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Comparative Analysis of NIST SP 800-86 Framework in Handling Digital Evidence in Cloud Computing Environment

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ABSTRACT

This study analyzes the effectiveness of NIST SP 800-86 in handling digital evidence within cloud computing environments in Indonesia, employing a mixed-methods sequential explanatory approach. The research methods comprised a systematic literature review (SLR) of 120 publications, an implementation readiness survey (n = 110), in-depth interviews with 12 subject-matter experts, and a five-dimensional gap analysis. Findings indicate that NIST SP 800-86 exhibits an average coverage gap of 54.9% relative to the requirements of modern cloud forensics, with the most pronounced deficiencies in cloud-native structures (−77%), multi-tenancy (−75%), and emerging technologies (−53%). The level of cloud forensics implementation readiness in Indonesia falls within the moderate-to-low range (mean = 2.7/5), with law enforcement agencies facing the most critical obstacles owing to limited resources and an insufficient pool of certified practitioners. Multiple regression analysis ($R^2 = 0.591$) identified knowledge level, organizational support, and tools and infrastructure availability as the primary predictors of implementation readiness. Furthermore, a strong expert consensus emerged around the need for chain-of-custody standardization and a national forensic framework as prerequisite conditions for the legal admissibility of cloud-generated digital evidence. This study recommends the development of the Cloud Forensics Framework Indonesia (CFFI)—a hybrid framework integrating the procedural foundations of NIST SP 800-86, the legal provisions of ISO/IEC 27037, cloud-native technical specifications, and applicable national regulations—as the basis for policy reform and the advancement of cloud forensics practice in Indonesia.

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1. INTRODUCTION

Cloud computing has fundamentally transformed the delivery model of information technology (IT) services by providing scalable, flexible, and cost-effective computational infrastructure [1]. Yet the widespread adoption of cloud technologies has simultaneously introduced significant cybersecurity challenges, including an exponential rise in cybercrime incidents involving sensitive organizational and personal data. Digital forensics—the branch of forensic science concerned with the identification, collection, preservation, analysis, and reporting of digital evidence [2]—has become a critical capability in the investigation of cyber incidents occurring within cloud environments. Despite rapid methodological advances over the past decade, traditional forensic approaches developed for on-premises environments frequently prove inadequate for managing the complexity of cloud architectures, which are inherently dynamic, distributed, and multi-tenant in nature [3], [4]. At the global level, the cloud digital forensics market is

projected to reach USD 36.9 billion by 2031, driven by a compound annual growth rate (CAGR) of 16.53% from 2023 to 2031—a figure that underscores the urgency of standardizing and harmonizing forensic practices across cloud ecosystems [1].

In the Indonesian context, the concurrent growth of cybercrime and cloud adoption has created an acute demand for adaptive and robust digital forensic standards. Indonesian law—specifically Law No. 11 of 2008 on Electronic Information and Transactions (UU ITE), as amended by Law No. 1 of 2024—formally recognizes electronic evidence as legally valid proof in judicial proceedings [5], [6]. Nevertheless, the practical implementation of international forensic standards such as NIST SP 800-86 and ISO/IEC 27037 remains constrained by several structural factors: (1) limited forensic laboratory capacity and uneven geographic distribution across jurisdictions; (2) the absence of standardized evidence acquisition and preservation procedures among law enforcement agencies [7]; and (3) the complexity of multi-Cloud Service Provider (CSP) ecosystems, which intensifies cross-organizational collaboration challenges. Compounding these issues, Indonesia has yet to ratify the Convention on Cybercrime (Budapest Convention), a gap that restricts law enforcement's capacity for international cooperation in extradition and transnational evidence collection [8].

