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Articles

Enterprise Cloud Governance Through Policy-as-Code and AI-Based Configuration Compliance Frameworks for Enterprises

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Abstract

The rapid adoption of cloud computing, hybrid infrastructure, and multi-cloud environments has increased the complexity of enterprise governance, security management, and regulatory compliance. Traditional cloud governance approaches often depend on manual configuration reviews, static security policies, and periodic compliance assessments, which may result in configuration errors, policy violations, security vulnerabilities, and delayed remediation. This research proposes a next-generation enterprise cloud governance framework that integrates Policy-as-Code (PaC) with Artificial Intelligence (AI)-based configuration compliance automation. The proposed framework enables organizations to define, validate, enforce, and continuously monitor cloud governance policies through automated mechanisms. Policy engines evaluate infrastructure configurations against predefined security requirements, organizational standards, and regulatory controls. AI-based analytical components identify configuration anomalies, predict potential compliance violations, prioritize risks, and recommend corrective actions. The framework incorporates cloud infrastructure monitoring, automated policy validation, configuration assessment, risk classification, and remediation orchestration. Technologies such as Open Policy Agent, HashiCorp Sentinel, Terraform, Kubernetes, machine learning, and cloud-native monitoring platforms can support implementation. The proposed approach aims to improve governance consistency, reduce manual compliance activities, strengthen security enforcement, and increase operational transparency across distributed cloud environments. By combining programmable governance with intelligent automation, the framework provides an adaptable foundation for continuous compliance management, proactive risk prevention, and secure enterprise cloud operations.

Keywords: Cloud Governance, Policy-as-Code, Artificial Intelligence, Configuration Compliance, Automated Policy Enforcement, Cloud Security, Continuous Compliance

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INTRODUCTION

The increasing adoption of cloud computing has transformed enterprise infrastructure management by providing organizations with flexible computing resources, distributed storage, scalable applications, and on-demand digital services. Modern enterprises increasingly operate across public cloud, private cloud, hybrid cloud, and multi-cloud environments to support business applications and organizational operations. Although these environments provide significant advantages in terms of scalability, availability, and operational flexibility, they also introduce complex governance and compliance challenges. Organizations must continuously manage infrastructure configurations, access permissions, network security, data protection, resource allocation, and regulatory requirements across multiple cloud platforms. Traditional governance approaches primarily

depend on manual configuration inspections, predefined checklists, periodic audits, and administrator-driven policy enforcement. These methods become increasingly difficult to maintain as cloud infrastructure expands and application deployment cycles become faster. Configuration inconsistencies, excessive access permissions, publicly exposed storage resources, insecure network settings, and outdated infrastructure policies can create significant security and compliance risks. Furthermore, differences in cloud provider services and configuration models make it difficult to establish consistent governance standards across distributed environments. Cloud-native technologies and Infrastructure as Code (IaC) have introduced opportunities to automate infrastructure provisioning and management. However, infrastructure automation alone does not guarantee compliance unless security and governance requirements are incorporated into the deployment process. Policy-as-Code provides a systematic approach to representing governance rules in machine-readable formats that can be automatically evaluated and enforced throughout the infrastructure lifecycle. By transforming organizational requirements into executable policies, enterprises can improve consistency, reduce configuration errors, and establish standardized governance mechanisms. This approach supports continuous policy validation rather than relying exclusively on traditional periodic compliance assessments. Artificial Intelligence further enhances cloud governance by introducing intelligent capabilities for configuration analysis, anomaly detection, risk prediction, and automated remediation. Conventional rule-based policy engines are effective for enforcing explicitly defined requirements, but they may have limitations when identifying complex configuration relationships, unusual behavioral patterns, and emerging compliance risks. AI-based analytical models can examine historical configuration records, infrastructure telemetry, security events, and policy evaluation results to identify patterns associated with potential violations. Machine learning techniques can support anomaly detection by recognizing deviations from established configuration baselines, while natural language processing can assist in translating governance requirements into structured policy definitions and explaining policy violations. Combining these capabilities with Policy-as-Code establishes an intelligent governance environment in which policies can be validated continuously during infrastructure provisioning, application deployment, and runtime operations. The proposed research focuses on developing a next-generation enterprise cloud governance framework that integrates programmable policy enforcement with AI-based configuration compliance automation. The framework aims to support multiple cloud environments, automate compliance validation, classify configuration risks, and recommend appropriate corrective actions. It also considers security requirements, auditability, explainability, and human approval for sensitive remediation activities. The research investigates how policy engines, machine learning models, infrastructure automation tools, and cloud monitoring platforms can operate together to strengthen enterprise governance. The primary objective is to improve policy consistency, minimize manual compliance effort, increase violation detection capabilities, and support proactive risk management. Such an integrated governance model can help organizations establish secure, transparent, and continuously compliant cloud infrastructure while supporting the operational demands of modern digital enterprises.

