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Conceptual Model for Raising Accounts Payable Accuracy Through Process Intelligence in Research Institutions

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Abstract

This paper presents a conceptual model for raising Accounts Payable (AP) accuracy in research institutions by embedding process intelligence across the procure-to-pay lifecycle. The model integrates process mining, rule-based controls, and machine-learning anomaly detection with grant compliance logic to reduce mismatches, duplicate payments, and breaches. It addresses the context of universities and research hospitals, where varied funding sources, sponsor terms, and decentralized purchasing create transaction patterns and compliance risk. The model positions AP as a data-driven assurance hub connecting principal investigators, central finance, and suppliers. The architecture has four layers: first, data acquisition that unifies ERP, e-procurement, and grant management logs via standardized event schemas; second, conformance engines encoding sponsor allowability, period of performance, three-way match, and delegation rules; third, analytics and prediction that combine process discovery, first-pass-yield forecasting, vendor normalization, and exception clustering; and fourth, workflow orchestration that returns prescriptive alerts to case managers and routes exceptions to approvers for timely resolution. Methodologically, the model adopts a design-science and DMAIC hybrid. Teams baseline cycle time, touchpoints, and first-pass accuracy; mine event logs to map as-is variants; prioritize failure modes through FMEA; implement targeted controls; and measure effects with interrupted time series and segmented regression. Data quality is elevated through master-data maintenance, vendor deduplication, and invoice OCR confidence thresholds with human-in-the-loop review. Expected outcomes include higher first-pass yield, fewer late-payment penalties, improved sponsor billing, and cleaner audit trails. Leading indicators exception rate, conformance score, and rework loops feed a control chart to sustain gains, while lagging indicators write-offs, questioned costs, and audit findings confirm risk reduction. The model also incorporates equity and accessibility by simplifying small-supplier onboarding and enabling transparent status notifications to reduce inquiry volume and payment anxiety. A change-management plan aligns incentives across finance, research administration, and procurement, with skills uplift delivered through training and playbooks. This conceptualization offers a scalable blueprint aligning AP accuracy with research integrity, stewardship of public funds, and overall operational resilience, enabling institutions to realize predictable, compliant payables operations and stronger supplier relationships.

Keywords: Accounts Payable Accuracy, Process Intelligence, Research Institutions, Process Mining, Continuous Controls Monitoring, Grant Compliance, First-Pass Yield, Duplicate Payment Detection, Conformance Checking, Audit Readiness

1. Introduction

This conceptual model proposes a structured, data-driven approach for raising accounts payable (AP) accuracy in research institutions by embedding process intelligence across the end-to-end procure-to-pay (P2P) lifecycle. Its purpose is to unify disparate data sources, standardize event logs, and continuously diagnose and prevent defects such as miscodings, duplicate payments, late postings, incorrect tax treatment, and sponsor-ineligible charges before they propagate into compliance issues or financial misstatements (Dako, *et al*., 2019, Onalaja, *et al*., 2019). The scope spans requisition, purchase order creation and change, goods/services receipt, invoice capture and three-way match, exception handling, approvals, payment execution, and

post-payment controls, with explicit coverage of sponsored project accounting, subaward/vendor management, and cross-border procurement nuances common to research settings (Olorunyomi, Adewale & Odonkor, 2022).

AP accuracy matters acutely in research institutions because external sponsors and regulators scrutinize allowability, allocability, and reasonableness at a granular transaction level. Vulnerabilities such as charging outside the period of performance, using incorrect object codes, or missing supporting documentation elevate audit findings, drive cost disallowances, and erode institutional credibility. Inaccurate AP also cascades into cash-flow volatility unplanned refunds, payment holds, and supplier disputes increasing days payable outstanding (DPO) variability, jeopardizing vendor relationships, and raising total cost of funding (Atere, Shobande & Toluwase, 2020, Farounbi, Ibrahim & Abdulsalam, 2020). Moreover, errors diminish the reliability of real-time budgets available to principal investigators (PIs), which can distort project burn rates and threaten timely completion of research aims. Against this backdrop, process intelligence offers a pragmatic route to tighten financial stewardship without adding manual burden: by mining event streams from ERP/eProcurement systems, OCR/IDP platforms, and ticketing tools, the institution can surface rule-based and pattern-based anomalies, quantify root causes, and automate targeted interventions (Ahmadu, *et al*., 2024, Farounbi, Oshomegie & Ogunsola, 2024, Omokhoa, *et al*., 2024).

The model's objectives are to materially reduce AP error rates and exception rework, improve first-pass yield of three-way matches, and increase on-time, accurate posting of sponsor-charged invoices within defined service-level agreements. Secondary objectives include shortening cycle time from invoice receipt to payment, lowering duplicate/overpayment incidence, enhancing documentation completeness at point of approval, and increasing the proportion of invoices automatically routed and cleared without human touch (Dako, *et al*., 2019). The guiding questions are: which process variants and control gaps most strongly predict AP inaccuracies on sponsored projects; what leading indicators (e.g., vendor risk signals, PO change-order density, free-text requisitions, attachment quality) forecast downstream exceptions; how can we align exception handling and approval pathways to risk rather than one-size-fits-all while preserving audit defensibility; what minimum data model and event-log standards enable cross-system traceability from requisition to payment; which interventions (policy edits, UI nudges, validation rules, worklist prioritization, vendor master hygiene) deliver the highest error-reduction per unit of effort; and how should continuous monitoring, feedback loops, and role-based dashboards be designed so PIs, department admins, central AP, and compliance can act quickly on the same, trusted signal (Ewim, *et al*., 2021, Farounbi & Ridwan Abdulsalam, 2021).

2.1 Methodology

The study adopts a design-science and quasi-experimental approach to raise accounts payable (AP) accuracy in research institutions by combining process intelligence, analytics, and automation within existing ERP and e-procurement ecosystems. We begin by integrating multi-source data: ERP/AP ledgers, purchase orders, goods-receipt logs, supplier master, grants management (allowability rules, period of performance, award terms), corporate card and travel systems, and ticketing/case tools. Each feed is mapped to a canonical voucher schema and supplier entities are deduplicated to eliminate shadow vendors and stale bank details; exchange-rate snapshots are captured to normalize foreign-currency invoices and to control FX-related mispostings. From these harmonized feeds we generate an event log with case IDs (voucher or PO), activities (create PO, receipt, service entry sheet, invoice received, three-way/two-way match, hold, approve, post, pay), timestamps, actors, and attributes (funding source, cost category, commodity code, PI/department, payment terms). Process mining then discovers actual AP pathways, variant frequencies, and conformance breaches against the target model, with specific attention to research-specific gates such as grant allowability, spend categories subject to prior approval, and period-of-performance cut-offs.

On the digital controls side, we encode a policy and conformance engine that evaluates each voucher against cost principles, sponsor-specific rules, tax/VAT requirements, segregation-of-duties constraints, and documentation completeness. Natural-language techniques are applied to OCR text and email threads to extract line-level descriptions, quantities, service dates, and ship-to/perform-at details; extraction confidence is logged so low-confidence fields automatically route to review. Analytical models focus on accuracy risks that drive disallowances and late close: duplicate invoice detection using fuzzy keys (supplier + amount + date ± tolerance, bank account IBAN, PO + line-total), vendor/bank changes with anomalous frequency, mismatched commodity–account combinations, service dates outside the period of performance, and suspicious split-billing patterns. Additional models predict first-pass-yield (FPY) at voucher creation using features such as PO coverage, receipt completeness, supplier error rate history, OCR confidence, line-item heterogeneity, and reviewer workload; low-FPY predictions are pre-emptively placed into a "pre-edit" lane for fast correction. Robotic process automation executes safe, repetitive actions with strong guardrails: pulling missing PO receipts, requesting corrected PDFs from suppliers via templated emails or chatbot, attaching award terms to cases, and posting clean vouchers in batches. High-risk exceptions are routed to a human-in-the-loop triage comprising AP analysts, research administrators, and PIs; each action writes a tamper-evident audit trail, and role-based access control enforces segregation between vendor maintenance, invoice entry, and payment release.

To quantify impact, we deploy a staged pilot-to-scale rollout across departments using an A/B or difference-in-differences design where one cluster adopts the full stack while matched controls retain baseline processing. Primary outcome metrics are AP accuracy (measured by FPY and proportion of vouchers requiring adjustment), questioned or disallowed costs on sponsored funds, duplicate/overpayment rate, cycle time from invoice receipt to post, exception aging, and month-end close duration. Secondary metrics include supplier response time, proportion of touchless vouchers, and reviewer workload distribution. A governance and model-risk-management layer defines change control for rules and models, periodic back-testing, drift monitoring on supplier and spend patterns, and explainability artifacts for auditors and sponsors. Dashboards provide near-real-time visibility by award, department, supplier, and

evaluator, while weekly control reviews evaluate top recurring defects and codify fixes into either deterministic rules (e.g., block list, mandatory fields, tighter tolerances) or retrained models with refreshed labels from recent adjudications.

