



An end-to-end digital pawn system for Pegadaian: A conceptual innovation framework based on advanced technologies

Celine Christina Handoko^{1,*}, Klemens Iwan Tjahjono Diposubagio²

¹ Independent Researcher, Mojokerto, East Java 61317, Indonesia;

² Independent Researcher, Malang, East Java 65117, Indonesia.

*Correspondence: celinechristina10@gmail.com

Received Date: February 10, 2026

Revised Date: August 10, 2026

Accepted Date: August 28, 2026

ABSTRACT

Background: Digital transformation has driven pawn institutions in Indonesia to pursue technological innovation, one of which is reflected in the development of the Tring! digital service application by Pegadaian. Despite this initiative, several core processes within online pawn services remain only partially digitalized, particularly those involving non-face-to-face valuation, physical asset handling, and end-to-end service integration. A more comprehensive digital architecture is needed to connect these processes into an integrated service lifecycle. **Methods:** This study adopts a qualitative conceptual approach based on library research and employs descriptive-analytical analysis of academic literature, regulatory documents, and industry reports published over the past decade. The analysis is used to identify key limitations in existing digital pawn services and to formulate an end-to-end digital pawn system model tailored to Pegadaian's operational and regulatory context. **Findings:** The analysis indicates that the current Tring! application continues to face limitations in processing speed, valuation accuracy, risk mitigation, transparency, and end-to-end service integration, particularly for non-face-to-face pawn transactions. To address these gaps, this study proposes an integrated digital pawn system incorporating continuous electronic-know your customer (e-KYC), artificial intelligence-enabled remote initial valuation, technology-supported asset pickup and custody, and a transparent and accountable audit trail mechanism. **Conclusion:** The proposed framework provides a conceptual architecture for integrating previously fragmented digital processes across the online pawn service lifecycle. By connecting identity verification, valuation, physical asset handling, risk control, and auditability within a unified system, the framework is expected to support more efficient, transparent, and accountable digital pawn services. **Novelty/Originality of this article:** The proposed framework has not yet been empirically tested and therefore requires future pilot implementation and performance evaluation. Its originality lies in proposing a holistic end-to-end digital pawn framework specifically contextualized for Pegadaian, extending beyond the digitalization of individual processes toward integrated service delivery across the entire online pawn lifecycle.

KEYWORDS: AI-based; digitalization; end-to-end; innovation; Tring! by Pegadaian.

1. Introduction

Pegadaian is one of Indonesia's state-owned enterprises that plays a strategic role in supporting national economic growth and financial inclusion. Its primary mandate is to provide financial through credit disbursement based on pledge (pawn) law, with a particular emphasis on serving micro and small-scale economic actors. Beyond profit-oriented objectives, Pegadaian functions as a policy-implementing institution that supports

Cite This Article:

Handoko, C. C., & Diposubagio, K. I. T. (2026). An end-to-end digital pawn system for Pegadaian: A conceptual innovation framework based on advanced technologies. *Community Service for Sustainable Community Journal*, 3(2), 108-125 <https://doi.org/10.61511/csjs.v3i2.2026.3355>

Copyright: © 2026 by authors. This article is distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).



government economic agendas and national development programs. This mandate is operationalized through its core business of delivering pawn-based credit services to the public, thereby enhancing access to formal financial services and contributing to economic stability (Angraeni, 2015). In the context of contemporary financial transformation, rapid technological advancement has substantially increased institutional demands for digital adoption, system modernization, and service integration. These developments necessitate a reconfiguration of Pegadaian's operational model to ensure that its institutional functions and public service responsibilities remain effective, competitive, and aligned with evolving user expectations in the digital era.

The rapid evolution of technology has fundamentally transformed the banking and financial services landscape, particularly through the widespread adoption of digital banking platforms (George, 2023). Competition among financial institutions—including fintech companies, online lending providers, and digital investment platforms—has intensified as these actors deliver increasingly innovative, flexible, and integrated financial solutions. Many of these institutions have leveraged advanced technologies such as artificial intelligence (AI), big data analytics, and digital risk assessment systems to improve operational efficiency, enhance decision-making accuracy, and strengthen risk management capabilities. Digital transformation has also reshaped consumer behavior, with users demonstrating a growing preference for financial services that are fast, easily accessible, application-based, and characterized by minimal physical interaction. This behavioral shift poses a significant challenge for Pegadaian as a conventional financial institution that has historically relied on branch-based, face-to-face service delivery models (Chen, 2024). In response to these structural changes within the financial ecosystem, Pegadaian has initiated a series of digital transformation efforts, including the launch of its digital service application, Tring!, as a strategic platform to maintain relevance and competitiveness in the digital era.

The innovation embedded in the Tring! application demonstrates Pegadaian's institutional commitment to responding to technological advancements and evolving market demands. The application has received formal authorization from the Indonesian Financial Services Authority, indicating compliance with applicable regulatory and supervisory standards. From a security perspective, Tring! incorporates multiple protection layers, including personal identification number (PIN) authentication and biometric verification, supported by electronic-know your customer (e-KYC) mechanisms to enhance identity validation and fraud prevention. At its current stage of implementation, Tring! enables users to access a range of digital financial services, including gold investment products, online pawn transactions, and financing facilities (Jawapos, 2026). An overview of the existing Tring! application features and service flows are presented in Figure 1.

Figure 1 indicates that the Tring! application still has several features that are either unavailable or not yet fully optimized, particularly within the online pawn service system. Although Tring! currently offers an online pawn feature that enables customers to conduct pawn transactions without face-to-face interaction, this service is presently limited to gold pawn products. Online pawn services for other asset categories—such as jewelry, electronic devices, and vehicles—have not yet been implemented within the application.

According to Oloke (2024), Pegadaian currently operates a hybrid service model that integrates traditional branch-based operations with digital services delivered through the Tring! application. Although both channels operate in parallel, transactions involving physical assets, such as jewelry, mobile phones, and laptops remain predominantly processed through conventional, in-person mechanisms. These processes require either customer visits to physical branches or on-site assessments conducted by professional appraisers, as physical assets must be directly inspected, valued, and securely stored as collateral. However, conventional face-to-face valuation practices are increasingly misaligned with the requirements of an end-to-end digital pawn system.

These practices rely on static and backward-looking valuation assumptions, resulting in structural limitations in processing speed, valuation accuracy, and adaptive capacity. In addition, such methods are highly dependent on subjective judgment, which reduces

consistency and scalability in digitally driven financial environments where price signals and risk conditions evolve rapidly. In emerging market settings, the limitations of traditional collateral-based valuation are further exacerbated by restricted data availability, jurisdiction-dependent reporting inconsistencies, and non-transparent asset custody mechanisms. These structural constraints weaken transparency, limit auditability, and undermine stakeholder trust within digital financial ecosystems.



