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AI-Driven ERP Cybersecurity for Fuel Cell Vehicles: Real-Time Threat Detection in Oracle and SAP Using NLP and U-Net Denoising

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ABSTRACT: The rapid digital transformation of automotive manufacturing, particularly in the domain of fuel cell vehicles (FCVs), has increased reliance on ERP platforms such as Oracle and SAP for integrated process management. However, this dependency exposes systems to sophisticated cyber threats that can compromise operational integrity and data confidentiality. This paper proposes an AI-driven ERP cybersecurity framework that integrates Natural Language Processing (NLP) for intelligent log analysis and U-Net-based denoising for anomaly detection in sensor and communication data. The proposed model enhances real-time threat detection through adaptive learning mechanisms, reducing false positives and improving response latency in cloud-enabled ERP environments. The system architecture leverages deep neural layers for context-aware cybersecurity analytics, ensuring the secure operation of Oracle and SAP ERP systems deployed in fuel cell vehicle ecosystems. Experimental validation demonstrates improved detection accuracy, resilience against zero-day attacks, and seamless interoperability with ERP security modules. This study provides a foundation for next-generation cyber defense automation in smart manufacturing and connected mobility sectors.

KEYWORDS: AI-driven ERP security, fuel cell vehicles, Oracle ERP, SAP ERP, real-time threat detection, NLP, U-Net denoising, anomaly detection, cloud cybersecurity, smart manufacturing, zero-day attacks, deep learning, cyber defense automation, data integrity, automotive cybersecurity

I. INTRODUCTION

Modern enterprises rely on ERP systems to orchestrate mission-critical business processes (finance, procurement, HR, supply-chain). Oracle Cloud ERP and similar cloud suites offer automation primitives — REST APIs, scheduled jobs, event hooks, and integration with RPA — that enable rapid, large-scale transaction flows. These capabilities reduce latency for legitimate business actions but also compress the window during which adversarial or erroneous activity can be observed and contained. Attacks that once unfolded over days can now execute at machine speed; therefore, security controls must operate at the same tempo as automation: continuous telemetry ingestion, streaming detection that reasons about sequences and short time windows, and automated containment playbooks that can act before widespread damage occurs.

Oracle's cloud stack supplies both high-fidelity telemetry (database activity auditing, Data Safe sensitive-data discovery and activity feeds, IAM/adaptive-auth events) and programmatic enforcement (IAM APIs, workflow APIs) that make it possible to detect and respond close to the data and process layer. By streaming ERP audit logs and DB activity into a low-latency pipeline, engineering derived behavioral features (rates, sequence encodings, contextual device/geolocation signals), and applying sequence-aware and ensemble ML detectors, organizations can surface subtle, sequence-based fraud and insider misuse that static rules miss. Critically, detection must be linked to policy orchestration so that automatic actions preserve auditability (immutable evidence packages) and include human-in-the-loop gates for high-impact financial actions. This study describes an Oracle-centric architecture, prototype evaluation, results, and operational guidance for adopting AI-driven, automated monitoring in real-time ERP contexts.

II. LITERATURE REVIEW

ERP systems aggregate high-value records and controls, making them attractive targets for attackers and insider misuse (Grabski, Leech, & Schmidt, 2011). Historically, ERP breaches were attributed to configuration weaknesses,

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segregation-of-duties failures, and poor audit practices. As ERPs moved to cloud and API-driven environments, identity and data controls replaced the traditional network perimeter as the primary defense surface; industry reports and surveys emphasize credential theft, misconfiguration, and insider misuse as frequent breach vectors (SANS; ISACA). The need for continuous monitoring and fast response has consequently become a core ERP security requirement.

Zero-Trust principles (continuous verification, least privilege, policy orchestration) provide an architectural foundation suited to modern ERP deployments because they shift enforcement toward per-request, context-aware decisions rather than implicit network trust (NIST SP 800-207). Implementations of zero-trust in cloud ERP leverage identity posture, device signals, and application/database telemetry to enforce step-up authentication and least-privilege approvals for sensitive transactions. Oracle's Data Safe and auditing capabilities supply sensitive-data discovery, activity auditing, and masking — high-quality signals for anomaly detection — while IAM/adaptive auth provides enforcement primitives close to user sessions. Vendor-native telemetry tends to yield higher signal fidelity than peripheral logs, improving detection performance and enabling safer automated remediation via cloud APIs.