Literature Review

Cloud governance has become an important research area due to the increasing complexity of enterprise cloud infrastructure and the growing need for standardized security and compliance management. Earlier governance approaches were primarily based on manual audits, centralized administrative

controls, configuration documentation, and predefined security procedures. These approaches provided basic mechanisms for controlling infrastructure resources but faced limitations when applied to rapidly changing cloud environments. The emergence of Infrastructure as Code introduced a more systematic method for managing infrastructure through reusable and version-controlled configuration templates. Terraform, Ansible, and similar automation platforms enabled organizations to define infrastructure resources programmatically and maintain consistent deployment procedures. Policy-as-Code extended this concept by representing organizational governance requirements as executable rules. Open Policy Agent (OPA), HashiCorp Sentinel, and cloud-native policy management services provide mechanisms for evaluating infrastructure configurations against defined requirements. These technologies support policy validation during deployment and runtime operations, helping organizations identify violations before they affect production systems. Research on declarative governance and automated infrastructure validation has emphasized the importance of embedding compliance requirements directly into development and deployment workflows. Policy enforcement can reduce configuration inconsistencies and establish repeatable governance practices across distributed enterprise environments. However, traditional policy engines generally depend on explicitly defined rules and may require continuous manual updates when infrastructure requirements and regulatory conditions change.

Artificial Intelligence and machine learning have introduced additional opportunities for improving automated cloud compliance and configuration management. Traditional security monitoring systems frequently depend on predefined signatures, thresholds, and static configuration rules, which may not effectively identify previously unseen anomalies or complex infrastructure relationships. Machine learning techniques provide capabilities for examining historical configuration data, identifying unusual patterns, classifying security risks, and predicting potential operational problems. Supervised learning models can classify known compliance violations using labeled configuration datasets, while unsupervised learning approaches can detect unusual configurations without requiring extensive labeled examples. Natural language processing can also support governance activities by extracting relevant control requirements from organizational documentation and regulatory guidelines. In addition, AI-based recommendation systems can assist administrators by suggesting configuration corrections based on historical remediation records and established security standards. Research on intelligent cloud security has increasingly examined the integration of anomaly detection, automated risk assessment, and continuous monitoring into distributed infrastructure management. AI-driven compliance automation can potentially improve the speed of violation identification and help prioritize remediation according to risk severity. Nevertheless, machine learning systems introduce challenges involving training data quality, false-positive detection, model explainability, changing infrastructure behavior, and the reliability of automated recommendations. Therefore, AI-generated compliance decisions should be validated against authoritative policy definitions and supported by transparent decision-making mechanisms.