Fig. 1. Current application of Tring! by Pegadaian

Against this background, the main challenge is not merely the availability of individual digital technologies, but also the limited integration of these technologies across the online pawn service process. Although the Tring! application provides an important foundation for digital service delivery, several critical processes, including identity verification, asset valuation, physical asset pickup and custody, risk control, and auditability, remain insufficiently integrated within a single end-to-end system. This condition indicates the need to move beyond partial digitalization toward a more integrated digital pawn service architecture. Accordingly, this study proposes an end-to-end digital pawn system for Pegadaian that integrates digital identity verification through e-KYC, AI-enabled remote initial valuation, technology-supported asset pickup and custody with real-time monitoring using internet of things (IoT) technologies, and a transparent and accountable audit trail. The proposed framework is intended to support the integration, efficiency, transparency, and accountability of online pawn services. The originality of this study lies in integrating these technological components across the pawn-service process rather than addressing them as separate technological applications. As a conceptual study, the proposed system has not yet been empirically tested and therefore provides a framework for future pilot implementation and performance evaluation.

This paper focuses on the improvement and development of the online pawn feature through the implementation of an integrated system that leverages state-of-the-art technologies within the end-to-end architecture of the Tring! application. The proposed innovation is expected to contribute to the optimization of Pegadaian's operational performance by enhancing service speed, accuracy, efficiency, and effectiveness. At the same time, simultaneously strengthening transparency and accountability in Pegadaian's service delivery to the public.

2. Methods

This study employs a qualitative conceptual approach based on library research and descriptive-analytical methods. It does not aim to empirically test hypotheses, but rather to analyze existing challenges and develop an innovation-oriented conceptual model for the advancement of Pegadaian's digital services through a systematic review of relevant literature, regulatory requirements, industry practices, and the existing digital service context of Pegadaian. This study was conducted from November 2025 to January 2026.

The research is classified as conceptual and focuses on solution design and innovation modeling for an end-to-end digital pawn system, covering digital identity verification, AI-based remote valuation, asset pickup and custody management, and transparent audit trails. The study relies entirely on secondary data obtained from academic journals, books, regulations, policy documents, industry reports, and credible media sources related to fintech, AI, blockchain, and digital financial services. These sources were selected based on their relevance to the technological components and operational requirements of digital pawn services, particularly within the context of Pegadaian.

Data collection was conducted through a systematic literature review using keywords such as digital pawnshop, e-KYC, AI-based valuation, asset custody, audit trail, and blockchain, with sources limited to publications from the last ten years. The collected information was analyzed using three complementary approaches: Descriptive analysis of Pegadaian's current services (particularly the Tring! application); comparative analysis with international practices; and conceptual analysis to formulate the proposed model.

The study proposes an AI-enabled, end-to-end digital pawn system integrated with e-KYC, computer vision, IoT-based asset custody, and transparent audit mechanisms to improve efficiency, accuracy, transparency, and accountability. The model is designed to align with prudential risk management, good corporate governance, and regulatory requirements, making it institutionally feasible for a state-owned financial institution. However, the model has not yet been empirically tested, and future research is required for pilot implementation and performance evaluation. Despite this limitation, the study provides a valuable conceptual framework for policymakers and practitioners and contributes to the literature on digital financial services, particularly in the context of emerging markets.

3. Results and Discussion

Currently, Pegadaian Indonesia operates a hybrid service architecture that integrates between conventional operations and digital services delivered through the Tring! application. Nevertheless, this architecture remains suboptimal due to a range of systemic and structural limitations, including constraints in processing speed, valuation accuracy, and adaptive capacity. Moreover, the existing system is susceptible to subjective judgment, high volatility in market prices, limited data availability, inconsistent data quality, fragmented custody workflows, and insufficient transparency across the service lifecycle (Oloke, 2024).

At the same time, the rapid expansion and diversification of asset classes have not been accompanied by a commensurate evolution of conventional pawnshop infrastructure. This structural mismatch has increasingly constrained Pegadaian's ability to meet the performance, scalability, and technological requirements imposed by digital financial instruments. This gap highlights the critical need for an integrated technological transformation encompassing both next-generation valuation models and digital infrastructure capable of operating in data-intensive and real-time environments. One strategically viable innovation for the Tring! application is the comprehensive redesign of the online Pegadaian service into a fully integrated end-to-end system underpinned by state-of-the-art technologies.

According to Margaret (2015), end-to-end encryption refers to a method of securely sending data from the sender to the recipient so that no third party can access it during

transmission. The data is encrypted by the sender and can only be decrypted by the intended recipient. As a result, the content remains fully protected and cannot be read or altered by others while it is being transmitted.

In the context of developing an end-to-end system, the main principle is that physical assets must continue to be transferred and handled in a safe and controlled manner. AI and blockchain technologies are used only to support accuracy and efficiency, but they should not act as the sole decision-makers. These technologies are merely tools, while trust is built through transparency, good governance, auditability, and proper risk control. A well-designed end-to-end system can increase customer trust by clearly showing how an asset is valued and what factors can increase or decrease its price. This transparency helps reduce the risk of asset substitution, manipulation, damage or loss, price manipulation by insiders, and other operational problems. Developing such an end-to-end process requires several strategic steps, including digital identity verification using advanced e-KYC, AI-powered initial remote valuation, secure pickup and custody, and a transparent and reliable audit trail, all of which are integrated using modern technologies. The analysis identifies four main areas requiring further digital integration within the online pawn service lifecycle, which are digital identity verification, remote asset valuation, physical asset pickup and custody, and transaction auditability. These areas are subsequently examined as interconnected components of the proposed end-to-end system rather than as independent technological solutions.

3.1 Digital identity verification using advanced e-KYC

As part of risk control efforts in response to the increasing number of fraud cases in many sectors, it is necessary to implement security systems that analyze large volumes of data to identify anomalous patterns, suspicious behavior, and potential cyber threats. One of the most widely used digital business processes is e-KYC, which is a digital identity verification process carried out without physical meetings, to ensure that a person is truly who they claim to be and not using a fake or stolen identity (Hannan et al., 2023). E-KYC is a digital identity verification system that combines several technologies, including computer vision, biometric systems, application programming interface (API) integration, security systems, AI-based machine learning, optical character recognition (OCR), face recognition, liveness detection, database verification, and risk scoring (Thokal et al., 2025). In the context of digital pawn services, fintech, and banking, e-KYC serves as a fundamental pillar for building trust and ensuring regulatory compliance.

The Tring! application has already implemented several components of the e-KYC framework, including OCR (email and national ID Card verification), biometric face recognition, and authentication and session security mechanisms such as PINs, biometrics, one-time passwords (OTP), and data encryption. However, the current implementation of e-KYC in the Tring! application, particularly within the online pawn feature, remains insufficiently robust for high-risk and fully remote transactions. Several critical technologies have not yet been fully optimized or integrated into the platform, including liveness detection, risk-based verification or tiered KYC, device fingerprinting and behavioral analysis, continuous authentication, fraud network analysis, explainability of e-KYC decisions, and step-up verification for high-risk actions. The current condition of the Tring! application and the proposed improvement concepts are illustrated in Table 1.

Table 1 presents a critical analysis of the limitations inherent in conventional e-KYC architectures that are still widely adopted in digital financial services, particularly those relying on static verification and one-time authentication mechanisms (Galbally et al., 2019). Current verification practices are typically confined to the capture of a single selfie or basic facial image, without support for active liveness detection and without differentiation of verification levels based on user risk profiles or transaction values (Financial Action Task Force, 2020). This approach introduces systemic vulnerabilities, including a high susceptibility to spoofing attacks using photographs, replayed videos, or deepfake media, as well as weak detection of multi-account usage from a single device,

account takeover, and organized identity abuse. The treatment of accounts as isolated entities without cross-device and network-level analysis further limits the identification of collective fraud patterns, while the low level of explainability in e-KYC decision-making complicates audit processes, dispute resolution, and compliance with governance and accountability principles (Miller, 2019). For these reasons, a fundamental transformation of the e-KYC framework is required.

