Integrating Gen Ai For Predictive Maintenance And Process Optimization In Chemical Manufacturing

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***Abstract* — This research is focused on the improvement of chemical production process in PT Mandiri Inovasi Bersama specifically in maintenance, quality check, and production schedules that are all still highly manual and often causes delays. To overcome these challenges, this thesis proposes an enterprise architecture design integrating Generative Artificial Intelligence (GenAI) to enable predictive maintenance and process optimization in the manufacturing process. DSR is used as the research method and The Open Group Architecture Framework is adopted as the architectural methodology and ArchiMate is used as the visualization medium. Architecture development takes place in the important phases of the TOGAF ADM like Architecture Vision, Business Architecture, Application Architecture and Technology Architecture. Validation by experts was performed via expert interview and measured using Content Validity Index (I-CVI and S-CVI/Ave). The results indicate that there is a strong perception of value, work efficiencies to be gained, and effectiveness with the model presented to address important production problems and performance, along with decreased downtime. This framework acts as a strategic plan for the adoption of GenAI into the industrial field to help a transformation from a reactive to proactive manufacturing environment.**

***Key words*— generative AI, enterprise architecture, TOGAF, predictive maintenance, quality control, process optimization**

I. INTRODUCTION

Chemical manufacturing industries are also globally important[1]. They make a huge variety of these input substances, many of which have multiple uses. These chemicals are needed to make products used every day as well as for special occasions, from scents to beauty items to high tech materials. Its importance in business is due to the scale and diversity of chemical production[2].

PT Mandiri Inovasi Bersama (PT MIB) is a chemical manufacturing company that specializes in high purity chemical products. This business has different business processes like maintenance, quality control, as well as manufacturing process scheduling that are critical towards the manufacturing process flow. But there are some operational issues that still occur such as equipment damages that are only known after they fail, time-consuming manually done quality checking, and inconsistent production due to lack of communication handling which frequently causes human error. These problems occur because the company still employs a reactive maintenance strategy and old-fashion systems which does not support predictive analytics or intelligent process monitoring.

This research has three primary questions. (1) What is the current IT architecture landscape of the manufacturing processes at PT MIB, including its challenges? (2) How should a target IT architecture that integrates GenAI into the production process to improve the efficiency of manufacturing processes at PT MIB be designed? (3) How should the target architecture for PT MIB be implemented?

Digital transformation and the uptake of new technologies could help to address such issues, more precisely, Generative Artificial Intelligence (GenAI), which has the ability to analyze historical data, predict conditions and generate outputs based on the data[3]. In manufacturing specifically GenAI can help in areas from predictive maintenance, quality control, to process optimization[4]. But, GenAI adoption also requires some planning so that its implementation can align with business needs and can be adopted well within the company.

This research aims to design an enterprise architecture using the TOGAF framework that integrates GenAI to support predictive maintenance, quality control, and process optimization automation in chemical manufacturing. The architecture will be modeled using ArchiMate and evaluated through expert validation using the Content Validity Index for result validity.

This research has three primary objectives, which are (1) Analyze the current IT architecture landscape of the manufacturing processes at PT MIB, including identifying its challenges. (2) Target IT architecture, integrating GenAI in the production process at PT IMB that improves the efficiency of their manufacturing processes. (3) Develop an implementation plan for the target IT architecture at PT MIB.

II. THEORETICAL REVIEW

Theoretical review supports the development of the proposed enterprise architecture. Every theory is chosen according to the relevance towards the focus of the research. The following theoretical reviews cover improtant key concepts.

A. Generative Artificial Intelligence (GenAI)

Generative Artificial Intelligence is defined as AI models that are capable of generating new content based on existing patterns or prompts[5]. In this research, GenAI is framed as an enabler of automation in business functions. GenAI uses past or live data to generate structured outputs to inform decisions and improve operations[6]. The focus within chemical companies has been on automating processes and outputs, and on generating outputs intelligently, with GenAI[7]. The use of GenAI in this research seeks to eliminate unnecessary manual tasks and allow for intelligent decision making in a manufacturing context.

