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A Smart Management Framework for Higher Education Accreditation Based on the PUDAL Engine and V-Model Approach

Kerangka Kerja Pengurusan Cerdas untuk Akreditasi Pendidikan Tinggi Berdasarkan Enjin PUDAL dan Pendekatan Model V

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ABSTRACT

Higher Education Institutions (HEIs) worldwide face growing pressure to reconcile traditional academic values with rapid digital transformation and increasingly stringent accreditation requirements. This paper proposes a novel Smart Management Framework (SMF), grounded in the smart engineering paradigm, to enhance quality assurance and optimize the PPEPP (Planning, Implementation, Evaluation, Control, and Improvement) cycle for accreditation compliance. Central to the framework is the PUDAL (Perception, Understanding, Decision, Action, Learning) engine, which functions as a cognitive intelligence layer that enables context awareness, adaptive decision-making, and autonomous learning from accreditation-related data. The framework is developed using a holistic methodology that integrates a four-layer ASTF (Application, System, Technology, Fundamental) architecture with a V-Model engineering process, providing a structured and data-driven approach to strategic management. Initial results demonstrate the feasibility of automated data collection and restructuring from heterogeneous institutional sources, establishing a critical foundation for intelligent quality assurance processes. This research contributes a systematic, technology-based solution to address data fragmentation and administrative burden in HEIs, while offering a proactive mechanism for continuous quality improvement. The key novelty of the proposed framework lies in the seamless integration of the PUDAL engine with the PPEPP cycle, representing a paradigm shift from conventional reactive quality assurance models toward an smart, adaptive, and learning-oriented system.

Keywords**:** accreditation, PPEPP cycle, PUDAL engine, V-model

ABSTRAK

Institusi Pengajian Tinggi (IPT) di seluruh dunia menghadapi tekanan yang semakin meningkat untuk menyelaraskan nilai-nilai akademik tradisional dengan transformasi digital yang pesat dan keperluan akreditasi yang semakin ketat. Kertas kerja ini mencadangkan Rangka Kerja Pengurusan Pintar (SMF) yang baharu, yang berasaskan paradigma kejuruteraan pintar, untuk meningkatkan jaminan kualiti dan mengoptimumkan kitaran PPEPP (Penetapan, Pelaksanaan, Evaluasi, Pengendalian dan Peningkatan) untuk pematuhan akreditasi. Enjin PUDAL (Persepsi, Pemahaman, Keputusan, Tindakan, Pembelajaran) yang berfungsi sebagai lapisan kecerdasan kognitif yang membolehkan kesedaran konteks, pembuatan keputusan adaptif dan pembelajaran autonomi daripada data berkaitan akreditasi menjadi teras kepada rangka kerja ini. Rangka kerja ini dibangunkan menggunakan metodologi holistik yang mengintegrasikan seni bina ASTF (Aplikasi, Sistem, Teknologi, Asas) empat lapisan dengan proses kejuruteraan Model-V, menyediakan pendekatan berstruktur dan dipacu data untuk pengurusan strategik. Keputusan awal menunjukkan kebolehlaksanaan pengumpulan dan penstrukturan semula data automatik daripada sumber institusi yang heterogen, mewujudkan asas kritikal untuk proses jaminan kualiti pintar. Penyelidikan ini menyumbang penyelesaian berasaskan teknologi yang sistematik untuk menangani pemecahan data dan beban pentadbiran di IPT, sambil menawarkan mekanisme proaktif untuk penambahbaikan kualiti yang berterusan. Kebaharuan utama rangka kerja yang dicadangkan terletak pada penyepaduan enjin PUDAL yang lancar dengan kitaran PPEPP, yang mewakili anjakan paradigma daripada model jaminan kualiti reaktif konvensional ke arah sistem yang pintar, adaptif dan berorientasikan pembelajaran.

Kata kunci**:** akreditasi, kitaran PPEPP, enjin PUDAL, model-V

INTRODUCTION

Higher Education Institutions (HEIs) are increasingly operating within a complex environment that requires balancing established academic traditions with the growing demand for innovation driven by digital transformation (Yousuf & Wahid 2021; Xiao 2019). Rapid developments in Artificial Intelligence (AI), data analytics, and digital technologies have compelled HEIs to adopt more advanced approaches to enhance operational efficiency, strengthen institutional decision-making, and improve the overall quality of education (Bokonda et al. 2020; Han et al. 2025; Ujir et al. 2025). AI is transforming pedagogical approaches in higher education, with adaptive learning platforms and smart tutoring systems providing more personalized, efficient and innovative learning for students (Govindarajan 2025). Within this context, the concept of a smart campus has emerged as a strategic approach that integrates digital technologies to optimize institutional management and academic operations (Surjawan et al. 2025). According to Rashid et al. (2022) the smart campus concept adopts the idea of a smart city and brings it to the campus operation, where the system can fulfill the user's needs by controlling the consumption of resources. Systematic studies show that the adoption of smart campus technology in higher education institutions has the potential to revolutionize operational management, improve administrative efficiency, and strengthen academic delivery by integrating smart technology across campus functions (Bakar 2025).