The transformation of e-KYC should be directed toward a risk-adaptive and continuous verification model supported by the integration of artificial intelligence and advanced analytics. Galbally et al. (2019) recommend several key developments, including the adoption of active video-based liveness detection that combines micro-movement analysis, challenge–response mechanisms, and facial texture analysis to strengthen resilience against identity spoofing; the implementation of tiered or risk-based KYC that dynamically adjusts the depth of verification according to transaction value, user behavior, and operational context; and the integration of device fingerprinting, behavioral analysis, and environment profiling to detect cross-session and cross-device anomalies. The reinforcement of continuous authentication, cross-account fraud network analysis, and step-up verification for high-risk activities enables e-KYC systems to function not only as an initial identity verification mechanism but also as a continuous risk management instrument. Enhancing explainability by providing clear reasons and classifications for verification failures becomes a critical element in establishing transparency, auditability, and trust, allowing e-KYC to support security, regulatory compliance, and the long-term sustainability of digital financial services. The next stage in this framework is the implementation of AI-based remote initial valuation.

Table 1. Improvement idea for current e-KYC in Tring!

Technology	Current condition	Risk/problem	Recommended improvement
Liveness detection	Basic selfie or simple face capture	Can be bypassed using photos, replayed videos, or simple deepfakes	Active video-based liveness detection (blink, head movement, challenge-response, texture analysis)
Risk-based verification (tiered KYC)	Same verification flow for all users	Low-risk and high-risk transactions have the same verification level	Tiered or risk-based KYC levels depending on transaction value and user risk profile
Device fingerprint and behavior analysis	Not systematically enforced	One device can be used for many accounts or by fraud rings without detection	Device fingerprinting and environment profiling (device ID, operating system, behavior patterns)
Continuous authentication	One-time verification at registration	Account takeover, account resale, or identity misuse cannot be detected	Re-authentication at critical actions (large transactions, account changes, device changes)
Fraud network analysis	Each account treated independently	Fraud syndicates can create many accounts using borrowed IDs without being	Cross-account relationship analysis (shared devices, IPs, patterns)
Explainability of e-KYC Decisions	User only sees “verification failed”	No clarity whether error is system or uses, difficult for audit and dispute handling	Explainable verification results (reason codes, failure classification)
Step-up verification for high-risk actions	Login with PIN or biometric allows all transactions	If account is hijacked, high-value assets can be pawned immediately	Step-up verification for sensitive actions (face re-check, OTP, video verification).

(Galbally, et al., 2019; Financial Action Task Force, 2020; Ross, et al., 2022; Varadharajan, et al., 2023; Hooi, et al., 2019; Miller, 2019)

3.2 AI-Powered initial remote valuation

Physical assets pledged through online pawn services are exposed to various risks, including counterfeiting, undetected damage, and manipulation of submitted images. In this context, artificial intelligence is positioned as a decision-support system for human appraisers, with a primary focus on standardization, process acceleration, and risk detection (Kokina & Davenport, 2017). At present, Pegadaian service options available in the Tring! application are still limited to gold savings pawn services, indicating that the platform has not yet implemented an AI-based automatic asset valuation system. The implementation of AI-based automatic asset valuation in Tring! is intended to improve operational efficiency, standardize appraisal quality, enhance transparency, strengthen risk management, and enable a truly end-to-end digital pawn service, while maintaining human appraisers as the final decision makers. The objective of AI-based valuation is not to replace human judgment, but to create a faster, more consistent, more transparent, and more risk-aware appraisal process (Shrestha et al., 2019). The workflow of the proposed AI valuation system consists of user-uploaded images and videos, an AI pre-processing engine, a market price engine, a valuation engine, a human appraiser review stage, and the final value decision issued by the Tring! application, as illustrated in Figure 2.

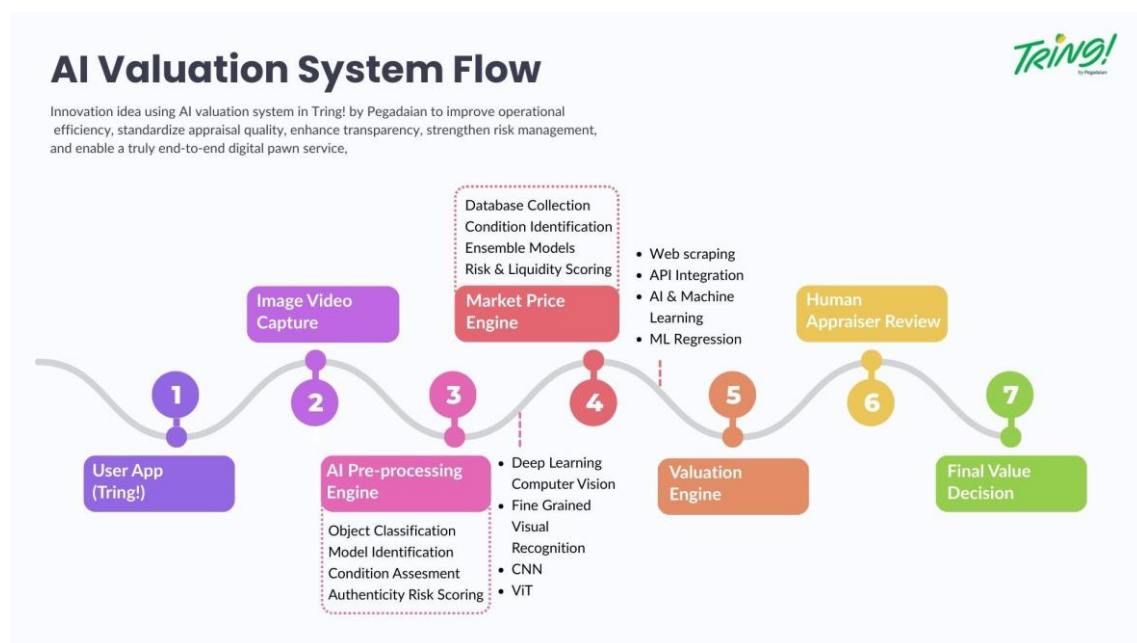


Fig. 2. AI valuation system flow

(Zaidi, et al., 2021; Juneja, et al., 2025; Tubbias, et al., 2024; Sun, et al., 2021; Gonsalves, et al., 2025; Patel, 2024)

Figure 2 illustrates the initial stage of the AI valuation system workflow, in which Tring! users upload images of the assets to be pledged by following several guided instructions, such as providing photographs from 5–8 different angles, including a 360° video of the item, and submitting close-up images of critical parts such as serial numbers, logos, clasps, and other distinguishing features. This procedure is designed to reduce the submission of low-quality inputs, including poorly framed, dark, blurred, or improperly angled images. The system performs automated checks on image blur, lighting, focus, and resolution, after which the asset is analyzed by the AI pre-processing engine. This engine consists of four main stages: object classification, model identification, authenticity risk scoring, and condition assessment (Zaidi et al., 2021).

