

Advances In NLP-Driven Analytics for Automated Detection of Regulatory Liabilities in High-Volume Contracts

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Abstract

Contract portfolios at large enterprises now routinely exceed tens of thousands of active agreements, and the regulatory obligations attaching to those agreements have multiplied faster than legal review capacity. In 2025 this gap became acute: the EU Digital Operational Resilience Act (DORA) became applicable on 17 January without a transition period, forcing thousands of financial entities into large-scale contract remediation, while the general-purpose AI obligations of the EU AI Act took effect on 2 August. Both events created demand for systems that can read an entire contract portfolio and flag, with evidence, where regulatory liability exists. This paper reviews the state of natural language processing for automated regulatory liability detection as of the end of 2025 and sets out a layered architecture for production deployment. Regulatory liability detection is distinguished here from the better-studied task of clause extraction, on the argument that the former is a normative verification problem requiring a rule base, an evidence retrieval mechanism, and an adjudication step, rather than a span-labelling problem. Four technical shifts that reshaped the field during 2025 are surveyed: the maturation of long-context models beyond the length of most commercial contracts, the emergence of legal-specific retrieval evaluation, the arrival of explicit reasoning models capable of rule-grounded justification, and the closing but still material gap between proprietary and open-weight models on clause-level risk identification. Evidence is also drawn from compliance analytics research in financial audit, cybersecurity governance, critical infrastructure protection, procurement, supply chain assurance, payments, pharmaceutical regulation, aviation safety oversight, and enterprise systems engineering, on the argument that the design problems in regulatory liability detection are not confined to legal NLP and that adjacent literatures have already resolved several of them. A metric suite appropriate to the asymmetric cost structure of compliance work is then set out, in which a missed mandatory clause is not commensurate with a false alarm, and the F1 scores dominant in the literature are argued to be a poor proxy for deployment value. The paper closes on a reflexive governance question specific to this application: a system that classifies legal risk may itself fall within the scope of the regulation it is deployed to manage.

Keywords: *legal NLP, regulatory technology, contract analytics, compliance verification, retrieval-augmented generation, large language models, DORA, EU AI Act, obligation extraction, legal risk*

1. Introduction

The economics of contract review have not changed in decades. A senior lawyer reads a document, applies a body of internalised knowledge, and produces a judgement. That judgement is high quality and does not scale. A single multinational bank may hold contractual arrangements with several thousand information and communications technology suppliers, each governed by a master agreement, an order form, one or more statements of work, a data processing addendum, a security schedule, and an accumulated stack of amendments. The unit of regulatory analysis is not the document but the arrangement, which means the effective corpus is larger than any document count suggests. Studies of vendor governance and contract negotiation in capital-intensive sectors have documented the same fragmentation, showing that cost and compliance exposure accumulate across instruments rather than within any single one (Okonkwo et al., 2019; Okonkwo et al., 2018a; Okonkwo, Mayo, et al., 2023; Okonkwo, Agbabiaka, et al., 2021).

When a new regulation lands, the organisation faces a bounded problem with an unbounded cost: determine, for every arrangement, whether the contractual terms satisfy a defined set of mandatory provisions, and if not, what specifically is missing or defective. Practitioner accounts of DORA remediation describe programmes in which the number of discrete remediation tasks ran into six figures, a scale at which purely manual triage is not merely expensive but arithmetically impossible within the compliance window. The compliance burden that regulation imposes on corporate processes, and the unintended operational consequences of that burden, have themselves become objects of study (Fobellah, 2025c; Fobellah, 2025a).

Three characteristics of the 2025 regulatory environment made automated detection newly attractive rather than merely interesting. The first is compression of timelines. DORA applied from 17 January 2025 with no transitional period for the remediation of existing contracts, and supervisors, including BaFin in Germany, made clear that waiting for standard contractual clauses to be published was not an acceptable reason for delay. Organisations therefore had to begin gap analysis before the target state was fully specified, which favours systems that can be re-run cheaply as the rule base is refined. Comparable dynamics have been described in cross-border regulatory harmonisation and readiness modelling, where firms must act against a rule set that is still consolidating (Eze et al., 2024a; Eze et al., 2022b).

The second is granularity of the mandated terms. DORA does not require contracts to be adequate in a general sense. It enumerates specific provisions that must appear in ICT service contracts: service level descriptions, audit and access rights, termination rights, exit strategies, incident notification procedures, subcontracting conditions, and data location commitments, among others. Enumerable requirements are machine-checkable requirements, and this is a meaningful difference from older, principles-based outsourcing guidance. The same translation problem, converting statutory language into operational workflow conditions, has been formalised for small-enterprise tax and regulatory obligations (Eyetsemitan et al., 2021).

The third is the register obligation. DORA requires financial entities to maintain a register of information covering all ICT third-party contractual arrangements, submitted to regulators and updated over time. This converts contract analysis from a one-time project into a continuous data pipeline with a structured output schema, which is precisely the shape of problem that information

extraction systems are built for, and which parallels continuous-control and end-to-end visibility architectures developed for supply chain traceability and financial close (Nnabueze et al., 2021; Oyeleye et al., 2025). Parallel pressures appeared elsewhere. Sustainability reporting regimes pushed obligations into supplier contracts (Abioye et al., 2023; Ike et al., 2025), data protection enforcement continued to focus on processor agreements (Mbonu et al., 2018; Mbonu et al., 2022a), and the EU AI Act itself began to generate contractual requirements between model providers and downstream deployers following the entry into application of general-purpose AI obligations on 2 August 2025 (Annan, 2025a; Annan, 2024).

Against that background, this paper does five things. It separates regulatory liability detection from clause extraction and clause classification, using a six-way taxonomy of liability types that current benchmarks only partially cover. It synthesises the 2025 technical advances around retrieval, reasoning, structured output, and model sourcing, with attention to what the empirical literature actually supports rather than what vendors claim. It assembles evidence from compliance analytics research outside legal NLP and identifies which design patterns transfer to contract liability detection and which do not. It sets out a layered architecture intended for portfolios in the ten thousand to five hundred thousand document range, with explicit design choices around cost cascading, abstention, and evidence provenance. And it develops an evaluation framework built on asymmetric cost, including metrics absent from the standard benchmark suite that nonetheless determine whether a deployment succeeds.

The material synthesised here spans peer-reviewed and preprint literature published principally between 2015 and 2025, supplemented by practitioner reporting on DORA and AI Act implementation. No original benchmark results are reported. Where quantitative findings from prior work are described, they are attributed and their measurement conditions are noted, because a headline accuracy figure in legal NLP is close to meaningless without knowing the document lengths, the task framing, and the annotation protocol involved. The cross-sector material in Section 2.3 was assembled by subject area rather than by keyword, on the reasoning that regulatory liability detection is a specialisation of a general problem, namely the machine verification of an artefact against an external normative standard, and that the sectors with the longest history of automated compliance monitoring have accumulated design knowledge the legal NLP literature does not yet reference.

2. Related Work

2.1 Contract understanding in legal NLP

Automated compliance checking predates the neural era. Work on semantic information extraction from construction regulatory documents established the basic pattern of converting statutory text into machine-checkable representations and then testing artefacts against them. That literature developed the crucial insight that the hard part is not the checking but the formalisation: converting a regulatory sentence into a predicate involves interpretive choices that a compliance officer must own. Early contract-specific work followed the same trajectory. Benchmarks of several thousand contracts with annotated element types demonstrated that structured extraction of parties, dates, and payment terms was tractable with sequence models, and hierarchical recurrent architectures were applied to obligation and prohibition extraction.

Domain adaptation then proved decisive. Evaluations of BERT adaptation strategies for legal corpora, and the release of legal-domain encoder families, established that legal language is specialised enough to justify pretraining rather than relying on general-purpose encoders alone.

Lease-specific and consumer-contract-specific models followed, and the CLAUDETTE system showed that unfair term detection in consumer contracts could reach useful accuracy with deep models. CUAD, released in 2021, changed the field's centre of gravity by providing expert annotation at sufficient scale to make contract review a standard evaluation target. ContractNLI reframed clause-level review as document-level natural language inference, which is closer in shape to liability detection than span extraction is, because it asks whether a hypothesis is entailed by a document rather than where a string appears. LegalBench subsequently assembled a broad collaborative benchmark spanning many legal reasoning tasks, including the restructured CUAD classifications, and the MAUD dataset addressed merger agreement understanding. The ACORD dataset, released in 2025, filled a specific gap by providing expert-annotated retrieval data for contract drafting, noting that prior contract datasets were built for extraction and reading comprehension rather than for ranking, and therefore could not support information retrieval research without substantial additional annotation. The most directly relevant 2025 contribution is the ContractEval benchmark, presented at the Natural Legal Language Processing Workshop, which evaluated four proprietary and fifteen open-source models on clause-level legal risk identification using CUAD. Its findings are worth stating carefully, because they are frequently over-summarised. Proprietary models outperformed open-source models on correctness and output effectiveness, though some open-source models were competitive on specific dimensions. Larger open-source models generally performed better, with diminishing returns. The authors characterised overall performance as comparable to that of junior legal assistants and concluded that open-source models require targeted fine-tuning before use in high-stakes legal settings. The benchmark also introduced a laziness metric measuring the rate at which a model incorrectly reports that no relevant clause exists, which is a direct proxy for the false negative that matters most in compliance work. A methodological detail from the same study bears on architecture: the longest contract in the CUAD test set exceeds 300,000 characters, and evaluation was restricted to models with context windows of at least 128,000 tokens in order to process documents whole. Legal-specific models with smaller windows, including some purpose-built legal LLMs, were excluded on this basis. Domain specialisation and context capacity have been in tension, and in 2025 the general-purpose long-context models frequently won that trade.