In Indonesia, all study programs are required to undergo formal accreditation to ensure compliance with national higher education quality standards. Accreditation bodies such as LAM Infokom are responsible for evaluating programs in specific disciplines, including Informatics and Computer Science, while mandatory data reporting to the Higher Education

Database (PDDikti) serves as a central reference for accreditation and quality assurance processes (Infokom 2025; PDDikti 2025). Despite the existence of these regulatory mechanisms, many HEIs particularly those with limited resources continue to face substantial challenges in meeting accreditation requirements. These challenges include fragmented and poorly integrated information systems, high administrative burdens associated with data reporting, and a tendency to adopt reactive rather than proactive approaches to quality improvement. Moreover, decision-making processes within academic institutions are inherently complex and multidimensional, often involving diverse stakeholders with differing perspectives. These processes are frequently constrained by limitations in time, human resources, data availability, and technological support, which can hinder effective strategic planning and continuous quality assurance.

To address these challenges, this study proposes the development of a Smart Management Framework (SMF) that integrates Machine Learning (ML) and Knowledge Management (KM) to support strategic, data-driven decision-making within internal quality assurance systems. Prior research (Anshari et al. 2023) highlights that the integration of ML and KM can optimise organisational knowledge processes, enabling more efficient data discovery, improved decision-making, and enhanced knowledge dissemination (e.g., optimisation of KM with ML enabled leads to more discoverable and shareable organisational knowledge). The proposed framework is designed to enhance the effectiveness of the planning, implementation, evaluation, control, and improvement (PPECI) cycle in supporting accreditation compliance, aligning with evidence that continuous and data-driven quality management strategies contribute significantly to institutional performance (Alfaridli & Iman 2025). Automating evaluation processes, generating accurate and timely analytical insights, and facilitating continuous improvement through improved stakeholder collaboration, SMF aims to strengthen institutional capacity for sustainable quality assurance. This paper presents the initial conceptual design of the SMF, its core components, the smart engineering methodology employed, and preliminary results from the automated data collection phase. Figure 1 illustrates the relationship between the Smart Management Framework, Machine Learning, and Knowledge Management.

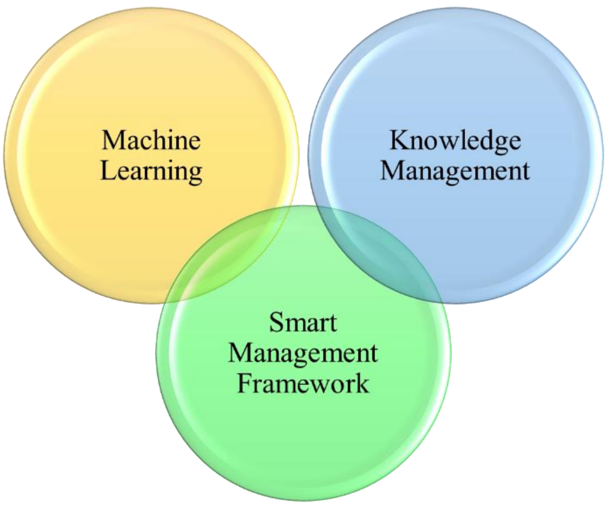

FIGURE 1. The relationship between smart management framework, machine learning and knowledge management

THEORITICAL BASIS

This section will address the theoretical basis of a study.

PPEPP CYCLE AND ITS CHALLENGES IN STUDY PROGRAM ACCREDITATION

The accreditation of study programs in Indonesia, administered by the National Accreditation Board for Higher Education (BAN-PT) and independent accreditation bodies such as LAM INFOKOM, functions as a strategic instrument for ensuring higher education quality through systematic external evaluation. This process highlights the importance of a robust Internal Quality Assurance System (SPMI) within the national higher education quality assurance framework (SPM Dikti).

SPMI is fundamentally structured around the PPEPP cycle that consists of planning, implementation, evaluation, control, and improvement which aims to ensure alignment between institutional quality standards, the National Higher Education Standards (SN-Dikti), and accreditation requirements. Despite its strategic role, the implementation of the PPEPP cycle at the study program level continues to face significant challenges. One prominent issue is the fragmentation of data management systems, which complicates the processes of data collection, validation, and analysis required for the Study Program Performance Report (LKPS) and the Self-Evaluation Report (LED). This condition not only increases administrative workload but also reduces the efficiency and reliability of quality assurance processes.

Moreover, control and improvement activities are frequently conducted in a reactive manner rather than being embedded as proactive and continuous quality enhancement mechanisms. As a result, study programs often struggle to achieve optimal accreditation outcomes. Addressing these limitations necessitates the adoption of innovative, technology-driven quality management approaches that integrate information systems and knowledge management to support a more effective, cohesive, and sustainable implementation of the PPEPP cycle (PDDikti 2025).

SMART SYSTEM MODEL

A system can be defined as a set of interrelated and interacting components that operate collectively as an integrated whole. According to Romero, a smart system is characterized by its ability to be fully utilized by users while logically addressing problems in a manner analogous to human reasoning, including the capacity to reflect upon, explain, and justify its problem-solving processes (Sidorov et al., 2017). Figure 2 illustrates the smart system processes based on varying levels of automation, comprising perception, understanding, decision, action, and learning stages (Sidorov et al. 2017; Imbar et al. 2021).