The object classification stage employs computer vision-based classification models to determine the category of the item depicted in the submitted images, such as gold, jewelry, smartphones, or laptops, and to assign a confidence score to the predicted class (Juneja et al., 2025). In the model identification stage, the system leverages fine-grained visual

recognition, a computer vision approach designed to distinguish object subcategories based on very subtle visual differences. This approach enables classification not only at a coarse category level but also at the level of brand, model, and variant, and, when necessary, other detailed specifications, by matching extracted visual features against a structured product database. Fine-grained visual recognition learns discriminative features among visually similar classes, allowing the system to differentiate items such as “Antam Gold 10 grams” or “iPhone 15 Pro 256GB” based on both visual characteristics and the associated product metadata generated by the model (Tubbias et al., 2024). Several studies have adopted similar approaches by combining image and product text information to improve fine-grained product recognition performance in retail environments, as demonstrated in multimodal fine-grained grocery product recognition systems (Sun et al., 2021). The subsequent stage is authenticity risk scoring.

Authenticity risk scoring is designed to identify the risk level associated with the authenticity of the pledged asset. This stage is critical; however, from a legal and governance perspective, AI must not act as the final authority in determining authenticity but rather as a decision-support source for human appraisers. The applied techniques may extend the use of fine-grained visual recognition or employ deep learning-based computer vision models such as convolutional neural networks (CNNs) or vision transformers (ViTs) to compare micro-level details and detect anomalous patterns, including logo shape analysis, dimensional proportions, engraving inconsistencies, texture variations, and abnormal material reflections (Gonsalves et al., 2025).

The final stage of the pre-processing pipeline is condition assessment, which evaluates damage maps, depreciation factors, and assigns product condition grades. Similar technologies have been deployed in several countries, including China and the United States, to support automated damage assessment of consumer electronics in retail environments (Patel, 2024). This stage also relies on deep learning-based computer vision to understand object geometry and to detect damaged areas. Rather than judging the item in a subjective manner, the system analyzes a set of visual parameters and assigns standardized condition categories such as like new, excellent, good, fair, and poor. The subsequent stage in the workflow is market price mapping.

Market price mapping refers to an automated price recommendation mechanism derived from actual market datasets using machine learning models and combined with human valuers in a human-in-the-loop framework. The objective of market price mapping is to produce an adaptive, dynamic, and real-time valuation score, to determine a prudent loan-to-value (LTV) level, and to support consistent and transparent appraisal standards by aligning market data projections with the physical condition of the asset (Oloke, 2024). The market price mapping approach may incorporate web-scraping and API integration, AI and machine learning techniques, historical price databases, ensemble models, as well as risk and liquidity scoring mechanisms. The overall workflow of the market price mapping process is illustrated in Figure 3.

Figure 3 illustrates the market price mapping stage, which consists of database collection, condition identification, ensemble models, risk and liquidity scoring, and the valuation engine. The database collection stage serves as the foundational layer of market price mapping and is responsible for aggregating comprehensive and up-to-date asset price data. At this stage, the system leverages web-scraping and API integration to gather price information from multiple sources, including local marketplaces, Pegadaian’s internal transaction records, auction results, and historical price trends in the secondary market. This multi-source integration strategy is intended to reduce single-source bias and improve the representativeness of the price dataset. The collected data subsequently undergo data cleaning and normalization processes to ensure format consistency, validity, and relevance to the domestic market context. This approach enables the system to capture actual price dynamics and market fluctuations more accurately than conventional manual valuation methods (Chen & Guestrin, 2016). The next stage is condition assessment.

The condition assessment stage aims to associate market prices with the physical condition and quality of the asset in an objective manner. This stage leverages artificial

intelligence and machine learning to analyze the relationship between condition attributes—such as the level of wear, completeness, usage age, and authenticity—and variations in market prices. Machine learning models are employed to perform feature extraction and price–condition correlation, while also filtering out anomalous or fake price data. As a result, the system is able to generate price estimates that are adjusted to the actual condition of the asset, thereby reducing appraisal subjectivity and improving valuation consistency (Bishop, 2016). The subsequent stage is ensemble models.



Fig. 3. Market price mapping flow
(Oloke, 2024; Chen & Guestrin, 2016; Bishop, 2016; Breiman, 2017; Bholat et al., 2021)

The ensemble model stage is designed to produce a stable and robust base market price estimate by combining multiple machine learning regression models. The system generates a representative market price, for example using the median value or a weighted average price, which serves as the foundation for valuation. Ensemble-based approaches have been shown to improve the accuracy and reliability of price predictions in heterogeneous and dynamic data environments, such as second-hand goods markets and pawned asset ecosystems (Breiman, 2017). The subsequent stage is risk and liquidity scoring and the valuation engine.

The risk and liquidity scoring and valuation engine stage constitutes the final process that translates the base market price into an operationally applicable pawn value. At this stage, the system applies cross-validation and error metrics to evaluate model performance, while simultaneously computing the asset's risk and liquidity scores. Factors such as liquidation speed, price volatility, and market risk are used to determine value adjustments and the optimal loan-to-value (LTV) ratio. The valuation engine then integrates all preceding outputs to produce a final, risk-adjusted pawn value that is transparent, auditable, and available in real time. This approach enables more measurable risk management while enhancing the sustainability and trustworthiness of the AI-based digital pawn system of Pegadaian (Bholat et al., 2021). The next stage presents the valuation results to the customer, as illustrated in the AI valuation result page shown in Figure 4.

The valuation engine stage constitutes the core of the AI-based remote initial valuation system and is responsible for generating an objective, standardized, and measurable estimate of the fair value of pawned assets (Singh et al., 2021). At this stage, the system integrates outputs from the AI pre-processing and computer vision modules—such as object classification, model identification, physical condition estimation, and authenticity scoring—with market price data collected through web scraping and API integration from multiple secondary market sources (Goodfellow et al., 2016). The valuation process is

performed using machine learning regression models, including gradient boosting, random forest regression, and neural network-based regression, which are capable of modeling nonlinear relationships between asset characteristics and market prices in real time (Galbally et al., 2019). This approach enables the system to produce valuations that are not only statistically accurate but also operationally relevant in the context of Pegadaian's risk management. Following the valuation engine stage, the next step is the human appraiser review.