A survey of AI and NLP in regulatory compliance presented at ACL Findings 2025 catalogued datasets for automated regulatory compliance and noted a structural limitation of the field: there is limited visibility into how large organisations actually deploy these systems, so the published literature systematically under-describes production practice. Domain-specific compliance systems include machine learning verification of data processing agreements against GDPR, decoding of regulatory documents with frontier models, and applications of natural language processing to surveillance and monitoring tasks in adjacent regulated domains (Atakpa et al., 2023). A recurring argument in this literature generalises well beyond any single domain: models focused on surface-level features and lacking explicit reasoning aligned to legal rules have limited utility in high-stakes settings, because compliance verification is normative and requires traceable, rule-grounded justification rather than a classification score.

2.2 Technical developments during 2025

By 2025 the context windows of frontier models comfortably exceeded the length of nearly all commercial contracts, removing a hard constraint that had shaped a decade of system design around chunking. It did not remove the underlying problem. The lost-in-the-middle effect shows

that retrieval performance within a long context is not uniform across positions, degrading for information located away from the beginning and end. For contracts this is a serious concern, because the provisions most relevant to regulatory liability, including limitation of liability, audit rights, and termination, are conventionally placed in the middle-to-late sections of an agreement, after the commercial terms and before the boilerplate. Two mitigations became standard. The first is explicit structural formatting: work in 2025 demonstrated that making document structure explicit in the input, through preserved headings and hierarchical numbering, improves legal document understanding relative to flattened text. Contracts are heavily structured artefacts, and discarding that structure during PDF extraction destroys signal that is expensive to recover. The second is to use long context as a verification stage rather than a search stage, retrieving candidate evidence first and then passing a focused context for adjudication.

The most consequential methodological development for this application was the arrival of legal-specific retrieval evaluation. LegalBench-RAG established a benchmark for retrieval-augmented generation in the legal domain, and the LRAGE toolkit provided instrumentation for legal RAG evaluation. Before these, practitioners tuned retrieval by intuition and measured only end-to-end answer quality, which conflates retrieval failure with reasoning failure and makes debugging nearly impossible. Several retrieval techniques proved well suited to contracts specifically. Hybrid lexical and dense retrieval matters because contracts contain defined terms that function as near-unique identifiers, and pure dense retrieval systematically underperforms on these, since embedding models normalise away exactly the surface distinctions a defined term encodes. Late chunking, in which contextual chunk embeddings are computed using long-context embedding models rather than embedding chunks in isolation, addresses a specific contract pathology: a clause fragment such as a cross-reference to a period specified elsewhere is semantically empty in isolation and meaningful only in document context. Hierarchical and structure-aware chunking, splitting on clause and sub-clause boundaries rather than token counts, preserves the units that regulatory rules actually target. And resolving defined terms to their definitions before retrieval measurably reduces a class of error in which a system reports the absence of a concept that is present under a contract-specific label. Chain-of-thought prompting had been established for some years, but 2025 saw the deployment of models trained specifically to allocate inference-time computation to reasoning. For regulatory liability detection this matters more than it does for extraction, because the task involves a genuine multi-step inference: identify the applicable rule, locate candidate evidence, read the substantive terms of that evidence, compare against the normative threshold, and determine whether any other provision qualifies the first. Statutory reasoning benchmarks established early that this class of inference is distinct from reading comprehension. The compliance-aligned framework literature makes the stronger argument that reasoning must be aligned to the legal rule structure rather than left free-form, because the output of a compliance system is consumed by a lawyer who must verify it, and verification is tractable only if the reasoning is structured in the same shape as the legal analysis the lawyer would perform. Comparable arguments appear in the audit literature on why automated findings must map to the control framework they are testing (Akomolafe et al., 2025; Fobellah, 2025b).

The move to schema-constrained generation, in which the model emits JSON conforming to a specified structure rather than prose, had two effects beyond convenience. It made grounding mechanically verifiable: if the schema requires that every finding carry evidence spans, and the spans are validated against the source document by exact string match after generation, then a whole category of fabricated citation is eliminated deterministically rather than probabilistically.

It also made abstention explicit, since a status enumeration that includes an abstain value permits the model to decline and permits the pipeline to route declines to human review rather than forcing a binary output under uncertainty. The importance of this is best understood against the empirical record on hallucination in legal AI. The preregistered evaluation of commercial AI legal research tools published in the *Journal of Empirical Legal Studies* in 2025 found that vendor claims about retrieval-augmented generation eliminating hallucination were overstated, a finding consistent with the broader hallucination corpus literature. RAG reduces but does not remove fabrication, and architectural verification is not optional.

Model sourcing became a substantive design question rather than a procurement one. Contract portfolios contain commercially sensitive and often privileged material, and a meaningful fraction of enterprise legal teams cannot send that material to a third-party API under their own client confidentiality obligations, their counterparties' contractual restrictions, or their regulators' data localisation expectations. Privacy-preserving architecture research for regulated-industry analytics addresses the same constraint directly (Atakpa & Abolaji, 2022; Mbonu et al., 2022a). This is why ContractEval's framing around local deployment for data confidentiality was well chosen, and its conclusion that open-source models are competitive on some dimensions but require targeted fine-tuning for high-stakes correctness sets a realistic expectation: an on-premises deployment is viable but is a fine-tuning project. Work comparing large general models against domain-trained models on structured contract tasks supports a hybrid conclusion. For narrow, well-specified extraction targets with adequate training data, a small fine-tuned model can approach or match a much larger general model at a fraction of the inference cost; for open-ended normative judgement, it cannot. Multi-stage pipelines in which a controller decomposes a compliance question into sub-questions, dispatches retrieval, and assembles findings also became common. The gains are real where the analysis genuinely requires iterative search across an arrangement's document set, and contract differencing work established the value of explicit comparison steps in this setting. The costs are also real: such pipelines multiply token consumption, introduce non-determinism that complicates audit, and can compound errors across steps. In a domain where a defensible audit trail is a regulatory requirement, unconstrained agency is a liability, and the pattern that reconciles these is bounded agency, meaning a fixed set of permitted operations, a maximum step count, and complete logging of every retrieval and intermediate judgement. This mirrors the orchestration and logging discipline established in security operations automation (Dosunmu & Ogundele, 2025c; Mbonu, Iwuanyanwu, et al., 2019). Confidence calibration received attention in high-stakes retrieval settings during the same period. For compliance deployment, calibration is not a refinement but the mechanism by which the system becomes economically useful, because the value of the system is not its accuracy but the reviewer hours it saves at an acceptable risk level. A system with 90 percent accuracy and well-calibrated confidence can be operated so that the top-confidence 60 percent of findings are accepted with a known and small error rate, and the remainder reviewed. A system with 93 percent accuracy and uncalibrated confidence cannot be operated that way at all, and every finding must be reviewed, which eliminates most of the benefit. Cyber risk quantification research makes the identical argument about the operational value of calibrated exposure estimates (Dosunmu & Ogundele, 2024b; Adegbite et al., 2025).

2.3 Compliance analytics in adjacent regulated sectors

The legal NLP literature treats regulatory liability detection as a self-contained problem. It is better understood as a specialisation of machine verification of an artefact against an external normative

standard, and several regulated sectors have been doing that at scale for longer than legal NLP has existed as a subfield. The purpose of surveying that work here is not to claim that these systems perform contract analysis, because with few exceptions they do not, but to identify design patterns already validated under supervisory scrutiny.

The financial audit function is the closest institutional analogue. It examines a population of artefacts against a normative standard, allocates finite assurance effort by risk, produces findings that must survive external challenge, and operates under a documented methodology. Conceptual and empirical work on technology-enabled internal audit quality, risk-based internal control models, and data-driven risk evaluation for financial institutions establishes the core pattern (Akomolafe & Agu, 2018; Akomolafe & Agu, 2019a; Akomolafe & Agu, 2019b; Akomolafe & Agu, 2019c). Later contributions extend this into risk-based auditing for strategic financial management, quantitative compliance risk assessment for emerging economies, and explicitly data-driven compliance analytics for risk governance (Akomolafe et al., 2023a; Akomolafe et al., 2023b; Akomolafe et al., 2025). Comparative analysis of SOX compliance frameworks in cross-border auditing bears directly on the multi-jurisdiction problem contract portfolios present (Agu et al., 2023a), while integrated data management and predictive risk forecasting address the data substrate on which any such analysis depends (Agu et al., 2023b; Agu et al., 2025). Procurement risk management in multinational enterprises has been treated within the same governance frame (Bello, Akomolafe, et al., 2023). Fraud analytics contributes the asymmetric-cost reasoning that Section 5 builds on. Predictive models for anti-money laundering detection, systematic reviews of machine learning in banking fraud detection, and anomaly detection in financial time series all operate in settings where the cost of a missed positive vastly exceeds the cost of an investigated false alarm (Atakpa, 2021; Atakpa & Abetoh, 2022; Atakpa & Fobellah, 2023). Audit analytics in healthcare financial oversight and artificial intelligence for healthcare payment fraud detection extend the same logic into a second regulated sector (Abetoh & Atakpa, 2024; Atakpa, Abetoh, et al., 2024). Privacy-preserving architectures for regulated-industry analytics under GDPR and HIPAA address a constraint contract analytics shares directly, namely that the data cannot always leave the perimeter (Atakpa & Abolaji, 2022). Work on portfolio risk optimisation, AI-driven risk assessment for investment fraud, financial due diligence, and predictive investment risk monitoring demonstrates the same detection pattern applied to transactional rather than textual evidence (Eboh & Aliliele, 2023; Eboh & Aliliele, 2024; Eboh & Aliliele, 2025a; Eboh & Aliliele, 2025b). Statistical forecasting for long-range trend estimation supplies the temporal dimension (Atakpa, Abolaji, et al., 2024), and work on cognitive bias in financial decision-making and on auditing AI-powered financial systems addresses the human and governance layers surrounding any automated finding (Fobellah, 2025a; Fobellah, 2025b). Public-sector accounting research contributes the statutory-reporting analogue, covering budget compliance and statutory reporting frameworks, reconciliation control redesign, cross-border segregation of duties, audit liaison and corrective action planning, and automated close controls embedded in public-sector ERP systems, all describing a control environment in which compliance determinations must be reproducible and auditable rather than merely accurate (Dogbatsey & Ebhojie, 2018; Dogbatsey et al., 2019; Dogbatsey et al., 2021; Ebhojie et al., 2023a; Oyeleye et al., 2025). Simulation-based approaches to accounting education illustrate how such control logic is transmitted to practitioners (Ebhojie et al., 2023b). Enterprise finance research supplies the decision-analytic framing. Financial analytics for enterprise value creation, tax governance and cross-border compliance analytics, transfer pricing risk assessment, and data-driven executive decision systems establish the pattern of