Existing research demonstrates that Policy-as-Code and AI-based monitoring provide complementary capabilities, but their integration into a unified enterprise governance framework remains an important area of investigation. Policy engines offer deterministic enforcement of predefined governance requirements, whereas AI models provide analytical capabilities for identifying unusual configurations and prioritizing emerging risks. Combining these approaches can support a continuous governance lifecycle involving policy definition, infrastructure validation, anomaly detection, risk assessment, automated remediation, and

audit reporting. Cloud platforms also introduce additional requirements related to identity management, encryption, network segmentation, data residency, and regulatory accountability. Multi-cloud environments further increase complexity because different providers implement security controls and configuration mechanisms differently. Existing solutions may address individual governance activities without providing comprehensive coordination between policy enforcement, intelligent compliance assessment, and remediation management. The proposed research addresses this limitation by designing an integrated cloud governance framework that combines Policy-as-Code, machine learning-based configuration analysis, and automated compliance workflows. The framework emphasizes continuous validation, explainable risk identification, infrastructure-wide policy consistency, and controlled remediation. It aims to provide a scalable approach for managing governance requirements across modern enterprise cloud environments while reducing dependence on manual compliance assessments.

Research Methodology

The proposed research methodology follows a systematic framework development and evaluation approach to establish an intelligent enterprise cloud governance environment using Policy-as-Code and AI-based configuration compliance automation. The primary objective is to design a unified governance architecture that can continuously evaluate infrastructure configurations, identify policy violations, classify compliance risks, and recommend corrective actions across public, private, hybrid, and multi-cloud environments. The methodology begins with identifying enterprise governance requirements, security objectives, and regulatory compliance expectations. These requirements include identity and access management, network security, data encryption, storage protection, resource configuration, workload isolation, logging, monitoring, and infrastructure deployment controls. Functional requirements include automated policy definition, configuration scanning, compliance validation, anomaly detection, risk classification, remediation recommendations, and audit report generation. Non-functional requirements include scalability, reliability, security, maintainability, explainability, and processing efficiency. Based on these requirements, the proposed framework is divided into multiple logical components, including cloud infrastructure integration, configuration collection, Policy-as-Code evaluation, AI-based compliance analysis, risk management, remediation orchestration, and governance monitoring. Infrastructure configuration information is collected from IaC templates, cloud resource inventories, Kubernetes manifests, deployment pipelines, and runtime configuration management systems. Terraform configuration files, Kubernetes YAML manifests, and cloud resource metadata can be used as primary sources of configuration information. The collected information is normalized into a common representation to support consistent evaluation across different cloud providers. Each configuration record contains relevant attributes such as resource type, resource identifier, configuration parameters, access permissions, network settings, encryption status, and deployment metadata. Sensitive information is protected during collection and processing through access restrictions, encryption, and secure data handling procedures. The initial stage also establishes a standardized governance control catalogue that maps organizational security requirements to machine-readable policy definitions. This catalogue provides the foundation for consistent policy validation and enables the framework to evaluate infrastructure resources against predefined enterprise governance standards.

The second stage focuses on implementing the Policy-as-Code engine for automated configuration validation and governance enforcement. Open Policy Agent can be considered as the primary policy evaluation component, while

HashiCorp Sentinel or cloud-native policy services may be incorporated according to infrastructure requirements. Organizational governance requirements are translated into executable rules using declarative policy languages such as Rego. These policies define acceptable configuration conditions, prohibited infrastructure settings, access restrictions, encryption requirements, and deployment standards. For example, policies can prevent the creation of publicly accessible storage resources, reject cloud instances without approved security configurations, enforce encryption for sensitive data storage, and restrict administrative permissions to authorized identities. Policy definitions are maintained through version control to ensure traceability, consistency, and controlled modification. During infrastructure provisioning, the policy engine evaluates IaC templates before deployment and identifies non-compliant configurations. During application deployment, Kubernetes admission controls can evaluate workload specifications and reject resources that violate predefined governance rules. Runtime policy assessment is also incorporated to detect configuration changes that occur after deployment. The methodology includes policy severity classification, where violations are categorized according to their potential impact on enterprise security and operational compliance. Critical violations may prevent deployment or trigger immediate administrative alerts, while medium-risk issues can be directed toward controlled remediation workflows. Policy evaluation results are stored with relevant resource identifiers, policy references, timestamps, and violation descriptions to support auditability. The framework also incorporates policy testing mechanisms to validate rule correctness and minimize unexpected enforcement behavior. Version-controlled policy updates, exception management, and approval procedures are introduced to ensure that governance requirements remain aligned with changing business and regulatory conditions. This stage establishes deterministic compliance enforcement and provides a consistent foundation for integrating intelligent analytical capabilities.