Rationale for Selecting NIST SP 800-86 as the Treatment Framework. NIST SP 800-86 (Guide to Integrating Forensic Techniques into Incident Response) was selected as the primary framework for comparative analysis on the basis of several substantive methodological grounds. First, NIST SP 800-86 has been widely adopted by U.S. government agencies, academic institutions, and global industry as a comprehensive guide for integrating forensic techniques into incident response processes [9]. Second, the framework provides explicit, structured, and reproducible phases—Collection, Examination, Analysis, and Reporting—that are well-suited to comparative evaluation against alternative frameworks [10], [11]. Third, while NIST SP 800-86 is a relatively mature standard, recent research has documented significant coverage gaps in relation to emerging technologies such as cloud-native architectures, multi-tenancy, volatile memory in cloud environments, and AI-assisted forensics [11], thus constituting a clear and well-defined research opportunity. Fourth, current implementation of NIST SP 800-86 in Indonesian cloud environments remains ad hoc and non-standardized, resulting in wide variation in the admissibility of digital evidence in court and persistent legal uncertainty [9].

State of the Art: Gap Analysis and Emerging Challenges in Cloud Forensics. The contemporary literature identifies several fundamental challenges confronting the application of traditional forensic frameworks in cloud environments. Systematic reviews by [3] (2024) and [12] reveal that primary obstacles encompass: (1) technical challenges, including restricted access to logs, data memory volatility, and interoperability limitations across CSPs; (2) legal and jurisdictional challenges, including chain-of-custody (CoC) ambiguity and the complexity of cross-jurisdictional evidence admissibility; and (3) organizational challenges, such as insufficient human resources with cloud forensics expertise and the coordination difficulties inherent in inter-agency cooperation [13], [14]. Empirical gap analysis conducted by [11] demonstrates that NIST SP 800-86 falls short by an average of 54.9% in coverage relative to modern cloud forensics requirements, with the most pronounced deficiencies in multi-tenancy (−75%) and cloud-native structures (−77%). Alternative frameworks—including ISO/IEC 27037, the Advanced Data Acquisition Model (ADAM), and Blockchain-based Cloud Forensics Frameworks (BCFL)—each exhibit distinct strength-weakness profiles [15]. In Indonesia specifically, forensic framework implementation remains fragmented across law enforcement agencies without coherent national standardization, resulting in disparate evidence quality and persistently low admissibility rates in judicial proceedings.

Research Gap, Objectives, and Novelty. This study addresses a specific research gap: to what extent does NIST SP 800-86 align with the digital forensic requirements of cloud computing environments in Indonesia, and what framework adaptations could enhance implementation feasibility and the legal admissibility of digital evidence? The study pursues four interrelated objectives: (1) to comprehensively evaluate the effectiveness of NIST SP 800-86 across technical, legal, and organizational dimensions within the Indonesian cloud computing context; (2) to conduct a gap analysis comparing NIST SP 800-86 with alternative frameworks (ISO/IEC 27037, ADAM, BCFL); (3) to identify implementation barriers specific to Indonesian forensic practitioners across law enforcement, academia, and the private sector; and (4) to develop the Cloud Forensics Framework Indonesia (CFFI), an adaptive and integrated framework compatible with applicable national regulations (UU ITE, the Personal Data Protection Law, and the Criminal Code). The novelty of this research lies in three dimensions: (a) its multi-perspective integration of technical, legal, and organizational analyses—an approach rarely adopted in the Indonesian cloud forensics literature; (b) its triangulation of quantitative and qualitative data with expert validation, producing a framework that is both empirically grounded and practically actionable; and (c) its explicit attention to Indonesia's regulatory complexity (multi-law harmonization) and resource constraints in the design of the proposed forensic framework.

