an electrical panel manufacturer with IoT technology. The sensors that are integrated into the electrical panel manufacturing equipment must be compatible with the hardware of the infrastructure. Gateways or edge devices (Tanghatari et al., 2023) are utilized to manage the data from these sensors prior to their transmission to the data processing platform. Large quantities of data must be accommodated and processed on a platform capable of carrying out data processing. Cloud computing may work with massive IoT sensor data. In addition, data processing can be performed locally near the source using edge computing technology, resulting in a quicker response time and decreased latency. Critical to this architecture is the network infrastructure as well. Data flows between sensors, edge devices or gateways, and cloud platforms must be supported by networks that are dependable, secure, and quick. Network dependability is vital to guarantee the timely and effective exchange of data. Moreover, for the infrastructure to function correctly, security components must be tightly integrated. Every communication point, including cloud platforms and sensors, must employ robust security protocols. The infrastructure must incorporate data encryption, rigorous authentication, and ongoing security monitoring. Additionally, the development of flexible and scalable architecture is critical. Without disrupting ongoing operations, infrastructure must be capable of accommodating system expansion, additional sensors, and extended capacity. Electrical panel companies can establish a robust framework for streamlined operations, informed decision-making, and heightened productivity by incorporating these elements into the infrastructure architecture for IoT integration with manufacturing systems. By doing so, the organization will sustain a competitive edge in the market for electrical panels and enable further adaptation to evolving technological developments.

Implementation and Evaluation Architecture

A Project Management Body of Knowledge (PMBOK) (Rooij, 2009), (Clemente & Domingues, 2023) based approach will provide a solid foundation for managing the implementation of IoT integration with electrical panel company manufacturing systems. Initially, it is imperative to formulate a thorough project plan that encompasses the project's extent, timetable, expenditures, necessary resources, and potential hazards. This plan will function as a comprehensive blueprint for the entire project team, guaranteeing that all team members possess a clear comprehension of their respective responsibilities, the established deadlines, and the objectives to be accomplished. Following this, the implementation phase will commence by executing the project plan that has been prepared. This encompasses the installation of hardware components, configuration of software, setup of the network, and integration of the entire system. During this phase, the project manager will oversee the execution of all steps in accordance with the plan, consistently monitor the progress of the project, and resolve any issues that may occur. Following the completion of implementation, the subsequent phase involves assessing the technology that has been put into effect. This entails gathering data and information on the performance of the system following the implementation of IoT integration. Testing and monitoring will be conducted to assess the system's ability to achieve the objectives established during the planning phase. This assessment will encompass the efficiency, dependability, data protection, and the extent to which the new technology delivers the anticipated advantages in the operations of the electrical panel company.

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PMBOK also underscores the significance of risk assessment. Hence, the evaluation process will encompass a comprehensive risk analysis of the implemented system. This will facilitate the identification of prospective issues or vulnerabilities that may emerge in the future, as well as the development of tactics to mitigate these risks. Furthermore, the evaluation will incorporate input from users and stakeholders, which will be crucial. Examining the system from the user's standpoint will yield valuable understanding regarding its usability and identify areas that require enhancement or refinement. Employing a well-organized, PMBOK-derived (Saleem et al., 2023) methodology for overseeing implementation will guarantee adherence to the intended course of action and the successful attainment of the desired objective. An extensive technological assessment will yield a comprehensive comprehension of the efficacy of IoT integration with the manufacturing system of an electrical panel company. At the same time, the management of potential risks and the incorporation of user feedback will aid companies in enhancing their operations in the future.

