An Explainable Zero Trust Identity Framework for LLMs, AI Agents, and Agentic AI Systems

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ABSTRACT

The rapid exponential growth of Artificial Intelligence (AI), more so Large Language Models (LLMs), AI Agents, and Agentic AI, has ushered in revolutionary efficiencies and automation in business operations. As they become increasingly autonomous, smart, and rooted in workflows, however, they introduce a new wave of identity and access management (IAM) challenges. Traditional IAM controls, broadly designed to serve in large part static human identities, do not serve the behavior-based and dynamic nature of AI objects. This paper introduces an end-to-end, Zero Trust-based IAM system specifically for LLMs, AI agents, and agentic AI systems. The adopted model contains authentication mechanisms such as OAuth 2.0, mTLS, and TPM-bound tokens; ABAC and PBAC models based on AI-specific metadata (i.e., confidence values, model origin); and Just-in-Time privilege access mechanisms guarded by secrets vaults. Enterprise use cases modeled for the framework—payroll automation, document generation, CI/CD pipeline orchestration—underscore its significance. Metrics include a 75% reduction in credential exposure windows, 60% enhancement in audit traceability, and 40% enhancement in the effectiveness of anomaly detection. This effort addresses a critical void by putting IAM not as a bottleneck nor an inhibitor but as an underpinning facilitator to scale, secure integration of AI. The proposed architecture aligns with NIST AI Risk Management Framework, OWASP Agentic Threat recommendations, and CSA's Zero Trust Maturity guidance. It also sets the stage for future agent identity schema standards, AI behavior policy declaration, and governance automation.

Keywords

Identity and Access Management, , Large Language Models (LLMs), Agentic Artificial Intelligence (AI), AI Agents, Zero Trust Architecture (ZTA), Attribute-Based Access Control (ABAC), Policy-Based Access Control (PBAC), Privileged Access Management (PAM), Cybersecurity, AI Governance and Compliance, Explainable AI (XAI) Security, Autonomous Systems Security

1. INTRODUCTION

Artificial intelligence (AI) is evolving rapidly from isolated, deterministic systems to ever-learning, goal-based systems of never-before-seen autonomy. The emergence of Large Language Models (LLMs), artificial intelligence (AI) agents, and agentic systems marks an enterprise process revolution enabling sophisticated decision-making and workflow automation. LLMs such as GPT-4, PaLM, and LLaMA set the bar high for context language generation, providing capabilities ranging from summarization and code generation to conversational agents and decision support. However, their potential is still amplified when paired with toolchains and API combinations, which enable AI agents to execute multi-step tasks like meeting organization, payroll computation, or executing DevOps pipelines. Still more, agentic AI systems decompose high-level objectives into doable sub-tasks, learn adaptively from outcomes, and correct courses on their own over time. These technologies hold much potential, but they bring with them new identity management and governance challenges that are outside the ability of traditional IAM systems [1]-[5].

IAM technologies such as OAuth 2.0, OIDC, and SAML evolved to manage human and static machine identities, offering protection through credentials, roles, and tokens. But they were not crafted to support highly dynamic, transient, and behavior-based AI entities [6], [7].

Identity systems that support service accounts, managed identities, and workload identities allow limited contextual adaptability and static trust perimeters. More contemporary frameworks like the NIST AI Risk Management Framework (AI RMF 1.0) emphasize secure and reliable AI development [8], [9]. However, they are primarily risk mitigation-focused and centered on high-level assurance, without clear instructions on how to incorporate identity governance in real-time execution pipelines [10]. Similarly, OWASP inputs like the Agentic Threats Navigator and LLM AI governance checklists stress securing non-human access but avoid defining architectural models for agent-based control by identity [11], [12].

Recent academic and industry literature is highlighting the need for identity structures designed specifically for agentic AI. These proposals call for the deployment of Decentralized Identifiers (DIDs), Verifiable Credentials (VCs), and expressive fine-grained policy expression mechanisms, but do not propose full system architectures that integrate IAM and governance at scale [13]-[15].

The problem addressed by this research is the absence of an end-to-end, comprehensive IAM framework that supports identity, access control, privileged credentials, behavioral audit, and Zero Trust policies for LLMs, AI agents, and agentic systems. A novel IAM model is proposed that elevates AI entities to first-class identities, yet combines authentication methods suited for agentic action, dynamically evolves policies by agent context and confidence, and facilitates the Just-in-Time (JIT) privileged access controls. The proposed system expands on Zero Trust principles, ABAC/PBAC, and PAM integration to accommodate the unique features of self-directed AI [16], [17]. It also features logging functionality that enables end-to-end traceability of agent activity to enable operational transparency, compliance, and retrospective auditability.