B. Enterprise architecture

Enterprise Architecture is a discipline that aligns IT strategy with business processes through a structured and holistic view. It helps document and design organizational structures, technology infrastructures as well as processes and workflows[8]. EA allows for organizations to deal with complexity and provide for future development in a systematic way. EA is the basis to ensure that business goals are enabled by appropriate technological solutions. Among the advantages of practicing EA in organizations are operation transparency and better departmental integration.

C. Reference Architecture

A Reference Architecture is a set of standardized references models, components, patterns and the relationships between them that can be customized for a particular organization[9]. For this study, Reference Architecture is applied to provide guidance for designing the improved system, architectural guidance of implementing GenAI in the system according to best practices. It serves as a reference and ensures that architectural modeling is comprehensive and consistent.

D. The Open Group Architecture Framework (TOGAF)

The Framework TOGAF defines a comprehensive architecture framework an enterprise architecture development process called the Architecture Development Method (ADM)[10]. All of the phases of the ADM including Architecture Vision, Business Architecture, Application Architecture, and Technology Architecture were used in this study[11]. TOGAF provides the framework to model the current and future states of the organization and how GenAI can fit into these to achieve business objectives. It makes the architectural process systematic, repeatable and stakeholder focused[12]. Shown in FIGURE 1.

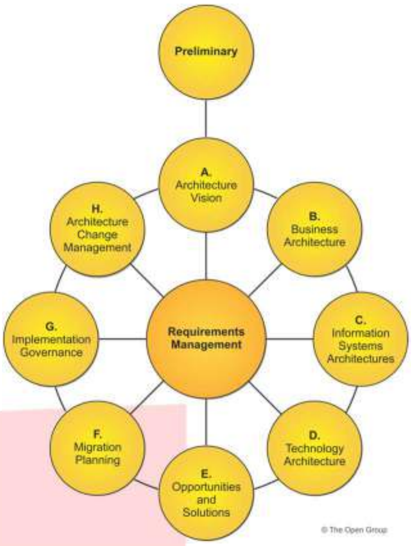

FIGURE. 1

TOGAF ADM Phases

a. Preliminary Phase: This phase is concerned with identifying appropriate business directives, architectural principles, defining vision, and identifying the stakeholders of the organization.
b. Architecture Vision: This is the phase in which a clear architectural vision that is consistent with the organization's business needs is developed.
c. Business Architecture: This phase deals with business processes that are significant in realizing the business goals of the organization.
d. Information Systems Architecture: This phase is concerned with applications and systems that meet the data and application requirements to support the business architecture.
e. Technology Architecture: This phase deals with identifying the technology infrastructure that will support the organization in its operations for applications and data.
f. Opportunities and Solutions: In this phase an implementation plan on the enterprise architecture design is elaborated along with possible solutions by looking into the opportunities that exist in the organization.
g. Migration Planning: In this phase key activities will aim at creating a detailed transition plan from the as-is to the target architecture.
h. Implementation Governance: This phase focuses on keeping the implemented architecture is still aligned with the target architecture
i. Architecture Change Management: This phase is concerned with the control of all the architectural changes necessary to keep the architecture relevant.

E. ArchiMate

The ArchiMate is a modeling language developed for the visual representation of enterprise architectures. ArchiMate is used to document and communicate architecture layers created using TOGAF. These comprise business process, applications and technology infrastructure modeling. The modeling performed with ArchiMate in this study helps stakeholders visualize the architecture's components and interdependencies at any stage of the TOGAF ADM.

F. Content Validity Index (CVI) Scale

The Content Validity Index (CVI) is a quantitative measure used to measure expert agreement regarding relevance and validity of content elements. In this study, the CVI is employed to assess the target architecture model proposed through expert opinion. Two types of CVI are applied which are Item-level CVI (I-CVI), that is used to evaluate individual items and Scale-level CVI (S-CVI/Ave) that aggregates the evaluation of all the items. This approach guarantees that the architecture is practically acceptable by experts in the domain. Shown in TABLE 1.