RESULT

Application Architecture

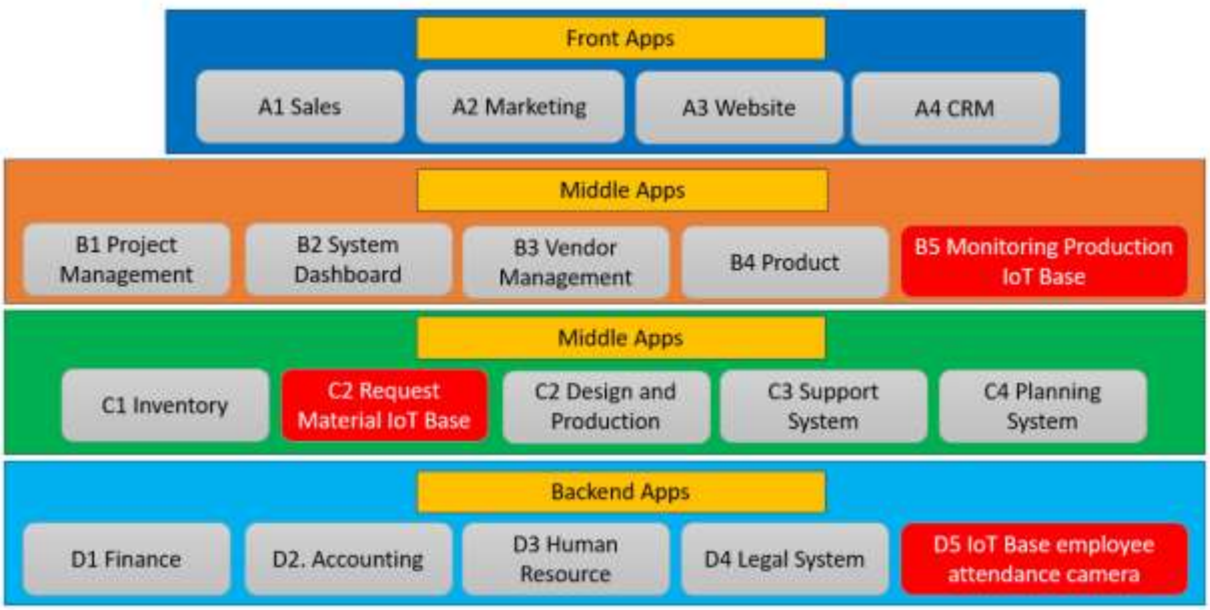

Figure 2. Proposed Application Architecture
Source: Researcher Property

The represented application architecture, as illustrated in figure 2, comprises multiple essential components that are interconnected to enhance operational efficiency. The initial element, C2, entails an IoT-based material requisition system that enables automatic procurement of necessary materials without direct human involvement. This minimizes the duration needed for the material acquisition procedure and enhances the overall productivity effectiveness. Component B5 involves the utilization of an IoT Base to monitor production. This enables the continuous monitoring of the production process in real-time. Through the utilization of IoT technology, the system is capable of precisely tracking machines and the entirety of the production process. This analysis offers a profound understanding of production performance, enables early identification of potential issues, and presents possibilities for prompt adjustments to enhance production efficiency. The D5 component serves as an Internet of Things (IoT) platform for monitoring

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employee presence using a camera. This is a novel approach to enhance the efficiency of employee attendance management. This system employs cameras to automatically detect the presence of employees, thereby minimizing the necessity for manual procedures in documenting attendance. This approach not only reduces the amount of time required but also decreases the likelihood of human errors when recording attendance. These three components are interconnected and function as essential elements of a unified system. Material requests made automatically from C2 have a direct impact on the monitoring of production from B5. Data obtained from production monitoring can have a direct influence on employee attendance management via D5. This architecture demonstrates the concept of interconnected IoT systems working together to enhance operational efficiency.

Alongside its operational advantages, this architecture also has significant implications for data analysis. By analyzing data collected from these diverse components, a comprehensive understanding of different facets of a company's operations can be obtained. This creates possibilities for more intelligent and timely decision-making based on the information that is currently accessible. In summary, the proposed application architecture offers the potential to enhance productivity, minimize human intervention, and deliver more valuable insights by seamlessly incorporating IoT technologies. If implemented correctly, this system can transform the company's operational environment, making it more efficient and adaptable to market demands.