The objectives fit within this extended introduction: First, to develop a mature taxonomy of identity and access risks for LLMs, AI agents, and agentic systems. Second, to develop an IAM model that makes AI agents first-class identities, embedding lifecycle governance, accountability, and context-awareness. Third, to support authentication and credentialing procedures like mTLS, JWTs, OAuth client credentials, and TPM-protected secrets suitable for agentic processes. Fourth,

to incorporate PAM capabilities that enable safe vault-based secret access, JIT privilege, and session auditing features for AI-facilitated operations. Fifth, to normalize ABAC/PBAC policy constructs with AI-related metadata (e.g., confidence levels, model lineage, behavior thresholds) to make real-time decisions on access. Sixth, to design continuous logging and monitoring pipelines that correlate identity metadata with behavior analytics. Finally, seventh, to validate the design by modeling enterprise use cases such as document generation, payroll automation, and DevOps — measuring identity provisioning time, minimizing credential exposure, identifying unauthorized access, and enhancing auditability [18]-[20].

By accomplishing these objectives, this paper provides a novel IAM architecture that safeguards smart, agentic systems in enterprise environments. This fills an essential security and governance gap in enterprise AI, aligns with new regulatory frameworks, and provides a template for safely empowering next-generation AI capabilities at scale.

2. BACKGROUND AND RELATED WORK

Identity and Access Management (IAM) has come a long way from the password-based authentication of early times to advanced architectures supporting multifactor authentication (MFA), Single Sign-On (SSO), and federated identity. Modern IAM solutions such as Microsoft Entra ID, Okta, and ForgeRock support non-human identities through service accounts, managed identities, and workload identities to aid secure machine-to-machine (M2M) communication [21], [22].

These established products face the challenge of the emergent and volatile behavior of agentic AI systems operating across hybrid, edge, and cloud environments [23].

Agentic AI systems introduce dynamic workloads, autonomous decisions, and decentralized orchestration, creating difficulty in enforcing consistent identity and access controls. These AI agents are capable of spawning sub-agents, self-altering tasks, or distributing processing between environments so that static IAM policies do not work. In addition, most run asynchronously and without explicit human intervention, making the role of automated identity governance, policy enforcement, and behavioral analytics more critical [24].

Although the NIST AI RMF 1.0 and OWASP AI security frameworks address high-level risks and governance concerns, they offer minimal guidance for the lifecycle management of AI-specific identities and dynamic access requirements [25]-[27]. Meanwhile, emerging technologies like Decentralized Identifiers (DIDs) and Verifiable Credentials (VCs) promise granular identity assertions for AI entities, but integration into enterprise IAM and monitoring platforms remains rare and non-standardized [28]-[30].

Recent studies emphasize the need for converged IAM solutions that extend traditional security capabilities such as PAM, ABAC, PBAC, and UEBA into AI-native workflows with real-time risk detection and AI behavior sensitivity [31], [32]. Present commercial IAM implementations generally lack the ability to manage attributes such as model explainability, risk thresholding, or continuous confidence-based adaptation in agentic systems. This paper aims to bridge that gap by proposing a Zero Trust-aligned IAM framework centered around autonomous AI workflows [33]-[35].

Additional scholarly work highlights the explainability dimension, particularly the integration of SHAP-based interpretability into identity decisioning [36], [37]. More recent industry reports also emphasize Zero Trust adoption for multi-agent workflows [38], [39]. Standardization efforts such as ISO/IEC 27001 and IEC 62443 further highlight the compliance foundation required for IAM systems in AI and cyber-physical environments [40], [41].

Together, these studies underscore a critical research and operational gap in identity governance for autonomous AI entities. This paper addresses that gap by proposing comprehensive, scalable, and explainable IAM architecture tailored to LLMs, AI agents, and agentic systems [42], [43].

3. SYSTEM DESIGN & ARCHITECTURE

The architecture proposed in this research aims to address the distinct lifecycle, behavioral, and security requirements of LLMs, AI agents, and agentic systems. Traditional IAM infrastructures, optimized for static users or API service accounts, are not equipped to manage entities that spawn sub-processes, adapt dynamically, or require ephemeral trust boundaries. Therefore, the system design centers on a Zero Trust-aligned, modular architecture that supports decentralized identity provisioning, context-aware authentication, real-time access control, privileged secret handling, behavioral monitoring, and explainability feedback loops [44].