The continuous-improvement loop operationalizes learning. Each exception outcome becomes training signal to refine anomaly thresholds and FPY predictors; conformance gaps revealed by process mining trigger upstream fixes such as PO policy changes, receipt discipline, and supplier enablement (updated invoice templates, structured e-invoicing, portal nudges). Where appropriate, blockchain-style immutable logs or e-signature attestations strengthen provenance of approvals and bank-detail changes. Digital twin simulations of AP workloads explore scenario impacts from policy tweaks (e.g., two-way vs three-way match thresholds, OCR confidence gates) on backlog, staffing, and cycle time before production changes. Benefit–cost tracking links automation hours saved, reduced rework, recovered duplicate payments, and avoided sponsor disallowances to financial statements. By institutionalizing these steps, the target state is a high-FPY, low-exception AP function aligned to research-sponsor requirements, delivering fewer errors, faster close, and stronger audit readiness.

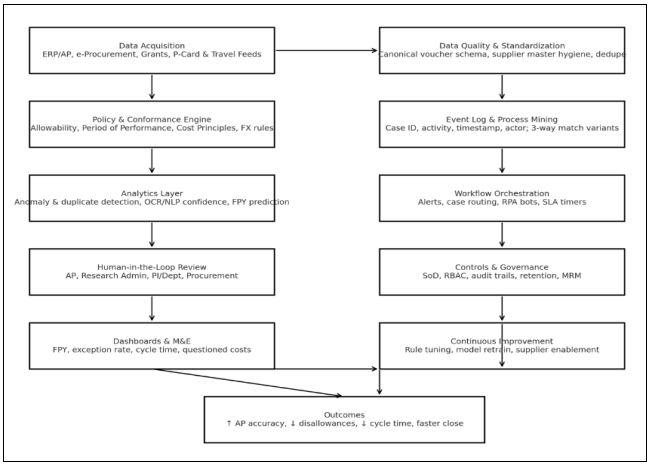

Fig 1: Flowchart of the study methodology

2.2 Institutional Context and Problem Definition

Research institutions operate within a uniquely demanding purchasing and payment environment where scientific urgency, diverse sponsor expectations, and academic decentralization intersect with strict financial stewardship. Grants, cooperative agreements, contracts, gifts, and internal funding each impose different cost principles, documentation thresholds, and audit trails, while the institution must consolidate them into a single procure to pay process. Principal investigators and lab managers initiate many purchases directly, often outside central finance offices, and they interact with suppliers of specialized goods and services that do not align neatly with standard catalog workflows (Bankole, *et al*., 2019). These conditions produce a high volume of low to medium value invoices with complex attributes such as cross border tax, hazardous materials surcharges, temperature controlled logistics, instrument calibration, software licenses, and subaward payments. Each attribute changes how allowability, timing, and supporting evidence should be assessed. Process intelligence becomes necessary because traditional controls that rely on sampling, manual approvals, and static policy memoranda cannot reliably prevent defects at scale when the pathway from requisition to payment varies widely by sponsor, department, and commodity (Osuji, Okafor & Dako, 2021).

Multi sponsor terms compound the challenge. A federal award will emphasize allowability, allocability to the project aims, reasonableness, and timing within the period of performance. A foundation grant may require explicit pre approvals for certain categories. An industry contract may build in milestone based invoicing with confidentiality clauses that limit document sharing. Cost sharing requirements add another dimension since the same invoice lines may be split across a grant, a departmental account, and an internal fund with different rules (Amini-Philips, Ibrahim & Eyinade, 2024, Oshomegie, Ogunsola & Farounbi, 2024). When a single vendor supplies both general and project specific items, the purchase order often contains mixed object codes and differing receiving instructions. These mixed terms increase the probability of posting to the wrong funding source, late adjustments, or cost transfers that invite scrutiny. Because sponsors audit at the transaction level, even a small rate of defects can cascade into questioned costs that erode credibility and consume staff time (Elumilade, *et al*., 2022, Eyinade, Amini-Philips & Ibrahim, 2022).

Decentralized requisitioning is a structural reality of research enterprises. Faculty and departmental administrators are empowered to move quickly to secure reagents, data subscriptions, equipment parts, or field services that can become gating items for experiments. They may use purchase orders, blanket orders, purchasing cards, or petty cash depending on urgency and vendor readiness. Decentralization supports scientific agility but introduces variability in how descriptions are written, how object codes are selected, whether quotes and sole source justifications are attached, and how receipts are recorded (Eziamaka, Odonkor & Akinsulire, 2024, Odonkor, Eziamaka & Akinsulire, 2024, Shittu, *et al*., 2024). Differences in local practice across schools and centers lead to divergent process variants that are invisible to central finance until exceptions appear. The lack of standardized event logs across requisitioning systems, e procurement catalogs, receiving modules, and accounts payable scanning solutions makes it difficult to reconstruct the true path of a transaction when something goes wrong. Process intelligence can address this by unifying clickstream and document events into a common reference timeline that resolves which human and system actions occurred, in what order, and with what data quality signals (Adewale, Olorunyomi & Odonkor2023, Farounbi, Okafor & Oguntegbe, 2023).

Baseline pain points begin with three way match failures. Quantity and unit of measure mismatches are frequent when scientific items are sold in kits or service hours, yet the purchase order was set up with a simplified quantity. Partial shipments and blanket orders result in receipts that are not recorded with enough detail to satisfy the match. Service receipts can be particularly vulnerable because the receiving step is a human attestation rather than a scanner based event, and staffing turnover in labs leads to sporadic completion (Abdulsalam, Farounbi & Ibrahim, 2021, Eyinade, Ezeilo & Ogundeji, 2021). Price mismatches arise when late change orders were not propagated to the invoice capture system. Freight and ancillary charges often appear on the invoice without a corresponding purchase order line, generating

exceptions that either require a manual ad hoc line or an off contract posting that breaks funding allocation rules. Each 3 way failure increases cycle time, consumes analyst effort, and raises the risk that a short paid invoice will damage vendor relationships needed for mission critical purchases. Figure 2 shows the conceptual framework presented by Osei-Assibey Bonsu, Wang & Guo, 2023.

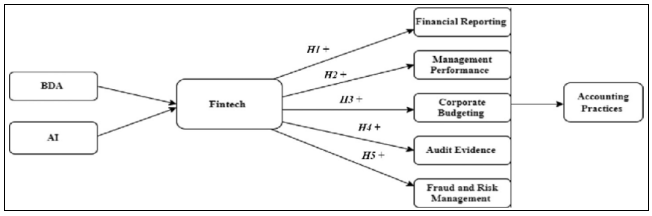

Fig 2: Conceptual framework (Osei-Assibey Bonsu, Wang & Guo, 2023)

Duplicate payments represent a second major pain point. Vendors may resubmit invoices through multiple channels when payment is delayed, such as email to a research unit and portal upload to the central team. Optical character recognition can misread invoice numbers with leading zeros or embedded slashes, causing the de duplication logic to miss exact matches (Amini-Philips, Ibrahim & Eyinade, 2023). Blanket orders and recurring service invoices create similar descriptions that pass naive duplicate checks. Credit memos and re bill invoices add complexity when they are not linked to the original transaction. Without event level lineage that ties scanned images, extracted fields, user edits, and approval actions to a single canonical invoice object, duplicate detection becomes a brittle process that relies on human vigilance (Farounbi, *et al*., 2018, Yetunde, Onyelucheya & Dako, 2018).

Allowability errors are more subtle and therefore dangerous. Expenses may be posted outside the period of performance because the scientific team ordered near the award end date and the supplier billed after the end date. Charges for entertainment, promotional items, or administrative salaries may be coded to grants that do not permit them. Foreign exchange and customs charges can be bundled into invoice totals without clear lines, leading to misclassification (Ibrahim, Amini-Philips & Eyinade, 2020, Oshomegie, Farounbi & Ibrahim, 2020). Software subscriptions raise concerns about license periods that extend beyond the project. Subawards introduce a separate layer of compliance in which invoices must be supported by technical progress and pass through terms. When allowability errors are found late, they force cost transfers that drain staff time and create audit exposure since repeated transfers suggest weak up front controls (Farounbi, Okafor & Oguntegbe, 2021, Omokhoa, *et al*., 2021).