TABLE. 1

CVI Formula

CVI	formula
I-CVI (item-level content validity index)	I-CVI = (agreed item)/ (number of experts) Sum of all I-CVI scores
S-CVI/Ave (scale-level content validity index based on the average method)	S-CVI/Ave = (sum of I-CVI scores)/ (number of items)

III. METHOD

The Methods section delivers the explanation of the research design, consisting the data collection process, analysis steps, and evaluation methods used in this research to build and validate the target enterprise architecture.

A. Data Collection Method

This research utilizes both primary and secondary data sources. The primary data was gathered from the expert interview with IT professionals from PT Mandiri Inovasi Bersama (PT MIB) based on their experience observing the manufacturing process and workflow of operations. The purpose of these interviews was to gain an understanding of the real-life situations and technological requirements that the company was facing. Secondary data was collected via a Systematic Literature Review (SLR) on scientific articles and journals. These insights are to support the findings from the expert interview. Combined, these two sources of data produce an understanding of the research problem and inform the proposed enterprise architecture research solution.

B. Data Processing Method

The data from expert interviews along with the SLR were further dissected and synthesized into critical categories relevant to the use of Generative AI for predictive maintenance and for process optimization in the context of chemical manufacturing. The purpose was to obtain and understand information such us important technological requirements, business processes, its actors and relevant issues posed at such industrial settings. The collected insights were then synthesized into an architectural structure representing systems, technologies, and organizational functions. This framework developed a reference architecture for integrating GenAI in PT MIB's manufacturing process. The ArchiMate modeling language was used to construct the architecture artifacts, which were visualized using the Archi application and also using Draw.io, facilitating structured and clear representation of complex systems. A full list of artifacts from TOGAF ADM is included in this study. Shown in TABLE 2.

TABLE. 2

TOGAF ADM Artifacts

TOGAF ADM	Artifacts
Preliminary Phase	Principle Catalog
Architecture Vision	Goal/Objective/Requirement Diagram
	Value Chain Diagram
	Solution Concept Diagram
Business Architecture	Functional Decomposition Diagram
	Business Interaction Matrix
	Actor Identification Matrix
	Business Footprint Diagram
Application dan Data Architecture	Application Requirement Catalog
	Application Use Case Diagram
	Application Portfolio Catalog
	Application Interface Catalog
	Application Organization Matrix
Technology Architecture	Technology Standards Catalog
	Technology Portfolio Catalog
	Environment Location Diagram

C. Evaluation Method

The proposed target architecture was assessed through interviews with experts, stakeholders in PT MIB's IT division. The main instrument for assessment was a structured Agreement Scale, consisting of a questionnaire that captured responses from 1 (Strongly Disagree) to 5 (Strongly Agree) through interviews. The questionnaire covered essential architectural aspects such as system capabilities, integration support, data management, and alignment with business requirements. The responses were helpful in understanding what aspects had strong agreement, as well as what portions of the architecture would benefit from the improvements made. This assessment together with experts' feedback will validate the use of the target architecture in actual situations and will indicate improvements.

IV. RESULT AND DISCUSSION

The Result and Discussion section explains the results of the research, consisting the development of the proposed architecture and its evaluation. The discussion points out how the findings label the identified problems and align with the research objectives.