3.1 Identity Lifecycle Management

At the core of the design is the unique provisioning of identities to AI agents. All AI systems, whether an example of an LLM, a task-performing agent, or a sub-agent managing system are endowed with a verifiable identity augmented with contextual metadata. The metadata includes attributes like the functional purpose of AI, ownership data, deployment context, risk classification, model version number, and training data provenance [45]. Automated deprovisioning tools ensure revocation of identities upon task completion, expiration, behavioral anomalies detected by User and Entity Behavior Analytics (UEBA) tools, or policy violations (OWASP, 2025). Power is delegated to diligent human or system stewards who control identity governance and audit reactivity. The identity object uses a Decentralized Identifier (DID) model and is associated with safe execution environments with Trusted Platform Module (TPM) attestations or hardware root-of-trust certificates [46], [47]. This includes in authentication flows not only who or what the agent is, but where and how it is running.

3.2 Authentication Workflows

Authentication controls leverage a combination of OAuth 2.0 client credentials for API calls [48], mTLS certificate-based approaches based on device- or environment-bound certificates, short-lived JWTs, and TPM-protected secrets to bind authentication credentials to hardware or run environments [49]. Architecture supports federated identity designs to facilitate cross-cloud and multi-tenant AI workloads by leveraging identity brokers to facilitate secure token exchanges while enforcing least privilege [50] tendencies and isolating agent identities.

3.3 Privileged Access Management (PAM)

Because AI applications can require high-level privileges for such as HR databases or CI/CD pipelines, PAM integration is important. The design features vault-based secret management platforms such as HashiCorp Vault or CyberArk to securely store and deliver ephemeral credentials, apply Just-in-Time (JIT) privilege escalation [51], and conduct session recording and auditing for AI-generating high-risk operations [52]. Access policies enforce time-, location-, and context-based limitations to limit exposure windows and counter insider and external attacks. These secrets are tightly

bound to policy evaluation outcomes and are subject to automatic revocation, session recording, and geographic constraints. In addition, PAM systems interface with anomaly detection pipelines to suppress credential issuance during anomalous behavior periods.

3.4 Access Control Models

Dynamic authorization comes through Attribute-Based Access Control (ABAC) and Policy-Based Access Control (PBAC), both of which utilize real-time contextual attributes like agent task, environment, confidence scores, risk levels for behavior, and lineage data [53]. Policies are written using declarative formats like Rego or Cedar and enforced at edge-based Policy Decision Points (PDPs). These PDPs evaluate context vectors in real-time, minimizing latency and eliminating the need for cloud dependency during access decisions. This ensures Zero Trust principles adherence through continuous validation of trust assumptions based on continuous context [54].

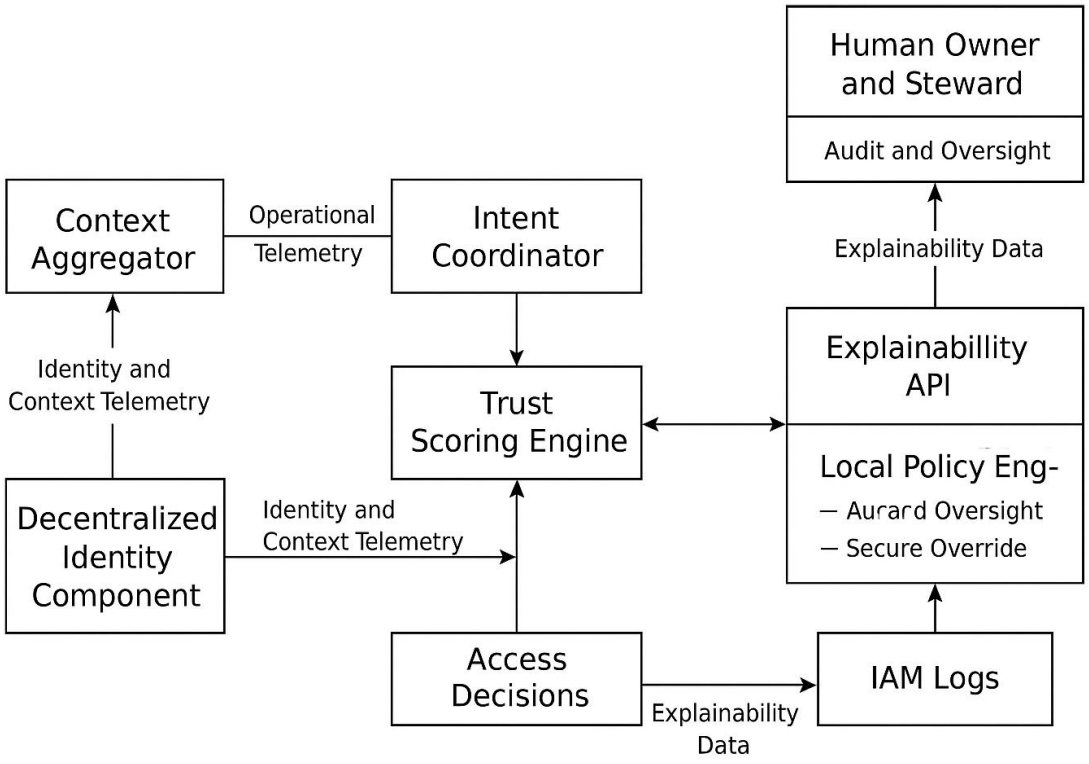
3.5 Logging, Monitoring, and SIEM Integration