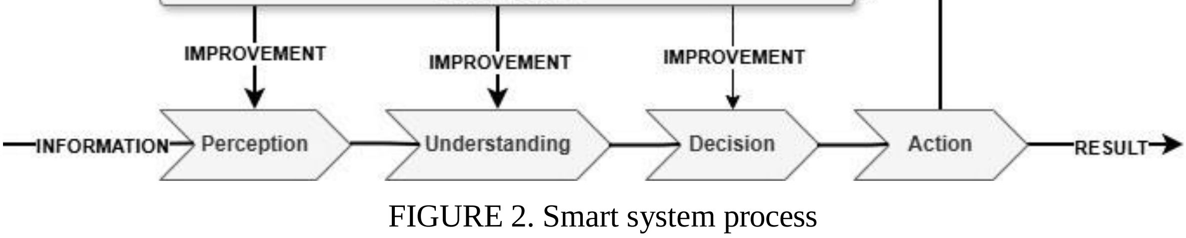

FIGURE 2. Smart system process

Each stage of the smart system process is described as follows:

1. Perception refers to the system's capability to autonomously acquire relevant and meaningful data.
2. Understanding involves transforming raw data into structured information that can be used to generate alternative action plans for subsequent stages.
3. Decision denotes the ability to select the most appropriate course of action from multiple alternatives based on predefined criteria and contextual factors.
4. Action represents the execution of selected decisions, resulting in observable outcomes.
5. Learning reflects the system's capacity to enhance its cognitive capabilities.
6. through continuous data analysis and experience accumulation.

In the context of higher education, smart management is characterized by the integration of advanced technologies to support decision-making and operational efficiency; the use of data analytics for strategic planning; enhanced collaboration among stakeholders; adaptability to evolving educational environments; strong stakeholder engagement; a commitment to sustainability and long-term institutional goals; and continuous improvement facilitated through systematic monitoring and evaluation (Shishakly et al. 2024).

Existing studies on smart management in HEIs have examined several key domains such as smart human resource management, smart financial management, smart asset management, and smart procurement, all of which aim to improve administrative efficiency and institutional performance (e.g., smart finance and asset management improve resource allocation and decision-making) (Surjawan et al 2025). Knowledge Management has also been identified as a critical enabler of smart campus initiatives, supported by emerging technologies such as the Internet of Things (IoT) and big data analytics (Hidayat & Sensuse 2022). IoT refers to a network that connects any item to the Internet for information exchange (Shihao et al. 2025). IoT technology has made a major contribution to the transformation of education, which refers to the provision of personalized learning anytime and anywhere (Murad et al. 2025). The IoT offers significant potential to enhance accessibility, availability, and scalability across educational environments (Ibrahim et al. 2023). As research on IoT use cases in campus settings explains, IoT technologies can support diverse smart campus applications from asset tracking and monitoring to improving safety and administrative functions suggesting that "NB-IoT technology has significant potential to enhance various aspects of educational institutions" through deeper connectivity and real-time data flow (Taruc & De La Cruz 2024). Through various connectivity protocols, IoT technologies facilitate seamless interaction between individuals and the virtual world by enabling a wide range of smart devices and services (e.g., sensor-based infrastructure and real-time analytics (Dehkordi, ET AL. 2023; Fawzi et al. 2019; Adat & Gupta 2018). A recent conceptual survey further argues that integrating IoT, AI, and cloud computing into administrative governance enables automation, interoperability, personalization, transparency, and adaptability in HEI operations, positioning smart administration as the backbone of future smart universities (Haggag et al. 2025).

Although various smart management frameworks have been proposed, including capability maturity models for assessing digital transformation readiness, there remains a lack of comprehensive models that systematically address the complex and multidimensional challenges associated with accreditation compliance. This study extends existing research by proposing a holistic smart engineering approach that specifically targets the PPEPP cycle in the accreditation context, integrating artificial intelligence, machine learning, and knowledge management to provide proactive, evidence-based decision support.

WEB SCRAPING

In the digital era, large volumes of information are readily accessible online and increasingly utilized for research and organizational decision-making. Web scraping is a technique employed to extract data from websites, such as product information from commercial platforms or statistical data from public information portals, and store it in structured formats including CSV, Excel, or JSON. While data plays a crucial role in supporting organizational performance, one of the primary challenges lies in acquiring high-quality and reliable data.

To address the challenges of acquiring reliable data from public portals, this research utilizes an automated data collection workflow powered by Robotic Process Automation (RPA). The workflow logic, implemented via the UiPath platform, focuses on navigating the heterogeneous structures of institutional and PDDikti websites to extract relevant accreditation evidence (Tejaswini& Sindhu 2024; Geetha et al. 2024). By automating these interactions, the system systematically transforms unstructured web data into structured tabular formats, ensuring data consistency and reliability for subsequent analytical processing while significantly reducing the manual administrative workload (Mishra et al. 2022; Khan & Khan 2023).

DETERMINATION OF KEY SUCCESS FACTORS

Critical Success Factors (CSF) represent a well-established methodology in strategic planning that identifies the essential conditions and activities required to achieve organizational success. CSFs may encompass aspects such as research and development, product innovation, customer service, and service quality (Laudon & Laudon 2004). In this study, the CSF methodology is employed to identify the key factors that most significantly influence the successful implementation of the proposed smart accreditation framework.

The strategic steps that will be taken are as shown in the following Figure 3.