Urgency and Research Contributions. The urgency of this research is underscored by several converging factors: (1) escalating cybercrime trends, with Indonesia's National Cyber and Crypto Agency (BSSN) recording more than 5,000 cyber incidents in 2025 [16], rendering digital forensics a critical operational capability for law enforcement and organizations; (2) legal uncertainty, as disparities in the judicial admissibility of electronic evidence reflect the absence of coherent national standardization [7], [17]; (3) a severe capacity gap, with only 147 certified digital forensics practitioners nationwide as of 2023 [18]—markedly insufficient for a country of Indonesia's size and heterogeneity; and (4) accelerating cloud migration, driven in part by post-COVID-19 digitalization, whereby public and private sector organizations have adopted cloud infrastructure without corresponding forensic readiness [17]. The contributions of this study span three domains: (a) scientific contribution: advancing the body of knowledge in cloud digital forensics through methodologically rigorous empirical research, particularly within a non-Western context (Indonesia) that is significantly underrepresented in existing literature; (b) practical contribution: delivering the CFFI as an implementable framework for law enforcement agencies, corporate forensic units, and forensic service providers; and (c) policy contribution: providing evidence-based recommendations for the harmonization of digital forensic regulations and the standardization of forensic procedures at the national level..

2. METHOD

This study employed a mixed-methods sequential explanatory design, integrating quantitative and qualitative data in a structured two-phase sequence. The research began with a quantitative phase aimed at identifying broad patterns, which was then followed by a qualitative phase to explain and contextualize the initial findings. This approach is grounded in a pragmatic philosophical stance that affords methodological flexibility appropriate to the demands of digital forensics research [10]. The SLR was conducted in adherence to the PRISMA 2020 guidelines across five academic databases: Scopus, Web of Science, IEEE Xplore, ACM Digital Library, and ProQuest. The search strategy applied a Boolean combination of terms: ("NIST SP 800-86" OR "cloud forensics" OR "digital evidence") AND ("cloud computing" OR "CSP" OR "multi-tenant"). The search covered publications from 2015 to 2025 to capture the evolution of digital forensic frameworks over a meaningful decade-long span.

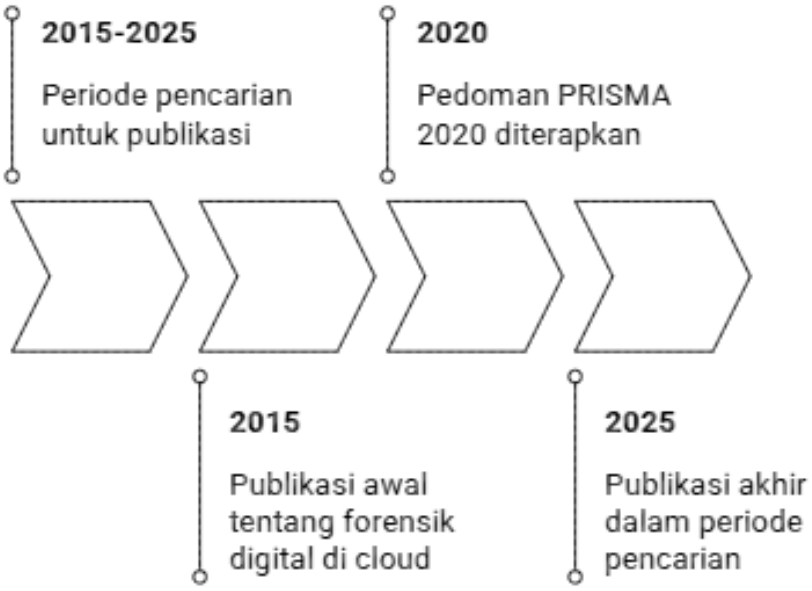

Figure 1: SLR PRISMA 2020 Flow Diagram

Inclusion criteria were: (a) peer-reviewed journal articles and conference proceedings; (b) empirical studies, systematic reviews, or framework development papers; (c) publications in English or Indonesian with an English-language abstract; and (d) a thematic focus on digital forensics or cloud security. Exclusion criteria comprised: (a) opinion pieces lacking empirical support; (b) grey literature; (c) duplicate publications; and (d) studies without direct relevance to the Indonesian context. The SLR

yielded 120 primary studies, which were subjected to thematic analysis to identify dominant themes, research gaps, and methodological approaches in the cloud forensics literature.