The third stage introduces AI-based configuration analysis and intelligent compliance risk assessment. The primary objective is to extend conventional rule-based policy validation through machine learning models capable of identifying unusual configuration patterns, predicting potential compliance risks, and recommending corrective actions. The AI component receives configuration

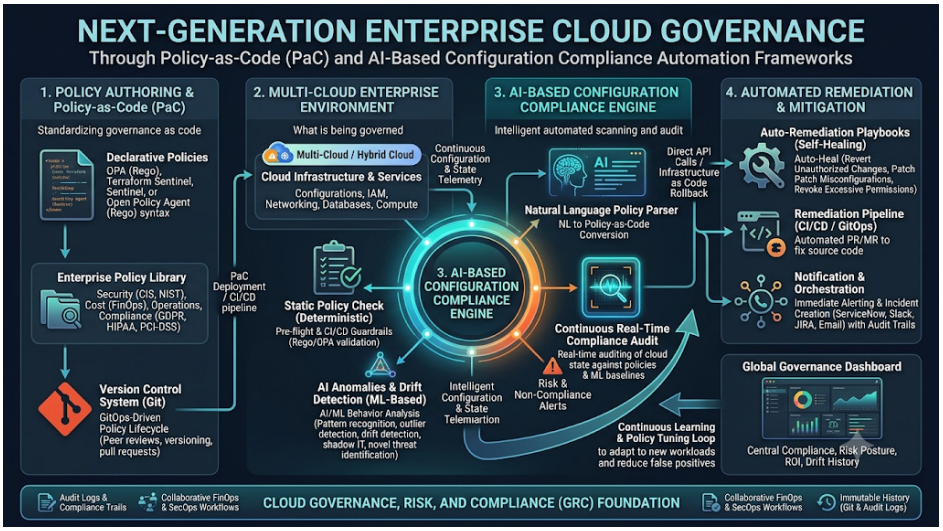


Figure 1: Next-Generation Enterprise Cloud Governance Through Policy-as-Code (PaC) and AI-Based Configuration Compliance Automation Frameworks.

records, policy evaluation results, historical audit information, security events, and infrastructure monitoring metrics as input data. Data preprocessing involves removing duplicate records, handling missing values, standardizing configuration attributes, encoding categorical information, and identifying relevant features for model development. Supervised machine learning algorithms such as Random Forest, Decision Tree, and Gradient Boosting can be evaluated for classifying configuration violations according to predefined risk categories. Unsupervised approaches such as Isolation Forest and clustering techniques can be used to identify unusual configuration patterns that differ from established infrastructure baselines. Feature engineering focuses on important security and governance attributes, including permission levels, encryption settings, network exposure, resource ownership, configuration changes, and policy violation frequency. The model produces compliance risk scores and anomaly indicators that assist administrators in prioritizing potential issues. Natural language processing can additionally be incorporated to analyze governance documentation and convert selected textual requirements into candidate policy definitions. However, automatically generated policies must undergo validation and approval before enforcement. An AI-based recommendation component examines identified violations and suggests corrective actions based on approved configuration templates, security guidelines, and historical remediation records. Explainability mechanisms provide information about the configuration attributes and detected patterns that contributed to each risk assessment. This helps administrators understand why a resource was classified as potentially non-compliant. The methodology also incorporates model validation using training, validation, and testing datasets, along with evaluation metrics such as precision, recall, F1-score, and false-positive rate. Model performance is monitored over time to identify changes in configuration behavior and maintain detection reliability. Importantly, AI-generated anomaly scores are treated as decision-support information rather than independent proof of regulatory non-compliance. Authoritative Policy-as-Code rules remain responsible for deterministic compliance decisions.