Late accruals and cut off issues undermine both sponsor reporting and internal cash management. Goods received not invoiced balances may swell at month end because receiving has not been completed, or because invoices are stuck in exception queues with missing documentation. Some departments delay confirming service receipts until a PI returns from travel, which pushes recognition into the next period. Manual spreadsheets for uninvoiced liabilities are prone to omission and double counting (Oshomegie, 2018). Reversing accruals in the next period becomes error prone when the underlying invoice posts with a different amount or funding split. These dynamics distort burn rates that PIs rely on for planning, and they propagate inaccurate financial statements until the errors are cleaned up (Amini-Philips, Ibrahim & Eyinade, 2020).

Underlying all these pain points is data fragmentation. Supplier master records may have incomplete tax information, bank details, or diversity attributes. Chart of accounts and project attributes are not always synchronized between the grant management system and the enterprise resource planning platform. Invoice capture solutions vary in how they extract line level data, and they struggle with scientific invoices that use non standard terminology (Eyinade, Ezeilo & Ogundeji, 2021, Onyelucheya, *et al*., 2021, Tewogbade & Bankole, 2021). Approval hierarchies live in separate tools from ticketing systems used to collect missing attachments. Without a unified data model and event timeline, analytics teams cannot produce reliable leading indicators or intervention rules. Figure 3 shows system architecture presented by Tater, *et al*., 2022.

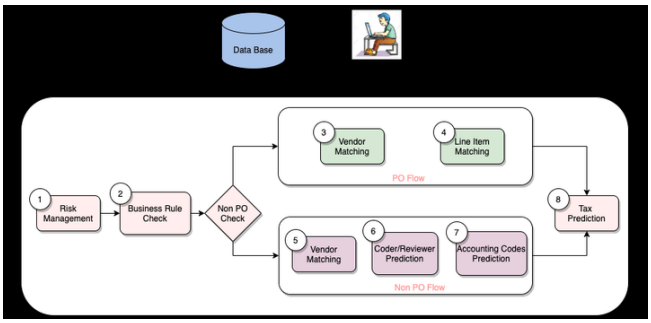

Fig 3: System architecture (Tater, *et al*., 2022)

The institutional problem definition therefore centers on how to raise AP accuracy by moving from reactive exception clearing to proactive detection and prevention based on process intelligence. The institution needs a canonical event model that spans requisition, purchase order, receiving, invoice capture, exception handling, approval, posting, and payment (Farounbi, Oshomegie & Ibrahim, 2022, Ogundeji, *et al*., 2022). It needs machine readable representations of sponsor terms and institutional policies that can be applied as validation rules at the moment of data entry and as monitors over live event streams. It needs to score invoices, vendors, and process variants for likelihood of 3 way failure, duplicate risk, allowability violation, and cut off breach, and then to route work to the smallest competent group with the right evidence requirements (Akinola, *et al*., 2024, Dako, *et al*., 2024, Olaogun, Amini-Philips & Ibrahim, 2024). It needs role based dashboards that give principal investigators, department administrators, AP analysts, and compliance officers a shared view of accuracy, cycle time, backlog, and risk at portfolio, department, and award levels.

Measurable baselines provide the starting point and anchor the business case. First pass match rate captures the proportion of invoices that clear automatically without human touch. Exception rate per thousand invoices quantifies the workload generated for analysts. Duplicate payment rate and recovery yield measure both control failure and remediation effectiveness. Average cycle time from invoice receipt to posting and from posting to payment addresses vendor relations and cash forecasting (Davidor, *et al*., 2022, Eyinade, Amini-Philips & Ibrahim, 2022). Proportion of invoices posted within sponsor service level

windows indicates compliance health. Percentage of invoices with complete documentation at approval time reflects the strength of front door controls. Late accrual rate and accuracy of accrual to invoice amount quantify financial close quality. By defining these metrics and connecting them to event level drivers, the institution can prioritize interventions and track progress (Olaogun, Amini-Philips & Ibrahim, 2024, Omokhoa, *et al*., 2024, Osuji, Dako & Okafor, 2024).

Finally, the problem statement must acknowledge the human and organizational dimensions. Decentralized requisitioning will remain, so success depends on designing unobtrusive validation rules and user interface nudges that improve data quality without slowing researchers. Vendor engagement is essential to improve invoice format consistency and to reduce channel duplication. Training programs for department staff should focus on interpreting sponsor terms at the point of entry rather than memorizing policy documents (Ogunsola, Oshomegie & Ibrahim, 2019). Process intelligence should be framed as a shared service that reduces rework and protects research time, not as a surveillance mechanism. When positioned this way, the model aligns academic agility with fiscal discipline and sets a realistic path to sustained accounts payable accuracy in complex research environments.

2.3 Conceptual Architecture

The conceptual architecture for raising accounts payable accuracy through process intelligence in research institutions is structured into four mutually reinforcing layers that together transform fragmented procure-to-pay activity into a governed, observable, and optimizable system. The data acquisition layer ingests and standardizes events from enterprise resource planning, e-procurement, grants management, and card programs. The policy and conformance engine codifies allowability, period of performance, and cost principle constraints into executable rules. The analytics layer applies process mining to reconstruct actual flows, and augments them with anomaly and duplicate detection to surface defects and leading indicators (Davidor, *et al*., 2022, Eyinade, Ezeilo & Ogundeji, 2022). The workflow orchestration layer operationalizes insights through alerts, case routing, and human-in-the-loop interventions that correct data, enrich documentation, and prevent recurrences. Designed as a loosely coupled architecture, each layer exposes APIs and event streams so new sponsors, systems, and rules can be added without destabilizing the whole.

At the foundation, the data acquisition layer builds a canonical event log across all purchasing and payment modalities. From the ERP, it captures vendor master changes, purchase order creation and change orders, goods receipt, invoice posting, accruals, and payments; from e-procurement, it ingests requisitions, catalog selections, approvals, and receiving confirmations; from the grants system, it retrieves award attributes such as sponsor, period of performance, cost sharing, budget categories, and approved rebudgeting; from card feeds, it takes transaction swipes, merchant category codes, split allocations, and receipt upload statuses (Eziamaka, Odonkor & Akinsulire, 2024, Odonkor, Eziamaka & Akinsulire, 2024). Each source is mapped to a shared schema with persistent, privacy-safe identifiers for supplier, award, project, requisition, purchase order, invoice, and line items. A streaming ingestion path publishes near-real-time events to a message bus for time-critical checks, while a daily batch path reconciles and densifies the log with late-arriving facts. The acquisition layer attaches data quality flags (completeness, uniqueness, plausibility), cryptographic hashes of invoice images for de-duplication, and lineage pointers that link raw documents to extracted fields and subsequent user edits (Dako, Okafor & Osuji, 2022, Olaogun, Amini-Philips & Ibrahim, 2022, Onalaja, *et al*., 2022). This layer also harmonizes units of measure and currencies, normalizes tax and freight treatments, and enriches commodities with controlled vocabularies so scientific services and mixed-bundle items do not evade downstream rules. Figure 4 shows a conceptual framework presented by Chong & Nizam, 2018.

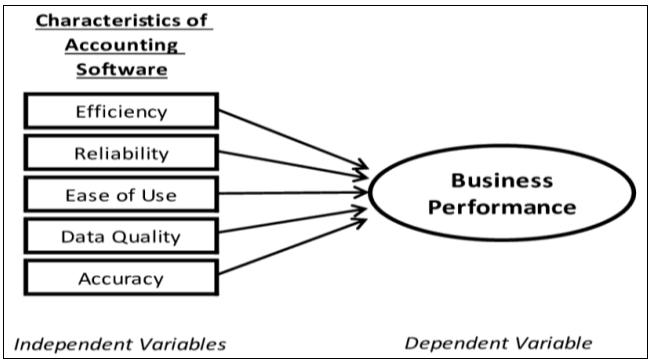

Fig 4: A Conceptual Framework (Chong & Nizam, 2018)

Sitting directly above acquisition, the policy and conformance engine translates finance policy and sponsor terms into machine-readable validations and monitors. Policies such as allowability of entertainment, equipment thresholds, service receipt evidence for personal services, or indirect cost exclusions are authored as declarative rules in a domain-specific language that supports temporal operators ("within period of performance"), relational joins ("subaward invoice requires PI attestation and technical progress flag"), and materiality thresholds ("flag if freight exceeds ten percent of line amount unless hazardous shipment") (Eyinade, Amini-Philips & Ibrahim, 2023, Farounbi & Ridwan Abdulsalam, 2023). Period-of-performance logic is encapsulated as interval constraints that compare invoice service dates and delivery dates to award boundaries, with exceptions for pre-award spending where authorized. Cost principles are parameterized by sponsor archetype so the same purchase behaves differently when charged to a federal award versus an industry contract or internal fund. The engine performs two kinds of checks: front-door validations at data entry to prevent defects from entering the system, and continuous conformance monitoring over the live event stream to detect drifts in practice, such as a department that has stopped recording service receipts or a vendor that began bundling software maintenance into equipment invoices. To ensure auditability, the engine emits a rule-evaluation trace showing inputs, rule version, outcome, and decision rationale so reviewers can understand why an invoice was blocked, auto-approved, or routed (Ibrahim, Amini-Philips & Eyinade, 2023, Ogundeji, *et al*., 2023).