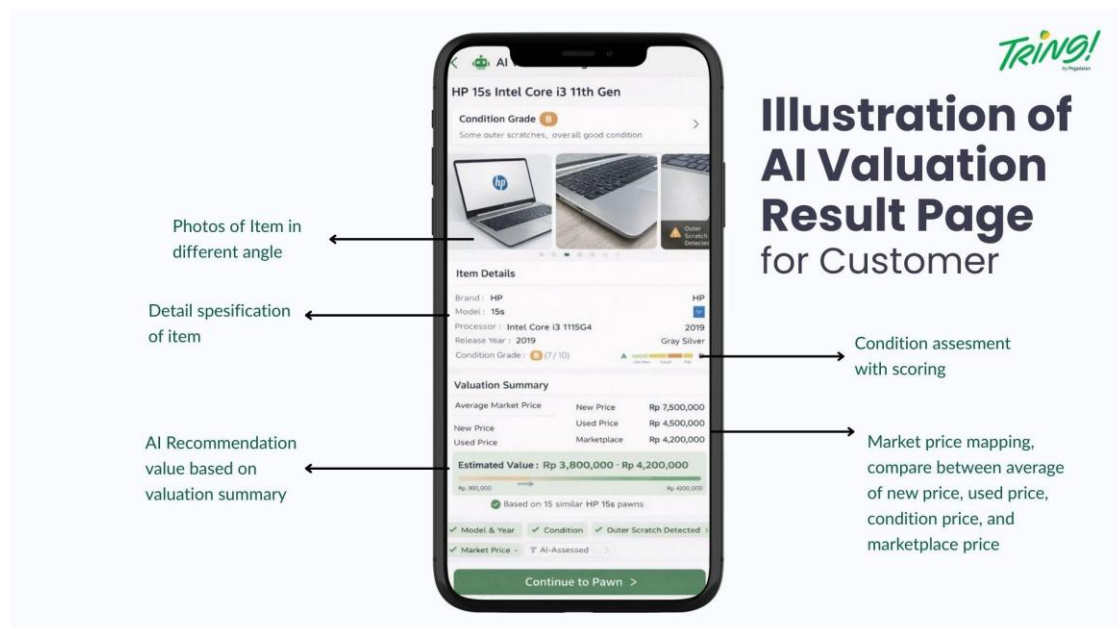


Fig. 4. Illustration of AI valuation result page for customer (Sing, et al., 2021; Goodfellow et al., 2016; Galbally et al., 2019)

The human appraiser review stage adopts a human-in-the-loop approach to ensure that AI-generated valuation decisions remain within the boundaries of prudence and regulatory compliance (Shrestha et al., 2019). Human appraisers verify the valuation results, particularly for high-value assets, assets with visually ambiguous conditions, or cases characterized by high model uncertainty. This stage functions both as a quality control mechanism and as a source of feedback for model refinement through continuous learning (Kroll et al., 2017). The final stage is the final value decision.

The final value decision stage integrates the AI-generated valuation results and the human appraiser's judgment into a single, consolidated final pawn value that is systematically documented. This final decision is stored in the system as an audit-ready record that supports transparency, valuation consistency, and accountability, thereby enabling the AI-based valuation system to strengthen the trust of customers, regulators, and other stakeholders in Pegadaian's end-to-end digital services (Kroll et al., 2017). The final appraisal value is delivered to the transaction system and, when necessary, to officers for verification. Every human intervention is logged in detail, including the identity of the officer, timestamp, and the rationale for any modification, ensuring that no undocumented decisions occur. Digital authentication technologies, electronic signatures, and immutable logging mechanisms are applied to secure the final decision against unilateral alteration. To further enhance integrity and trust, the valuation results and key parameters can be hashed and stored within a cryptographic verification system or blockchain infrastructure as proof that the value represents a legitimate decision made at a specific point in time (Yaga et al., 2018).

The AI analysis results are integrated into the officer assignment and logistics management system through a risk-based operational management approach. By leveraging optimization algorithms that consider location, operational capacity, and asset risk level, the application automatically determines the most appropriate officer or logistics

partner to perform the pickup process. Assets with high value or high risk are prioritized to be handled by officers with specialized competencies or through logistics channels with stricter security standards. This approach reflects risk management practices that have been widely adopted in financial services and digital logistics operations across various countries.

3.3 Secure pickup and custody in Tring!

The pick-up and custody stage constitutes a critical component of Pegadaian's end-to-end digital system, as it directly relates to the safeguarding of physical assets and the mitigation of operational risks. The pick-up and custody process refers to the collection of pledged assets from the customer's location by authorized Pegadaian officers or verified logistics partners, followed by the custody, storage, and management of the assets at Pegadaian's facilities after receipt (Christopher, 2016). The pick-up and custody workflow consists of the assignment of pick-up attendants, customer data verification, preliminary physical item inspection, the item handover process, item intake at Pegadaian, digital item registration in the custody system, secure storage, and IoT-based monitoring, as illustrated in Figure 5. The implementation of the pick-up and custody process in Tring! enables Pegadaian services—particularly the online pawn feature—to become more transparent, secure, and technology-driven, in line with the digital transformation of the financial services sector.

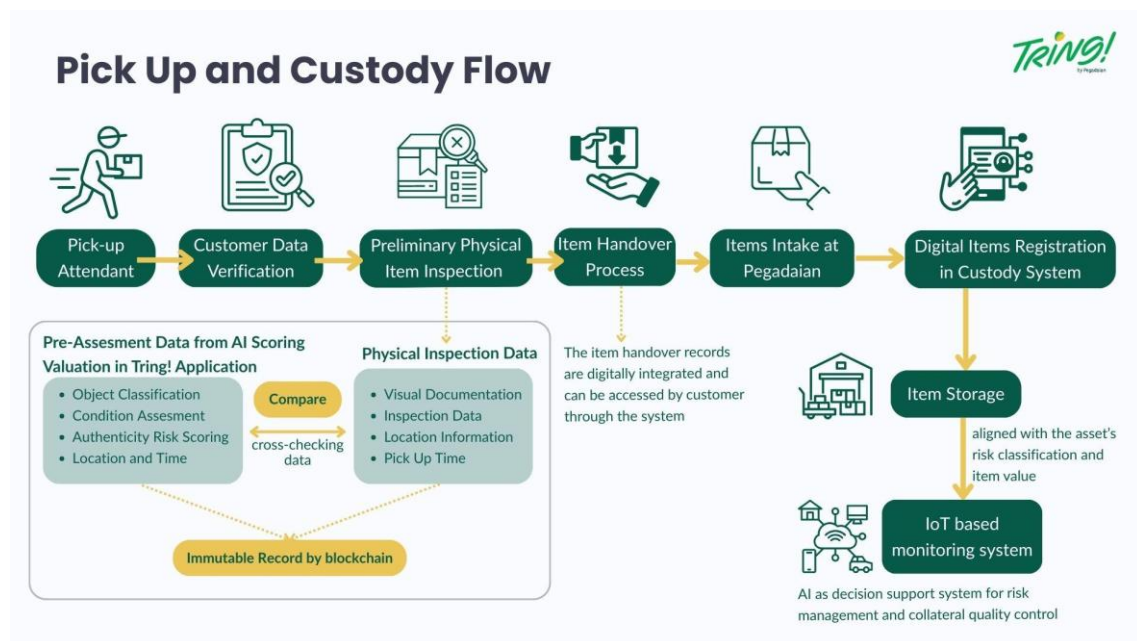


Fig. 5. Pick-up and custody flow
(Bholat et al., 2021; Suyono, 2025; Casino et al., 2019; Reyna et al., 2018)

Figure 5 illustrates that the process begins with the role of the pick-up attendant, who is responsible for collecting the pledged asset from the customer after the remote initial valuation process has been completed. Prior to the collection, the system performs customer data verification by referring to the results of the e-KYC process and the AI-based risk scoring generated during the initial valuation stage. This verification ensures the consistency of the customer's identity, the pledged asset, and the scheduled time and location of collection, thereby reducing the risk of handover errors, identity fraud, and potential disputes. This data integration reflects the application of continuous and adaptive e-KYC principles within the context of digital financial services (Bholat et al., 2021). The subsequent stage is preliminary physical item inspection.