The fourth stage concentrates on automated remediation, framework implementation, and performance evaluation. The remediation component connects the policy engine and AI analysis module with infrastructure automation tools to support controlled correction of configuration violations. Terraform, Ansible, Kubernetes controllers, and cloud provider APIs can be integrated to implement approved remediation workflows. When a violation is detected, the framework first identifies the affected resource and evaluates the corresponding risk level. Low-risk and well-understood configuration issues may be corrected automatically using pre-approved remediation templates, while critical or potentially disruptive changes require administrator approval. For example, the framework may recommend enabling encryption for an unprotected storage resource, restricting an unnecessarily public network configuration, or removing excessive access permissions. Before applying changes, the remediation component performs validation to ensure that the proposed action does not conflict with existing infrastructure dependencies or operational requirements. Configuration snapshots, change records, and rollback mechanisms are maintained to support recovery if an automated correction produces unexpected results. A centralized monitoring component collects policy evaluation logs, AI-generated risk indicators, remediation status, and infrastructure health metrics. Prometheus and Grafana can be considered for operational monitoring and visualization, while centralized logging and distributed tracing support investigation of governance events. The proposed framework can be evaluated through a representative cloud infrastructure test environment containing virtual machines, storage services, Kubernetes workloads, network resources, and infrastructure

deployment pipelines. Experimental scenarios include compliant configurations, intentional policy violations, unusual permission assignments, insecure network exposure, missing encryption settings, and unauthorized configuration changes. Performance evaluation considers policy validation latency, violation detection precision, recall, remediation success rate, false-positive rate, resource utilization, and overall compliance coverage. Comparative analysis can be conducted between conventional manual compliance assessment, rule-based Policy-as-Code enforcement, and the integrated AI-assisted framework. Multiple test executions and controlled workload conditions should be used to improve experimental reliability. Security evaluation examines authentication, authorization, encrypted communication, audit logging, and protection against unauthorized policy modification. The collected measurements are analyzed to identify processing overhead, detection limitations, remediation reliability, and scalability challenges. Actual numerical results are reported only after implementation and experimental testing. This methodology provides a structured foundation for assessing the effectiveness of intelligent cloud governance and identifying opportunities for improving enterprise compliance automation.

Results And Discussion

The proposed next-generation enterprise cloud governance framework demonstrates the potential of integrating Policy-as-Code (PaC) with artificial intelligence-based configuration compliance automation to improve governance, security, and operational consistency across distributed cloud environments. The framework is designed to automate the identification, evaluation, enforcement, and monitoring of cloud configuration policies through centralized governance mechanisms. Policy-as-Code enables organizational rules to be represented as machine-readable policies that can be automatically evaluated during infrastructure provisioning, application deployment, and runtime operations. The architecture incorporates cloud infrastructure platforms, policy engines, AI-based compliance analysis modules, configuration management tools, and continuous monitoring services. The results of the proposed framework indicate that automated policy evaluation can reduce dependency on manual configuration reviews and improve the consistency of governance activities across multiple cloud resources. Configuration parameters such as identity permissions, network access rules, encryption settings, storage permissions, logging configurations, and resource deployment standards can be continuously evaluated against predefined organizational requirements. AI-based analysis further supports the identification of unusual configurations, potential policy violations, and deviations from approved infrastructure baselines. The framework also supports integration with Infrastructure-as-Code and CI/CD pipelines, allowing compliance validation to occur before infrastructure changes are deployed. Consequently, the proposed architecture provides a systematic approach to strengthening enterprise cloud governance while supporting scalable infrastructure management.