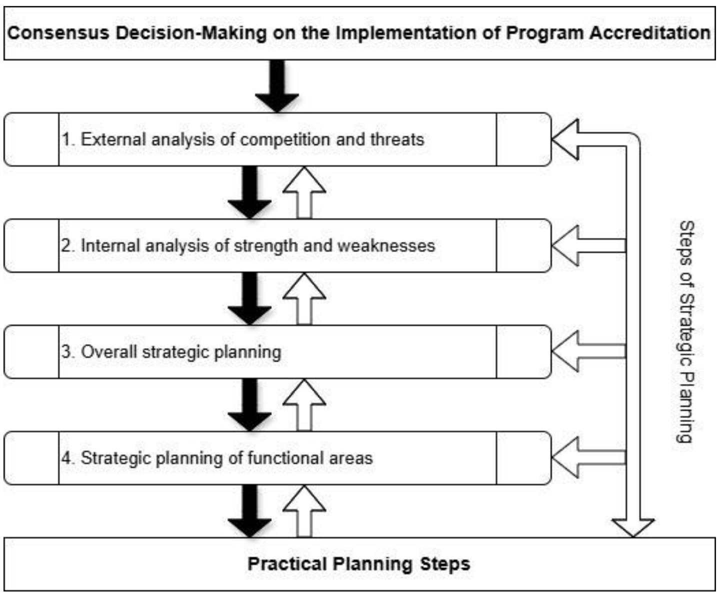

FIGURE 3. CSF methodology for practical planning

The identification of CSFs involves both external and internal analyses. The first step focuses on identifying competitors to establish performance benchmarks and anticipate potential threats. The second step examines internal organizational resources and capabilities to address challenges and capitalize on opportunities identified through external analysis. In general, five criteria are commonly used as guidelines for identifying CSFs, as presented in Table 1 (Schniederjans et al. 2010).

TABLE 1. CSF criteria used for consensus building

CSF Criteria	Example
Contribution to measurable academic outcomes	Stakeholders assess each alternative based on its expected impact on accreditation-related performance indicators that are prioritized in external evaluations
Alignment with institutional strategic direction	Alternatives that strongly support the institutional strategic plan tend to gain broader collective agreement during consensus discussions
Relevance to the academic development stage	Options perceived as outdated or requiring immediate improvement are more likely to be jointly prioritized through consensus
Support for core academic processes	Alternatives that directly enhance core academic processes are more easily accepted as shared priorities among stakeholders
Feasibility in terms of resource commitment	Consensus is achieved by selecting alternatives that are considered most realistic and implementable within existing resource constraints

PROPOSED SMART MANAGEMENT FRAMEWORK

The proposed SMF is developed to address the increasing complexity of quality assurance and accreditation processes in HEIs by integrating advanced digital technologies with a systematic smart engineering methodology. The framework provides a comprehensive, data-driven approach to optimizing the PPEPP cycle, thereby enabling continuous quality improvement and ensuring compliance with national accreditation standards

ANNOTATION PROCESS

The SMF is conceptualized as an integrated smart system that combines ML and KM to support strategic and operational decision-making throughout the PPEPP cycle. ML techniques are employed to analyze institutional data and generate predictive insights, while KM mechanisms facilitate the capture, formalization, and dissemination of accreditation-related knowledge and best practices. The primary objective of the framework is to automate evaluation processes, reduce administrative burdens caused by fragmented data sources, and deliver accurate, timely, and actionable information to stakeholders. Through enhanced collaboration and evidence-based decision-making, SMF supports sustainable quality improvement and accreditation readiness in accordance with standards established by LAM Infokom and PDDikti.

CORE COMPONENTS OF THE FRAMEWORK

Both the SMF and its functionality are constructed from several key components that are interrelated:

PPEPP CYCLE INTEGRATION

The SMF is functionally integrated across all stages of the PPEPP cycle:

1. Planning: Supports the formulation of quality standards aligned with national regulations and institutional objectives.

2. Implementation: Monitors the execution of academic and operational processes against predefined standards.
3. Evaluation: Facilitates systematic assessment of implementation outcomes, addressing challenges related to data fragmentation and manual reporting.
4. Control: Enables early detection of deviations and supports corrective and preventive actions.
5. Improvement: Assists in the design and execution of continuous quality improvement initiatives based on evaluation results.

This comprehensive integration ensures that quality assurance activities are managed holistically and continuously refined.

PUDAL ENGINE

At the core of the SMF is the PUDAL (Perception, Understanding, Decision, Action, Learning) engine, which governs the smart and adaptive behavior of the system. Figure 4 shows the flow diagram of PUDAL engine.

1. Perception: Automatically acquires relevant data from heterogeneous sources, including PDDikti, SIAKAD, publication repositories, and institutional performance reports.
2. Understanding: Applies Natural Language Processing (NLP) techniques for document analysis and ML models for performance prediction, mapping extracted information to the accreditation ontology to establish contextual understanding.
3. Decision: Utilizes an ontology-based reasoning engine to compare current institutional conditions with ideal accreditation standards, identify gaps, and generate alternative decision scenarios.
4. Action: Produces analytical dashboards, gap analysis reports, and prioritized recommendations to support managerial decision-making.
5. Learning: Incorporates feedback from accreditation outcomes to refine predictive models and reasoning rules, enabling continuous system improvement.

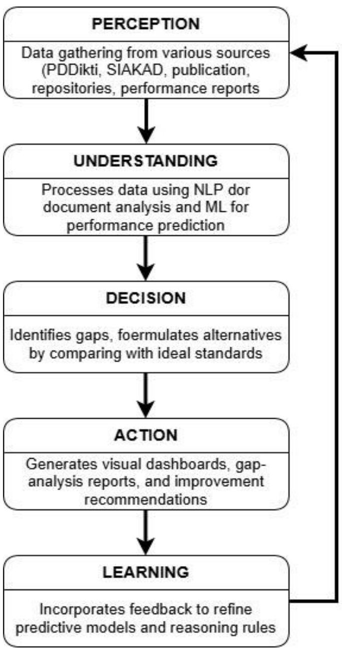

FIGURE 4. PUDAL engine flow diagram

ASTF LAYERED ARCHITECTURE

The SMF adopts a four-layer ASTF (Application, System, Technology, Fundamental) architecture as part of a holistic smart engineering approach. Each layer is systematically validated using the PICOC (Population, Intervention, Control, Outcome, Context) framework to ensure scientific rigor and traceability.