The analytics layer consumes the canonical event log and rule outcomes to derive insight and prediction. Process mining discovers the true variants of the procure-to-pay process by stitching requisition, purchase order, receiving,

invoice capture, exception handling, approval, posting, and payment events per case. The resulting models quantify conformance to the ideal path and highlight where detours occur such as frequent invoice-first flows without a purchase order, or high rework loops around price mismatches for certain suppliers. Performance metrics such as cycle time distributions, touch time, rework rate, first-pass-match rate, and backlog aging are computed by award, department, supplier, and commodity, enabling targeted interventions (Dako, *et al*., 2022, Eyinade, Amini-Philips & Ibrahim, 2022, Onalaja, *et al*., 2022). Anomaly detection models operate at multiple levels: field-level anomalies catch improbable unit prices or tax patterns; sequence anomalies spot unusual event orders (e.g., payment before receiving); and peer-group anomalies compare a transaction to its expected behavior given supplier, award type, and commodity. Duplicate detection blends deterministic keys (supplier, normalized invoice number, date, amount) with fuzzy features (edit distance on reference numbers, image hash similarity, line-level vector embeddings) to catch near-duplicates and resubmissions across channels. A risk scoring model synthesizes rule violations, anomalies, and context features such as vendor tenure, department defect history, and award complexity to prioritize analyst attention (Adewale, Olorunyomi & Odonkor2021, Shobande, Atere & Toluwase, 2021). The analytics layer is also where what-if simulators estimate the impact of policy or configuration changes, for instance, how enabling auto-receipting for low-risk commodities might shift the exception workload, or how tightening freight validation would reduce overpayments while increasing touch time.

Insights only matter if they change outcomes, and the workflow orchestration layer ensures they do. Alerts are emitted on the message bus for events such as a rule breach, a rising duplicate risk, a missing receipt near period close, or a predicted late accrual. A routing engine evaluates recipient, priority, and service-level agreements to assign items to the smallest competent group: a department buyer for missing quotes, a central AP analyst for price variance, a grants accountant for allowability guidance, or a PI delegate for service confirmation (Dako, *et al*., 2020, Eyinade, Amini-Philips & Ibrahim, 2020). Human-in-the-loop patterns are central: forms pre-populate with known context (award terms, prior vendor behavior, similar resolved cases), nudges propose the likeliest correction (e.g., “move freight to object code X and attach airway bill”), and inline policy explanations reduce back-and-forth emails (Farounbi, Okafor & Oguntegbe, 2022, Olaogun, Amini-Philips & Ibrahim, 2022). Escalation paths and timers embed accountability, while a unified case object aggregates all messages, documents, and actions so that approvals reflect a single source of truth. When a human decision creates a new rule candidate say, repeatedly approving small tool purchases on internal funds with specific wording the system can suggest codifying that pattern as a safe auto-approval with capped thresholds and post-audit sampling, closing the loop between practice and policy (Adesanya, Akinola & Oyeniyi, 2023, Farounbi, Ibrahim & Abdulsalam, 2023).

Cross-cutting concerns make the architecture resilient and adoptable. Metadata management maintains a policy catalog with versioning, a sponsor-term library with inheritance, and a data dictionary that defines canonical entities and relationships. Security and privacy enforce role-based access to attachments and sensitive supplier data, and redact personally identifiable information in analytics outputs while allowing full access for authorized auditors. Observability instruments each microservice with logs, metrics, and traces; a health dashboard shows ingestion lag, rule throughput, alert queues, and case resolution aging so platform teams can scale components before bottlenecks appear (Amini-Philips, Ibrahim & Eyinade, 2021, Farounbi, Ibrahim & Abdulsalam, 2021). Governance formalizes ownership: procurement stewards commodity mappings, grants accounting owns sponsor term codifications, AP leads duplicate and anomaly thresholds, and IT stewards schemas and integrations. Change management is embedded through feature flags that allow piloting new rules on shadow mode, monitoring impact without interrupting operations, then progressive rollout across departments (Bankole & Tewogbade, 2024, Famoti, *et al*., 2024, Sakyi, *et al*., 2024).

The layers interact continuously to improve accuracy. When the analytics layer identifies a recurring conformance failure such as service receipts missing for fieldwork vendors the workflow layer can deploy a targeted campaign that requests vendors include signed service attestations; simultaneously, the policy engine can add a pre-payment hold rule for that vendor category until evidence is attached (Adewale, Olorunyomi & Odonkor2021, Dako, *et al*., 2021, Okafor, *et al*., 2021). The acquisition layer can be extended to ingest vendor-provided structured attestations, reducing human touch. Conversely, when alerts surge for a new sponsor’s unusual freight terms, policy authors can quickly encode the interpretation, and analytics can simulate the backdated effect to correct pending cases (Adesanya, Akinola & Oyeniyi, 2021, Okafor, Dako & Osuji, 2021). This virtuous cycle reduces 3-way match failures, duplicate payments, allowability errors, and late accruals by preventing defects at the front door, detecting residual risks early, and resolving exceptions with the lowest friction possible.

Finally, the architecture is deliberately platform-agnostic to fit the heterogeneity of research institutions. It can operate alongside incumbent ERPs and scanning tools, accelerating value with light-touch integrations such as SFTP drops and REST webhooks before progressing to event streaming. It supports both centralized and federated operating models: central finance can run enterprise rules while departments have local dashboards and self-service views of their own conformance and backlog (Ibrahim, Oshomegie & Farounbi, 2020). Over time, the institution can extend the same pattern to purchasing cards, travel expenses, and subaward management, compounding benefits. By aligning data acquisition, codified policy, rigorous analytics, and orchestrated human action, the architecture turns accounts payable from a reactive exception factory into a predictable, compliant, and auditable process that protects sponsor trust and research velocity (Adewale, Olorunyomi & Odonkor2022, Omowole, *et al*., 2022).

2.4 Data Standards and Integration Design

A robust data standards and integration design is the backbone of process intelligence for accounts payable in research institutions, because every conformance check, anomaly model, and workflow decision depends on clean, consistent, and richly contextualized data. The foundation is a canonical invoice/voucher schema that normalizes how payables are represented across ERP modules, e-

procurement portals, scanning/OCR tools, purchasing cards, and subaward invoices. The schema must separate header, party, payment, and line-distribution concepts while preserving traceability to original documents. At the header level, required fields include a globally unique voucher_id; supplier_id and remittance profile; legal_invoice_number in normalized form and its raw counterpart; invoice_date, service_start_date, service_end_date, received_timestamp, posting_timestamp; currency_code, fx_rate_source, tax_total, freight_total, discount_total, invoice_gross, invoice_net; payment_terms_code, due_date, payment method, and intended_settlement_account. A document bundle associates the header with machine-verifiable hashes for the image/PDF, packing slips, service receipts, quotes, and approvals, enabling downstream duplicate detection and audit reconstruction. Line items are expressed with line_id, sequence number, quantity, unit_price, unit_of_measure, extended_amount, commodity_code, description, and taxability attributes. Distributions are modeled separately to support split coding: each distribution carries chart of accounts segments (fund, cost center, program, project, award, activity, account/object code), percentage or amount, and a cost_transfer_indicator for subsequent adjustments (Oghenekome, Theodore & Edith, 2024, Urefe, Odonkor & Agu, 2024). A many-to-one relationship binds multiple distributions to a line, and a many-to-many structure links invoice lines to receipts and purchase order lines to preserve three-way match lineage. Every entity includes status fields, version numbers, and a provenance block (created_by, created_system, source_record_id, last_update fields) to support event sourcing and root-cause analysis (Farounbi, Okafor & Oguntegbe, 2023, Wedraogo, *et al*., 2023).

Supplier master governance is equally critical because identity defects ripple into duplicate payments, tax misclassification, and sanction exposure. The supplier master should be treated as a governed domain with golden-record management, comprising legal_name, doing_business_as, country, registration_type, tax identifiers with type and jurisdiction, and validation status; remittance profiles with bank_account masked values, routing/BIC/IBAN checks, account_owner verification evidence, and effective-dating; addresses with geocoding and purpose codes (legal, remit-to, ship-from); contact channels; diversity indicators and certification expiries; risk flags (sanction screening, debarment, conflict-of-interest declarations); and performance attributes such as on-time delivery and invoice defect rates (Amini-Philips, Ibrahim & Eyinade, 2023, Dako, *et al*., 2023). Governance policies must define steward roles for creation, change, and inactivation; reference-data codelists (vendor_type, commodity families, MCC/UNSPSC) with versioning; and survivorship rules for deduplicating candidates detected by fuzzy matching on name, TIN, address, and bank fingerprints. Change controls enforce maker-checker patterns for sensitive updates like banking, with dual confirmation and automated alerts to AP and Treasury. Integrations should keep a historical snapshot of the master to evaluate risk trends over time and to support forensics when a new duplicate pattern emerges after a vendor merger or alias change (Ibrahim, Amini-Philips & Eyinade, 2022, Oshomegie, Ibrahim & Farounbi, 2022).