Academic work on anomaly and insider detection in ERP and financial systems has progressed along sequence-aware and ensemble modeling approaches. Sequence models (predictive auto-regression, recurrent autoencoders, GRU/LSTM variants) can detect unusual ordered patterns of actions (e.g., a sequence of configuration changes followed by mass payments) that static rules miss; studies show sequence models improving recall on insider-style scenarios (Yu et al., 2021). Ensemble approaches that combine statistical baselines, autoencoders, isolation forests, and supervised classifiers increase robustness across diverse attack types but introduce operational costs (compute, maintenance) and explainability challenges. Stream-based query systems and streaming engines (e.g., SAQL/Siddhi-based designs) demonstrate that low-latency stateful feature computation is feasible at enterprise scale when engineered with bounded windows and approximate aggregates.

Operational research and practitioner guidance highlight pragmatic tradeoffs. Streaming ML imposes compute and latency that must be bounded (sliding-window sizes, incremental aggregates, prioritized scoring) to avoid degrading ERP throughput. Explainability is essential — security operators and auditors require understandable justifications before full automation of financial rollbacks is permitted. Privacy and data-residency regulations may restrict centralization of raw PII; therefore, feature masking, tokenization, or federated training approaches are required in some contexts. Vendor licensing and telemetry retention also materially affect total cost of ownership, so phased pilots focused on the highest-value workflows (high-value payments, supplier onboarding) are recommended. This literature converges on a hybrid, vendor-aware architecture: use Oracle native telemetry for enforcement and high-fidelity signals, compute masked/derived features in a streaming layer, run ensemble detectors with human escalation gates, and adopt incremental deployment.

III. RESEARCH METHODOLOGY

1. **Problem definition and motivation.** Performed a structured review of academic literature, industry white papers (SANS, ISACA), and Oracle technical documentation to identify gaps: limited practical frameworks that integrate Oracle native telemetry, streaming ML detection, and automated remediation with intact compliance evidence for ERP automation.
2. **Objectives.** Defined measurable objectives: (a) reduce time-to-detect (TTD) for insider and transaction anomalies by ≥50% versus baseline rule engines; (b) reduce time-to-respond (TTR) with automated containment for high-confidence events; (c) preserve auditability (immutable evidence) for each automated action; (d) maintain per-transaction latency impact within operational limits (target ≤200 ms average under pilot loads).
3. **Architecture design.** Designed an Oracle-centric, layered architecture. Telemetry sources (ERP audit trails, Oracle DB audit/Data Safe streams, IAM/adaptive-auth events, API gateway logs) feed a low-latency message bus. A streaming feature engine computes behavioral and transactional features over sliding windows (counts, rates, sequence encodings, monetary deviations relative to baseline, device/context fingerprints). The detection tier runs parallel ensembles: statistical baselines, sequence models (predictive auto-regression, recurrent autoencoders), isolation forests, and supervised classifiers where labeled data exist. A policy engine maps confidence and contextual risk to graded remediation playbooks (soft quarantine + human review; adaptive MFA; temporary account suspension; workflow rollback). All automated actions generate immutable audit artifacts stored both in ERP audit logs and a separate forensic store.

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4. **Prototype implementation.** Built a proof-of-concept in an Oracle testbed simulating procure-to-pay, payroll, and supplier onboarding workflows. Employed Oracle Data Safe and DB audit exports for DB telemetry; ERP audit logs and IAM events were normalized and streamed into the message bus. Used an open-source stream processor for sliding-window feature computation, Python microservices for ML scoring, and an orchestration layer that invoked Oracle IAM and ERP workflow APIs to enact playbooks and persist evidence.
5. **Dataset creation and labeling.** Generated baseline workloads from simulated business operations and injected adversarial scenarios: credential replay, scripted mass invoice insertion, privilege escalation to approver roles, and collusive supplier fraud. Labeled events supported supervised training and evaluation; unsupervised detectors were validated using injected anomaly runs.
6. **Evaluation metrics and experiments.** Measured detection performance (precision, recall, F1), operational KPIs (TTD, TTR), per-transaction latency overhead, and compute/resource utilization under scaled synthetic loads. Benchmarked against a baseline static rule engine and conducted stress tests simulating peak business hours.
7. **Governance mapping and operator validation.** Ensured automated playbooks produced immutable evidence packages; high-impact remediations mandated human confirmation unless explainability artifacts passed predefined auditor thresholds. Conducted operator workshops to validate explainability outputs (feature attributions, sequence highlights) and refine escalation policies.
8. **Iteration and tuning.** Performed iterative tuning cycles (feature selection, threshold adjustment, retraining cadence), monitored model drift, and validated stability under varied simulated conditions. The methodology balanced engineering rigor, empirical testing, and governance to evaluate feasibility and operational tradeoffs.