translating regulatory exposure into a quantified management input (Lawal & Oduleye, 2018a; Lawal & Oduleye, 2018b; Lawal & Oduleye, 2019a; Lawal & Oduleye, 2019b). Capital allocation decision models, alignment of planning analytics with corporate strategy, decision analytics for sustainable profitability, and behavioural financial analytics extend it (Lawal & Oduleye, 2021a; Lawal & Oduleye, 2021b; Lawal & Oduleye, 2023a; Lawal & Oduleye, 2023b). Comprehensive financial reporting for compliance and accountability, financial planning for sustainable profitability, and integrated predictive analytics for strategic forecasting address the reporting interface (Medon & Oduleye, 2022; Medon & Oduleye, 2023; Medon & Oduleye, 2024), as do models for cash flow optimisation and for measuring the strategic impact of financial analysis (Oduleye & Medon, 2023a; Oduleye & Medon, 2023b), while executive dashboards for real-time oversight and capital efficiency optimisation describe the delivery surface (Walawalkar, Adesuyi, et al., 2025; Walawalkar, Kalu, et al., 2025). Treasury research contributes multinational cash flow consolidation and FX risk control, CRM-based forecasting for lending institutions, CFO-led strategic finance in cross-border partnerships, post-pandemic resilience models for banks and capital markets, machine learning in insurance underwriting, and longitudinal evaluation of training effectiveness (Dada et al., 2021a; Dada et al., 2021b; Dada et al., 2024; Isiekwu et al., 2021; Isiekwu et al., 2025; Oluwo et al., 2024). DORA is, in substance, a third-party ICT risk regulation enforced through contract terms, which makes cybersecurity governance research subject matter rather than analogy. Continuous cloud misconfiguration monitoring, API governance and risk prioritisation in financial institutions, enterprise data sensitivity classification with regulatory traceability, and HIPAA-compliant data architecture establish the pattern of mapping technical state onto regulatory requirement (Aliliele et al., 2023a; Aliliele et al., 2023b; Aliliele et al., 2024a; Aliliele et al., 2024b). AI-assisted continuous auditing for technology risk oversight and data lakehouse governance for loss prevention extend it to the continuous case (Aliliele et al., 2025a; Aliliele et al., 2025b), and predictive analytics for institutional risk management shows the same machinery applied outside finance (Aliliele et al., 2023c). Legal and ethical risk modelling in enterprise data protection governance, comparative analysis of data protection regulations with secure cloud implementation, and data protection impact assessment models in multi-cloud financial infrastructure are the closest direct analogues to contractual gap analysis under a data protection regime (Mbonu et al., 2018; Mbonu, Aliliele, et al., 2019; Mbonu et al., 2022a). Identity and access management integration, infrastructure-as-code governance, cloud identity and access governance optimisation, and IT general controls with SOX audit automation supply the control-testing pattern (Mbonu et al., 2020; Mbonu et al., 2020b; Mbonu et al., 2022b; Mbonu et al., 2022). Risk-based business intelligence architecture in financial technology, AI techniques for secure software testing, applications of artificial intelligence in software testing, forensic analytics for fraud detection and regulatory compliance, enterprise log analytics with automated incident response, agile supply chain transformation with embedded IT risk controls, and deep learning for autonomous threat detection complete the picture (Mbonu et al., 2021a; Mbonu et al., 2021b; Borah et al., 2022; Mbonu et al., 2021; Mbonu, Iwuanyanwu, et al., 2019; Mbonu et al., 2020a; Odejobi et al., 2025).

Enterprise cyber defence research contributes the continuous-validation paradigm that Section 4 borrows for drift detection. Security audit and enterprise risk assessment frameworks, intrusion detection and prevention, incident response and digital forensics, threat intelligence integration, and threat actor analysis establish the operational base (Dosunmu & Ogundele, 2019; Dosunmu & Ogundele, 2020; Dosunmu & Ogundele, 2021; Dosunmu & Ogundele, 2022; Dosunmu &

Ogundele, 2023). Breach and attack simulation, cyber risk quantification for investment prioritisation, enterprise-scale continuous security validation for regulated infrastructures, and threat-informed defence engineering for measuring control effectiveness are the direct methodological parallels to continuous contract re-evaluation (Dosunmu & Ogundele, 2024a; Dosunmu & Ogundele, 2024b; Dosunmu & Ogundele, 2024c; Dosunmu & Ogundele, 2024d). Adversary simulation design, board-level cyber defence performance measurement, and security orchestration and automation address the governance and throughput layers (Dosunmu & Ogundele, 2025a; Dosunmu & Ogundele, 2025b; Dosunmu & Ogundele, 2025c). Network-layer and IoT-specific work on amplification attack mitigation, security in IoT-driven critical infrastructure, and the role of frameworks in cybersecurity governance rounds out the frameworks question (Jimoh & Ahmed, 2024; Jimoh, Abolle-Okoyeagu, et al., 2023; Jimoh, Ahmed, et al., 2023), while research on the effectiveness of security awareness training addresses the human factor determining whether any control regime holds (Onche et al., 2024).

Operational technology security is the sector where compliance verification against enumerated mandatory controls is most mature, because standards such as NERC CIP have required it for years. Systematic review of OT network security in electric utilities under NERC CIP is the closest existing analogue to enumerated-provision contract checking (Adegbite et al., 2020). Security architecture for IT and OT convergence in regulated energy networks, ICS and SCADA threat detection architectures, and zero trust architecture for OT in North American critical infrastructure describe the target state (Adegbite et al., 2022; Adegbite et al., 2023; Ahmed et al., 2021). Adversarial machine learning threat modelling and AI-augmented threat detection in industrial control systems address the reliability of the detection layer itself (Adebayo et al., 2022; Adebayo, Adegbite, et al., 2023). Vulnerability governance architecture moving from exposure mapping to remediation, AI-driven security operations for utility sector SOCs, and cyber risk quantification and governance architecture for critical infrastructure supply the escalation and prioritisation logic adapted in Section 4 for reviewer routing (Adegbite et al., 2024a; Adegbite et al., 2024b; Adegbite et al., 2025). Procurement research is where contracts are actually managed as a population rather than as individual documents, and it is therefore the most operationally relevant adjacent literature. Regulatory compliance and supplier risk assessment frameworks in international pharmaceutical procurement, and cross-border supplier relationship management, address the multi-jurisdiction problem directly (Akin-Oluyomi et al., 2023b; Akin-Oluyomi et al., 2024). Green procurement balancing cost against environmental responsibility and supplier sustainability metrics evaluated through data-driven frameworks describe obligations that increasingly flow into contract terms (Akin-Oluyomi et al., 2023a; Akin-Oluyomi, Okoruwa, et al., 2023). Process automation for procurement efficiency and transparency, negotiation optimisation, supplier relationship management for strategic objectives, and big data and business intelligence for procurement optimisation establish the automation baseline (Akinleye & Adeyoyin, 2021; Akinleye & Adeyoyin, 2022a; Akinleye & Adeyoyin, 2022b; Akinleye et al., 2023). Profitability analysis in retail procurement, predictive demand forecasting in e-commerce procurement, and data visualisation for procurement decision-making address the analytics interface (Akin-Oluyomi et al., 2020; Akin-Oluyomi, Atima, et al., 2023; Babatope et al., 2023). Data-driven operations management, sustainable procurement in local manufacturing, lean supply chain optimisation, and post-pandemic supply chain resilience indices supply the operational framing (Efobi et al., 2021; Efobi et al., 2022a; Efobi et al., 2022b; Efobi et al., 2023), while lean guardrails and multi-enterprise ETL architecture for autonomous value chains, decision frameworks reconciling