The preliminary physical item inspection stage serves as a physical validation of the AI-based valuation results. At this stage, an initial visual inspection of the asset is conducted,

including visual documentation, recording of the actual physical condition, the pickup location, and the pickup timestamp. The physical inspection data are then systematically compared with the pre-valuation data generated by the AI valuation engine, such as object classification, condition estimation, and authenticity risk scores. This process enables early detection of condition discrepancies, potential manipulation, or asset mismatches, thereby functioning as a quality assurance mechanism and an operational risk mitigation measure. All inspection and comparison data are digitally recorded and stored as part of the system's audit trail (Suyono, 2025). The subsequent stage is the item handover process.

In the item handover process stage, the asset is formally transferred from the customer to the officer, and the entire process is documented within the digital system. This process includes recording the asset status, visual evidence, timestamps, and location information, which are subsequently integrated into Pegadaian's information system. To ensure data integrity and authenticity, all handover records are stored as immutable records using blockchain technology, preventing any alteration or manipulation after registration. The application of blockchain at this stage serves as a trust layer that ensures transparency, accountability, and traceability throughout the pawn asset lifecycle. This approach is aligned with best practices in high-value asset management and distributed technology-based logistics systems (Casino et al., 2019). The next stage is item intake at Pegadaian and digital item registration in the custody system.

The items intake at Pegadaian and digital item registration in the custody system stage marks the full transfer of responsibility for the asset from the customer to Pegadaian as an institution. At this stage, the received asset is digitally registered in the custody system, including the asset's identity, final condition, storage location, and its linkage to customer data and the corresponding pawn contract. The subsequent stage is item storage using an IoT-based monitoring system, in which the asset is stored in a secured storage facility integrated with IoT-based monitoring technologies, such as temperature, humidity, vibration, and physical access sensors, to ensure asset quality and security throughout the custody period. The IoT sensor data are transmitted in real time to the central system and analyzed using an AI-based decision support system to detect anomalies, potential damage, or security risks. The integration of AI, IoT, and blockchain in this custody stage enables more proactive, measurable, and transparent management of pawned assets, while simultaneously strengthening risk management and customer trust in Pegadaian's end-to-end digital services (Reyna et al., 2018).

The implementation of this application concept is highly feasible within the Tring! platform, as similar approaches have already been adopted in many countries through online pawn shops and asset-backed digital lending services. In the United States and the United Kingdom, several digital pawn and resale platforms have utilized AI-assisted visual assessment to perform preliminary asset valuation before the items are physically shipped or picked up. Furthermore, technology-based custody concepts have been widely adopted in the logistics and digital inventory management sectors in countries such as Japan and Singapore (Gomber et al., 2017). The integration of AI in the management and monitoring of physical assets represents a mature and practical approach that is well-suited to be implemented in the custody system of Pegadaian's digital services, namely Tring!. The next stage is the transparent audit trail and trust mechanism.

3.4 A transparent and reliable audit trail

Transparent audit trails and trust mechanisms in Pegadaian's digital services are designed as a comprehensive and sequential recording system of all critical activities throughout the pawn transaction lifecycle, from the application stage to storage and monitoring (Kroll et al., 2017). This process begins with the creation of a unique transaction identity that serves as a binding reference for all related data and events. Consequently, every customer interaction, e-KYC result, initial visual evidence upload, and process status is recorded as an event log from the very beginning of the transaction.

From the user perspective, the audit trail is presented in the form of a user-accessible audit view that displays a timeline of asset status, initial photo or video evidence, and verification timestamps, enabling customers to obtain process transparency without being exposed to sensitive internal data. On Pegadaian's internal side, all activities are recorded in a more granular manner through event-based logging and immutable records, documenting AI-based valuation results, human appraiser interventions, pick-up processes, and custody status.

The system is further strengthened by adopting a hybrid architecture that leverages cryptography and blockchain as a verification layer, in which hashes and timestamps of critical events are stored on a private or consortium blockchain without directly storing raw data (Casino et al., 2019). This approach enables independent auditing and verification, supports the principles of explainability and accountability, and minimizes the risk of data manipulation. Accordingly, the transparent audit trail does not merely function as a documentation tool, but rather as a trust infrastructure that underpins governance, risk control, and the operational legitimacy of Pegadaian's intelligent technology-based digital services. An illustration of the audit trail view from both the user perspective and Pegadaian internal staff perspective is shown in Fig. 6.

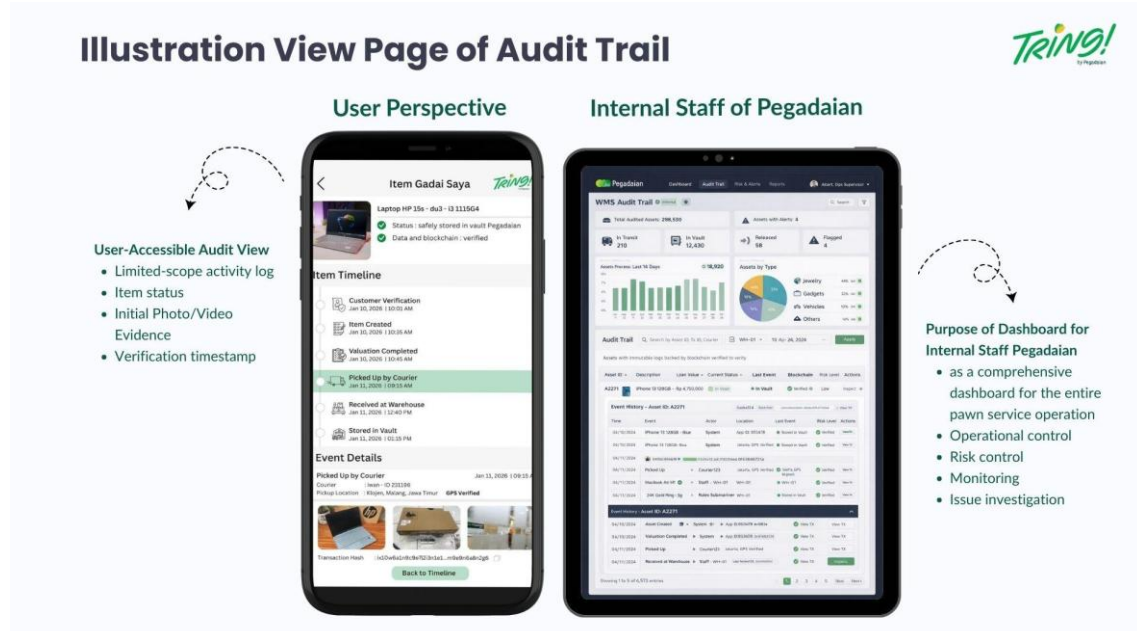


Fig. 6. Illustration of view pages for audit trail and transparency (Yaga, et al., 2018; Casino, et al., 2019; Doshi-Velez & Kim, 2017; Kroll, et al., 2017)

The concept of the transparent audit trail and trust process in Figure 6 begins with transaction initiation and the creation of a unique digital identity, followed by the user-accessible audit view, explainable internal logging, cryptography and blockchain integration, the utilization of an internal audit dashboard, and finally the establishment of trust. The transparent audit trail is designed as a multi-stage process that begins with transaction initialization and the creation of a unique digital identity when customers submit an online pawn application through the Tring! application. This identity serves as a transaction identifier that binds all data, decisions, and operational activities throughout the asset lifecycle. All initial interactions, including e-KYC, asset photo or video uploads, and submission confirmation, are recorded as timestamped events using an event-based logging approach to ensure a complete and chronological audit trail (Yaga et al., 2018).