A. Current Problem

PT Mandiri Inovasi Bersama (PT MIB) currently faces urgent issues in production processes such as Failure Prevention, Maintenance Management, Quality and Scheduling shown in Table IV 1. In the Failure Prevention and Maintenance Recommendation, the company is still proactive towards machinery maintenance. These practices result in unplanned shutdowns, disruption in workflow, costly repairs, loss of productivity and more. There are no predictive and/or condition monitoring systems available that would give real-time information about the health of a machine to identify early signs of deterioration. Because these systems are absent, PT MIB has difficulty ensuring these production deadlines, and regularly reaches their production targets. This can be especially problematic in high demand, and time sensitive. In terms of Quality Control, the present procedure continues to apply a manual inspection done by the QC team after production has finished. The defect detection process is not supported by any automated systems or tools, meaning quality decisions are all made without any analysis of the data. When flaws are found, informal feedback of the quality is communicated to the production teams often through WhatsApp messages or verbal commands leading to communication errors and loss of time. There is no automated digital traceability system that could help keep track of recurring problems with quality, and of quality data over time. The product quality would therefore be suspect and rework cycles would only tighten available production schedules. In PT MIB production orders continue to be organized through a manual updated Excel and WhatsApp system. Orders get sent to Whatsapp group, and the schedule gets updated in a spreadsheet. This could potentially lead to untracked tasks and time consuming. Shown in TABLE 3.

TABLE. 3

PT MIB Problems & Effects

No	Problem	Effect
1	Performs equipment maintenance only after failures occur	Leads to increased costs associated with repairs, unanticipated downtime, reliability and worsened disruption to production timelines.
2	Quality control processes are executed manually and rely on informal dialogue	results in poor quality decisions, increased delays during corrections, and repeatable processes.
3	There is no integration across different systems within the company.	Scheduling in this context is highly susceptible to miscommunication, task overlap, capacity underutilization, and consistent delays

B. Systematic Literature Review

The goal of this research is to develop an integrated enterprise architecture model for predictive maintenance and process optimization of chemical manufacturing using Generative AI (GenAI) on PT Mandiri Inovasi Bersama (PT MIB) as a case study. A Systematic Literature Review (SLR) method was applied in order to analyze and compile existing applications, technologies, and frameworks related to AI-enabled industrial systems, to support the foundation for developing architecture in AI-integrated industrial systems.

The SLR process is structured into three main phases which are design, selection, and synthesis. As part of the design phase, outlining the research question first determine the relevant academic information sources, and create a search plan that is relevant to the goals of this research. During the selection phase, a systematic gathering focus is adopted to ensure the relevance and quality of filtered articles based on set criteria. In the synthesis phase, key findings about the reasons or needs behind the architecture, and how the system is shaped and then all of these findings are brought together to support and explain why it makes sense to design an enterprise architecture for PT MIB using GenAI. The three main phases for the SLR are shown in FIGURE 2.

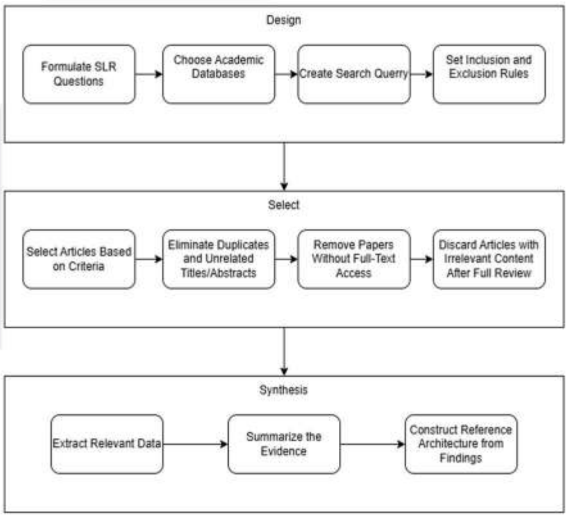

FIGURE. 2

Systematic Literature Review

C. Synthesis

The synthesis phase extracts architectural components relevant to the integration of Generative AI (GenAI) into predictive maintenance and process optimization for the manufacturing industry. Bibliography is first captured to keep the analysis clear and easy to track. Then, recurring patterns, trends, and challenges concerning GenAI application in industrial systems are extracted. In the end, these components are organized into several abstraction layers as defined in the ArchiMate modeling framework which contain stakeholders, drivers, assessments, goals, business functions, application components, application services, and technology components. These grouped components form the basis for an enterprise architecture model design meant for PT Mandiri Inovasi Bersama (PT MIB). The architectural components can be seen on TABLE 5.