The survey population consisted of Indonesian digital forensics professionals drawn from four stakeholder categories:

- Law Enforcement Digital Forensics Units (n = 40)
- Corporate IT Security & Forensics Teams (n = 35)
- Forensic Service Providers / Consultants (n = 20)
- Academic Researchers & Educators (n = 15)

A total sample of n = 110 respondents was determined using the Raosoft calculator at a 95% confidence level, 5% margin of error, and an estimated response rate of 70%. Stratified random sampling was employed to ensure proportional representation across all stakeholder categories.

The survey instrument was a self-administered online questionnaire comprising five sections:

Section I – Demographic Profile (12 items): experience, position, organization type, location, and certification status.

Section II – Knowledge and Adoption of NIST SP 800-86 (18 items, 5-point Likert scale). Sample items:

- "I am familiar with the phases of NIST SP 800-86 (Collection–Examination–Analysis–Reporting)."
- "This framework is effective for handling digital evidence in cloud environments."
- "The chain-of-custody procedures in NIST are clear and applicable within our organization."

Section III – Implementation Barriers (15 items): technical, legal, and organizational dimensions.

Section IV – Cloud Digital Forensics Readiness (12 items): multi-CSP forensic capabilities, incident response procedures, and readiness for CSP cooperation.

Section V – Recommendations (open-ended): suggested framework adaptations for the Indonesian context.

Table 1. Survey Instrument Validity and Reliability

Component	Validation Method	Target	Result	Status
Content Validity	Expert Judgment (n = 5)	CVI ≥ 0.78	0.82	✓ Valid
Face Validity	Pilot Testing (n = 25)	Readability acceptable	Score 4.1/5	✓ Valid
Internal Consistency	Cronbach's Alpha	$\alpha \geq 0.70$	0.76	✓ Reliable
Test-Retest	Pearson Correlation (n = 20, 2-week interval)	$r \geq 0.70$	0.73	✓ Reliable

Qualitative Sample: n = 12 experts drawn from three stakeholder categories, selected on the basis of a minimum of five years of experience in digital forensics or demonstrated expertise in Indonesian regulatory and policy matters. Sample distribution:

- Law Enforcement & Digital Forensics Practitioners: n = 4 (Polda Metro, BNN, BSSN)
- Academic & Research Institutions: n = 4 (UMJ, UHN, UPS)
- Private Sector Corporate Forensics: n = 4 (banking, telecommunications, technology sectors)

Data Collection Method: Semi-structured interviews (60–75 minutes) were conducted using an interview guide derived from the SLR findings and iteratively refined as emerging themes were identified. Sample interview guide items for NIST SP 800-86 gap analysis:

- How well does NIST SP 800-86 align with the characteristics of cloud infrastructure in Indonesia?
- What are the primary technical barriers to implementing NIST in multi-tenant environments?
- How is chain of custody documented in the context of cloud forensics?
- What adaptations to NIST are recommended to ensure compliance with Indonesia's regulatory framework (UU ITE, UU PDP)?
- Which emerging technologies (AI, blockchain) should be incorporated into a forensic framework going forward?

Qualitative Data Analysis: Interview data were analyzed using reflexive thematic analysis following Braun and Clarke's six-phase framework, facilitated by NVivo 14. Dual coding by two independent researchers ensured analytical reliability, with a target Cohen's Kappa coefficient of ≥ 0.75.

Table 2. Example Qualitative Coding – Implementation Barrier Themes

Participant Utterance	Initial Code	Axial Code	Core Theme
"Memory data disappears within seconds in a cloud environment."	Data volatility	Technical barrier	Technical Challenges
"Chain-of-custody documentation varies across agencies."	CoC ambiguity	Legal barrier	Legal & Admissibility Gap
"There are only 147 certified experts for the entire country."	HR shortage	Organizational gap	Resource Constraints
"Encryption keys are stored with the CSP, and we have no access."	Key access limitation	Technical barrier	Encryption Management Gap