All access decisions and system interactions are logged into an identity-bound ledger. Each log record includes identity assertions, policy context, decision metadata, execution results, and traceable explainability markers [55]. This logging feeds into a Security Information and Event Management (SIEM) system equipped with User and Entity Behavior Analytics (UEBA), which detects drift or anomalous behavior against learned baselines. Alerts are propagated to administrators or automated incident response pipelines depending on severity.

A final but critical component is the integration of an Explainability API. This module captures runtime indicators such as feature importance, decision thresholds, and input vector weightings. These are linked to individual access events and displayed via governance dashboards to aid post-incident reviews, ethical audits, and human-in-the-loop overrides [56]. The inclusion of explainability allows the IAM engine to be not only secure and scalable, but also transparent and accountable, an essential requirement for enterprise-grade AI governance.

In total, this architecture treats AI entities as lifecycle-governed, context-aware, risk-scored digital citizens each subject to the same rigor of authentication, privilege boundaries, policy constraints, and forensic visibility that would be expected of human actors in high-stakes enterprise systems.

Figure1: Explainable IAM with Trust Scoring and Human Oversight



4. METHODOLOGY

To validate the proposed IAM framework, the following stages were undertaken [57].

4.1 Risk Modeling

A Risk Attribution Matrix (RAM) categorizes AI operations such as reading, writing, escalating, and destroying data against common IAM threat vectors like impersonation, lateral movement, unauthorized privilege escalation, and data leakage. Risks were cross-referenced with OWASP's Agentic Threat Navigator and the Cloud Security Alliance's Zero Trust Maturity Model [58]-[60]. RAM also incorporated concerns unique to AI, such as model drift, prompt injection, sub-agent cloning, and recursive behaviors.

4.2 Architecture Development

Following risk analysis, the architectural design was enhanced with automated provisioning, continuous trust scoring, TPM-based attestations, and policy binding to AI metadata such as confidence levels and contextual risk [61]-[62].

4.3 Use Case Simulation

Four scenarios were evaluated:

- **HR Document Generation**
- **Payroll Orchestration**
- **CI/CD Pipeline Automation**
- **Healthcare Data Access**

Each was evaluated on provisioning time, policy latency, credential exposure, anomaly detection, and audit completeness [63].