1. Application Layer: Captures stakeholder requirements and decomposes accreditation standards into operational quality indicators.
2. System Layer: Defines the overall system architecture, including the interaction among PUDAL modules.
3. Technology Layer: Specifies the selection and implementation of ML algorithms, NLP tools, and integration APIs using Random Forest, XGBoost, and Artificial Neural Networks (ANN) for predictive analytics, alongside spaCy for NLP.
4. Fundamental Layer: Focuses on the development of a formal accreditation domain ontology and the formulation of logical axioms and rules. Establishes a formal knowledge structure using the Web Ontology Language (OWL) to define classes.

KNOWLEDGE MANAGEMENT AND ONTOLOGY

One of the principal academic contributions of this research is the development of a formal accreditation domain ontology using the OWL. The ontology represents accreditation criteria, indicators, evidence types, and their interrelationships as defined by BAN-PT and LAM standards. This formal knowledge structure serves as the backbone of the SMF, enabling logical reasoning, automated gap analysis, and consistent interpretation of accreditation requirements, thereby addressing a critical gap in existing accreditation knowledge representation models.

MACHINE LEARNING AND NATURAL LANGUAGE PROCESSING

The SMF incorporates ML and NLP techniques to extract, classify, and analyze accreditation evidence from unstructured data sources such as LKPS, LED, and RPS documents. ML models, including Random Forest, XGBoost, and ANN, are employed to predict accreditation outcomes and identify critical performance areas, while NLP tools such as spaCy support semantic analysis and information extraction. Within the PUDAL engine, NLP primarily supports the Understanding phase, whereas ML contributes to the Decision and Learning phases by generating predictive insights and enabling adaptive model refinement.

The framework integrates NLP techniques specifically designed to resolve linguistic ambiguities inherent in unstructured documents. By identifying semantic entities and contextual nuances, the system meticulously maps textual evidence to a formal accreditation domain ontology. This mapping ensures a standardized interpretation of diverse textual expressions, allowing the PUDAL engine to perceive phrases as specific evidence types within the broader accreditation framework rather than mere keywords. This deep contextual alignment transforms unstructured data into actionable, contextually understood information for accurate compliance assessment.

TECHNICAL ARCHITECTURE AND SYSTEM WORKFLOW INTEGRATION

To provide a concrete technical overview of the system's operation, the following Figure 5 outlines the integrated data flow and architectural interactions.