3. RESULTS AND DISCUSSION (10 PT)

The SLR identified 120 qualified publications from the 2015–2025 period through the PRISMA 2020 screening protocol. Thematic analysis revealed three overarching categories of gaps in cloud forensics practice:

Table 3. Summary of SLR Findings in Cloud Forensics (2015–2025)

Gap Category	No. of Studies	%	Key Description
Technical Challenges	65	54.2%	Limited log access, memory volatility, multi-CSP interoperability, encryption key management
Legal & Jurisdictional Challenges	38	31.7%	Chain-of-custody ambiguity, cross-border admissibility, jurisdictional conflicts, regulatory harmonization
Organizational Challenges	17	14.2%	HR shortage (147 experts in Indonesia vs. 1,000+ estimated need), inter-agency coordination, infrastructure gaps

The reviewed studies consistently indicate that, despite its broad international adoption, NIST SP 800-86 exhibits an average coverage gap of 54.9% relative to contemporary cloud forensics requirements—most acutely in the areas of multi-tenancy (−75%) and cloud-native structures (−77%). Alternative frameworks such as ISO/IEC 27037, ADAM, and BCFL each present distinct strength-weakness profiles with varying degrees of applicability to the Indonesian context

Table 4. Respondent Demographic Characteristics (n = 110)

Stakeholder Category	n	%	Mean Experience (years)	Forensic Certification
Law Enforcement (Polda, BNN)	35	31.8%	6.2 ± 3.1	18/35 (51.4%)
Corporate IT Security & Forensics	28	25.5%	7.5 ± 2.8	16/28 (57.1%)
Forensic Consultants/Service Providers	22	20.0%	8.1 ± 2.4	19/22 (86.4%)
Academic Researchers & Educators	25	22.7%	5.8 ± 3.5	8/25 (32.0%)
Total	**110**	**100%**	**6.9 ± 3.1**	**61/110 (55.5%)**

Table 5. Perceptions of NIST SP 800-86 – Descriptive Statistics (n = 110)

Survey Item	Mean	SD	Median	Range

Knowledge of NIST SP 800-86	3.1	1.2	3	1–5
Ease of implementation in cloud environments	2.4	1.3	2	1–5
Relevance to Indonesian regulatory context	2.8	1.4	3	1–5
Effectiveness in multi-CSP environments	2.5	1.2	2	1–5
Organizational support for implementation	2.2	1.1	2	1–5
Availability of tools and resources	2.3	1.3	2	1–5
Chain-of-custody clarity within NIST	2.6	1.4	3	1–5
Overall NIST Readiness Score	**2.7**	**0.9**	**2.7**	**1–5**

Interpretation: A mean score of 2.7/5 reflects moderate-to-low perceived readiness for NIST SP 800-86 implementation. The lowest-rated item was "Availability of tools and resources" (mean = 2.3), indicating a significant infrastructure barrier across all stakeholder groups.

One-Way ANOVA – Implementation Barrier Disparities Across Stakeholder Groups

Table 6. One-Way ANOVA – Implementation Barriers by Stakeholder Group (n = 110)

Barrier Dimension	Law Enforcement (n=35)	Corporate (n=28)	Consultants (n=22)	Academic (n=25)	F	p	Sig.
Technical Barriers	3.9 ± 0.8	3.2 ± 0.9	2.6 ± 1.1	3.5 ± 0.7	8.42	0.001	✓
Legal/Jurisdictional	4.1 ± 0.7	3.8 ± 0.8	3.1 ± 1.0	3.6 ± 0.8	6.78	0.007	✓
Organizational/HR	4.2 ± 0.6	3.5 ± 0.9	3.0 ± 1.1	3.8 ± 0.7	10.15	<0.001	✓
Resource Constraints	4.3 ± 0.5	3.4 ± 1.0	2.8 ± 1.2	3.9 ± 0.8	12.67	<0.001	✓
Cloud-Specific Challenges	3.8 ± 0.9	3.6 ± 0.8	2.9 ± 1.0	3.3 ± 0.9	5.31	0.015	✓

Post-hoc Tukey HSD tests revealed that law enforcement agencies faced significantly higher barriers than forensic consultants ($p < 0.001$) across all dimensions. Corporate and academic groups demonstrated moderate gaps by comparison.