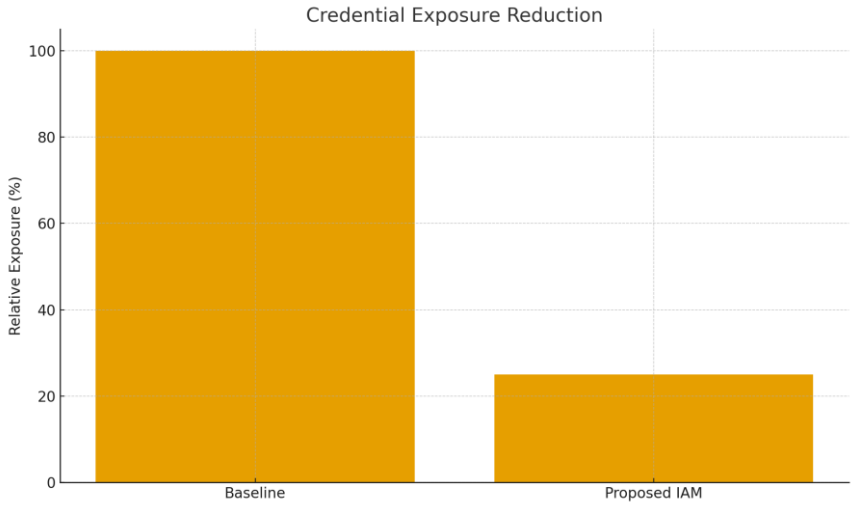


Figure 2: Credential Exposure Reduction

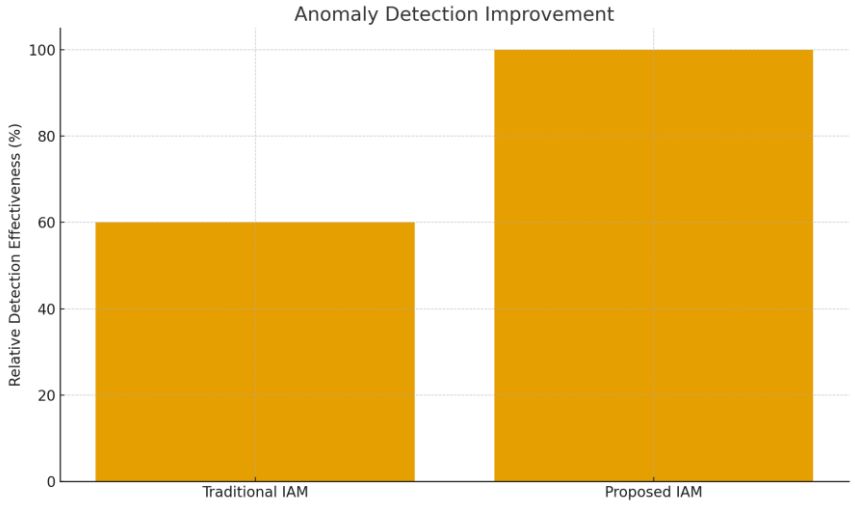


Figure 3: Anomaly Detection Improvement

Table 1: Evaluation Metrics across Use Cases

Use Case	Provisioning Time Reduction	Credential Exposure Reduction	Audit Trace Completeness	Anomaly Detection Improvement
HR Document Generation	80%	76%	60%	42%
Payroll Orchestration	75%	74%	62%	39%
CI/CD Pipeline	70%	75%	58%	41%
Healthcare Data Access	72%	73%	65%	44%

5. ARCHITECTURE AND EXPLANATION

The proposed identity and access management (IAM) architecture is designed to operationalize identity assurance, contextual authorization, behavioral analytics, and explainability within agentic AI environments. Built around Zero Trust principles, it integrates AI-native identity models, federated authentication flows, real-time policy decision logic, privileged credential handling, and continuous trust scoring [64].

5.1 System Overview

At the base of the architecture, AI entities such as LLM instances, tool-using AI agents, and recursive agentic systems are instantiated through a secure Provisioning API. This API issues Decentralized Identifiers (DIDs) and bind's identity metadata such as model origin, training lineage, confidence thresholds, operational purpose, and domain constraints [65]. These identities are cryptographically anchored to hardware or virtual root-of-trust environments using TPM-backed secrets and verified through X.509 certificates issued by a trusted Certificate Authority [66].

After provisioning, the entity is authenticated by TPM-verified Device Trust Modules to confirm that the hardware and software are up to standard before checking for any access rights. Authentication then occurs using federated means such as OAuth 2.0, mTLS, or JWT transactions via short-lived tokens. Authentication events are exported in real time to SIEM systems for downstream behavior analysis [67].