Infrastructure Architecture

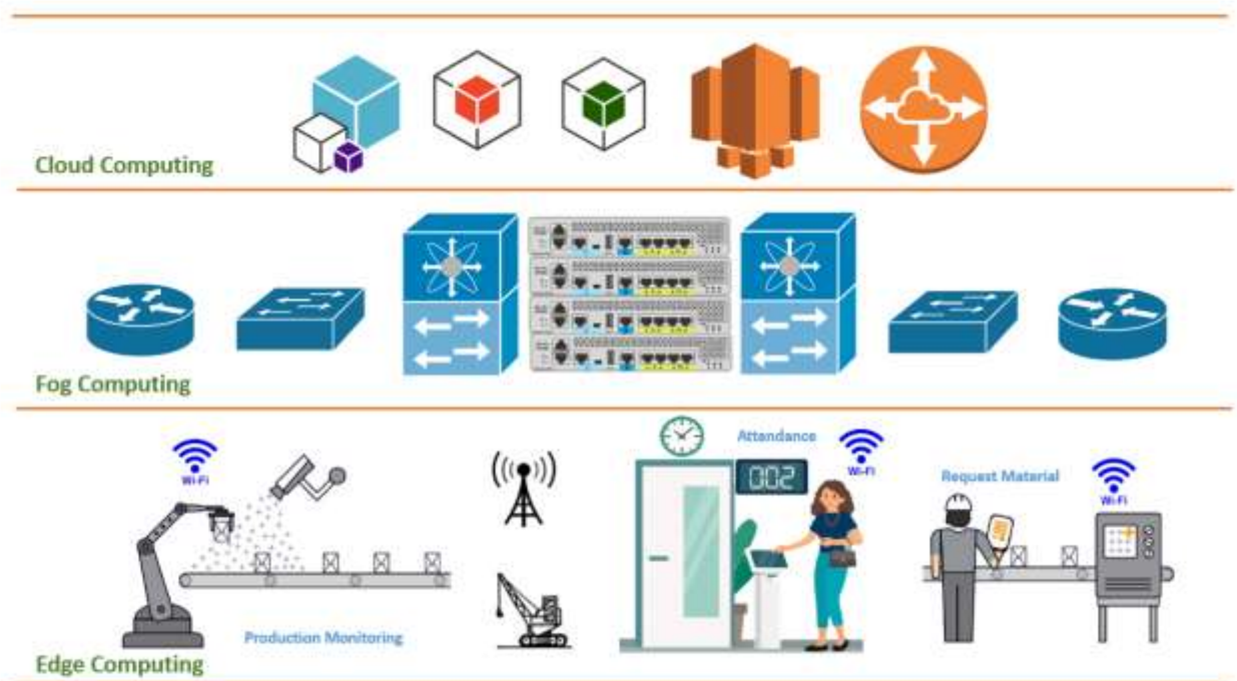

Figure 3. Proposed Infrastructure Architecture
Source: Researcher Property

The infrastructure architecture presented in figure 3 illustrates a holistic strategy for leveraging diverse computing technologies to enhance operational efficiency in manufacturing companies. This architecture comprises three primary components: edge computing, fog computing, and cloud computing. Its purpose is to facilitate essential functions, including production monitoring, employee attendance, and material requests.

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Edge computing is an essential component of contemporary technological infrastructure that functions as the initial stage for gathering and analyzing data. The proximity of its location to data sources, such as machines on the production floor, offers inherent benefits. Processing data directly at the source yields numerous significant operational advantages. An essential benefit of edge computing is its capacity to minimize latency. By performing data processing at its source, information can avoid the need to traverse significant distances to reach a central data center or cloud. This leads to an accelerated response to the gathered data. In industrial settings, such as production floors, where time is of utmost importance, this decrease in latency offers significant advantages. Enhanced response speed facilitates expedited decision-making and enhances adaptability to real-time changes. Edge computing enables enhanced local data processing efficiency. Through the capability of conducting on-site processing, only pertinent or processed data is required to be transmitted to the subsequent layer, specifically fog computing. This minimizes the burden on the network and enables more effective utilization of bandwidth. Edge computing enhances the dependability of data collection. Because data processing occurs at the origin, the system will remain functional even in the event of a disruption in the network connection to the cloud. This guarantees the uninterrupted continuation of operations despite any disruptions in connectivity. Given these benefits, edge computing has emerged as a crucial cornerstone for expediting decision-making processes and enhancing operational effectiveness across diverse sectors, particularly in the manufacturing industry. Edge computing facilitates the computation of data at its origin, leading to substantial advancements and effectiveness in the management and analysis of information produced by IoT devices in industrial settings.