Grants and award semantics require a first-class rules catalog that externalizes policy from code and allows rapid adaptation as sponsor terms evolve. Each award entry should define sponsor_archetype, allowability matrices by cost category, period_of_performance intervals with pre- and post-award allowances, budget by segment and carryforward rules, cost sharing requirements, prior approval triggers, indirect cost base and rate schedules, capital/equipment thresholds, and documentation requirements (e.g., service receipt for professional services, participant support restrictions). Rules are authored as declarative artifacts preferably in a DSL or JSON/YAML forms that support operators for temporal checks, joins (invoice → PO → award), thresholds, exception whitelists, and evidence bindings (Bankole & Lateefat, 2021, Farounbi, *et al*., 2021). The catalog must support inheritance and overrides: institutional policy forms the base, sponsor archetype modifies defaults, and specific award terms override both. Versioning is mandatory: each rule has an effective date range, semantic version, author, approver, and deprecation status; evaluation engines attach the exact rule version used to each decision outcome to ensure auditability. A test harness with synthetic cases validates new rules against edge scenarios (mixed commodities, split funding, period-close accruals) before promotion (Amini-Philips, Ibrahim & Eyinade, 2023).

To power process mining and conformance analytics, the model requires a normalized event log that stitches procure-to-pay lifecycles across systems. Each event record carries case_id representing the process instance; for payables, multiple case perspectives are useful and should be materialized: requisition_id, purchase_order_id, receipt_id, voucher_id, and, when warranted, an award_case_id that aggregates all spend against an award-period window. The activity field enumerates lifecycle states such as REQUISITION_SUBMITTED, PO_APPROVED, GOODS_RECEIPT_POSTED, INVOICE_CAPTURED, 3WAY MATCH FAILED, MATCH RESOLVED, VOUCHER_POSTED, PAYMENT_ISSUED, ACCRUAL BOOKED, and COST TRANSFER POSTED. The timestamp is precise to milliseconds and paired with timezone and a processing_time to distinguish event_time from system ingestion time. The actor is decomposed into actor_id, actor_type (user, system, vendor portal), org_unit, and role, enabling RACI checks. Optional attributes include resource_id for bots or queues, variant_id for process variant discovery, lifecycle markers (start/complete), correlation keys (voucher_id ↔ po_line_id), and payload digests that capture salient values (amount, vendor risk score, rule outcomes) without bloating the log. Every event is immutable; corrections produce compensating events to preserve a faithful history for root-cause and statistical analysis (Abdulsalam, Farounbi & Ibrahim, 2023, Eyinade, Ezeilo & Ogundeji, 2023).

The integration layer must accommodate heterogeneous systems and varying maturities while minimizing reconciliation gaps. Three complementary patterns establish resilience. First, APIs and webhooks enable low-latency event emission for user-initiated actions and document uploads. REST endpoints expose canonical resources (invoice, receipt, vendor, award) with idempotency keys and pagination; webhook subscriptions publish rule violations, duplicate suspicions, or case assignments to collaboration tools (Bankole, *et al*., 2019). Second, ELT pipelines land raw tables and files into a governed data lakehouse; source extracts are ingested in their native schema, then transformed to the canonical model with versioned dbt or

SQL pipelines, ensuring reproducibility and lineage. Third, change data capture (CDC) streams reflect committed changes from ERP and e-procurement in near real time using log-based connectors. CDC events carry operation type (insert, update, delete), before/after images, transaction boundaries, and source LSN/watermarks so downstream processors maintain exactly-once semantics (Eyinade, Amini-Philips & Ibrahim, 2022, Osuji, Okafor & Dako, 2022). For sources that cannot support CDC, scheduled extracts and SFTP drops are wrapped with checksum manifests and control tables to detect drift and re-ingest only deltas. A message bus ties these modes together: APIs emit, CDC mirrors, and batch reconciles downstream services subscribe to a unified topic structure (e.g., /ap/invoice/, */supplier/*, /award/*) to trigger policy evaluation and workflow (Dako, Okafor & Osuji, 2021, Okafor, Osuji & Dako, 2021).

Data quality is engineered, not inspected in, so the design embeds rules at capture, transit, and warehouse layers. Quality dimensions include completeness (mandatory fields at header, line, and distribution levels), uniqueness (no duplicate invoice number for the same supplier and amount within a rolling window; no repeated image hash), validity (codes exist in codelists; dates within plausible ranges; currency codes ISO-compliant), accuracy (unit prices within historical bands for commodity and supplier), consistency (sum of distributions equals line extended amounts; line totals roll to header totals), timeliness (invoice received within defined days of service end), and referential integrity (supplier_id exists and active; award segment valid for date) (Eziamaka, Odonkor & Akinsulire, 2024, Odonkor, *et al*., 2024). Rules fall into three classes. Preventive validation at source forms and APIs reject or hold transactions with clear defects, providing actionable messages and quick fixes (e.g., normalize invoice number patterns, prompt for missing service dates). Detective monitors run continuously on CDC streams to catch post-entry issues such as a late vendor master change that invalidates a voucher's remittance profile. Corrective pipelines constrain bad data from polluting gold tables: rows failing conformance are quarantined with reason codes; downstream aggregates exclude quarantined records unless explicitly requested. Each rule has a severity, owner, threshold, and an SLO defining acceptable defect rates; metrics are surfaced in an observability dashboard that shows rule fire counts, quarantine backlog, mean time to remediation, and the financial exposure tied to open exceptions (Bankole, *et al*., 2023, Essandoh, *et al*., 2023).

Master and reference data stewardship underpins stability across integrations. Reference tables for chart of accounts, commodity codes, tax rates, payment terms, and organizational structures must be standardized and synchronized; every table carries effective dating, status flags, and parent-child hierarchies to support historical reporting and reorganizations. A lightweight MDM service exposes matching/merging APIs for suppliers and, where applicable, award identifiers imported from external sponsor systems (Amini-Philips, Ibrahim & Eyinade, 2022, Farounbi, Ibrahim & Abdulsalam, 2022). Governance workflows require dual approvals for structural changes (e.g., closing an account segment), publish impact assessments to analytics owners, and trigger backfills in transformation pipelines to prevent orphan records. Metadata and lineage are first-class: every transformation and rule execution writes to a catalog indicating source columns, transformation logic, and downstream dependencies; data consumers can trace a dashboard KPI to the fields, rules, and source systems that produced it (Shobande, Atere & Toluwase, 2019).

Security and privacy are integral to the design. Role-based access control maps least-privilege roles to data domains; sensitive attributes such as bank numbers and tax IDs are tokenized at rest, with reversible vaulting limited to authorized services. Line-level security can restrict award-linked transactions to grants accountants and project teams. All integrations use mutual TLS, signed payloads for webhooks, and rotating credentials for SFTP fallbacks. Pseudonymized datasets power analytics and model training; when full fidelity is required for audit, just-in-time access is logged with purpose-of-use flags, and every event in the log includes the actor so an immutable audit trail exists for stewardship (Eyinade, Amini-Philips & Ibrahim, 2023, Omowole, *et al*., 2023).

Finally, the design embraces progressive adoption. Institutions can begin by mapping their most common sources to the canonical schema and enabling a narrow event log around invoice capture and posting. As confidence grows, CDC is turned on, more lifecycle events are added, and stricter quality rules shift left into APIs. The grants rules catalog starts with a small set of high-impact checks and expands as stewards codify tribal knowledge (Oshomegie, Matter & An, 2017). Over time, standardized data and reliable integrations allow the process intelligence stack to deliver measurable reductions in duplicate payments, allowability errors, and late accruals, while creating a durable substrate for future capabilities such as supplier risk scoring, autonomous three-way matching for low-risk commodities, and self-service conformance analytics for departments and principal investigators (Famoti, *et al*., 2024, Ibrahim, Amini-Philips & Eyinade, 2024, Omokhoa, *et al*., 2024).