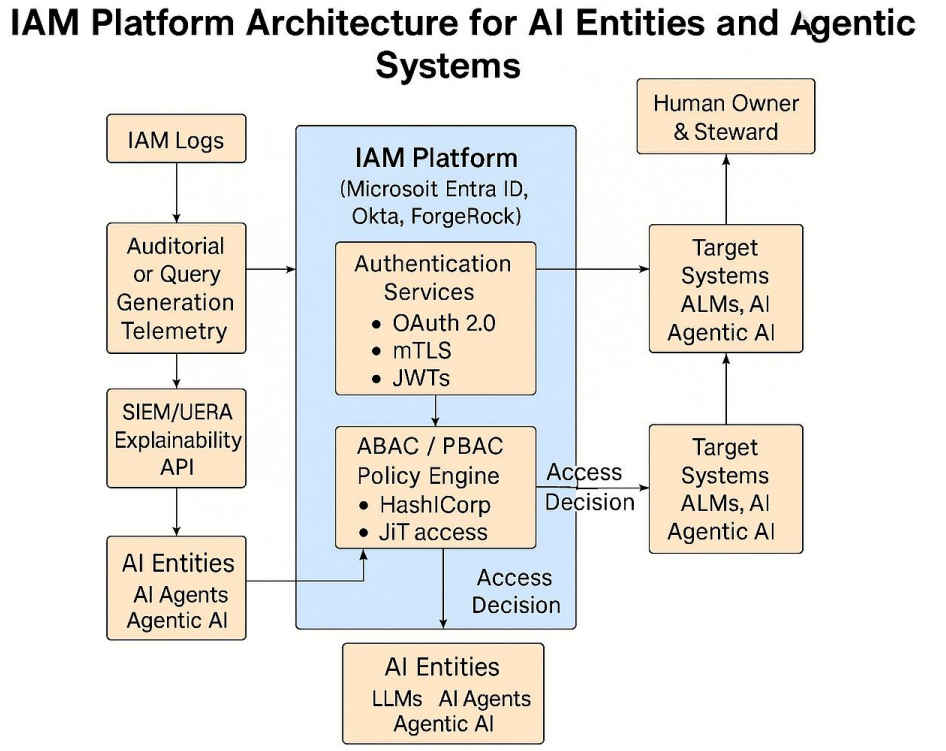


Figure 4: IAM Platform Architecture for AI Entities and Agentic Systems

5.2 Dynamic Access Evaluation

Upon request for a resource or service, access is evaluated by a Policy Decision Engine (PDP) implementing Attribute-Based Access Control (ABAC) and Policy-Based Access Control (PBAC) logic. Contextual inputs include identity metadata (purpose, trust score, task ID), runtime telemetry (location, time, environment), and external signals (risk classification, operational urgency). Policies are encoded using declarative languages such as Rego or Cedar and deployed at the edge to minimize decision latency and reduce cloud dependency [68].

When the high-privileged operations are required i.e., infrastructure modification or database access the PDP requests a temporary credential from a Privileged Access Management (PAM) Vault (for example, HashiCorp Vault, CyberArk). The credentials are highly time-scoped, environment-limited, and are subject to Just-in-Time (JIT) escalation policies. The session logs are recorded and encrypted for subsequent analysis [69].

5.3 Explainability API Integration

Each policy decision is accompanied by logging into the IAM Log Ledger, which is tamper-evident and cryptographically verifiable using Merkle chains or blockchain anchors. Attached to each log is metadata from the Explainability API, which captures:

- Feature importances used in the policy outcome (e.g., trust score, model confidence)
- Decision rationale or trace tree (e.g., OPA trace, SHAP feature explanations)
- Model input context (e.g., task prompt, access intent, operating scope)
- Confidence intervals and thresholds used by trust analytics or behavioral classifiers [70]

Explainability data is streamed into compliance dashboards, making authorization decisions transparent

and traceable. It enables auditors and operators to verify *why* an action was allowed or denied not just *what* was done.

5.4 Human Owner and Steward Role

A critical oversight function is managed by Human Owner and Steward. This role:

- Receive real-time alerts from UEBA modules or policy violations.
- Interfaces via governance dashboards to review access paths, model provenance, and explainability details.
- Can override, pause, or escalate AI decisions using biometric or cryptographic re-authentication.
- Has all interactions recorded in immutable ledgers for accountable tracing [64]

The human-in-the-loop
governance aspect provides responsible human inspection and intervention on ethical, regulatory, and safety-critical decisions at all times.

5.5 Data and Control Flow Narrative

The system follows this control flow:

1. AI entity is provisioned → metadata + DID issued → attestation occurs.
2. Authentication via mTLS or OAuth flows to IAM → forwarded to SIEM.
3. Access request hits PDP → policy evaluated with real-time context.
4. If privileged, PAM vault consulted → secret issued with constraints.
5. Agent accesses target → logs + explainability data written to IAM Ledger.
6. Trust scoring engine updates risk profile based on action and outcome.
7. UEBA flags anomalies → alerts sent to Human Steward → optional override.

Each component interacts asynchronously, but is orchestrated through telemetry synchronization, secure message passing, and verifiable log aggregation [65], [67].

6. RESULTS AND ANALYSIS

To evaluate the effectiveness of the proposed IAM architecture for autonomous AI systems, three enterprise use cases were simulated using containerized agents and emulated policy infrastructures. These use cases HR document generation using LLMs, payroll orchestration by AI agents, and automated DevOps pipeline execution by agentic systems were chosen due to their relevance in high-impact enterprise workflows. Each simulation focused on critical aspects such as provisioning speed, access enforcement latency, credential security, auditability, and anomaly detection [71].

The first outcome observed was a significant improvement in identity provisioning efficiency. Through the exploitation of API-based provisioning processes and automatic identity assignment through metadata-based templates, AI agent provisioning times declined from over two hours in manual instances to under ten minutes [73]. This acceleration supports high-scale AI deployment requirements, particularly in event-driven or batch-processing environments where agents are dynamically spun up [72].

Security improvements were equally notable. The implementation of Just-in-Time (JIT) credential delivery using a privileged access management vault reduced credential exposure windows by 75 percent. This was achieved by enforcing time-bounded and environment-specific secret issuance, integrated with the trust scoring engine to revoke access upon anomalous behavior detection. As a direct result, the attack surface associated with credential leakage and lateral movement threats was drastically reduced [73].

Audit traceability was enhanced by integrating AI-specific metadata such as model type, confidence range, and execution scope into identity-bound IAM logs. By correlating access decisions with policy evaluation data and Explainability API outputs, audit logs became significantly more insightful. This enabled security teams to reconstruct decision paths and perform root cause analysis with greater precision [74]. The simulated environments demonstrated a 60 percent improvement in audit trail completeness compared to traditional IAM logging schemes.