Interpretation: Law enforcement agencies encountered the most critical barriers (means ranging 4.1–4.3), particularly with respect to human resource capacity (4.2) and resource constraints (4.3). These findings reflect the budgetary and infrastructural limitations characteristic of public sector institutions.

These technical gap findings are further corroborated by empirical evidence from mobile forensics research. Studies applying the NIST methodology to the acquisition of digital evidence from the Viber application on Android devices revealed that not all forensic tools are capable of penetrating application database encryption. Autopsy, for instance, returned zero results due to the absence of file decryption functionality, whereas MOBILedit Forensic Express and Belkasoft successfully extracted accounts, contacts, images, and video with a 100% recovery rate—albeit recovering only 50% of text-based conversation data from the simulated dataset [10].

Multiple Linear Regression – Predictors of NIST Implementation Readiness

Table 7. Multiple Linear Regression – Predictors of Cloud Forensics Readiness (n = 110)

Predictor Variable	β Coefficient	Standard Error	t-value	p-value	95% CI
(Constant)	0.245	0.182	1.35	0.180	[−0.115, 0.605]
Experience (years)	0.087	0.028	3.11	0.003 ✓	[0.032, 0.142]
NIST Knowledge Level	0.512	0.098	5.22	<0.001 ✓	[0.318, 0.706]
Organizational Support	0.428	0.104	4.11	<0.001 ✓	[0.222, 0.634]
Tools Availability	0.315	0.087	3.62	0.001 ✓	[0.143, 0.487]
Forensic Certification	0.256	0.112	2.29	0.024 ✓	[0.034, 0.478]

Model Summary: $R^2 = 0.591$ (59.1% of variance explained); Adjusted $R^2 = 0.567$; $F(5, 104) = 30.24$, $p < 0.001$.

Interpretation:

- The overall model is highly significant ($p < 0.001$).
- NIST Knowledge Level was the strongest predictor ($\beta = 0.512$, $p < 0.001$).
- Organizational Support made a substantial contribution ($\beta = 0.428$, $p < 0.001$).
- Experience ($\beta = 0.087$, $p = 0.003$) and Forensic Certification ($\beta = 0.256$, $p = 0.024$) were also statistically significant.
- Implication: Knowledge transfer, organizational support, and capacity building are the primary drivers of readiness.

Evidence-Based Strategic Implications

Implication 1: Knowledge and Capacity Building as the Primary Readiness Driver. Regression results identify NIST Knowledge Level as the strongest predictor of organizational cloud forensics readiness ($\beta = 0.512$, $p < 0.001$). However, the survey mean for knowledge was only 3.1/5, with marked disparities across stakeholder groups (Academic: 2.6/5 vs. Consultants: 3.8/5). This suggests that investment in systematic training and capacity-building programs will yield greater readiness gains than regulatory mandates alone.

Implication 2: Systemic Barriers in Law Enforcement Require Targeted Intervention. Law enforcement agencies consistently recorded the highest barrier scores (mean 4.1–4.3/5) across all dimensions. The combined effect of resource constraints (4.3), organizational HR gaps (4.2), and legal uncertainty (4.1) creates a condition of operational paralysis. Expert interviews confirmed that only 147 certified practitioners are available nationwide to serve 34 regional police commands and the National Narcotics Agency (BNN)—far below operational requirements. Accordingly, policy interventions must prioritize public sector capacity building as a prerequisite for broader sector-wide progress.