chemical safety with circular-economy targets, integrated digital platforms for procurement transparency, and digital procurement transformation for global supply chains describe the emerging automated state (Ogundairo, 2025; Okojie & Abioye, 2020; Okoruwa, Babatope, et al., 2024; Okoruwa et al., 2025). Energy and infrastructure procurement contribute the regulated-environment variant. Supply chain risk management for EPC and gas processing projects, GIS-enabled ERP procurement, data-driven vendor evaluation and bid selection, and supply chain resilience for critical infrastructure establish the sector context (Agbabiaka et al., 2019; Ahiaeke Patrick et al., 2020; Ahiaeke Patrick et al., 2021; Ogunwole et al., 2021). Digital supply chain governance, secure and scalable supply chain systems supporting national energy reliability, predictive procurement planning for operational uptime, procurement strategy and ERP adoption, digital supply chain models for cost control, and supply chain automation through service management platforms describe the systems layer (Okonkwo et al., 2024a; Okonkwo et al., 2024b; Okonkwo et al., 2024c; Okonkwo et al., 2024d; Okonkwo et al., 2024e; Okonkwo et al., 2024f). Demurrage elimination and port logistics efficiency, materials readiness, national-scale supply chain optimisation, IT systems engineering integrated with supply chain operations, and asset lifecycle management with inventory visibility extend it (Okonkwo et al., 2020; Okonkwo, Agbabiaka, et al., 2021; Okonkwo et al., 2025; Okonkwo, Ahiaeke Patrick, et al., 2023; Okonkwo, Mayo, et al., 2023). Most directly relevant, work on regulatory-compliant procurement in high-risk energy environments, strategic procurement optimisation in oil and gas, inventory availability and plant uptime, and cost reduction through contract negotiation and vendor governance addresses the contract layer explicitly (Okonkwo, Ogunwole, et al., 2021; Okonkwo et al., 2018a; Okonkwo et al., 2018b; Okonkwo et al., 2019). Programme and project governance research supplies the delivery model for large remediation efforts, covering project governance in multinational infrastructure, risk management and compliance frameworks in healthcare infrastructure projects, data centre lifecycle management, and strategic project management for energy deployments (Amayo et al., 2023a; Amayo et al., 2023b; Amayo et al., 2024a; Amayo et al., 2024b; Amayo et al., 2024c), alongside work on team composition and delivery success (Amayo et al., 2023c; Amayo et al., 2025a; Amayo et al., 2025b; Amayo et al., 2025c). Sustainability and traceability obligations are increasingly imposed through contract terms, which makes that literature directly relevant to detection of absent and defective provisions. Automated ESG reporting using blockchain-driven smart compliance management, digital twin-driven environmental compliance for sustainable procurement, and AI integrated with ESG metrics in infrastructure auditing describe automated verification of obligations originating in contracts (Abioye et al., 2023; Ike et al., 2025; Okojie, Filani, et al., 2023). End-to-end visibility frameworks for transparency, compliance, and traceability are the operational counterpart to the DORA register (Nnabueze et al., 2021). Predictive analytics for demand forecasting, real-time risk dashboards in hospital supply chains, quantitative risk architecture for public-private partnerships, nanomaterials in healthcare supply chains, supplier relationship management for resilience, and lean supply chain practices supply the analytics and operational layers (Aifuwa et al., 2020; Filani et al., 2022; Ike et al., 2024a; Ike et al., 2024b; Ike et al., 2021; Ike et al., 2022), while predictive monitoring of emissions and infrastructure risk, renewable energy programme strategy, preventive maintenance programme design, and policy and compliance programmes for safety and environmental standards demonstrate the same verification logic in energy contexts (Okojie, Ike, et al., 2023; Yeboah & Ike, 2020; Yeboah, Enow, et al., 2024; Yeboah, Enow, et al., 2025). Process improvement research contributes the workflow-design knowledge that determines whether a

compliance system is usable, spanning Lean Six Sigma adaptation for small enterprises, multi-stakeholder governance alignment in joint ventures, translation of tax and regulatory requirements into compliance workflows, and change management in digital transformation (Ambali et al., 2021; Eyetsemitan et al., 2020; Eyetsemitan et al., 2021; Eyetsemitan et al., 2023a), together with user acceptance testing, integrated lean-digital scaling, standard operating procedures as strategic assets, CRM and workflow automation, data-driven process optimisation, and cycle time reduction in client onboarding (Eyetsemitan et al., 2023b; Eyetsemitan et al., 2025; Eyetsemitan et al., 2022; Eyetsemitan et al., 2024a; Eyetsemitan et al., 2024b; Oyeleye et al., 2022).

Payments research is notable for treating the contract itself as executable, which inverts the detection problem. Global interoperability models for distributed ledger cross-border payments, AI-driven risk scoring for trade payment transactions, fraud detection ecosystems for international payment channels, and resilience models under geopolitical risk describe a regulated environment with continuous obligation monitoring (Adesuyi et al., 2023; Adesuyi et al., 2024; Adesuyi et al., 2025a; Adesuyi et al., 2025b). Smart contract automation for supplier payments and smart contract-based dispute resolution for international supplier payments are the closest existing systems in which contractual terms are machine-executed rather than machine-read (Akomolafe et al., 2022; Akomolafe et al., 2024b). Predictive models for remittance liquidity, scalable blockchain payment gateway architecture, collaborative governance for cross-border payment data sharing, and standardisation for payment interoperability address the infrastructure (Akomolafe et al., 2023; Akomolafe et al., 2024a; Akomolafe et al., 2025a; Akomolafe et al., 2025b), while regulatory compliance adaptation for payment product redesign and macroeconomic modelling of blockchain payment adoption address the rule-change dynamics that produce drift (Olaogun et al., 2023; Olaogun et al., 2025). Pharmaceutical regulation offers the most explicit treatment of regulatory readiness as a measurable organisational property, through cross-border regulatory harmonisation modelling, risk-based accelerated approval decision models, drug shortage early warning and regulatory response, integrated regulatory readiness maturity modelling, and pharmaceutical supply chain governance with environmental risk management (Eze et al., 2024a; Eze et al., 2024b; Eze et al., 2022a; Eze et al., 2022b; Eze et al., 2023). Healthcare cybersecurity and digital health governance contribute the sector-specific control literature, including cyber risk pricing and insurance structuring for health technology platforms, zero trust cost effectiveness in healthcare infrastructure, financial forensics for cyber-enabled fraud in telemedicine, and ransomware economics and financial resilience in hospital networks, all of which quantify regulatory and security exposure in financial terms (Adebayo, Adepoju, et al., 2023; Adebayo et al., 2025; Ekechi et al., 2022; Ozowara, Anunagba, et al., 2025). Blockchain-based cross-border data exchange with regulatory transparency, privacy-focused digital identity verification, machine learning for predictive energy management, cybersecurity investment and financial performance, and audit quality strengthened through data analytics complete that set (Kumuyi et al., 2023; Kumuyi et al., 2024b; Kumuyi et al., 2024a; Ozowara et al., 2022; Ozowara, Adebayo, et al., 2025). Digital health governance research addresses the oversight structures surrounding automated systems, covering comparative governance of AI-driven healthcare management, organisational readiness for generative AI integration, privacy-preserving health data governance, and AI-driven early detection systems (Afrihyia, Akinse, et al., 2024; Afrihyia et al., 2025; Afrihyia, Ojukwu, et al., 2024; Afrihyia et al., 2023), alongside work on equity and access in health interventions (Akinse, Ekechi, et al., 2023; Akinse, Ohanebo, et al., 2023). Related research on telehealth user trust and regulatory compliance, data-informed learning platforms, real-time analytics for performance

dashboards, ethical data practices in health education technology, digital equity, and data governance in digital health learning systems provides the trust and adoption evidence drawn on in Section 6 (Akintola et al., 2025; Orise & Niniola, 2020; Orise & Niniola, 2022; Orise & Niniola, 2023; Orise & Niniola, 2024; Orise & Niniola, 2025).

Aviation has the longest continuous history of regulator-mandated, evidence-based compliance monitoring, and its literature is unusually explicit about maturity and prediction. A predictive compliance monitoring framework for detecting systemic safety risks is a direct conceptual ancestor of portfolio-level liability detection (Adeyelu, 2018), and adaptive safety management system implementation, AI-driven risk quantification, management of encroachments through regulatory frameworks, risk-tiered oversight of unmanned aircraft, comparative benchmarking of certification compliance, and maturity modelling for predicting safety audit outcomes describe an ecosystem in which compliance state is continuously estimated and audit outcomes forecast rather than discovered (Adeyelu, 2019; Adeyelu, 2020; Adeyelu, 2021; Adeyelu, 2023; Adeyelu & Dagodzo, 2022; Adeyelu, Dagodzo, et al., 2024 [b]).

Contracts do not sit in a vacuum. They live in document management systems, CRM platforms, procurement suites, and ERP instances, and the quality of the ingestion layer described in Section 4 is determined by how those systems are governed. Governance frameworks for AI-assisted CRM workflows covering deployment and risk management, comparative evaluation of DevOps tooling, CI/CD pipeline strategies, ETL design and data integration, governance for regulated healthcare environments, privacy-by-design role-based security, version control and code review governance, and integration patterns in multi-cloud architectures describe the controls determining whether upstream data is trustworthy (Badmus et al., 2025; Badmus et al., 2020; Badmus et al., 2018; Badmus et al., 2019a; Badmus et al., 2019b; Badmus et al., 2024; Badmus et al., 2022a; Badmus et al., 2022b). Broader enterprise IT research addresses the operational environment, spanning offline assessment of security-critical systems, Active Directory attack signatures and enterprise network management, IT service management, integrated network and security operations, cloud migration lessons and best practices, ServiceNow for IT service management, and access control policies based on privacy requirements (Ladapo et al., 2018; Ladapo, Dosunmu, et al., 2023a; Ladapo et al., 2019; Ladapo, Dosunmu, et al., 2023b; Ladapo, Dosunmu, et al., 2024; Ladapo et al., 2025; Ladapo, Jooda, et al., 2022; Ladapo, Jooda, et al., 2023a; Ladapo, Jooda, et al., 2023b). Two contributions are directly methodological here: work on human-in-the-loop machine learning and on human-centred automated annotation with generative AI informs the reviewer-routing design in Section 4 (Ladapo, Dosunmu, et al., 2022; Ladapo, Jooda, et al., 2024). Service delivery research on predictive capacity planning, KPI-driven optimisation for IT service portfolios, identity-centric zero trust governance, security analytics and digital forensics for enterprise risk management, enterprise cybersecurity threat evolution, privacy-centric security engineering, and performance optimisation for high-demand technology programmes completes the operational picture (Edivri & Oteri, 2022; Edivri & Oteri, 2024; Ogbole et al., 2021; Ogbole et al., 2025; Okoruwa, Fadayomi, et al., 2024; Okoruwa et al., 2020; Oteri & Edivri, 2024).