TABLE. 4

Architectural Aspects

Architectural Aspect	Definition
Motive	Primary reason to implement AI systems in manufacturing to enhance efficiency, predictive maintenance, and product quality.
Driver	The Influencing factors that steer the cause of implementing AI in manufacturing.
Assessment	The evaluation of the problems that arise due to the driver.
Goal	The planned outcome that is expected to be achieved through the development.
Application Component	A software element that handles specific tasks and data that assists specific business functions.
Technology Component	The hardware, software, and networks that collects data and provides the foundation for running the application component.
Business Function	Set of tasks that contribute to meeting organizational objectives.
Stakeholder	The entities or an individual who are included in, or affected by the system.

The SLR process assists in gathering information about the current state of implementation of Generative AI in manufacturing with regards to predictive maintenance and process optimization. Only then by examining the relevant academic articles was able to construct the necessary components, obstacles, and best approaches that defend the design of the proposed enterprise architecture model. The architecture generated then would be supported by insights from evidence, and it would be suitable for the operations of PT Mandiri Inovasi Bersama (PT MIB).

D. Expert Interview

In the Expert Interview, experts took part, each profiling the IT department of PT MIB. This session was initiated with an explanation of the solution concept diagram which they gave evaluations and comments on each of the business core functions. In the Predictive Maintenance function, the experts mentioned the real time monitoring of the equipment condition to be able to detect early signs of failure. They also agreed on the use of an AI based real-time performance tracking system to reduce unplanned downtime and increase machine life. For the Quality Control function, the experts agreed that intelligent inspection systems with enhanced capabilities to analyze data and information to reduce the time it takes to identify defective products, and also to improve consistency in quality of production. In terms of Process Optimization, centralized systems for aggregation and control of data have been seen as a critical component to ensure efficient flow through the production process as well as timely decisions to be made in regards to scheduling as well as performance tuning was a great idea according to the experts. The experts felt that the designed solution concept diagram and the Application use case diagrams that were then delivered after also got a matching response, were in match with current business processes and needs, as well as future needs.

E. Solution Concept Diagram

The solution concept diagram is a graphical representation of the proposed design of a solution for addressing the needs in developing the intended architecture. This diagram illustrates the relationship between the components that will exist in the target architecture, including the business functions, application systems, and the technology, and how they are represented in the solution concept diagram. The Solution Concept Diagram attempts to give a visual concept of how the integration of Gen AI for predictive maintenance and process optimization of chemical manufacturing can lead to an increase in manufacturing process performance. The diagram acts as a big picture to stakeholders about the structure of the proposed architectural solution shown in FIGURE 4.

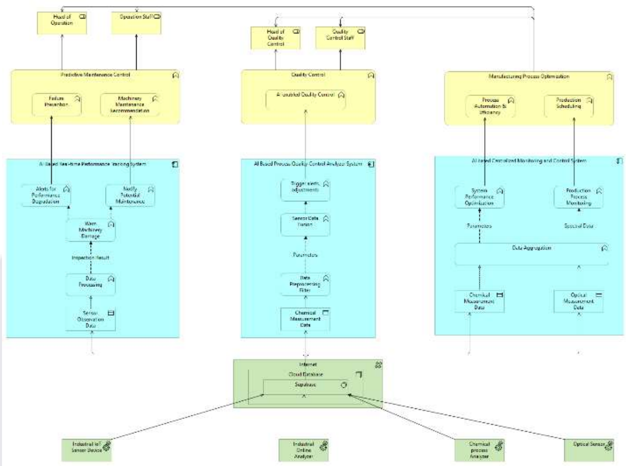

FIGURE. 3

Solution Concept Diagram

F. Application Requirement Catalog

An Application Requirement Catalog contains a set of functional requirements that the application systems must fulfill to service the business goals of the company. The catalog details critical application requirements such as system features, integration, and usability. The following requirements are considered to make sure that all these applications will support PT MIB's operational objectives. The catalog helps match software capabilities with business priorities, by ensuring that predictive maintenance, quality control, and process monitoring tools all work in an integrated and straightforward way. The application requirement catalog for the corporate environment of PT MIB is presented in the next section shown in TABLE 9.