2.5 Methods and Process-Intelligence Toolkit

The methods and process intelligence toolkit focus on turning raw transactions into actionable controls that raise accounts payable accuracy in research institutions. The first capability is process discovery that reconstructs procure to pay lifecycles from event logs aggregated across requisitioning, purchase ordering, receiving, invoicing, matching, and payment. Event logs with case identifiers for purchase orders, receipts, vouchers, and award cases are transformed into directly follows graphs and frequency weighted models that reveal typical paths and outlier variants (Atere, Shobande & Toluwase, 2019). Discovery produces metrics such as median cycle time from invoice captured to voucher posted, rework loops where three way match fails then resolves, and bottlenecks where approvals queue for specific roles. Conformance checking compares these observed paths to a reference model aligned to institutional policy and sponsor rules. The checker evaluates fitness, precision, and simplicity scores and emits violation instances, such as payment issued before receipt posted, voucher posted outside period of performance, or cost transfer posted without prior approval. Each violation is linked to the underlying event evidence, which creates a defensible audit trail and a feed into automated case creation (Dako, *et al*., 2023, Osuji, Dako & Okafor, 2020).

To prevent recurrence rather than only detect it, the program applies Failure Modes and Effects Analysis across the AP chain. The team identifies discrete failure modes, such as miskeyed invoice number, split distribution that does not sum to line totals, mismatched tax codes for foreign suppliers, duplicate vendor remittance profile, unallowable commodity against an award, or missing service dates. For each mode the team defines a severity score that reflects sponsor clawback or financial loss, an occurrence score estimated from historical prevalence per commodity and supplier segment, and a detection score based on current control strength (Oghenekome, Theodore & Edith, 2024, Urefe, Odonkor & Agu, 2024). The Risk Priority Number is computed as the product of severity, occurrence, and detection, then used to prioritize design actions. High RPN items lead to preventive data quality rules at capture, stronger supplier master maker checker workflows for banking changes, or mandatory attachment prompts for service receipts. FMEA is revisited quarterly with new evidence from conformance violations and exception clusters to validate that RPNs fall as mitigations take hold (Amini-Philips, Ibrahim & Eyinade, 2023, Oshomegie, Farounbi & Ogunsola, 2023).

To measure control performance and to enable planning, the toolkit estimates first pass yield at multiple stages. First pass yield is defined as the proportion of vouchers that pass all checks and post without rework on their first attempt. Baseline FPY is computed and segmented by department, supplier, commodity, and award archetype. A predictive FPY model uses features such as OCR confidence distributions at header and line level, supplier invoice defect history, three way match completeness at the time of capture, presence of period of performance dates, complexity indicators such as number of distributions, and seasonality signals around quarter close (Davidor, *et al*., 2023, Lateefat & Bankole, 2023, Olaogun, Amini-Philips & Ibrahim, 2023). Gradient boosted trees or calibrated logistic regression provide probability of first pass success. These probabilities power triage queues that send low probability items to enhanced review before posting, which reduces downstream corrections and late accruals.

Exception clustering accelerates root cause discovery by grouping similar defects that should be addressed with a single fix. The pipeline embeds structured attributes such as reason codes, rule identifiers, supplier and commodity codes, along with embeddings derived from invoice text, help desk notes, and rule messages. A density based algorithm such as HDBSCAN groups exceptions without requiring a fixed cluster count and can detect noise points. Each cluster is profiled with top tokens, top suppliers, and shared rule failures. Product owners inspect the highest volume and highest exposure clusters to identify a common cause (Adesanya, Akinola & Oyeniyi, 2021, Yetunde, Onyelucheya & Dako, 2021). Examples include a supplier portal that formats invoice numbers with leading zeros that collide with existing records, a set of lab services coded to the wrong commodity that bypasses a documentation requirement, or a specific department missing service end dates due to a local template. The corrective action can be a supplier education note, a portal validator, an updated mapping in the canonical schema, or a revised purchase order template. Clusters and their fixes are tracked as hypotheses with pre and post metrics that confirm defect rate reduction (Ibrahim, Amini-Philips & Eyinade, 2021).

Since many research institutions rely on scanned or portal submitted PDFs, OCR quality is a key determinant of accuracy. The toolkit enforces OCR confidence thresholds at field and document level. Each extracted field carries a confidence score and a redundancy flag that indicates whether the value was corroborated by an independent source such as an embedded text layer, a barcode, an XML e invoice payload, or a check against purchase order values. Header fields like invoice number, invoice date, and supplier name are assigned stricter thresholds than narrative description (Farounbi, Okafor & Oguntegbe, 2023, Oshomegie, 2023). If the average line level confidence for unit price or quantity falls below a defined band, the system routes the document to assisted capture and blocks automated posting. A calibration process sets these thresholds per supplier and document type, because vendors with structured XML or machine readable portals can sustain near zero manual touch, while image heavy service invoices require higher scrutiny. The system also monitors drift in confidence distributions to catch scanner miscalibration or new vendor templates that degrade extraction quality (Odonkor, *et al*., 2024, Ojukwu, *et al*., 2024).

Duplicate and near duplicate detection protects against double payment and erroneous accruals. The logic begins with strict keys such as supplier identifier, normalized invoice number, currency, and invoice amount within a tolerance. It then expands to fuzzy strategies that use phonetic encodings and token set ratios for invoice numbers that differ due to hyphens or spaces, cosine similarity of image hashes, and graph linkages among purchase order, receipt, and line distributions. Temporal windows reflect expected recurrence patterns, for example 30 to 90 days for monthly service invoices (Dako, *et al*., 2019). The detector produces a similarity score and an explanation vector that lists the fields that contributed to the match. Matches above a hard threshold are auto held for review, while mid band scores prompt a just in time warning in the analyst workbench. To prevent alert fatigue, a suppression mechanism merges duplicate alerts for the same candidate pair and expires holds based on documented adjudication outcomes. Downstream learning captures analyst decisions and improves thresholds by supplier category (Adesanya, *et al*., 2020, Osuji, Dako & Okafor, 2020).

The final layer delivers prescriptive next best actions that convert predictions and checks into guided work. The policy combines business rules, model scores, and FMEA priorities to select an action, a responsible role, and a service level. For a voucher predicted to fail first pass due to missing period of performance dates, the action is to request service start and end dates from the department administrator with an embedded form that validates valid ranges and pushes an update back to the voucher. For a near duplicate involving a common vendor, the action is to compare the current document image to the held version, and if confirmed, cancel the duplicate and notify the supplier with the canonical invoice number that already exists (Osuji, Okafor & Dako, 2020). For a three way match failure on quantity, the action is to request receipt verification from the lab manager, and if the mismatch recurs across suppliers, to open a continuous improvement ticket that examines receiving practices. The playbook is encoded as decision tables with auditable versioning, and each recommendation records acceptance or override with reason. This creates a

closed loop that tunes both models and rules (Dako, *et al*., 2020, Farounbi, Ibrahim & Oshomegie, 2020).

The operationalization of these methods follows a steady cadence. Daily, the system discovers processes, runs conformance checks, predicts first pass yield, detects duplicates, pushes next best actions, and publishes exception clusters. Weekly, governance reviews FMEA RPNs, revises thresholds, and evaluates top clusters (Bankole, *et al*., 2020, Eyinade, Ezeilo & Ogundeji, 2020). Monthly, the team recalibrates OCR thresholds, retrains predictive models with the latest labeled outcomes, and refreshes the control tower dashboards that show milestone adherence, backlog by reason, and risk heat maps. Success is measured by rising first pass yield, falling rework rate, shorter time to post, and a reduction in sponsor related allowability exceptions. Because the toolkit is modular and evidence based, institutions can begin with high impact checks and scale to full process intelligence while maintaining a defensible audit trail and transparent human in the loop oversight (Ibrahim, Amini-Philips & Eyinade, 2024, Omokhoa, *et al*., 2024, Shittu, *et al*., 2024).

2.6 Controls, Compliance, and Governance

Controls, compliance, and governance form the backbone of the conceptual model for raising accounts payable accuracy in research institutions, ensuring that process-intelligence enhancements operate within a defensible, auditable, and ethically responsible environment. The core philosophy is that automation and analytics cannot replace governance; instead, they reinforce internal controls by making violations visible earlier, strengthening consistency in policy application, and creating a transparent, tamper-proof trail of decisions. Continuous control monitoring serves as the first line of defense, transforming static periodic reviews into real-time assurance mechanisms (Amini-Philips, Ibrahim & Eyinade, 2023, Bankole & Lateefat, 2023, Okafor, Dako & Osuji, 2023). Event streams from ERP, e-procurement, grants management, and OCR/IDP platforms feed rule engines that continuously evaluate transactions against allowability conditions, approval requirements, duplicate detection thresholds, vendor master hygiene rules, and period-of-performance constraints. These checks run at the moment of transaction creation and at each handoff, making it possible to block risky postings at the source rather than reverse them later. Continuous monitoring detects segregation-of-duties violations in flight such as the same actor initiating and approving a voucher, changing banking instructions, or performing receipts and invoice approvals for the same transaction. These alerts integrate with identity governance systems to enforce least privilege and support detective controls when preventative enforcement is not possible due to legacy system limitations (Osuji, Okafor & Dako, 2023, Yetunde, Onyelucheya & Dako, 2023).