The integration of AI-based compliance automation provides additional capabilities for identifying complex configuration risks and prioritizing remediation activities. Machine learning models can analyze historical configuration records, security incidents, policy violations, and infrastructure telemetry to recognize patterns associated with non-compliant resources. Natural language processing techniques can assist in interpreting governance documentation and translating organizational requirements into structured policy recommendations. The framework can classify detected violations according to severity, business impact, resource sensitivity, and potential security exposure. For example, publicly accessible storage resources, excessive identity permissions, missing encryption configurations, and unrestricted network access can be identified and prioritized for corrective action.

Automated remediation mechanisms can generate recommended configuration changes or execute approved corrective workflows through controlled deployment processes. However, AI-generated recommendations must be validated against established security policies to avoid incorrect modifications and unintended infrastructure disruptions. Human approval should remain necessary for high-risk changes involving production workloads, sensitive information, and critical business services. The discussion also highlights the importance of explainability, auditability, and continuous model evaluation. AI-based compliance systems should provide clear explanations of detected violations, supporting evidence, policy references, and recommended corrective actions. These capabilities improve transparency and help cloud administrators make informed governance decisions while reducing repetitive compliance activities.

The overall discussion demonstrates that combining Policy-as-Code, AI-based configuration analysis, and automated remediation creates a proactive governance model for enterprise cloud environments. Continuous policy enforcement helps organizations maintain configuration consistency across public, private, hybrid, and multi-cloud infrastructures. Integration with cloud-native monitoring and orchestration platforms enables governance policies to be evaluated throughout the infrastructure lifecycle rather than only during periodic audits. The framework also supports centralized reporting through compliance dashboards that provide visibility into policy violations, remediation status, configuration trends, and governance performance. Nevertheless, practical implementation involves several challenges, including policy conflicts, changing regulatory requirements, inconsistent cloud provider configurations, false-positive alerts, and the complexity of managing large policy repositories. These challenges require standardized policy definitions, version control, automated testing, exception management, and well-defined governance responsibilities. Security mechanisms such as role-based access control, encryption, secure policy repositories, and immutable audit records are essential for protecting governance operations. Furthermore, organizations should establish measurable evaluation criteria, including violation detection accuracy, policy enforcement time, remediation success rate, false-positive rate, and compliance coverage. Overall, the proposed framework offers a promising foundation for improving cloud governance through intelligent automation, continuous compliance validation, and consistent policy enforcement across enterprise infrastructure.

Conclusion

The proposed study presents a next-generation enterprise cloud governance framework that integrates Policy-as-Code and AI-based configuration compliance automation to strengthen security, reliability, and regulatory alignment across distributed cloud infrastructures. Traditional cloud governance approaches frequently depend on manual configuration reviews, periodic audits, and administrator-driven policy enforcement, which can introduce operational delays and inconsistent security practices. The proposed framework addresses these limitations by transforming organizational governance requirements into machine-readable policies that can be continuously evaluated and enforced throughout the cloud infrastructure lifecycle. Policy-as-Code provides a standardized mechanism for defining, testing, versioning, and implementing governance requirements, while artificial intelligence enhances the ability to identify configuration anomalies, recognize potential compliance violations, and prioritize corrective actions. The integration of these capabilities supports automated compliance validation during infrastructure provisioning, application deployment, and runtime operations. Furthermore, connecting governance mechanisms with Infrastructure-as-Code, CI/CD pipelines, and cloud monitoring

platforms enables organizations to incorporate compliance requirements directly into their development and operational workflows. The framework can evaluate critical configuration parameters involving identity management, network security, encryption, storage access, logging, and infrastructure resource allocation. This approach establishes a proactive governance environment that reduces dependence on manual intervention and improves visibility into enterprise cloud operations. It also supports consistent policy enforcement across heterogeneous cloud platforms and distributed organizational environments.