The final cluster is the least obviously related and the most methodologically transferable, because these literatures have solved measurement problems compliance analytics has not. Attribution modelling addresses which evidence caused an outcome, which is structurally the same question as which clause satisfies a requirement, and systematic review of attribution methods resolving bias in multi-touch journeys, analytical models for return on investment measurement in regulated contexts, and machine learning models addressing uncertainty in cross-channel forecasting are the

relevant contributions (Sanni, Atima, et al., 2022; Sanni et al., 2020a; Wedraogo & Sanni, 2024). Process mining for auditable automation lifecycle control is a direct methodological import for the audit trail described in Section 4 (Sanni et al., 2025), as are federated learning for secure cross-organisational analytics and blockchain-enabled smart contracts for verifiable workflow provenance (Sanni et al., 2023; Sanni et al., 2024). Adaptive control models for AI-driven automation in financial compliance environments address the regulated deployment case explicitly (Sanni, Iwuanyanwu, et al., 2022). Analytics-driven frameworks addressing compliance and sustainability complexity, business intelligence dashboards resolving executive visibility gaps, market research in highly regulated industrial services, and data-driven positioning in regulated professional services describe the same tension between analytical ambition and regulatory constraint (Sanni & Atima, 2021a; Sanni & Atima, 2021b; Sanni & Attah, 2023c; Sanni et al., 2020b), and predictive segmentation, customer lifecycle prediction, telemetry-driven value realisation, adoption-gap analysis for supply chain AI, paradigm shifts for autonomous agents, digital transformation in capital markets, AI-assisted content optimisation, funnel optimisation, and product management in emerging markets complete the cluster (Atima et al., 2022; Ogundairo & Ayivi-Donkor, 2023a; Ogundairo & Ayivi-Donkor, 2023b; Ogundairo & Ayivi-Donkor, 2024a; Ogundairo & Ayivi-Donkor, 2024b; Sanni & Attah, 2023a; Sanni & Attah, 2023b; Sanni & Wedraogo, 2024; Sanni et al., 2020c). Predictive analytics research contributes forecasting and monitoring patterns through data-driven lifecycle performance management for infrastructure, predictive models for financial risk detection in public systems, performance intelligence for large-scale programmes, resilient logistics, and localised supply chain modelling (Adelanwa et al., 2023a; Adelanwa et al., 2023b; Adelanwa et al., 2024; Anene & Clement, 2022; Anene & Clement, 2024), together with audience segmentation and forecasting, real-time analytics and monitoring, attribution and yield optimisation, and traffic forecasting (Basnet et al., 2021; Basnet et al., 2023; Basnet et al., 2024; Oghenemaiga et al., 2024). Retail and operations analytics contributes demand forecasting for revenue projection, predictive cash flow modelling, geospatial predictive methods, algorithmic process optimisation, predictive cost optimisation, asset valuation, vendor risk assessment for procurement, real-time KPI tracking, and route optimisation (Tonoyan et al., 2021a; Tonoyan et al., 2021b; Tonoyan et al., 2022a; Tonoyan et al., 2022b; Tonoyan et al., 2022c; Tonoyan et al., 2023; Tonoyan et al., 2024a; Tonoyan et al., 2024b; Tonoyan et al., 2025), of which the vendor risk assessment contribution is particularly relevant, since it applies predictive modelling to precisely the counterparty population DORA's register obligation covers.

The survey extends further, into regulated domains where compliance obligations are enforced through documented evidence rather than through contract text. Relevance to contract analytics varies across these clusters, and they are included for the breadth of regulated practice they represent rather than as direct methodological precedents.

Occupational safety and construction risk management is the largest of these and the most institutionally similar, because contractor obligations in that domain are imposed contractually and verified by audit. Governance-oriented models for contractor safety performance in multi-contractor environments, governance frameworks for subcontractor safety performance management, and reviews of contractor safety compliance systems in infrastructure projects address the same principal-agent verification problem that third-party ICT risk regulation creates (Arumosoye & Obriki, 2020; Obriki & Arumosoye, 2024a; Obogo, Uduokhai, et al., 2021). Internal QHSE audit systems, incident investigation approaches oriented toward prevention learning, and reviews of occupational safety management systems in oil and gas maintenance

describe the assurance machinery (Obogo et al., 2020a; Obriki & Arumosoye, 2024b; Obogo et al., 2020c), while organisational learning-based maturity modelling for continuous safety performance, conceptual models for institutionalising safety practices across project organisations, and frameworks linking leading safety signals to sustained performance supply the graded-capability framing discussed at the close of this section (Arumosoye & Obriki, 2021; Obriki & Arumosoye, 2021; Obriki et al., 2025). Proactive hazard recognition and near-miss reporting, systematic review of near-miss and hazard observation data utilisation, hazard identification systems for large-scale construction, continuous hazard monitoring, and proactive hazard identification using digital safety data streams collectively describe continuous rather than periodic verification (Obogo, Arumosoye, et al., 2021; Arumosoye & Obriki, 2019; Obogo, Nwafor, et al., 2025; Obriki, Arumosoye, et al., 2023; Obriki & Arumosoye, 2023). Environmental safety compliance frameworks for construction and infrastructure, environmental risk control and ESG performance through waste handling, and sustainable environmental practices within safety management systems bear on obligations that increasingly appear in supplier contracts (Obogo, Ozobu, et al., 2024; Arumosoye et al., 2025; Obogo, Arumosoye, et al., 2024). The remaining contributions in this cluster address heat stress risk modelling, lifting and rigging risk pathways, crane installation risk management, emergency response readiness, emergency preparedness and evacuation in high-density buildings, safety leadership in temporary project organisations, leadership-driven safety culture transformation, safety culture development in construction, safety governance for large commercial facilities, integrated safety management for multi-zone urban infrastructure, hazard identification and risk control in urban construction, incident prevention in industrial maintenance, construction safety risk governance for multi-contractor environments, data-driven occupational safety risk control in energy operations, management safety walkthrough frequency and coverage, human error causation, recurrence mechanisms of unsafe behaviours, workforce safety training, and behavioural safety programmes (Arumosoye & Obriki, 2018; Arumosoye & Obriki, 2022; Obogo et al., 2020b; Arumosoye & Obriki, 2023; Obriki et al., 2022b; Arumosoye & Obriki, 2024; Obogo et al., 2019a; Obogo et al., 2023; Obogo et al., 2022; Obogo, Sanusi, et al., 2025; Obogo et al., 2019; Obogo, Obriki, et al., 2021; Obogo et al., 2019b; Obriki & Arumosoye, 2018; Obriki & Arumosoye, 2019; Obriki & Arumosoye, 2020; Obriki & Arumosoye, 2022; Obriki et al., 2022a; Obriki, Obogo, et al., 2023).

Physical asset and corridor oversight contributes the remote-evidence problem, in which compliance state must be established for assets no inspector can visit at the required frequency. Conceptual frameworks for UAV integration into national grid inspection programmes, reviews of UAV applications in transmission line inspection, UAV-based pipeline and corridor monitoring, and integrated UAV, LiDAR, and GIS frameworks for corridor management describe the evidence acquisition layer (Dagodzo, 2018a; Dagodzo, 2018b; Dagodzo & Ahiaeké Patrick, 2020; Dagodzo & Ahiaeké Patrick, 2021b). GIS applications in utility asset management, integration of drone operations into enterprise GIS systems, right-of-way encroachment detection using geospatial technologies, national-scale UAV deployment in power infrastructure, and deep learning for vegetation classification in corridor management extend it (Dagodzo & Ahiaeké Patrick, 2021a; Dagodzo & Ahiaeké Patrick, 2023a; Dagodzo & Ahiaeké Patrick, 2022; Dagodzo & Ahiaeké Patrick, 2025; Dagodzo et al., 2022), while review of UAV regulatory frameworks in developing economies addresses the jurisdictional variation that any multi-country compliance system must accommodate (Dagodzo & Ahiaeké Patrick, 2023b). Related work on regulatory evidence frameworks for assessing unauthorised structures within protected surfaces, and on data-driven

wildlife hazard monitoring, applies the same evidence logic in aviation settings (Adeyelu, 2022; Adeyelu, Dagodzo, et al., 2024). Autonomous mobile robotics research contributes path planning and slotting optimisation for high-density fulfilment, systematic review of AI-driven autonomous mobile robots in micro-fulfilment, and multi-agent frameworks for robot fleet coordination, all of which describe automated decision systems operating under operational constraint (Akanbi & Sunday, 2024; Akanbi & Sunday, 2025; Akanbi et al., 2025).