Role-based access control aligns system permissions with organizational roles, risk levels, and regulatory requirements. Research institutions' AP workflows involve PIs, department administrators, central AP, procurement analysts, compliance officers, and auditors, each with distinct responsibilities. The model ensures roles are mapped to granular privileges: creating requisitions, modifying purchase orders, posting journals, updating vendor master data, adjudicating exceptions, and approving high-risk expenditures. Access reviews occur quarterly, supported by automated extracts that show privilege usage, dormant accounts, anomalous login patterns, and cross-role conflicts (Oghenekome, Theodore & Edith, 2024, Urefe, Odonkor & Agu, 2024). Embedded identity analytics evaluate whether access patterns deviate from population norms, prompting reassessment of privileges or multi-factor authentication triggers. By linking access governance to event logs, the institution can detect when privileges are exercised in unusual sequences, signaling potential fraud or training gaps.

Policy-as-code plays a central role by translating sponsor-specific terms, federal cost principles (e.g., OMB Uniform Guidance), period-of-performance rules, indirect cost structures, and institutional policies into machine-readable logic. Instead of relying on staff to manually interpr*et al*lowability rules across thousands of awards, the model operationalizes rules such as: items must fall within the award's performance period; alcohol and entertainment are unallowable; equipment purchases above a threshold require prior approval; foreign subawards require additional documentation; and travel costs must align with institutional per-diem standards (Amini-Philips, Ibrahim & Eyinade, 2022, Elumilade, *et al*., 2022). Codifying policies as structured logic tables, JSON rulesets, or decision trees ensures that the same rule applies for every transaction, eliminating inconsistencies in human judgment. Policy-as-code also facilitates rapid updates when sponsor terms change, allowing compliance officers to push new logic to the engine without waiting for manual retraining. Changes are versioned, timestamped, and linked to release notes so auditors can reconstruct the exact ruleset that evaluated a transaction at any point in time (Farounbi, *et al*., 2021, Tewogbade & Bankole, 2021).

Audit trails and retention mechanisms guarantee that the evidence underpinning decisions remains complete, immutable, and accessible for internal audit and external sponsor reviews. Every transformation from OCR extraction, rule evaluation, conformance check, exception classification, next-best action, and analyst override is logged with timestamp, actor, system, prior values, new values, and justification code. These logs exist in append-only storage formats that meet retention requirements for federal awards, typically three to seven years post-closeout depending on sponsor rules (Eziamaka, Odonkor & Akinsulire, 2024, Urefe, *et al*., 2024). Traceability across systems is maintained by canonical identifiers that persist through the entire lifecycle: requisition ID, PO ID, voucher ID, receipt ID, award ID, and vendor ID. The model enforces retention of original invoice images, extracted data, intermediary validation results, and all communications with suppliers during exception resolution. This ensures that during a sponsor audit, the institution can produce a complete, sequential narrative of how an invoice was handled what rules it triggered, who intervened, why an override occurred, and what evidence was supplied (Odonkor & Urefe, 2024).

Privacy and security controls are built to protect sensitive financial data and personally identifiable information that may appear in invoices, vendor documents, subaward agreements, and grant files. Encryption at rest and in transit is mandatory, with key management separated by environment tier. Access to raw invoice images is restricted, and redaction engines remove sensitive fields before datasets are used for model training or analytics. Data minimization principles ensure only necessary attributes

flow into the machine-learning layer (Dako, *et al*., 2024, Okafor, Famoti, *et al*., 2024, Osuji & Dako, 2024). Continuous vulnerability scanning, intrusion detection, and SOC-2 aligned operational controls protect the data pipeline and API endpoints that move voucher events from source systems into the intelligence layer. Data residency and cross-border transfer restrictions are respected, especially for global research consortiums. Security logs feed into a SIEM so anomalous access, suspicious sequences of approvals, or unusual vendor master updates generate real-time alerts. Vendor master changes such as banking updates require dual approval and certificate-based authentication to mitigate fraud (Adewale, Olorunyomi & Odonkor2022, Omowole, *et al*., 2022).

Model risk management governs the lifecycle of all analytical models deployed for AP accuracy including duplicate detection, first-pass yield prediction, anomaly scoring, OCR confidence validation, and exception triage. Each model undergoes documentation of purpose, theoretical basis, data sources, feature list, training sample, performance metrics, and known limitations. Validation teams periodically test models for accuracy, bias, drift, and stability. Drift detection compares current feature distributions with those used during training; if variance exceeds tolerance, retraining or threshold adjustments are triggered. Backtesting evaluates whether model decisions align with auditor-validated outcomes (Bankole, *et al*., 2020, Tewogbade & Bankole, 2020). Override analysis examines human reviewers' decisions to understand where models underperform or falsely escalate transactions. Interpretability techniques (feature importance, SHAP values, rule extracts) provide transparent explanations so staff understand why a transaction was flagged, which reinforces trust and supports defensible reporting to regulators (Elumilade, *et al*., 2024, Famoti, *et al*., 2024, Omokhoa, *et al*., 2024).

Performance monitoring dashboards bring all governance elements together into a unified control tower. Dashboards visualize sponsor allowability exceptions, duplicate detection outcomes, first-pass yield trends, rework rates, cycle time distribution, period-of-performance violations, and SoD conflicts by department. Risk heat maps highlight suppliers, commodities, departments, or award types with rising error patterns. Control effectiveness indicators measure rule hit rates, override counts, model precision/recall, and compliance adherence. User behavior metrics show whether approvers are meeting SLA expectations and whether exception queues are accumulating. Governance committees review these dashboards monthly to initiate corrective actions, prioritize policy changes, allocate training resources, and evaluate whether new controls or workflow improvements are required (Abdulsalam, Farounbi & Ibrahim, 2021).

Collectively, these governance mechanisms ensure that process-intelligence enhancements do not weaken control environments but strengthen them by making AP accuracy measurable, transparent, continuously monitored, and defensible under the rigorous scrutiny typical of research institutions and their sponsors (Ibrahim, Amini-Philips & Eyinade, 2023, Elumilade, *et al*., 2023).

2.7 Implementation Roadmap and Change Management

The implementation roadmap for raising accounts payable accuracy through process intelligence in research institutions begins with a focused pilot that is carefully scoped to de-risk delivery while demonstrating value within one fiscal quarter. The pilot domain should target two to three departments with heterogeneous purchasing patterns such as a clinical research center, an engineering school, and central administration covering at least five high-volume supplier categories (lab consumables, equipment, services, travel, and subawards). Systems in scope include the ERP AP module, e-procurement, grants management, expense, and the invoice capture/OCR platform (Eyinade, Ezeilo & Ogundeji, 2020, Shobande, Atere & Toluwase, 2020). The functional scope spans ingestion of invoice and voucher events, event-log standardization, policy-as-code checks for allowability and period of performance, duplicate/near-duplicate detection, exception queue orchestration with human-in-the-loop, and dashboards for first-pass yield and cycle time. Milestones are sequenced as week 0–2 environment setup and data access; week 3–4 event-log canonicalization and data quality profiling; week 5–6 rules deployment and duplicate logic tuning; week 7–8 workflow integration to route alerts and capture analyst outcomes; and week 9–12 stabilization with daily standups, KPI readouts, and change requests. Exit criteria include a working control tower, statistically significant improvement on at least two KPIs, and positive usability scores from AP analysts and research administrators (Ibrahim, Amini-Philips & Eyinade, 2021, Ogundeji, *et al*., 2021).

KPI baselining precedes any configuration to ensure observed gains are attributable to the intervention rather than seasonal effects. A twelve-week historical window is extracted for the pilot units to compute first-pass yield (percentage of invoices that post without exception), exception rate (share of invoices generating any hold or review), average and median cycle time from invoice receipt to voucher posting, rework loops per case, and questioned costs identified by internal audit or sponsors. Supplemental metrics include duplicate detection true positives and false positives, proportion of allowability violations caught pre-posting, OCR extraction accuracy by field, and period-of-performance violations per 1,000 invoices. Baselines are segmented by supplier category, funding source, and invoice channel (PO vs. non-PO, P-Card, subaward) to isolate where gains concentrate (Adewale, Olorunyomi & Odonkor2023, Farounbi, Okafor & Oguntegbe, 2023). A contemporaneous control group units not exposed to the new process enables difference-in-differences analysis of FPY and cycle time to control for seasonal volume spikes during grant deadlines. Control limits are set for each metric using historical variability, and weekly run charts with rules for special-cause variation help the team distinguish signal from noise during stabilization (Amini-Philips, Ibrahim & Eyinade, 2023, Oshomegie & Ibrahim, 2023).