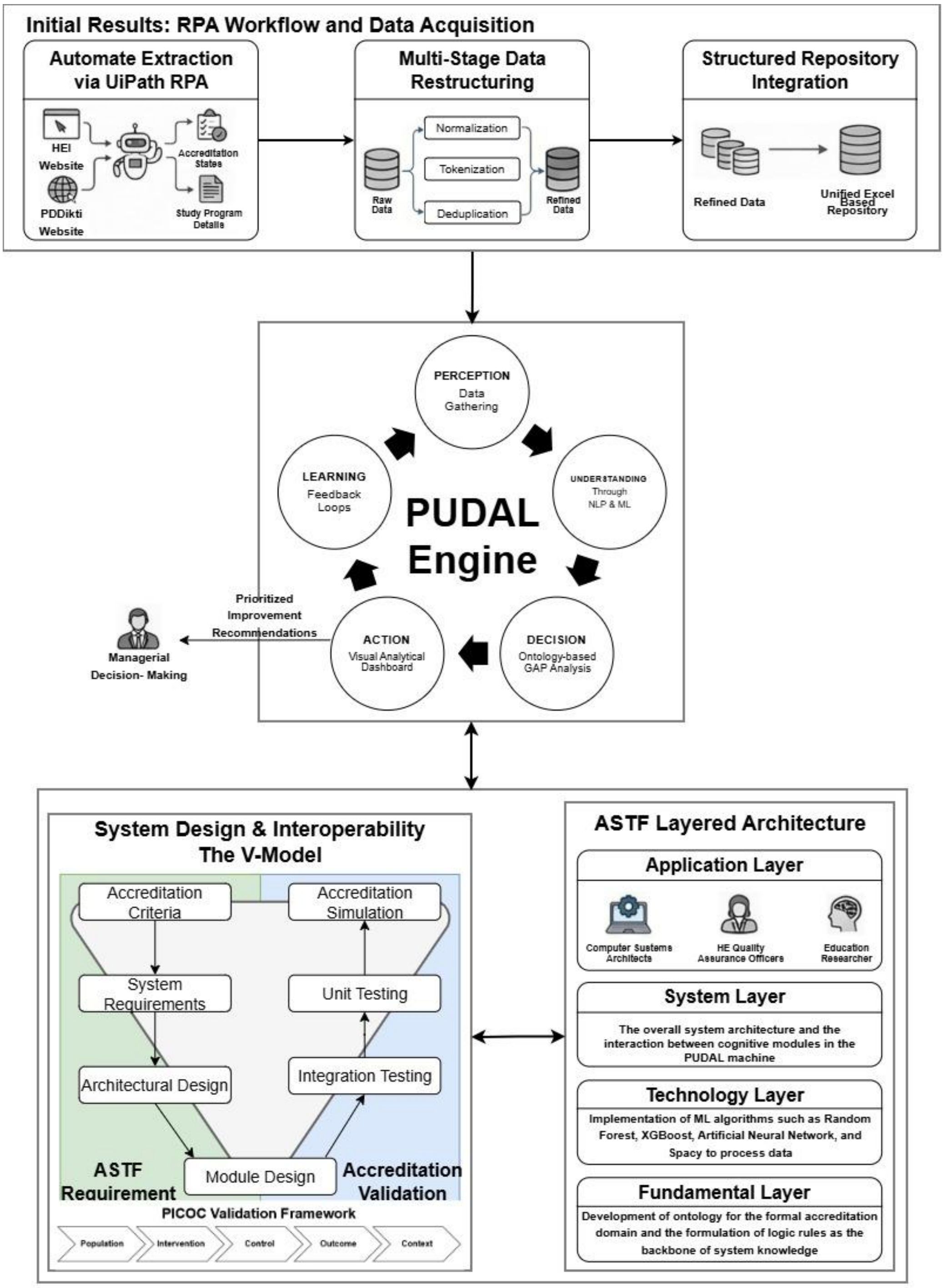

FIGURE 5. Integrated technical architecture and PUDAL engine data flow of the SMF

The SMF is operationalized through a four-layer Application, System, Technology, Fundamental architecture, where the system layer manages the interaction between internal PUDAL modules and ensures interoperability with external academic systems like PDDikti, while the Technology Layer implements advanced ML algorithms such as Random Forest and XGBoost alongside spaCy for NLP. This architecture facilitates the PUDAL engine's technical data flow, beginning with Perception through automated UiPath RPA data acquisition, moving into Understanding for semantic document analysis, and then to Decision, which utilizes a formal accreditation domain ontology to perform logical reasoning and automated gap analysis. The technical feasibility of this integrated flow is demonstrated by initial results where raw, heterogeneous data from institutional websites are systematically restructured via normalization, tokenization, and de-duplication to ensure high quality input for smart processing. Finally, the entire framework is governed by a V-Model engineering methodology and systematically validated at every architectural layer using the Population, Intervention, Control, Outcome, Context framework, providing a structured, verifiable, and prescriptive path from conceptual design to technical execution.

RESEARCH METHODOLOGY

The research methodology follows a V-Model approach, in which each phase of system decomposition and specification on the left side summarized in Table 2 is systematically validated by a corresponding integration and verification phase on the right side, as presented in Table 3, within the ASTF architectural layers. This structured methodological framework ensures scientific rigor and practical relevance by explicitly linking system design activities to validation mechanisms, thereby supporting the development of reliable and verifiable solutions for complex quality assurance and accreditation challenges in higher education.

TABLE 2. V-model (left – specification)

V-Model (left-specification)	Main Activity
Requirement analysis (application)	Identify accreditation decision bottlenecks; define functional and usability requirements; translate accreditation criteria into system requirements
System design (system)	Design data flow between PUDAL modules; define interoperability with academic systems; model PPEPP-aligned workflows
Technology design (technology)	Select NLP feature extraction methods; design hybrid reasoning and prediction pipelines; define data preprocessing strategies
Fundamental research (fundamental	Formalize accreditation concepts into ontology; define logical constraints and reasoning rules; develop competency questions

Interoperability between the SMF and external systems like PDDikti and SIAKAD is governed in Table 2. This phase defines the communication protocols for the Perception module, ensuring that data retrieved via web scraping or APIs is systematically mapped to the fundamental ontology to maintain data consistency across institutional processes. To ensure technical rigor, the ML and NLP pipelines are validated using the PICOC framework in Table 3. This process evaluates the classification accuracy and robustness of the system by comparing automated outcomes against expert manual assessments during an accreditation simulation, ensuring that the framework is both reliable and verifiable.

TABLE 3. V-model (right – validation)

V-Model (right-validation)	PICOC Validation
Acceptance testing	P: Quality assurance teams; I: SMF-based decision support; C: Manual accreditation assessment; O: Time efficiency, consistency, user confidence; C: Accreditation simulation
System integration and testing	P: Integrated system components; I: Full PUDAL cycle execution; C: Isolated component execution; O: System stability, latency, interoperability; C: Integration testing environment
Component integration and testing	P: Accreditation datasets; I: NLP + ML pipeline; C: Single-method analysis; O: Classification accuracy, robustness; C: Experimental evaluation
Unit Testing	P: Ontology entities and rules; I: Automated logical reasoning; C: Expert manual validation; O: Logical consistency, inference completeness; C: Ontology validation session

DIAGRAM REPRESENTATION OF THE V-MODEL

Figure 6 illustrates the V-Model representation of the proposed SMF, highlighting the structured relationship between system development phases and their corresponding testing and validation activities. On the left-hand side, the development process begins with the definition of Accreditation Criteria, followed by the derivation of System Requirements, Architectural Design, and detailed Module Design. On the right-hand side, each development phase is explicitly associated with a corresponding validation activity: Module Design is verified through Integration Testing, Architectural Design is validated through Unit Testing, and both System Requirements and Accreditation Criteria are ultimately confirmed via Accreditation Simulation. This bidirectional structure ensures traceability between requirements and validation outcomes, thereby aligning system functionality with accreditation objectives and reducing implementation risks.