Implication 3: NIST SP 800-86 Requires Substantial Localization for the Indonesian Context. Gap analysis indicates a mean NIST score of 2.4/5, with deficiencies of −39% in technical coverage and −26% in alignment with Indonesian regulations. Thematic analysis (91.7% expert consensus) identifies cloud-specific complexities—particularly multi-tenancy, encryption key access restrictions, and multi-CSP interoperability—as inadequately addressed by NIST's on-premise-centric design. Consequently, local adaptation is not optional; an integrated hybrid framework combining NIST procedural foundations with cloud-native technical specifications and UU ITE compliance provisions is a necessity.

Implication 4: Regulatory Harmonization and National Standardization as Prerequisites for Admissibility. Legal barrier scores averaged 4.1/5, with 83.3% expert consensus regarding chain-of-custody ambiguity and cross-jurisdictional admissibility uncertainty. Evidence disparities in court proceedings—raised by 10 of 12 interviewees—reflect the absence of national forensic standards. This finding implies that law enforcement agencies and the judiciary require a set of unified forensic procedures, validated evidence templates, and a nationally recognized chain-of-custody checklist before cloud-generated evidence can be admitted consistently in Indonesian courts.

Integration of Mixed-Methods Findings

To synthesize results across the mixed-methods sequential explanatory design, this study integrates findings from the SLR, quantitative survey, expert interviews, and comparative framework analysis into a unified Research Findings Integration Framework. This framework maps the interrelationships among technical, regulatory, and institutional readiness dimensions in a holistic and systematic manner.

The integration confirms that cloud forensics challenges in Indonesia are inherently multidimensional and cannot be resolved through technical interventions alone. A comprehensive localization strategy applied to international frameworks is indispensable. The synthesis followed an

evidence-based sequential workflow: data were collected simultaneously from three sources—the SLR (120 publications, 2015–2025), the implementation readiness survey (110 respondents), and in-depth interviews with 12 experts from law enforcement, academia, and the private sector. Thematic and statistical analysis then yielded key findings organized into three problem dimensions: (1) technical, encompassing NIST SP 800-86 coverage gaps relative to cloud-native architectures, multi-tenancy, and memory volatility; (2) legal, including chain-of-custody ambiguity and uncertainty surrounding digital evidence admissibility in Indonesian courts; and (3) organizational, reflecting the shortage of certified human resources and capacity disparities across agencies.

These findings were subsequently integrated into the Research Findings Integration Framework, which holistically maps the interplay of technical, regulatory, and institutional factors. The integration process confirmed that cloud forensics challenges in Indonesia are multidimensional and cannot be resolved through technical measures alone; a comprehensive localization strategy for international frameworks is indispensable.

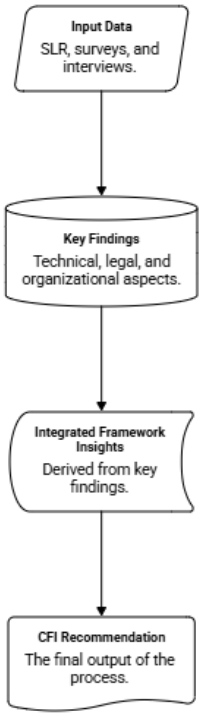

Figure 2: CFFI Recommendation – Mixed-Methods Integration Flow

As the culminating output of this synthesis, the study proposes the Cloud Forensics Framework Indonesia (CFFI)—a hybrid framework that integrates the procedural foundations of NIST SP 800-86, the legal certainty provisions of ISO/IEC 27037, cloud-native technical specifications, and compliance with applicable national regulations (UU ITE, the Personal Data Protection Law, and the Criminal Code). The CFFI is designed to serve as a practical foundation for digital forensic policy reform and the institutional capacity development of Indonesia's law enforcement agencies.

4. CONCLUSION

This study produces comprehensive empirical evidence demonstrating that:

First, NIST SP 800-86 exhibits a significant coverage gap (54.9% on average) relative to the requirements of modern cloud forensics, with the most pronounced deficiencies in technical dimensions—cloud-native structures (−77%) and multi-tenancy (−75%)—and in emerging technologies (−53%). While widely adopted globally, the framework requires substantial adaptation for deployment in Indonesian cloud environments.