Regulated facility design and health system delivery supply a further variant, in which compliance is designed into an asset rather than verified after the fact. Regulatory-compliant design systems for molecular and pathology laboratories, risk-managed construction strategies for highly regulated healthcare facilities, and governance and accountability models for public-private partnerships in healthcare infrastructure are the closest analogues (Ogbete et al., 2019; Ogbete et al., 2021; Aminu-Ibrahim et al., 2024). Cost control and financial accountability frameworks for national healthcare construction, lifecycle performance evaluation of purpose-built diagnostic laboratories, sustainable performance metrics for long-term asset management, and BIM-enabled coordination for complex medical facility delivery describe the assurance and lifecycle layers (Aminu-Ibrahim et al., 2025a; Ogbete et al., 2023; Aminu-Ibrahim et al., 2025c; Ogbete et al., 2025a), while healthcare infrastructure as a public health intervention, sustainable diagnostic laboratory models for resource-constrained settings, capital project delivery for high-risk healthcare infrastructure, infrastructure-driven expansion of diagnostic access, infrastructure resilience planning under public health stress, translation of infrastructure investment into population health outcomes, laboratory spatial planning, sustainable materials and energy efficiency in medical laboratories, design standards for blood collection networks, and healing-centred design principles complete the cluster (Aminu-Ibrahim & Ogbete, 2023; Aminu-Ibrahim et al., 2018; Aminu-Ibrahim et al., 2019; Aminu-Ibrahim et al., 2020; Aminu-Ibrahim et al., 2025b; Ogbete & Aminu-Ibrahim, 2024; Ogbete et al., 2018; Ogbete et al., 2020; Ogbete et al., 2022; Ogbete et al., 2025b). Health system strategy research contributes the data backbone governance and architecture framework for system transformation, real-world evidence and predictive analytics for decision making, and analysis of artificial intelligence as a force multiplier together with its implementation risks (Ilodigwe & Adesemoye, 2021; Ilodigwe & Adesemoye, 2024a; Ilodigwe & Adesemoye, 2025a), alongside health insurance financing and provider payment reform, the gap between scientific innovation and system adoption, pharmacy-led delivery models, strategic frameworks for resilient health systems, and change models for executing transformation at scale (Ilodigwe & Adesemoye, 2019a; Ilodigwe & Adesemoye, 2019b; Ilodigwe & Adesemoye, 2020; Ilodigwe & Adesemoye, 2024b; Ilodigwe & Adesemoye, 2025b). Pharmaceutical care research contributes quality assurance in pharmaceutical manufacturing reconceptualised as a determinant of access, lean process improvement for pharmaceutical inventory and distribution, and supply chain inefficiencies affecting affordability (Asiedu & Asiedu, 2024b; Asiedu, 2025; Asiedu & Asiedu, 2023b), together with drug interaction risk frameworks in antenatal care, diagnostic integration in infectious disease management, digital PCR for viral reservoir quantification, last-mile distribution barriers, comparative bioavailability of botanical compounds, and equitable access to chronic therapies (Asiedu, 2022; Asiedu, 2023; Asiedu, 2024; Asiedu & Asiedu, 2022; Asiedu & Asiedu, 2023a; Asiedu & Asiedu, 2024a). Clinical research in this collection covers hypertension management guidelines, lifestyle modification and cardiovascular health, triglyceride-glucose index association with cardiovascular risk, plant-based diets, nurse-led dementia care interventions, integration of metabolic indices with echocardiographic

parameters, and coordinated project management for multisite rehabilitation implementation (Abah, Oladosu, et al., 2025; Abah, Oladosu, Yohanna, et al., 2025; Amadi et al., 2025; David et al., 2025; Obi et al., 2025; Okwah, 2022; Omo Enabulele et al., 2025).

Energy and environmental engineering contribute the monitoring and prediction layer that continuous compliance verification depends on. Transitioning from reactive to predictive maintenance in mechanical systems, smart fault detection in HVAC systems using sensor-based monitoring, vibration-based condition monitoring of rotating machinery, and thermodynamic efficiency and control strategies in residential air conditioning describe condition-based rather than schedule-based assurance (Sunday et al., 2020; Sunday & Omoegun, 2022; Omoegun et al., 2023; Sunday et al., 2019). NDT-based integrity management and corrosion risk assessment, non-destructive testing for weld integrity in high-capacity systems, welding inspection standards and quality assurance practices, and green corrosion inhibitors address inspection against engineering standards (Atta et al., 2020; Atta et al., 2021; Atta et al., 2022; Atta et al., 2018), while solar integration in small-scale manufacturing and electrical load distribution optimisation for hybrid installations address deployment (Sunday & Omoegun, 2018; Sunday & Omoegun, 2019). Energy transition research contributes interpretable machine learning for early failure prediction in distributed renewable systems, tiered digital twins bringing predictive diagnostics to resource-constrained assets, edge intelligence for resilient microgrid control, and smart grid architectures for high renewable penetration (Komi & Adamolekun, 2021; Komi & Adeniji, 2023; Komi & Ganiu, 2023; Adenuga, 2022), alongside hybrid deep learning for wind power forecasting, fairness constraints in deep learning load prediction, control architecture review for distributed systems, battery storage in weak-grid regions, and multilevel inverter design (Komi, 2021; Komi, 2023; Komi & Adamolekun, 2022; Komi & Ganiu, 2022; Tackie et al., 2023). A distinct sub-thread treats equity as a measurable compliance-adjacent property, covering social license as a predictable variable, diversification pathways beyond one-for-one job replacement, econometric and skills-mapping analysis of worker displacement, co-optimisation of technical performance and community affordability, financing mechanisms for inclusive access, causal links between community trust and project survival, and intersectional frameworks in universal programmes (Komi, 2024; Komi, 2025; Komi & Adamolekun, 2024; Komi & Adeniji, 2020; Komi & Adeniji, 2024a; Komi & Adeniji, 2024b; Komi & Ganiu, 2025). Produced water research addresses lifecycle risk assessment in offshore management, integrated treatment strategies, decentralised systems for remote assets, and resource recovery and beneficial reuse (Falegan & Aniebonam, 2022; Falegan & Aniebonam, 2023; Falegan & Aniebonam, 2024; Falegan & Aniebonam, 2025). Renewable fuels and materials work covers environmental corrosion and degradation of crystalline silicon cells, charge transport and recombination losses in thin film cells, rubber seed and used cooking oil in diesel, renewable energy in telecommunications, and hydrogen infrastructure (Atta et al., 2025; Atta et al., 2024; Bello, Azeez, et al., 2023; Monye, Bello, et al., 2025; Monye, Daniyan, et al., 2025). Power systems and telecommunications engineering contributes power electronics and efficiency review, voltage control with distributed generation, telecommunication deployment for network quality, and objective function optimisation for single-phase induction motors (Adenuga, 2023; Oshevire et al., 2017; Amayo & Popoola, 2017b; Amayo, 2017; Amayo & Popoola, 2017a; Amayo et al., 2015). Energy-harvesting and wireless systems research contributes systematic review of radio frequency harvesting strategies, maintenance-free wireless infrastructure simulation, energy, reliability, and latency trade-offs in green communication, epoch-aligned reliable broadcast in intermittent sensor networks, characterisation frameworks for

those trade-offs, impedance mismatch modelling, throughput degradation prediction in Wi-Fi 6 networks, and test automation in wireless hardware engineering (Asiedu & Quainoo, 2023a; Asiedu & Quainoo, 2023b; Asiedu & Quainoo, 2024; Asiedu & Quainoo, 2025; Asiedu et al., 2025; Quainoo et al., 2024; Quainoo et al., 2025a; Quainoo et al., 2025b).

Agricultural and food value chains carry traceability, safety, and policy-alignment obligations that increasingly reach supplier contracts. Analysis of alignment between agricultural policy frameworks and national sustainable development targets, data-driven agricultural policy models, and circular economy frameworks for waste reduction and resource efficiency describe the policy-to-practice translation problem (Michael & Ogunsola, 2021a; Michael & Ogunsola, 2021c; Michael & Ogunsola, 2024b). Digital agriculture tools shaping inclusive food systems, digital platform integration for market access, predictive data models for crop resilience, quantitative agricultural economics models for system efficiency, and artificial intelligence in agricultural decision-making describe the analytics layer (Michael & Ogunsola, 2021b; Michael & Ogunsola, 2023b; Michael & Ogunsola, 2023c; Michael & Ogunsola, 2023a; Michael & Ogunsola, 2025c), while agribusiness finance access, agribusiness education and entrepreneurial competencies, climate-smart practice contribution to household food security, extension services and innovation adoption, socioeconomic barriers to technology adoption, gender inclusion across value chains, rural innovation hubs, entrepreneurship education in agribusiness curricula, renewable energy for sustainable irrigation, international research collaboration, rural agribusiness innovation strategies, diversification for economic volatility, and sustainable agriculture curriculum integration complete the cluster (Michael & Ogunsola, 2019a; Michael & Ogunsola, 2019b; Michael & Ogunsola, 2021d; Michael & Ogunsola, 2021e; Michael & Ogunsola, 2022a; Michael & Ogunsola, 2022b; Michael & Ogunsola, 2023d; Michael & Ogunsola, 2023e; Michael & Ogunsola, 2024a; Michael & Ogunsola, 2024c; Michael & Ogunsola, 2025a; Michael & Ogunsola, 2025b; Michael & Ogunsola, 2025d). Livestock and feed science contributes the product-safety verification analogue, most directly through aflatoxin detection and quantification in commercially available poultry feeds, which is a contaminant-against-threshold test structurally similar to the defective-provision detection described in Section 3 (Tawose, Oluwadele, et al., 2023). The remainder of that cluster covers acceptability and utilisation of graded forage levels, physiological responses of sheep to graded diets, phenotypic characterisation of indigenous chickens, farm residue feeding and nitrogen balance, silage supplementation, cooking method effects on meat quality, alternative energy sources in broiler diets, feed intake and carcass characteristics, dietary fibre optimisation, cost-benefit analysis of alternative feeds, stress indices in scavenging chickens, nutritional potential of tuber peel meals, water hyacinth and cassava peel silage utilisation, and haematological responses to that silage (Aye & Tawose, 2015; Aye & Tawose, 2016; Ekeocha et al., 2021; Oluwadele, Aganga, et al., 2025; Oluwadele, Aganga, et al., 2024; Oluwadele, Tawose, et al., 2024; Oluwadele, Samuel, et al., 2025; Oluwadele, Tawose, et al., 2024 [b]; Oluwadele, Akinlabi, et al., 2025; Oluwadele, Ekeocha, et al., 2025; Oluwadele et al., 2023; Tawose & Oluwadele, 2025; Tawose, Ekeocha, et al., 2023; Tawose et al., 2024). Agricultural process engineering contributes development and evaluation of poultry de-feathering machinery, gum production from cassava waste peels, and factor analysis of de-feathering machines (Bello, Adama, et al., 2022; Bello et al., 2024; Bello, Tawose, et al., 2022).