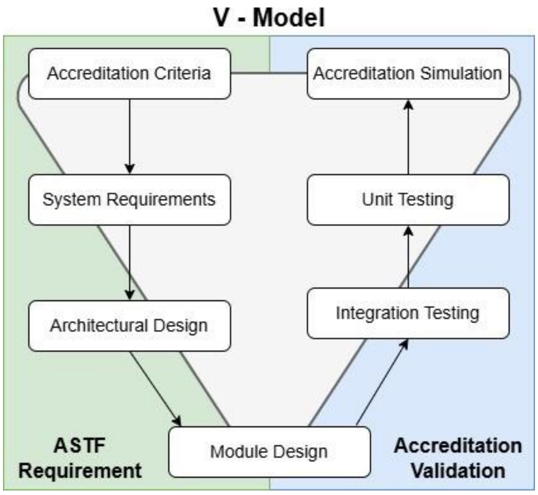

FIGURE 6. V-model diagram

RESEARCH OBJECTIVES

This study aims to: (1) design and develop a Smart Management Framework integrating ML and KM to support all stages of the PPEPP cycle for data-driven quality assurance and accreditation compliance; (2) identify suitable ML and NLP techniques for extracting and analyzing accreditation evidence from heterogeneous unstructured data sources; and (3) implement an ASTF-based smart system that integrates knowledge representation, logical reasoning, and ML to enhance stakeholder collaboration, objectivity, and proactive achievement of accreditation standards.

COMPARISON WITH RELATED SMART FRAMEWORKS

Existing smart campus frameworks predominantly focus on enhancing operational efficiency, digital service delivery, and stakeholder engagement through technologies such as the Internet of Things (IoT), learning management systems, and integrated dashboards. While these initiatives have contributed to the digital transformation of higher education institutions, they generally operate at the application and operational levels and exhibit limited formal engineering validation or explicit alignment with accreditation cycles (Imbar Et al. 2021).

Similarly, KM initiatives in higher education particularly within the Indonesian context have emphasized the capture, organization, and reuse of institutional knowledge through ontologies and metadata repositories. However, such initiatives often remain fragmented and insufficiently integrated with decision-support mechanisms or proactive quality assurance processes for accreditation compliance (Hidayat &. Sensus 2022). Capability maturity and digital readiness models provide structured diagnostic tools for assessing organizational preparedness, yet they remain largely descriptive, offering high-level roadmaps without prescriptive, technically grounded implementation strategies.

To address the need for clearer differentiation from existing frameworks, the proposed SMF distinguishes itself by transitioning from traditional reactive quality assurance models toward a proactive, smart, and learning-oriented system through the seamless integration of the PUDAL engine with the PPEPP cycle. Unlike standard smart campus initiatives that primarily target operational efficiency or resource control, the SMF introduces a unique cognitive intelligence layer that enables context awareness and autonomous learning specifically from accreditation-related data (Surjawan et al., 2025). Furthermore, while existing digital readiness or maturity models in HEIs are often descriptive and lack technical implementation strategies, the SMF provides a structured, verifiable, and prescriptive approach by utilizing the ASTF layered architecture and the V-Model methodology to ensure traceable validation at every stage. This differentiation is further strengthened by the development of formal accreditation domain ontology, which serves as a backbone for automated gap analysis and logical reasoning as a substantive advancement over the fragmented or limited metadata repositories typically found in current institutional knowledge management systems.

The proposed SMF provides a substantive advancement over existing initiatives categorized by three critical dimensions. First, regarding engineering rigor, while standard SMF often lack formal validation and operate only at operational levels, the SMF utilizes a four-layer ASTF architecture integrated with a V-Model engineering process. This structured approach ensures scientific rigor and traceability by explicitly linking design activities to systematic validation through the PICOC framework. Second, in terms of proactivity, the SMF represents a paradigm shift from conventional reactive quality assurance models toward a smart, adaptive system. By integrating the PUDAL engine with the PPEPP cycle, the framework enables context awareness and autonomous learning, transforming accreditation into a continuous quality enhancement mechanism rather than a periodic administrative burden. Third, the framework’s technical grounding moves beyond the high-level roadmaps of existing digital readiness models by providing a prescriptive implementation strategy. As illustrated in the integrated technical architecture in Figure 5, the SMF employs advanced ML algorithms and NLP tools to extract evidence from unstructured documents. This is underpinned by a formal accreditation domain ontology that serves as a knowledge backbone, enabling automated logical reasoning and gap analysis that significantly surpasses the fragmented metadata repositories found in traditional institutional systems.

INITIAL RESULTS: AUTOMATED DATA COLLECTION FOR ACCREDITATION

The initial phase of this study was dedicated to establishing a robust and reliable data acquisition foundation, which is essential for supporting the subsequent smart functionalities of SMF. The results obtained at this stage confirm the feasibility and efficiency of the proposed automated data collection and data restructuring approach.

AUTOMATED DATA COLLECTION VIA WEB SCRAPING

Data collection was systematically automated using Robotic Process Automation (RPA) implemented through UiPath. This phase focused on two primary data sources: the official websites of Private Higher Education Institutions (Perguruan Tinggi Swasta, PTS) and the Pangkalan Data Pendidikan Tinggi (PDDikti) portal, which is administered by the Ministry of Education, Culture, Research, and Technology. The overall data collection workflow is illustrated in Figure 7.