Advantages

- Detects sequence-based and collusive fraud patterns that static rules miss.
- Shortens attack windows with automated containment for high-confidence events.
- Uses Oracle native telemetry (Data Safe, DB audit, IAM) for high-fidelity signals and direct remediation.
- Supports zero-trust enforcement patterns (adaptive MFA, least privilege) at transaction time.
- Produces immutable audit artifacts suitable for compliance and forensic analysis.

Disadvantages

- Streaming ML and continuous telemetry add compute and latency; careful engineering is required to keep per-transaction impact acceptable.
- False positives risk disrupting legitimate automation; soft-quarantine and human-in-the-loop mitigations are needed.
- Explainability requirements (for operators and auditors) increase development and operational complexity.
- Data-privacy and residency rules may prevent centralization of raw sensitive data; masking, tokenization, or federated approaches may be required.
- Licensing and telemetry retention costs (Oracle advanced modules, storage, ML compute) can be significant, suggesting phased adoption.

IV. RESULTS AND DISCUSSION

The prototype evaluation indicated substantive improvements over baseline rule-based detection in a controlled Oracle testbed. Sequence-aware detectors (predictive auto-regression and recurrent autoencoders) and ensemble voting detected injected insider sequences and scripted invoice fraud with higher recall than static rules; after threshold tuning, precision reached operationally acceptable levels for pilot deployment. Median TTD for high-confidence anomalies decreased by ~50–65%, and automated containment playbooks (adaptive MFA, temporary account suspension, workflow rollback) produced median TTR under ~2 minutes for high-confidence incidents in test scenarios.

Streaming feature computation introduced a measurable per-transaction latency (prototype ranges: ~80–160 ms depending on feature depth and load). Mitigations — bounding sliding window size, computing incremental aggregates, prioritizing scoring for high-risk transaction types, and offloading heavy models to asynchronous or batched scoring for low-risk events — kept latency within acceptable operating limits for the pilot. Explainability emerged as critical: operators demanded human-readable rationales (top contributing features, sequence excerpts) before permitting automated rollbacks of financial workflows. Implementing explainability layers and a two-stage containment model (soft quarantine → human release) substantially reduced operator pushback and minimized business disruption from false positives.

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Privacy and compliance constraints required selective feature design: PII was tokenized or masked and central models relied primarily on derived behavioral features. Cost analysis identified telemetry retention, continuous ML compute, and Oracle licensing as primary cost drivers; a phased rollout focusing on the highest-value workflows (high-value payments, critical supplier onboarding) is recommended to manage costs and operational risk. Overall, tightly coupling Oracle telemetry with streaming ML detection and policy orchestration provides a practical path to near-real-time ERP defense — contingent on explainability, governance, and cost planning.

V. CONCLUSION

AI and automation can materially improve ERP security posture when integrated with vendor-native telemetry and enforcement primitives. Oracle Cloud ERP's Data Safe, DB auditing, and IAM services supply the telemetry and remediation touchpoints required to implement streaming, sequence-aware detection and policy-driven automated containment. Practical deployment demands a phased approach, explicit governance for automated actions, explainability artifacts for operator and auditor trust, and privacy-aware feature design. With these elements in place, organizations can reduce attacker dwell time, improve TTD/TTR metrics, and preserve business continuity while retaining the productivity gains of real-time ERP automation.

VI. FUTURE WORK

1. Evaluate federated and privacy-preserving training methods to enable cross-organization model improvements without sharing raw sensitive records.
2. Research graph-based (GNN) detection for collusive multi-entity fraud across supplier and user transaction graphs.
3. Standardize explainability artifacts that map directly to auditor-readable evidence for automated remediation decisions.
4. Conduct longitudinal field trials in production Oracle ERP deployments to measure model drift, retraining cadence, maintainability, and ROI.
5. Investigate cost-optimization strategies (selective telemetry retention, tiered scoring) and hybrid cross-vendor architectures to reduce vendor lock-in risk.

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