Education research contributes two threads of direct relevance. The first is statutory compliance in special education services, where documentation adequacy is itself the regulated artefact: comprehensive review of IDEA compliance frameworks, critical review of procedural safeguards

and regulatory compliance, conceptual risk assessment models for special education documentation and accountability, and conceptual models for monitoring implementation fidelity and service delivery describe a regime in which the completeness and defensibility of a written record determines legal exposure, which is the closest structural parallel to contract liability detection found anywhere in this collection (Oloto & Yeboah, 2022; Oloto & Yeboah, 2024; Oloto & Yeboah, 2025; Yeboah & Oloto, 2023). Data-driven individualised programme development, systematic review of behaviour intervention plan effectiveness, PBIS integration models, structured parent engagement frameworks, comparison of behavioural intervention approaches, inclusive instructional frameworks, and data-driven personalisation using student progress data extend that thread (Yeboah & Oloto, 2022; Oloto & Yeboah, 2023; Yeboah & Oloto, 2025a; Yeboah & Oloto, 2025b; Ogbona et al., 2023; Yeboah & Oloto, 2024; Yeboah et al., 2022). The second thread concerns multilingual documentation, where terminological challenges in the translation of civil registry and administrative documents, and comparative analysis of administrative French in Francophone African states, bear directly on the non-English contract analysis gap identified in Section 6 (Kpoka, 2024; Kpoka, 2023). The remaining contributions address ICT and mathematical thinking, comparative mathematics curriculum reform, pedagogical strategies in resource-constrained settings, teacher education curriculum reform for special learning needs, structured advising and mentorship for academic recovery, belonging-centred retention modelling, multilingual ecofeminism and environmental justice, intersectionality and identity, cross-disciplinary language and collaboration, cross-cultural communication, leadership supporting student-athlete mental health, coaching education and career transition, home-school partnerships, AI-powered personalisation and hyperlocalisation in basic education, technology integration and accessibility, professional development and teacher competence, and teacher resilience and retention (Boakye et al., 2020; Boakye et al., 2021; Bobga et al., 2018; Bobga et al., 2025; Githinji & Atobatele, 2025a; Githinji & Atobatele, 2025b; Lilian et al., 2024; Lilian et al., 2025a; Lilian et al., 2025b; Lilian et al., 2020; Ogbona et al., 2024; Ogbona et al., 2020a; Ogbona et al., 2020b; Seun et al., 2023; Seun, Elumilade, et al., 2024; Seun, Yeboah, et al., 2024; Yeboah et al., 2019; Yeboah, Bobga, et al., 2024; Yeboah, Bobga, et al., 2025).

Finally, international relations research addresses the jurisdictional dimension that Type 4 conditional liabilities depend on, since whether a contractual arrangement is compliant frequently turns on the regulatory posture of a counterparty's jurisdiction rather than on the instrument itself. Cross-border security cooperation modelling, policy alignment modelling between national policy and global climate commitments, and governance reform impact modelling describe how jurisdictional posture is formalised as an analytical variable (Liadi, 2024c; Liadi, 2022a; Liadi, 2024b), while continental peace integration frameworks, peacebuilding effectiveness frameworks, linkage of diplomatic engagement to sustainable development outcomes, economic interdependence modelling, oil diplomacy diversification, soft power projection, and humanitarian diplomacy modelling complete that cluster (Liadi, 2022b; Liadi, 2022c; Liadi, 2023a; Liadi, 2023b; Liadi, 2023c; Liadi, 2024a; Liadi, 2024d).

Four patterns from this body of work transfer cleanly. Every mature compliance discipline surveyed allocates verification effort in proportion to consequence rather than uniformly, a discipline contract analytics has not adopted and whose absence explains the metric conventions criticised in Section 5. Security control validation, OT monitoring, and ESG traceability have all moved from point-in-time assessment to continuous re-evaluation, whereas contract analysis remains predominantly project-shaped. Aviation and pharmaceutical regulation both treat

compliance capability as a graded organisational property with predictive value for audit outcomes, whereas contract compliance is still treated as binary per clause. And process mining, forensic analytics, and audit liaison research all treat the reconstructability of a determination as equally important to its correctness. Two patterns do not transfer. Most of these systems verify structured signals against thresholds, whereas contract liability detection must first construct the signal from unstructured natural language, introducing an error source the adjacent literatures do not face. And the normative standards in security and safety domains are typically more precisely specified than contractual language permits, so the interpretive burden falls more heavily on the rule base in the legal case.

3. Problem Definition

A regulatory liability in a contract is here defined as a state of the contractual text, or of the arrangement it documents, that places a party in actual or prospective breach of an external legal requirement, or that fails to secure a right or protection an external legal requirement obliges the party to secure. Three features of this definition matter for system design.

It is external-referential. The liability does not exist in the contract alone; it exists in the relation between the contract and a regulatory instrument. A contract with no audit rights clause is unremarkable commercially and defective under DORA. The system therefore cannot be trained to recognise liabilities as intrinsic textual properties and must carry an explicit representation of the applicable rule, which is the same structural insight underpinning traceability-oriented data classification, where sensitivity is a property of the regulatory mapping rather than of the data itself (Aliliele et al., 2024a). It is asymmetric in cost. A false negative on a mandatory clause means the organisation reports compliance it does not have, and the error surfaces during supervisory examination. A false positive means a lawyer spends twenty minutes confirming the clause is present. These are not commensurable outcomes, and any metric that averages them discards the information that matters. Risk-based auditing has long operated on this premise, allocating assurance effort in proportion to consequence rather than uniformly (Akomolafe & Agu, 2018; Akomolafe & Agu, 2019a; Akomolafe et al., 2023a). It is temporally unstable. The rule base changes, and the EU AI Act timeline has already been amended once through the digital omnibus process, moving certain high-risk obligations. A contract compliant against the March rule base may not be compliant against the November one, so systems must treat the rule base as versioned data rather than as training signal baked into weights, a requirement paralleling the design of regulatory adaptation models in payment product governance (Olaogun et al., 2023). Existing contract NLP benchmarks are dominated by one liability type. A working taxonomy is broader. Type 1 is an absent mandatory provision, where the regulation requires a term and the contract does not contain it. This is the type most amenable to automation and the type most benchmarks approximate, though it is harder than it appears, because absence must be established across the whole document set for an arrangement, and because a provision may be present in substance under an unexpected heading or in an unexpected instrument. Type 2 is a present but defective provision, where the term exists but fails a substantive threshold: a notification clause specifying fifteen business days where the regulation contemplates immediate notification, or a termination right conditioned on the counterparty's consent. Detection requires reading a value out of the clause and comparing it against a normative threshold, which is a different computational operation from classification. Type 3 is a prohibited or incompatible provision, where the contract contains a term

the regulation does not permit or that conflicts with a mandatory term elsewhere; unfair terms detection in consumer contracts is the mature example.

Type 4 is conditional liability, where the provision is compliant only if a factual predicate holds. A subcontracting clause may be adequate provided the subcontractor is not located in a jurisdiction lacking an adequacy decision. The contract text alone cannot resolve the question, so the system must either fetch external data or mark the finding as conditional and route it to a human with the predicate made explicit. Comparative studies of data protection regimes and cross-border governance describe exactly this dependency on jurisdictional facts external to the instrument (Mbonu, Aliliele, et al., 2019; Annan, 2022). Type 5 is cross-instrument liability, where the defect emerges from the interaction of documents: the master agreement grants audit rights, an amendment three years later narrows them, and a side letter suspends them for one region. No single document is defective; the arrangement is. Type 6 is drift liability, where the contract was compliant when executed and is not compliant now, because the rule changed, the counterparty was subsequently designated as a critical provider, or the service was reclassified as supporting a critical or important function. Detection requires re-evaluation triggered by changes in the rule base or in entity metadata rather than by changes in the document, and continuous monitoring architectures developed for cloud misconfiguration and control validation address the analogous problem in infrastructure (Aliliele et al., 2023a; Dosunmu & Ogundele, 2024c). Types 4 through 6 are essentially absent from public benchmarks, and any claim that a system solves contract compliance review should be read as a claim about Types 1 and 3.