Furthermore, the study emphasizes that effective cloud governance requires a combination of intelligent automation, security controls, transparent decision-making, and human supervision. AI-based compliance analysis can improve the identification and classification of configuration risks, while automated remediation can help organizations respond to policy violations more efficiently. However, automated decisions must operate within clearly defined governance boundaries to prevent unauthorized changes and unintended operational consequences. Explainable AI, policy versioning, approval workflows, audit logging, and exception management are therefore important components of a reliable compliance automation framework. The integration of these mechanisms enables organizations to maintain accountability while benefiting from automated governance operations. Although challenges associated with cloud interoperability, policy complexity, model accuracy, and regulatory changes remain, they can be addressed through standardized policy management, continuous testing, and adaptive compliance monitoring. The proposed framework provides an architectural foundation for organizations seeking to modernize their cloud governance strategies and establish continuous compliance practices. Ultimately, combining Policy-as-Code with AI-driven configuration compliance automation can support secure, scalable, transparent, and efficient enterprise cloud management while improving organizational readiness for evolving digital governance requirements.

Future Work

Future research can enhance the proposed cloud governance framework by incorporating advanced artificial intelligence techniques for predictive compliance management and autonomous policy optimization. Current policy enforcement systems generally evaluate infrastructure configurations against predefined governance rules. Although this approach is effective for detecting known violations, it may have limitations when identifying emerging threats, complex configuration dependencies, and previously unseen compliance risks. Machine learning and deep learning techniques can be investigated to analyze historical infrastructure configurations, audit records, security alerts, and operational telemetry for predicting potential policy violations before they occur. Reinforcement learning could be employed to optimize policy enforcement strategies according to infrastructure conditions, organizational priorities, and changing security requirements. Generative AI and large language models could further support natural-language policy creation, policy documentation, compliance report generation, and automated interpretation of regulatory requirements. An intelligent governance assistant could allow administrators to describe organizational requirements in natural language and generate corresponding Policy-as-Code templates for validation. Multi-agent AI architectures could also be developed to distribute governance responsibilities among specialized agents responsible for identity compliance, network security, encryption validation, resource configuration, and regulatory monitoring. These agents could collaboratively identify policy conflicts, evaluate configuration dependencies, and recommend corrective actions. However,

future implementations should incorporate explainability, human approval, and controlled execution mechanisms to ensure that AI-generated policies remain accurate, secure, and aligned with organizational governance objectives.

Another important direction for future research involves extending the framework to support advanced multi-cloud governance, regulatory interoperability, and privacy-preserving compliance automation. Modern enterprises increasingly distribute applications and sensitive information across multiple cloud providers, hybrid infrastructure, and edge computing environments. Consequently, future implementations should investigate standardized policy models capable of maintaining consistent governance requirements across different cloud platforms. Integration with zero-trust security architectures, confidential computing, attribute-based access control, and automated identity governance could strengthen infrastructure protection. Future research may also explore blockchain-based audit mechanisms to establish tamper-evident records of policy modifications, compliance decisions, and remediation activities. Privacy-preserving machine learning techniques could support collaborative compliance analysis without requiring organizations to centralize sensitive operational information. In addition, research should focus on developing adaptive governance mechanisms that automatically incorporate changes in regulatory standards and organizational security requirements while maintaining backward compatibility with existing policies. Experimental evaluation should measure policy detection accuracy, false-positive and false-negative rates, compliance coverage, remediation time, enforcement overhead, scalability, and operational cost. Comparative studies involving manual audits, conventional policy engines, and AI-enhanced governance systems would provide a stronger understanding of the proposed framework's practical benefits. Finally, real-world implementation across banking, healthcare, manufacturing, retail, and government cloud environments could help identify domain-specific governance requirements. These developments may contribute to establishing intelligent, explainable, interoperable, and continuously adaptive enterprise cloud governance platforms capable of supporting future digital transformation initiatives.

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