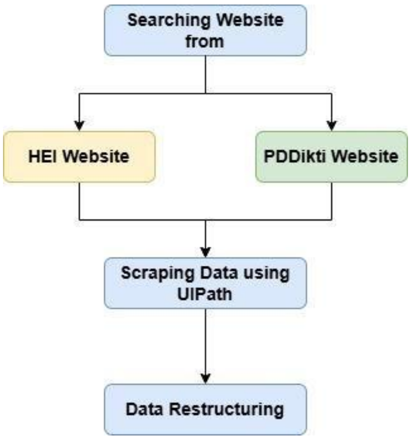

FIGURE 7. Scheme for data collection

The automation process comprised several sequential stages. First, the software robot identified relevant user interface (UI) elements and accepted website URLs as input parameters. Subsequently, it performed automated navigation and interaction by traversing web pages, interacting with UI components such as menus, hyperlinks, and search fields, and extracting the required information. The extracted data were then transformed into a structured tabular format using UiPath’s data extraction and wizard functionalities, thereby ensuring compatibility with subsequent data processing and analysis stages.

DATA RESTRUCTURING AND INTEGRATION

The collected data were further processed through a data restructuring phase that included data cleaning to remove duplicate records and incomplete entries, followed by normalization, tokenization, and de-duplication to ensure consistency across all attributes. This process ensures that the raw data is refined into a high quality, structured repository suitable for the smart processing modules of the SMF. Data sourced from PDDikti and private higher education institutions (PTS) located in Jakarta were consolidated, resulting in an initial dataset comprising 75 universities characterized by five key attributes: institution name, geographic location, number of study programs, tuition fees, and institutional accreditation status.

Additional information, including complete institutional addresses, official websites, detailed study program names, and corresponding program-level accreditation statuses, was retrieved from each university’s PDDikti page. All datasets were subsequently integrated into a single Excel-based repository, forming a comprehensive database to support the early stages of SMF development. Table 4 presents a sample of 10 private universities from the dataset, highlighting selected attributes and indicating the nationally recognized accreditation levels in Indonesia, namely Excellent, Very Good, and Good.

TABLE 4. Sample data of private universities

University	Accreditation	No of Study Programs
University A	Excellent	31
University B	Excellent	41
University C	Very Good	15
University D	Very Good	13
University E	Good	22
University F	Excellent	13
University G	Good	21
University H	Excellent	82
University I	Good	28
University J	Very Good	21

The initial web scraping activities were conducted on private higher education institutions located in Jakarta and served as a pilot study to validate the proposed data acquisition methodology. This limited geographical scope was intentionally adopted, as only a subset of data attributes was required at this stage to support the preliminary development of the Smart Management Framework. Future research will expand the web scraping coverage to institutions in other regions in order to further validate the framework using a broader and more diverse dataset.

DATA EXPANSION VIA UNIVERSITY WEBSITES

The final stage of the initial data collection process involved extracting supplementary information from the official websites of each identified private higher education institution.

RPA robots were systematically configured to navigate institutional web pages and automatically retrieve relevant data elements. All information collected during this phase was subsequently integrated into the existing Excel-based dataset, resulting in a unified, structured, and consistent database that serves as the primary input for the development of the Smart Management Framework. In the subsequent phases of this research, data collection will be extended to include additional attributes and fields that are aligned with the framework's decision-making and analytical requirements.

During the initial testing phase, several challenges were encountered in the application of web scraping techniques for data collection from higher education institution websites and the PDDikti portal. The most prominent challenge stemmed from the heterogeneous, inconsistent, and predominantly unstructured nature of the source data, which complicated automated extraction processes. Moreover, the raw data obtained through web scraping frequently contained duplicate records, thereby requiring a substantial and time-consuming data pre-processing effort. To mitigate these issues, a systematic data restructuring process was implemented, encompassing normalization, tokenization, and de-duplication. These steps were critical to enhancing data quality and ensuring the reliability and suitability of the dataset for subsequent analytical tasks and smart processing within the Smart Management Framework.

CONCLUSION

This paper presents the conceptual design of a Smart Management Framework (SMF) aimed at enhancing quality assurance in Higher Education Institutions (HEIs) through the optimization of the PPEPP cycle via a robust, four-layer ASTF (Application, System, Technology, Fundamental) architecture and a V-Model engineering process. This systematic, technology-based approach integrates Machine Learning (ML), Knowledge Management, and the PUDAL (Perception, Understanding, Decision, Action, Learning) engine, representing a central technical milestone through its seamless integration with the PPEPP cycle to create a paradigm shift from reactive quality assurance toward an intelligent, proactive system. The framework's technical rigor is further reinforced by the development of a formal accreditation domain ontology using Web Ontology Language (OWL), which serves as a verifiable backbone for automated logical reasoning and precise compliance gap analysis. Initial findings demonstrate the foundational feasibility of the framework through the successful deployment of UiPath RPA robots to automate data acquisition from 75 universities, followed by a multi-stage restructuring process involving normalization, tokenization, and de-duplication to establish a unified repository for intelligent processing. Methodological rigor is established by applying the PICOC (Population, Intervention, Control, Outcome, Context) framework to systematically validate every architectural layer, ensuring that the developed technical solutions are reliable and scientifically traceable. Future work will focus on identifying Critical Success Factors (CSFs) among stakeholders through structured methods like the Delphi technique and the full implementation of the PUDAL engine, including advanced ML and Natural Language Processing (NLP) models using tools like spaCy for deeper data analysis and real-world effectiveness evaluations. Ultimately, the SMF is intended to provide HEIs with a comprehensive tool to strengthen quality governance, enhance accreditation readiness, and foster an adaptive, collaborative, and data-driven quality culture.

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