The second stage is the user-accessible audit view, which aims to enhance transparency and customer trust by providing a limited and read-only timeline containing key information such as verification status, pick-up time, and initial visual evidence, accompanied by verification timestamps. This mechanism applies a privacy-by-design

approach by maintaining transparency without exposing sensitive internal data or decision parameters (Casino et al., 2019).

The third stage focuses on explainable internal logging, where all internal activities are recorded in greater detail, including AI valuation outputs, risk scores, human appraiser decisions, and asset status changes during the pick-up and custody processes. Each intervention is recorded as a new event without overwriting previous records, forming an immutable chronological record that supports explainable decision-making for audit, regulatory oversight, and dispute resolution (Doshi-Velez & Kim, 2017). The fourth stage is the integration of cryptography and blockchain as a data integrity verification layer using a hybrid architecture, in which detailed data remain in internal systems while cryptographic hashes and timestamps of critical events are recorded on a private or consortium blockchain. This mechanism enables independent verification and immediate detection of data tampering without compromising efficiency and scalability (Yaga et al., 2018). The fifth stage is the utilization of an internal audit dashboard for governance and risk control, presenting operational summaries, risk indicators, and real-time activity monitoring to detect anomalies, potential fraud, and procedural deviations, as well as to support evidence-based investigations (Kroll et al., 2017). The final stage is trust formation, achieved through a balance between limited customer-facing transparency and full internal accountability supported by granular logging and cryptographic verification, transforming the audit trail into an active trust infrastructure (Casino et al., 2019).

The development of end-to-end technology-based innovation in the Tring! application represents a strategic response to Pegadaian's digital transformation challenges. The integration of advanced e-KYC, AI-assisted valuation, technology-based pick-up and custody systems, and a transparent audit trail reinforced by cryptography and blockchain is expected to improve efficiency, appraisal consistency, transparency, and risk control while positioning technology as a decision support system that complements human roles.

The implementation of this model is expected to enhance service quality, accessibility, real-time monitoring, and public trust, while also opening opportunities for asset expansion and broader financial inclusion without compromising security and regulatory compliance. Although the study remains conceptual and lacks empirical validation, its findings provide a foundation for policy development, system design, and future research on the implementation of digital innovation within Pegadaian's operational context.

4. Conclusions

The transformation of Pegadaian's services toward a digitally driven model supported by an integrated end-to-end system represents a strategic necessity rather than an optional initiative, given the increasing complexity of pledged assets, rising public expectations for fast and transparent financial services, and rapid advancements in financial technology. Based on the literature review and conceptual analysis, the Tring! application constitutes an initial step toward digitalization; however, it continues to face structural limitations in valuation accuracy, process integration, risk control, and service transparency within non-face-to-face pawn transactions. These gaps indicate the need for the development of a more integrated and adaptive system architecture that is capable of responding effectively to dynamic data environments and evolving operational risks in digital pawn services.

The integration of advanced technologies—including continuous digital identity verification, artificial intelligence–assisted valuation, technology-enabled asset pickup and custody, and a transparent and trustworthy audit trail reinforced by cryptographic mechanisms and blockchain—has the potential to shape a more efficient, accountable, and reliable Pegadaian digital ecosystem, particularly within online pawn services. Such integration enables real-time processing and monitoring across the entire service lifecycle, thereby enhancing operational coherence and service transparency. The application of artificial intelligence as a decision support system facilitates the standardization of valuation quality, accelerates processing time, and strengthens risk detection capabilities. At the same time, the adoption of a human-in-the-loop approach ensures that final decision-

making remains aligned with prudential principles and regulatory compliance. Furthermore, an audit trail architecture based on event logging and cryptographic verification significantly enhances transparency and accountability, serving as a critical foundation for building and sustaining public trust in Pegadaian's digital services.

The proposed end-to-end innovation model is assessed as both logical and feasible for implementation within the Tring! application, as it aligns with international best practices and leverages technological advancements that are already mature within the financial services and digital logistics sectors. Although this study does not include empirical testing, the findings and the resulting conceptual framework provide an initial reference for policymakers and system developers in formulating strategies to strengthen Pegadaian's digital services. Future research is recommended to empirically evaluate the effectiveness of the proposed model, assess infrastructure and human resource readiness, and examine regulatory implications to ensure that implementation is sustainable, compliant, and inclusive.

Acknowledgement

The authors would like to express sincere gratitude to their parents and professional seniors for their continuous support and encouragement throughout the completion of this research. The author also extends appreciation to colleagues, siblings, and friends for their valuable insights, constructive feedback, and ideas that contributed to the development and refinement of this manuscript. In particular, the author would like to thank Juliani Sri Bintarti and Nurlaila Hidayaty for their assistance in reviewing this manuscript and for their constructive comments and suggestions, which significantly improved the quality and academic rigor of this work.

Author Contribution

Conceptualization, Methodology, Data Curation, Validation, Resources, Writing – Original Draft Preparation, and Writing – Review and Editing: K. I. T. D. Formal Analysis, Investigation, Software, Visualization and Illustration, Project Administration, Supervision, and Funding Acquisition: C. C. H. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Ethical Review Board Statement

Not available. This study is based solely on a review of published literature and conceptual analysis and did not involve human participants, animals, or the collection of primary data.

Informed Consent Statement

Not available.

Data Availability Statement

No new data were created or analyzed in this study. Data sharing is not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

Declaration of Generative AI Use

During the preparation of this work, the authors used ChatGPT to assist in identifying and locating relevant academic journals and literature related to the research topic. After using this tool, the authors reviewed, selected, and evaluated all referenced sources independently and ensured that all citations accurately reflect the content and context of

the original works. The authors take full responsibility for the integrity, interpretation, and presentation of the information included in this manuscript. The use of ChatGPT was limited solely to supporting the literature search and organization process, and it did not contribute to the analysis, conclusions, or writing of the findings.

Open Access

©2026. The authors. This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original authors and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit: <http://creativecommons.org/licenses/by/4.0/>