TABLE. 5

Application Requirement Catalog

No	Requirements	Description
1	Real-time Monitoring of Equipment Conditions	The system must be capable of continuously monitoring machine status through Industrial IoT Sensors and embedded systems to detect performance changes early and prevent breakdowns.
2	Application and system Analysis from Chemical reading and Visual Data	The application must integrate to the devices to automatically function its purpose to help business needs.
3	The Predictive Maintenance Recommendation system	The platform must analyze historical and real-time data to provide proactive maintenance alerts and suggestions to maintenance teams before equipment failure.
4	Centralized Storage of Processed Data	The system must store the collected and processed data into a centralized database
5	Access to the Visualization Dashboard.	A dashboard must be available for staff to easily access, read, and act on real-time system performance.

G. Application Interface Catalog

The Application Interface Catalog shows the connection between the logical applications within PT MIB's enterprise architecture. It delivers how each application interacts with each other. This shows that all logical applications are integrated using a cloud database and are connected to the Supabase logical application with its relationship.

No	Logical Application	Relationship		Connected Logical Application
		Interface	Technology	
1	AI Based Real-time Performance Tracking System	Cloud Database	REST API	Supabase
2	AI Based Process Quality Control Analyzer System	Cloud Database	REST API	Supabase
3	AI based Centralized Monitoring and Control System	Cloud Database	REST API	Supabase

H. Technology Portfolio Catalog

Technology Portfolio Catalog is an artifact that presents a portfolio of technologies handled for the development of the enterprise architecture PT Mandiri Inovasi Bersama. It shows the technological services with systems supporting critical functions, such as predictive maintenance, quality control, and process optimization. This shows the technology portfolio catalog employed in PT MIB's target architecture. Shown in TABLE 10.

TABLE. 6

Technology Portfolio Catalog

Logical Technology Component	Technology Service	Description
Industrial IoT Sensor Device	Sensor Monitoring Service	Hardware sensors that collect real-time machine data
Industrial Online Analyzer	Chemical pH Analysis Service	A real-time analyzer system that monitors the pH levels of chemical substances
Chemical process Analyzer	Chemical Texture Analysis service	An analyzer used to examine the texture of chemicals
Optical Sensor	Color Detection and Inspection Service	A sensor that reads and evaluates color accuracy of chemicals

I. Environment Location Diagram

The Environment Location Diagram represents where the applications are being put, it shows which applications are being utilized in those certain places, and points out which area links with the applications along with the technologies used in which location. It gives a clear vision to view the relationship with the locations, applications operated in that place, and the technology supported. Shown in FIGURE 6.

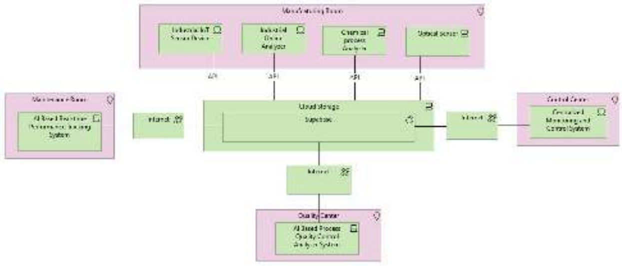

FIGURE. 4

Environment Location Diagram

J. Evaluation

The last phase in the Design Science Research process is evaluation, targeting at evaluating how effectively the designed solution can label real life cases. This section delivers on the benefits of the reference architecture design in integrating Gen AI for predictive maintenance and process optimization in chemical manufacturing. A questionnaire is distributed to the experts such as head of IT Department, Head of Quality Control, Quality Control Staffs, Head of