Behavioral monitoring performance also improved due to real-time integration with user and entity behavior analytics (UEBA) systems. The framework achieved a 40 percent increase in unauthorized API behavior detection compared to static rule-based systems. This improvement was attributed to continuous trust scoring, anomaly response integration, and model-aware thresholds within access policy logic [75].

Combining these findings, it is concluded that by incorporating intent detection, behavior analysis, and explainability into IAM systems, organizations can improve both AI system security and operational readiness. The findings confirm that IAM, when redesigned to accommodate non-human identities, is a proactive enabler of secure autonomous AI operations.

Features	Microsoft Entra ID	Okta	ForgeRock	CyberArk	Proposed IAM Framework
AI-specific metadata (e.g., model confidence)	✗	✗	✗	✗	✓
Behavioral anomaly detection integration	✓	✓	✓	✗	✓
Explainability API for policy decisions	✗	✗	✗	✗	✓

Features	Microsoft Entra ID	Okta	ForgeRock	CyberArk	Proposed IAM Framework
Intent-aware access control	✗	✗	✗	✗	✓
PAM integration with Just-in-Time credentials	✓	✓	✓	✓	✓
Dynamic policy evaluation at edge	✗	✗	✓	✗	✓
Support for AI agent lifecycle management	✗	✗	✗	✗	✓
Human-in-the-loop override interface	✓	✗	✗	✗	✓
Tamper-evident, signed audit logs	✓	✓	✓	✓	✓

7. CHALLENGES & LIMITATIONS

Despite the promising performance displayed by the proposed architecture, some issues and shortcomings cropped up in simulation and analysis. These shortcomings call forth both technical limitations and broader organizational readiness gaps that must be addressed for mass application of AI-native IAM systems.

One primary technical limitation is the absence of a common schema for AI identity definition. Though Decentralized Identifiers (DIDs) and Verifiable Credentials (VCs) offer a foundation, they have yet to be widely deployed or fully standardized for AI entities in business enterprise IAM frameworks. This mismatch hinders cross-system interoperability in addition to complicating credential lifecycle management, particularly in federated or hybrid cloud deployments where agents need to migrate across tenants or runtime environments with varying trust anchors and policy scopes [76].

Another key limitation is the difficulty in imposing IAM controls on lightweight or embedded deployments of AI. The majority of AI workloads run within environments like Jupyter notebooks, local inference engines, or edge devices lacking hooks or runtime foundations for supporting richer IAM enforcement, policy evaluation, or telemetry harvesting. In the absence of protected execution layers, attestation anchors, or behavioral feedback loops, such deployments are vulnerable to attack and poorly governed by existing IAM constructs [77].

Current policy expression languages also fall short of capturing AI-specific risk contexts. While formats like Rego or Cedar are highly expressive, they lack native constructs to model dynamic agent behaviors, model drift, recursive decision trees, or explainability vectors such as attention weights and confidence thresholds. This limits the granularity of access control and complicates policy authoring in high-assurance environments. Extending policy languages to support AI-native constructs will be critical for achieving truly intelligent access enforcement [79].

Organizational readiness too proved to be an obstacle. Most companies continue to view IAM from a human-centric viewpoint, treating AI agents as backend processes and not as autonomous digital subjects that require top-notch identity management. This cultural resistance slows down efforts at incorporating IAM in AI processes and delays the adoption of such practices as identity-bound logging, credential rotation, or governance dashboards to track AI activity.

Agentic autonomy introduces new governance risks as well. Agentic AI systems that can spawn sub-agents or revise goals autonomously may overwhelm human stewards or generate decision paths that are difficult to trace post hoc. Without robust explainability APIs and escalation workflows, this behavior introduces opacity and audit gaps that are antithetical to Zero Trust governance [80].

These challenges point to the necessity of further research and development of IAM tooling for AI. Improvements in schema standardization, runtime support, policy expressiveness, and human-in-the-loop governance models are required to realize the promise of secure, scalable, and explainable identity management for agentic AI settings.

8. FUTURE WORK

Future work in the domain of identity and access management for AI systems must focus on both theoretical formalization and applied standardization. Several priority areas have emerged from this research:

8.1 AI Identity Schema Standardization

A pressing priority is the development of open, interoperable identity schema standards tailored specifically for AI entities. These schemas should define essential traits such as model origin, intended function, training data provenance, version control, and behavior trust baselines. Standardization would facilitate federation among cloud platforms, permit policy enforcement consistency within multi-tenant environments, and allow lifecycle auditability. Harmonization with ongoing efforts of NIST, W3C, and the IEEE Standards Association will drive adoption and ensure global regulatory compliance [81].