References

- Angraaeni, M. A. (2015). *Studi deskriptif perilaku dan kinerja perusahaan PT Pegadaian (Persero)*. Universitas Pendidikan Indonesia.
- Bholat, D., Hansen, S., Santos, P., & Schonhardt-Bailey, C. (2021). *Machine learning in central banking* (Staff Working Paper No. 865). Bank of England. <https://www.bankofengland.co.uk/working-paper/2021/machine-learning-in-central-banking>
- Bishop, C. M. (2016). *Pattern recognition and machine learning*. Springer.
- Breiman, L. (2017). *Classification and regression trees*. Routledge.
- Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications. *Telematics and Informatics*, 36, 55–81. <https://doi.org/10.1016/j.tele.2018.11.006>
- Chen, Q. (2024). Challenges and opportunities of fintech innovation for traditional financial institutions. *Frontiers in Business, Economics and Management*, 13(3), 28–33. <https://doi.org/10.54097/p49f1543>
- Chen, T., & Guestrin, C. (2016). XGBoost: A scalable tree boosting system. In *Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining* (pp. [page range to be verified]). Association for Computing Machinery. <https://doi.org/10.1145/2939672.2939785>
- Christopher, M. (2016). *Logistics and supply chain management* (5th ed.). Pearson.
- Doshi-Velez, F., & Kim, B. (2017). *Towards a rigorous science of interpretable machine learning*. arXiv. <https://doi.org/10.48550/arXiv.1702.08608>
- Financial Action Task Force. (2020). *Guidance on digital identity*. <https://www.fatf-gafi.org/publications/financialinclusion/documents/digital-identity-guidance.html>
- Galbally, J., Marcel, S., & Fierrez, J. (2019). Face presentation attack detection: Fundamentals, advances, and challenges. *IEEE Signal Processing Magazine*, 36(4), 26–45. <https://doi.org/10.1109/MSP.2019.2904797>
- George, A. S. (2023). Securing the future of finance: How AI, blockchain, and machine learning safeguard emerging neobank technology against evolving cyber threats. *Partners Universal Innovative Research Publication*, 1(1), 54–66. <https://doi.org/10.5281/zenodo.10001735>
- Gomber, P., Koch, J.-A., & Siering, M. (2017). Digital finance and fintech: Current research and future research directions. *Journal of Business Economics*, 87, 537–580. <https://doi.org/10.1007/s11573-017-0852-x>
- Gonsalves, V. P., Shaikh, T. H., Pathan, M. A., & Dias, P. F. (2025). Detection of authenticity of images. *International Journal of Engineering and Advanced Technology*, 15(1), 11–17. <https://doi.org/10.35940/ijeat.E4674.15011025>
- Goodfellow, I., Bengio, Y., & Courville, A. (2016). *Deep learning*. MIT Press.

- Hannan, M. A., Shahriar, M. A., Ferdous, M. S., Chowdhury, M. J. M., & Rahman, M. S. (2023). A systematic literature review of blockchain-based e-KYC systems. *Computing*, 105(10), 2089–2118. <https://doi.org/10.1007/s00607-023-01176-8>
- Hooi, B., Shin, K., Song, H. A., Beutel, A., Shah, N., & Faloutsos, C. (2019). Graph-based fraud detection in dynamic networks. In *Proceedings of the 25th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining* (pp. 1476–1486). Association for Computing Machinery. <https://doi.org/10.1145/3292500.3330879>
- Jawapos.com. (n.d.). *Keunggulan Tring by Pegadaian dan cara registrasi ulang akun*. Jawa Pos. <https://www.jawapos.com/ekonomi/016734255/keunggulan-tring-by-Pegadaian-cara-registrasi-ulang-akun>
- Juneja, M., Aggarwal, N., Saini, S. K., & Pathak, S. (2025). A comprehensive review on artificial intelligence-driven preprocessing, segmentation, and classification techniques for precision analysis. *Multimedia Tools and Applications*. <https://doi.org/10.1007/s11042-024-20119-9>
- Kokina, J., & Davenport, T. H. (2017). The emergence of artificial intelligence: How automation is changing auditing. *Journal of Emerging Technologies in Accounting*, 14(1), 115–122. <https://doi.org/10.2308/jeta-51730>
- Kroll, J. A., Huey, J., Barocas, S., Felten, E. W., Reidenberg, J. R., Robinson, D. G., & Yu, H. (2017). Accountable algorithms. *University of Pennsylvania Law Review*, 165(3), 633–705. <https://pennlawreview.com/2017/02/23/accountable-algorithms/>
- Margaret, R. (2015). *End-to-end encryption (E2EE)*. SearchSecurity. <https://www.google.com/amp/s/searchsecurity.techtarget.com/definition/end-to-end-encryptionE2EE%3famp=1>
- Miller, T. (2019). Explanation in artificial intelligence: Insights from the social sciences. *Artificial Intelligence*, 267, 1–38. <https://doi.org/10.1016/j.artint.2018.07.007>
- Oloke, K. (2024). End-to-end asset tokenization systems using AI: Enhanced valuation models on decentralized cloud infrastructure. *International Journal of Financial Management and Economics*, 7(2), 822–832. <https://doi.org/10.33545/26179210.2024.v7.i2.678>
- Patel, S. R. (2024). *Role of computer vision in retail stores* [Doctoral dissertation]. <https://doi.org/10.13140/RG.2.2.33928.94729>
- Reyna, A., Martín, C., Chen, J., Soler, E., & Díaz, M. (2018). On blockchain and its integration with IoT: Challenges and opportunities. *Future Generation Computer Systems*, 88, 173–190. <https://doi.org/10.1016/j.future.2018.05.046>
- Ross, A., Jain, A. K., & Das, S. (2022). User interaction patterns for continuous authentication. *ACM Transactions on Privacy and Security*, 25(2), 1–28. <https://doi.org/10.1145/3494672>
- Shrestha, Y. R., Ben-Menahem, S. M., & von Krogh, G. (2019). Organizational decision-making structures in the age of artificial intelligence. *California Management Review*, 61(4), 66–83. <https://doi.org/10.1177/0008125619862257>
- Sing, T. F., Yang, J., & Yu, S. M. (2021). Boosted tree ensembles for artificial intelligence-based automated valuation models (AI-AVM). *Journal of Real Estate Finance and Economics*, 65(4), 649–674. <https://doi.org/10.1007/s11146-021-09861-1>
- Sun, X., Wang, P., Yan, Z., Xu, F., Diao, W., Chen, J., Li, J., Feng, Y., Xu, T., Weinmann, M., Hinz, S., Cheng, W., & Fu, K. (2022). FAIR1M: A benchmark dataset for fine-grained object recognition in high-resolution remote sensing imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*, 184, 116–130. <https://doi.org/10.1016/j.isprsjprs.2021.12.004>
- Suyono, W. P. (2025). A systematic review of tools, applications, and challenges of AI integration in auditing. *RIGGS: Journal of Management and Informatics*, 4(2). <https://doi.org/10.31004/riggs.v4i2.1024>
- Tubbias, A., Chim, Y. H., Kaufhold, L., Hundt, F., & Fritz, M. (2024). Multimodal fine-grained grocery product recognition using image and OCR text. *Machine Vision and Applications*, 35, Article 79. <https://doi.org/10.1007/s00138-024-01549-9>

- Varadharajan, V., Tupakula, U., & Kalloniatis, C. (2023). Context-aware continuous authentication techniques: A survey. *IEEE Communications Surveys & Tutorials*, 25(1), 420–455. <https://doi.org/10.1109/COMST.2022.3211789>
- Yaga, D., Mell, P., Roby, N., & Scarfone, K. (2018). *Blockchain technology overview* (NIST Interagency/Internal Report 8202). National Institute of Standards and Technology. <https://doi.org/10.6028/NIST.IR.8202>
- Zaidi, S. S. A., Ansari, M. S., Aslam, A., Kanwal, N., Asghar, M., & Lee, B. (2021). *A survey of modern deep learning-based object detection models*. arXiv. <https://doi.org/10.48550/arXiv.2104.11892>

Biographies of Authors

Celine Christina Handoko, holds a Bachelor's degree (S1) from the Faculty of Agricultural Technology. Her academic and professional interests focus on digital transformation, user-centered digital systems, and applied technology in public and financial services. Currently, an independent researcher based in Mojokerto, East Java, Indonesia.

- Email: celinechristina10@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Klemens Iwan Tjahjono Diposubagio, an independent researcher from Malang, East Java, Indonesia who has received multiple national awards.

- Email: klemens.iwan17@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A