Fog computing represents the subsequent stage in the data processing cycle following edge computing. Fog computing operates at a higher level compared to edge computing, serving as an initial filter and processing location for data before it is stored in a manufacturing company's extensive data system. Fog computing primarily serves the purpose of conducting meticulous preprocessing of data gathered from diverse sources through edge computing. Once the data has been processed on the local device, fog computing is responsible for further refining the data through filtration. This process encompasses data validation, elimination of extraneous information, and filtration to discern data with greater inherent worth. Therefore, the data stored in the subsequent phase, known as manufacturing company big data, is the data that has undergone a more comprehensive and organized filtering process. Fog computing not only filters data but also carries out additional preprocessing. This may involve consolidating data from various sources, conducting additional calculations to generate metrics or performance indicators, or even merging data for subsequent analysis. This process facilitates the creation of a well-organized and significant data framework prior to storing the data in a more extensive storage system. The preprocessing phase in fog computing offers the benefit of reducing the time and resources required for comprehensive data analysis. By conducting the majority of the processing at this level, the burden of managing manufacturing companies' extensive data is alleviated. This feature enables the system to concentrate on pertinent information and offer more profound observations, thereby enhancing overall effectiveness in data processing and analysis. In the data processing chain, fog computing plays a crucial role by refining data from edge computing before it is stored in big data. Fog computing significantly enhances data quality and relevance by employing advanced filtering and preprocessing techniques. This ensures that the data used for analysis and decision-making at the manufacturing company level is of high quality and directly applicable.

Cloud computing is the primary element of this architecture, functioning as a comprehensive data storage and analysis platform. The data obtained and analyzed from fog computing is stored in the extensive data infrastructure of the manufacturing company. This data is utilized in a machine learning-based decision-making process that has improved intelligence. Utilizing large datasets stored in cloud computing offers a robust foundation for more intelligent decision-making. The system makes use of AI and machine learning algorithms to analyze data thoroughly, leading to significant insights. This presents possibilities

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for enhancing production processes, overseeing employee attendance, and fulfilling material requirements with greater efficiency and punctuality. The architecture is a meticulous integration of diverse computing technologies designed to create an environment that can offer enhanced insights and quicker responses to the operational requirements of a manufacturing company. This infrastructure architecture offers enhanced operational efficiency and improved adaptability to changes in the business environment through a well-coordinated and integrated approach.

Implementation Architecture

The S curve offers a comprehensive representation of the allocation of time or effort across each phase of implementation, enabling targeted focus on the stages that demand scrutiny. The significance of establishing a robust technical framework, conducting comprehensive testing, and employing technology intelligently is emphasized in the process of planning and executing IoT integration in the manufacturing of electrical panels.

S Curve

NO	Task	Price	Time	Weight (%)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Graph
1	Preparation	Rp 10.000.000,00	6	1,24	0,21	0,21	0,21	0,21	0,21	0,21	100
2	Server and supporting device	Rp 250.000.000,00	2	31,06		15,53	15,53				80
3	Internet of Things (Edge Computing)	Rp 100.000.000,00	2	12,42		6,21	6,21				60
4	Fog Computing	Rp 175.000.000,00	1	21,74			21,74				40
5	Network Infastructure	Rp 120.000.000,00	3	14,91			4,97	4,97	4,97		20
6	Rollout all device	Rp 150.000.000,00	1	18,63					18,63		0
		Rp 805.000.000,00		100,00	0,2[illegible]	21,95	48,65	[illegible],18	23,8[illegible]	0,21	
	Accumulative amount				1,52	22,15	70,81	75,98	99,79	100,00	

Figure 4. Curva S Implementation Infrastructure Internet of Things
Source: Researcher Property

The diagram in Figure 4 illustrates the S Curve representing the allocation of time or work at each stage of implementing the Internet of Things (IoT) infrastructure in electrical panel manufacturing. The first phase, preparation (1.24%), involves the planning and development of the overall project strategy. Despite the relatively low percentage, this stage plays a crucial role in laying the groundwork for a successful implementation by identifying initial requirements and formulating a robust strategy. Allocating a significant amount of time is necessary for the configuration and establishment of the technical infrastructure needed to handle and store data from IoT devices, including servers and their associated equipment (31.06%). This process entails the establishment of servers, databases, and storage infrastructure that can accommodate the extensive and intricate data requirements of IoT sensors. The implementation of Edge Computing in the context of the Internet of Things is represented by a time allocation of 12.42% to bring the concept into action. Edge Computing facilitates on-site data processing, thereby minimizing network congestion and enhancing the overall system's responsiveness. Fog Computing (21.74%) is a significant phase that encompasses the advancement and execution of Fog Computing technology. This technology enables local data processing, allowing for advanced analysis and more intelligent decision-making prior to transmitting the data to a central server. Network infrastructure (14.91%) pertains to the development and enhancement of the physical and virtual framework that facilitates the transmission of data among Internet of Things (IoT) devices. This stage is crucial to guarantee the optimal and dependable transmission of information among all interconnected devices. The last phase, encompassing 18.63% of the process, entails the tangible integration of IoT devices into the entirety of the electrical panel manufacturing system. This includes the process of installing, configuring, and conducting comprehensive testing on each device to guarantee seamless operations.