Operations, Operations Staff, and the CEO of PT MIB. The assessment was conducted using a 4-point Likert scale questionnaire, where:

1. Score 1 being really not helpful
2. Score 2 being not helpful
3. Score 3 being helpful
4. Score 4 being really helpful

TABLE. 7

CVI Evaluation

Variable	Results from experts				I-CVI	Interpretation
	1	2	3	4		
Has supported the Machinery Maintenance Recommendation business function in the manufacturing process at PT Mandiri Inovasi Bersama.	0	0	2	4	1	Agreed
Has supported the Quality Control business function in the manufacturing process at PT Mandiri Inovasi Bersama.	0	0	2	4	1	Agreed
Has supported the Manufacturing process Optimization business function in the manufacturing process in PT Mandiri Inovasi Bersama	0	0	2	4	1	Agreed
S-CVI/Ave					**1**	

Evaluated by the expert and stakeholder in PT Mandiri Inovasi Bersama shown in TABLE 11, the result of this proposed enterprise architecture solution was relevant and practical to help in the enhancement of the core business process in the chemical manufacturing process. This is evidenced by a S-CVI/Ave (Scale-Level Content Validity Index average) score of 1, showing a high level of agreement among experts as to the helpfulness of the system in which all variables were interpreted as "Agree". Several experts admired the aspects of the proposed target architecture, especially the ability to integrate Generative AI (GenAI) to help predictive maintenance, AI-enabled quality control and the optimization of manufacturing processes. The design was praised for reducing unplanned downtime, improving consistency of product and scheduling production, as well. It was also viewed as a viable solution that can be deployed on a larger scale, and applied across production lines and work environments. The visualization of system functions, implementation of a cloud database (Supabase), and structured data streaming from devices to AI systems were seen as major benefits for a connected, data driven, and intelligent manufacturing process. The collaborative nature of the architecture that took place in the cross functional integration of operations with quality control and production planning segments were seen as a positive step towards more efficient, automated and reliable chemical manufacturing processes at PT MIB.

V. CONCLUSION

The Conclusion is based on the research and the development of the target architecture for the integration on Gen AI for predictive maintenance and process optimization, beginning with the preliminary phase to the technology architecture, answering the problems stated for this research.

(1) PT MIB faces obstacles to its current manufacturing operations. Important production processes like maintenance, quality control or production scheduling have yet to introduce any kind of intelligent system, and are done completely manually. This situation results in human error, time consuming processes and overall performance that trickles down to reliability in production. (2) The target IT architecture is designed to deploy GenAI in order to improve the efficiency and intelligence of PT MIB's manufacturing processes. This target architecture facilitates the integration of the most important production tasks of predictive maintenance, quality control and process optimization through AI supported applications that reads real time data. These systems are supported by cloud-based infrastructures and other centralized control platforms, which enable them to share data, as well as coordinate processes. With the inclusion of GenAI in its target architecture, PT MIB can autonomously identify anomalies, predict decisions and adjust processes with minimal human intervention. Each element, whether it be the IoT sensors, the performance tracking, or the AI based analyzers, are all designed to integrate to provide a more efficient, reliable and responsive production environment. (3) The target architecture that has been proposed can be developed gradually by integrating AI in the core manufacturing processes of PT MIB. This includes installing IoT sensors and analyzers to monitor machinery and chemical quality connected to a centralized AI and cloud database for real time analytics. Initial implementation must be done on one production line, in order to set the system as reliable, before spreading it across the others. The transition will be supported through staff training and collaborating with IT stakeholders to make sure the IT integrations are adopted and support the business objectives is essential. Applying the architecture in phases allows for it to be more relevant and aligned with the operational goals of PT MIB.

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