Training and playbooks convert the conceptual model into reliable practice. Role-specific curricula are authored for AP analysts, departmental research administrators, central compliance, procurement, and PIs. Content covers reading the control tower, interpreting policy-as-code explanations, adjudicating exceptions with standardized reason codes, requesting overrides with documentary evidence, and closing the loop with suppliers. Micro-learning modules (10–15 minutes each) are embedded in the workflow UI, triggered contextually when a user encounters a rule for the first time (Eyinade, Amini-Philips & Ibrahim, 2022, Omokhoa, *et al*., 2022). A searchable playbook captures

standard operating procedures for the top twenty exception types (e.g., missing receipt, mismatched quantities, out-of-period charges, restricted commodity, bank detail change), with checklists, acceptable evidence examples, and turnaround SLAs. Calibration sessions occur biweekly during the pilot, where analysts review a stratified sample of cases to align decisions and maintain inter-rater reliability; disagreements are documented, rules refined, and playbooks updated. Certification quizzes with scenario-based items verify comprehension, and access to high-risk adjudications is gated behind passing scores to reinforce quality (Adesanya, *et al*., 2022, Olaogun, Amini-Philips & Ibrahim, 2022, Okafor, Osuji & Dako, 2022).

A clear RACI model anchors accountability and accelerates decision-making. The process intelligence product owner is accountable for backlog prioritization, rule governance cadence, and KPI delivery; data engineering is responsible for pipelines, canonical schemas, and data quality monitors; compliance authors and approves policy-as-code; AP operations owns workflow tuning, queue staffing, and service levels; departmental research administrators are responsible for timely document submission and PO hygiene; procurement stewards supplier master governance; internal audit consults on control design and validates evidence sufficiency; information security approves access patterns and encryption controls; the steering committee of the CFO, VP Research, and CIO is informed via monthly benefits realization reviews (Amini-Philips, Ibrahim & Eyinade, 2022). Incentives are aligned to outcomes: AP team performance plans include targets for FPY uplift and cycle time reduction; departments receive recognition for PO hygiene and on-time confirmations; suppliers are eligible for accelerated payments or lower dispute rates when they consistently meet e-invoicing data standards. To prevent gaming, metrics are triangulated high FPY accompanied by rising questioned costs triggers a review and exception aging is monitored to deter deferral of difficult cases (Bankole, *et al*., 2022, Eyinade, Ezeilo & Ogundeji, 2022).

Supplier enablement is essential because accuracy is shaped as much upstream as within AP. The roadmap includes a parallel track to onboard the top 50 suppliers by invoice count and spend to e-invoicing or standardized cXML/EDI formats with mandatory data fields for award number, PO line, receipt reference, and period-of-performance date ranges. A supplier data quality scorecard is published monthly, showing rejection rates, duplicate submissions, missing fields, and average response time to queries. Banking detail changes move to a secure portal with dual-factor verification and documentary validation, reducing risk and AP workload. Contract terms are amended to embed data standards, turn-around SLAs for dispute resolution, and acceptance of retrospective credit memos for overcharges detected by duplicate logic (Dako, *et al*., 2023, Eyinade, Ezeilo & Ogundeji, 2023, Yetunde, Onyelucheya & Dako, 2023). For high-risk categories such as services and subawards, statement-of-work templates enforce granularity in deliverables and time windows to support allowability checks. Supplier webinars and quick-reference guides reduce friction and create shared accountability for clean first submissions.

Feedback loops make the system self-improving. Every exception routed to a human has a structured outcome: confirmed violation, false positive, missing data, or rule gap, with mandatory reason codes and free-text justification. These outcomes retrain detection thresholds, refine policy-as-code, and target training. A weekly "exceptions retrospective" reviews the top recurring patterns by supplier, commodity, department, and award type; action items could include updating the rule library, clarifying policy language in the playbook, or addressing a root-cause such as purchase orders without itemized lines (Adesanya, Akinola & Oyeniyi, 2022, Eyinade, Ezeilo & Ogundeji, 2022). The model uses override analytics to identify rules that generate frequent justified exceptions, signaling either mis-specification or a legitimate business variant that should be whitelisted with compensating controls. User experience telemetry identifies clicks, dwell time, and error prompts to streamline the adjudication path and reduce cognitive load. Sponsor audit findings, questioned costs, and management letter comments are codified back into rules with traceable release notes, ensuring the environment reflects the latest risk learnings (Dako, *et al*., 2019).

Change management emphasizes transparent communication, leadership sponsorship, and incremental wins. A kick-off town hall explains the "why" of AP accuracy in grant-funded contexts sponsor scrutiny, reputational risk, and cash flow robustness and frames the pilot as an enablement initiative rather than a surveillance tool. Weekly highlights celebrate resolved pain points, such as a reduction in period-of-performance violations for a specific department or a supplier's improvement in e-invoice completeness (Bankole & Tewogbade, 2019). A change network of department champions surfaces adoption barriers early and translates central guidance into local practices. Resistance is addressed empathetically by showing before/after case studies that demonstrate fewer back-and-forth emails, clearer decisions, and quicker payments. Where automation displaces manual steps, the roadmap includes redeployment plans for staff into higher-value activities like supplier relationship management, root-cause analysis, and proactive outreach to departments with chronic hygiene issues (Oghenekome, Theodore & Edith, 2024, Urefe, *et al*., 2024).

Scaling beyond the pilot follows a phased expansion guided by readiness criteria. Departments join the program once their master data meets minimum quality thresholds and their PIs and admins have completed training. Rule packs are templatized by commodity and sponsor type, enabling faster rollout with parameterization rather than re-authoring. Quarterly governance cycles introduce new controls gradually, pairing each with a stabilization period and help-desk surge capacity. Infrastructure is right-sized to handle peak volumes during fiscal close and major grant deadlines, with autoscaling for the event ingestion and rules engines (Famoti, *et al*., 2023, Ibrahim, Amini-Philips & Eyinade, 2023). A sustainability plan budgets for model monitoring, rules maintenance, supplier onboarding, and ongoing training, with benefits tracked against a multi-year business case that includes reduced questioned costs, avoided audit findings, and working-capital gains from predictable cycle times. By anchoring the roadmap in disciplined piloting, rigorous baselining, human-centered enablement, aligned incentives, supplier partnerships, and learning feedback loops, research institutions can institutionalize process intelligence as a durable capability that measurably raises accounts payable accuracy and withstands sponsor scrutiny (Bankole, *et al*., 2020, Okafor, Dako & Osuji, 2020).

2.8 Conclusion

This conceptual model shows that process intelligence can convert fragmented, manual accounts payable into a controlled, data-driven operation suited to the compliance demands of research institutions. By standardizing event logs across ERP, e-procurement, grants, card feeds, and invoice capture, and by codifying sponsor terms as executable rules, the institution can raise first-pass yield, reduce exception aging, and cut rework loops. Expected outcomes include higher accuracy at the line level, materially fewer sponsor disallowances detected after posting, faster period and year-end close through earlier resolution of allowability and period-of-performance issues, and more reliable sponsor billing with cleaner accruals and fewer subsequent true-ups. Duplicate and near-duplicate payments decline as similarity logic matures and supplier data quality improves. Cycle time contracts because exceptions are routed to the right role with clear evidence requirements and timers, while audit trails and retention support both internal and external reviews.

To sustain these gains, the model embeds operational analytics into routine management. Control charts track first-pass yield, exception rate, duplicate catch rate, and invoice cycle time by unit and commodity, with clear rules for detecting special cause variation and triggering root-cause reviews. Quarterly governance reviews refresh the policy-as-code library for new sponsor terms, validate segregation of duties and access controls, recalibrate duplicate thresholds, and retire rules that drive justified overrides. A small center of excellence maintains data quality monitors on supplier master, award metadata, and invoice capture fields, publishes a monthly scorecard, and coordinates training refreshers tied to observed error modes. Benefits realization is reported against a multiyear business case that includes avoided questioned costs, reduced write-offs, and working capital improvements from more predictable posting.

Future enhancements extend value beyond accuracy into planning and partner experience. Predictive cash forecasting uses approved and in-flight vouchers, seasonality, and sponsor billing cadence to forecast disbursements and cash needs at award and portfolio levels. Supplier portals mature from basic e-invoicing to two-way collaboration that includes secure bank updates, structured dispute workflows, and automated credit memo issuance. Adaptive policies leverage reinforcement learning and human feedback to tune rule severity by context, offering guardrails for high-risk patterns while minimizing false positives. Together these steps keep the control environment current, reduce friction for researchers and suppliers, and preserve timeline predictability and billing integrity at scale.

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