* Corresponding author

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DISCUSSIONS

Two research questions are relevant to this context:

How is the architectural application design planned? (RQ 1)

The architectural application design is meticulously planned by incorporating multiple interconnected main components to bolster overall operations. With meticulous consideration given to their placement, these components are designed to guarantee seamless process continuity and optimal connectivity. In response to company demands, this design seeks to improve operational efficiency. Each part of the application architecture is chosen by first considering how it will contribute to the overall function. An example of this would be the C2 component's ability to automate the process of requesting materials through the Internet of Things (IoT), which would otherwise require human intervention. Component B5, which is monitoring production via IoT Base, allows for efficient management of production processes through real-time monitoring. Next, the D5 component provides for the management of employee attendance through cameras by utilizing IoT technology. Requests for materials, production tracking, and employee attendance tracking can all be seamlessly integrated. This enhances both operational efficiency and a holistic view of the entire business process. One prominent feature of this application's architectural design is its dedication to embracing cutting-edge technology, like the Internet of Things (IoT). Consequently, businesses can confidently ensure that they will enhance their operations by capitalizing on advancements. The goal of outlining these interdependent parts of the architectural application design is to lay the groundwork for a more responsible, productive, and efficient business that can meet the rising demands of the market.

How is the infrastructure structure planned in the proposal? (RQ 2)

The proposed infrastructure comprises three primary components that collaborate harmoniously to facilitate diverse critical functions within the manufacturing company. This structure, comprising edge computing, fog computing, and cloud computing, is specifically designed to oversee the management of data from its origin to more advanced decision-making procedures. Edge computing is a form of data collection that takes place near the data source, such as machines on the production floor. The purpose of this system is to carry out data processing on-site, thereby minimizing the delay and allowing for a quicker response to the gathered information. Processed data from edge computing is subsequently transmitted to fog computing. Fog computing, situated at an upper level, serves as an initial filter and conducts additional data processing prior to its storage in the manufacturing company's extensive data repository. This process encompasses the tasks of filtering, validating, and processing data in order to generate a more organized and structured data framework, which is then stored in a more extensive storage system. Cloud computing serves as a high-level platform for storing large amounts of data and conducting advanced analysis. The manufacturing company's big data repository stores the data that has undergone the edge and fog computing process. Within the realm of cloud computing, this data is utilized to enhance the efficiency and precision of the decision-making process through the application of machine learning techniques. This infrastructure plan outlines a comprehensive strategy for the management of data, encompassing its collection at the origin and its subsequent analysis at a sophisticated level. By strategically combining these technologies, companies can effectively utilize information to enhance operational efficiency, optimize production processes, and make more informed decisions through comprehensive data analysis.

CONCLUSION

Based on this research, the application proposal and architectural infrastructure show a dedication to maximizing the operational efficiency of manufacturing companies. The application architecture is devised by leveraging IoT technology to enhance material requisitions, production surveillance, and employee attendance administration. The objective is to expedite procedures, minimize human intervention, and offer enhanced insights. Simultaneously, the suggested infrastructure, utilizing a blend of edge computing, fog

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computing, and cloud computing, provides a comprehensive approach to data management and analysis. By harnessing this technology in tiers, data can be efficiently processed from its origin to advanced analysis, facilitating more intelligent decision-making. It is prudent to implement project management by closely monitoring the S curve. The S curve facilitates the tracking of a project's advancement over time, enabling the detection of sluggish growth phases or potential future risks. This offers the chance to implement proactive or adaptive measures as needed by the project. In summary, the comprehensive strategy of integrating application architecture, sophisticated infrastructure, and efficient project management through an S-curve offers significant enhancements in productivity, enhanced data analysis capabilities, and heightened responsiveness in project management. This demonstrates a dedication to technological advancement and a focused approach to improving the efficiency and accountability of manufacturing firms in response to swiftly evolving market requirements.

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* Corresponding author