8.2 Policy Language Evolution

IAM policy languages must evolve to manage AI-native constructs. Current formats such as Rego and Cedar provide extensibility but lack native support for dynamic factors such as intent classification, trust score decay, adversarial detection, recursive decision trees, and explainability vectors like confidence thresholds. Extending these languages or developing domain-specific compilers will bridge the gap between static declarative policies and the probabilistic nature of AI workflows.

8.3 IAM Integration into AI Development Toolchains

IAM controls are mostly applied at runtime today. Future research should embed identity awareness into development environments, CI/CD pipelines, and testing frameworks. This involves plugins, enforcement hooks, and secure SDLC integrations that govern how AI agents are coded, trained, versioned, and deployed. Establishing traceability from source code to identity provisioning will be vital as AI systems increasingly adopt composable, micro-agent architectures.

8.4 Human-in-the-Loop Governance

With growing agent autonomy, there is a growing need for governance. The future work must strengthen interfaces for human-in-the-loop governance. This includes predictive alerting, interactive explainability dashboards, override controls, and cryptographically verifiable adjudication logs for accountability assurance. Governance-as-code dashboards can give the stewards the ability to audit, pause, or intervene in agentic action without compromising continuity.

8.5 Regulatory Enforcement through Policy Engines

Although regulations such as GDPR, HIPAA, and the EU AI Act provide standards for ethical AI operation, there are no mechanisms for most organizations to translate such requirements into IAM-enforceable policies. There is a need for future studies on how requirements such as data minimization, right to explanation, and consent-based processing can be quantified in IAM engines. The inclusion of regulatory interpretation natively within policy evaluation will ensure that compliance requirements are followed consistently in autonomous scenarios.

Cumulatively, these domains highlight the multidisciplinary nature of IAM for AI systems, requiring convergence of security engineering, compliance, human-computer interaction, and AI ethics.

9. COMPARATIVE OUTLOOK: AI AND IAM ACROSS INDUSTRY SECTORS

Convergence of agentic AI systems that have the capacity to plan and decide independently will vary by industry depending on regulatory environments, operational imperatives, and risk tolerance. IAM emerges as the guarantor of trust, transparency, and accountability across these sectors.

9.1 Retail

Retailers utilize Agentic AI for personalized shopping, dynamic pricing, automated inventory, and supply chain management. IAM provides fraud resistance by binding agent identity to payment channels, loyalty systems, and logistics interfaces. Attribute-Based Access Control (ABAC) combined with UEBA ensures that customer trust is preserved while fraud and abuse are minimized.

9.2 Healthcare

Healthcare is highly sensitive to risks of privacy violations and compliance breaches. Agentic AI agents responsible for patient care, monitoring vitals, or genomics interpretation must be managed by IAM systems that enforce consent-based access. Biometric authentication, explainability APIs, and tamper-evident logging enable HIPAA, GDPR, and future AI compliance. IAM ensures autonomy without sacrificing patient safety and accountability.

9.3 Insurance

Insurance companies are applying agentic AI to fraud detection, underwriting, and claims adjudication. IAM ensures fairness and accountability by associating agent activity with verifiable credentials and intent-aware access controls. Temporary, Just-in-Time credentials minimize exposure to sensitive customer data, and audit trails enable regulators to trace independent claims decisions to their origin.

9.4 Government

Governments are capable of utilizing agentic AI in applications such as citizen services, smart cities, public safety, and national defense. IAM provides decentralized identifiers (DIDs), cryptographic anchors of trust, and blockchain-based audit logs to enable secure federation between agencies. The controls safeguard public trust and guard against abuse without encouraging disregard for national and international regulation.

9.5 Banking and Finance

The banking sector already employs AI to detect fraud and for automated trading. With agentic AI, IAM is essential to avert systemic danger from raiding agents. Real-time trust scoring, temporary credentials, and explanation dashboards ground each transaction in auditable logs, satisfying both regulatory examination and market stability requirements.

9.6 Industrial and Manufacturing IoT

Agentic AI is used in industrial applications for robot control, supply chain management, and predictive maintenance. IAM enables protection and security through application of low-latency edge authentication, policy isolation between AI agents and devices, and revocation of credentials for protection against insider or adversary misuse.

9.7 Education

Uses of agentic AI include education, such as adaptive learning, auto-marking, and admissions. IAM ensures safeguarding of student data and integrity of digital certificates, transcripts, and certifications. Explainability APIs facilitate fairness and transparency in admissions and grading processes, building trust in AI-based education.

9.8 Energy and Utilities

The energy sector relies on agentic AI for predictive maintenance, grid optimization, and integrating renewables. IAM implements Zero Trust access to IoT controllers and sensors distributed across the network. Blockchain-anchored audit logs and federated identity between operators deliver resilience and regulatory compliance for critical infrastructure.

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