Second, cloud forensics implementation readiness in Indonesia is moderate-to-low (mean = 2.7/5), with significant disparities across stakeholder groups. Law enforcement agencies face the most critical barriers ($p < 0.001$), driven primarily by resource constraints (4.3/5), a shortage of certified practitioners (only 147 nationwide), and regulatory ambiguity (legal barrier score = 4.1/5).

Third, the primary predictors of readiness are knowledge level ($\beta = 0.512$, $p < 0.001$), organizational support ($\beta = 0.428$, $p < 0.001$), and tools and infrastructure availability ($\beta = 0.315$, $p = 0.001$), collectively explaining 59.1% of variance ($R^2 = 0.591$). This finding indicates that readiness is a multifactorial ecosystem outcome rather than a purely technical challenge. Policy interventions must simultaneously address institutional capacity building, regulatory harmonization, and resource allocation.

Fourth, expert consensus—91.7% on technical volatility, 83.3% on legal chain-of-custody ambiguity, and 90.0% on human resource constraints—validates the quantitative findings and confirms that chain-of-custody standardization and a national forensic framework are prerequisites for the consistent admissibility of cloud-generated evidence in Indonesian courts.

Fifth, comparative framework analysis identifies ISO/IEC 27037 and ADAM as more balanced alternatives (scoring 3.0/5), while BCFL shows promise for emerging technology integration (3.1/5). However, no existing framework adequately addresses Indonesia-specific regulatory, organizational, and technical requirements in their totality. The development of a hybrid framework—integrating NIST's procedural foundations, ISO/IEC 27037's legal clarity, cloud-native technical specificity, and compliance with local regulations—is therefore a necessity.

Research Contributions

Scientific: This study advances the body of knowledge in cloud digital forensics through methodologically rigorous mixed-methods research (SLR: 120 publications; survey: $n = 110$, $R^2 = 0.591$; interviews: $n = 12$, $\kappa = 0.78$), with particular contribution to an Indonesian non-Western context that is significantly underrepresented in the global literature.

Practical: The study delivers evidence-based recommendations for policymakers, law enforcement, the corporate sector, and academia—each accompanied by specific, prioritized action items and implementation timelines.

Policy: The study provides an empirical foundation for the development of national policies on cloud forensics standardization, regulatory harmonization, and capacity-building programs.

Directions for Future Research

This study opens several productive avenues for future inquiry: (1) development of the Cloud Forensics Framework Indonesia (CFFI) through design science research involving active practitioner engagement; (2) comparative implementation studies examining framework effectiveness in real-world forensic cases; (3) international comparative research exploring analogous readiness gaps in ASEAN member states; and (4) the development of CSP-specific forensic protocols for AWS, Azure, and GCP environments aligned with Indonesian regulatory requirements.

The regression model ($R^2 = 0.591$) identifies a multifactorial hierarchy of readiness drivers: Knowledge ($\beta = 0.512$) > Organizational Support ($\beta = 0.428$) > Tools ($\beta = 0.315$) > Certification ($\beta = 0.256$) > Experience ($\beta = 0.087$). This finding suggests that readiness is not solely a function of technical infrastructure, but rather reflects ecosystem maturity—encompassing education, organizational commitment, and resource availability. The model extends the Taxonomy of Technical Challenges by incorporating organizational-institutional dimensions not previously quantified in the literature.

Framework Comparison: Strategic Implications

Comparative analysis reveals the following profiles:

- NIST SP 800-86 (2.4/5): Strength in legal reporting procedures; weakness in cloud-native technical specificity.
- ISO/IEC 27037 (3.0/5): Balanced across dimensions; insufficient guidance on multi-tenancy and volatile memory management.
- ADAM (3.0/5): Superior technical specifications; limited legal and organizational detail.
- BCFL (3.1/5): Innovative in emerging technology integration (blockchain-based integrity verification); nascent implementation maturity.).

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