This is why the task is not clause extraction. The Contract Understanding Atticus Dataset established clause extraction as the canonical contract NLP task, annotating provisions across 41 categories, and LegalBench restructured much of that data into binary classification tasks. Those results are genuine but measure a different thing. Clause extraction asks whether a limitation of liability clause is present and where. Regulatory liability detection asks whether, given a specific article of a specific regulation, the arrangement satisfies the requirement, on what evidence, and if not, what the specific gap is. The second question requires the first as a subroutine and adds a normative comparison, an evidence chain, and an actionable output. Extraction accuracy therefore sets an upper bound on liability detection accuracy but does not predict it: a system with excellent retrieval of termination clauses may still fail systematically at Type 2 defects because it never learned to read thresholds against a rule.

Formally, let an arrangement $A = \{d_1, \dots, d_n\}$ be a set of documents, let $R = \{r_1, \dots, r_m\}$ be a versioned rule base in which each rule r_j carries a predicate, an applicability condition, and a severity weight w_j , and let M be arrangement metadata covering counterparty, service classification, jurisdiction, and criticality. The task is to produce, for each applicable rule, a finding:

$$f_j = \langle \text{status}_j, E_j, c_j, g_j \rangle$$

where $\text{status}_j \in \{\text{satisfied}, \text{deficient}, \text{conditional}, \text{abstain}\}$, E_j is a set of evidence spans with document and character offsets, $c_j \in [0,1]$ is a calibrated confidence, and g_j is a natural language gap description conditioned on E_j . Two constraints distinguish this from a classification objective. First, E_j must be verifiable, in that every span must exist verbatim in some d_i , which permits mechanical validation of grounding independent of the model. Second, the abstain option must be available and must be costed, because forcing a decision under uncertainty in a high-stakes domain converts a manageable workload problem into an unmanageable reliability problem.

4. System Architecture

The layered design described below is synthesised from the techniques surveyed in Section 2.2, from reported practice in large remediation programmes, and from the cross-sector patterns identified at the close of Section 2.3. It targets portfolios in the range of ten thousand to several hundred thousand documents.

Table 1. Layer functions and the failure modes they address, presented top-down from output to input.

Layer	Function	Primary failure mode addressed
L7	Audit trail, versioning, reproducibility store	Undefensible determinations under supervisory review
L6	Verification, calibration, human routing	Uncalibrated confidence, ungrounded evidence
L5	Arrangement-level reconciliation across instruments	Type 5 cross-instrument liabilities
L4	Clause adjudication against rule predicates	Type 2 defective provisions, threshold misreading
L3	Evidence retrieval, hybrid and structure-aware	Type 1 false negatives from retrieval miss
L2	Rule base of versioned predicates and applicability logic	Type 6 drift liabilities, interpretive opacity
L1	Document typing, arrangement assembly, scope triage	Fragmented arrangements, out-of-scope processing cost
L0	Ingestion, OCR, layout and structure preservation	Silent text loss, destroyed clause hierarchy

Ingestion and structure preservation (L0). Most enterprise contract corpora are heterogeneous, comprising native PDFs, scanned executions, Word originals, and images embedded in email. The dominant failure mode at this layer is silent quality loss: a scanned amendment that OCRs poorly does not raise an error but produces text retrieval will never match, and the resulting finding is a confident false negative. Design requirements are per-document OCR confidence scoring with quarantine below threshold, preservation of heading hierarchy, clause numbering, and table structure rather than flattening to plain text, retention of character offsets against the source rendering so evidence spans can be displayed in place, and explicit handling of tables, since service levels and notification periods frequently live in tables that naive extraction destroys. Data quality governance research in enterprise environments treats this ingestion boundary as the principal determinant of downstream analytical reliability (Aliliele et al., 2025b; Badmus et al., 2020).

Arrangement assembly and triage (L1). Documents must be grouped into arrangements before analysis, and arrangements scoped before expensive processing. Under DORA, defining which services are in scope is itself a substantive exercise that supervisors expect to be documented, and broad definitions of ICT services pull in categories such as data analytics and data feeds previously outside regulatory guidance. Assembly links master agreements to their amendments, order forms, and schedules through a combination of metadata matching, counterparty entity resolution, and explicit cross-reference extraction from document text. Triage applies a cheap classifier to determine whether an arrangement is in scope so that the expensive layers process a filtered set, and should be tuned to high recall with a deliberately generous margin, since the cost of over-inclusion is compute and the cost of under-inclusion is an undetected liability. Vendor evaluation and supplier segmentation research supplies mature methods for the entity resolution and classification steps (Ahiaeke Patrick et al., 2021; Tonoyan et al., 2024a).

Rule base and retrieval (L2 and L3). Converting a regulatory article into a set of machine-checkable predicates is legal interpretation. It determines everything the system can detect and cannot be automated away, because the interpretive choices carry professional responsibility. Practice emerging during 2025 DORA programmes suggests the rule base requires versioning with effective dates so findings can be reproduced against the rule base as it stood on the assessment date, provenance to source so each predicate cites the specific article, paragraph, and any implementing technical standard it derives from, explicit interpretive notes recording where the legal team resolved ambiguity and how, severity weighting distinguishing provisions whose absence is a hard breach from those where a deficiency is a supervisory finding, and applicability logic, since most rules apply conditionally based on service classification, counterparty type, or criticality designation. Organisations that treated the rule base as a spreadsheet of keywords produced systems that failed on Type 2 defects; organisations that treated it as a structured, versioned, legally owned artefact produced systems that could be re-run when the interpretation changed, which happened repeatedly during 2025 as technical standards were finalised. The regulatory readiness maturity literature makes the same point about the difference between documented and undocumented interpretive positions (Eze et al., 2022b).

For each applicable predicate, the retrieval layer assembles a candidate evidence set from the arrangement. The retrieval query is derived from the rule rather than from the document, which is the inversion distinguishing this design from clause extraction pipelines. Practical configuration combines hybrid sparse and dense retrieval with reciprocal rank fusion, retrieval over clause-level units with late-chunked contextual embeddings, a deliberately high candidate count, since the adjudication layer can discard irrelevant candidates but cannot recover evidence retrieval never surfaced, and a query expansion step including the contract's own defined terms as resolved at L0. Retrieval recall should be measured independently against a held-out annotated set, because retrieval failure and adjudication failure require entirely different remedies and are indistinguishable from end-to-end output.

Adjudication (L4). The adjudication layer receives a rule predicate and a candidate evidence set and produces a finding. Every non-abstaining finding must cite spans, and spans are validated post hoc by exact match, with findings failing validation rejected and reprocessed or escalated. The prompt or fine-tuning target should require the model to walk the elements of the predicate in order rather than produce free-form justification. The status enumeration includes an abstain value with

a required reason, and abstention rate is monitored, since a rising rate signals rule base ambiguity or corpus drift and is useful telemetry rather than a failure. Cascade routing sends findings with unambiguous evidence and mechanical threshold comparison to a cheap model, and Type 2 defects, conflicting evidence, and anything the cheap model abstains on to a stronger reasoning model. In portfolios the majority of rule-arrangement pairs would be expected to resolve at the cheap tier, which is what makes the economics work at scale.

Arrangement-level reconciliation (L5). This layer addresses Type 5 liabilities. Its input is the full set of clause-level findings for an arrangement plus the document chronology, and its function is to detect contradictions and supersessions: a right granted in the master agreement and narrowed by a later amendment, two schedules specifying different notification periods, an exit assistance obligation whose duration is inconsistent between instruments. Implementation is naturally graph-based, with nodes as provisions and edges as amends, supersedes, references, and conflicts-with relations extracted from cross-reference language, so that conflict detection reduces to graph queries, which are deterministic and auditable rather than requiring further model inference. End-to-end traceability architectures in supply chain assurance solve a structurally identical reconciliation problem across custody events rather than across instruments (Nnabueze et al., 2021; Okonkwo, Mayo, et al., 2023). This layer is the least mature in reported practice and is where the largest accuracy gains would be expected over the next development cycle.

Verification, calibration, and human routing (L6). Mechanical verification confirms span existence, schema conformance, and internal consistency between the status and the cited evidence. Calibration maps raw model confidence to an empirically calibrated probability using a labelled validation set, with recalibration whenever the model, prompt, or rule base version changes. Routing assigns findings to review queues by expected cost, computed as the product of calibrated error probability and rule severity weight; this ordering, rather than confidence alone, is what maximises risk reduction per reviewer hour. A low-confidence finding on a low-severity rule may reasonably be accepted unreviewed, while a high-confidence finding on a hard-breach rule may still warrant sampling. Vulnerability governance research provides a validated precedent for exactly this exposure-times-severity queueing discipline (Adegbite et al., 2024a; Dosunmu & Ogundele, 2024b), and human-in-the-loop machine learning research supplies the interaction design (Ladapo, Dosunmu, et al., 2022).

Audit trail (L7). Every finding must be reproducible, so the rule base version, model version, prompt or fine-tune identifier, retrieval configuration, retrieved candidates, and raw model output are all retained. This is partly good engineering and partly regulatory necessity, since a supervisor asking how a compliance determination was reached is entitled to an answer that does not reduce to an appeal to the model. Process mining approaches to auditable automation lifecycles offer a mature template for the log schema (Sanni et al., 2025), and corrective action planning research describes how findings are tracked to closure once raised (Ebhojie et al., 2023a).

5. Evaluation

Nearly all published contract NLP results report precision, recall, and F1, and F1 weights precision and recall equally. In regulatory liability detection they are not equally important, and the ratio is not a matter of taste but of the organisation's risk appetite and reviewer capacity. Consider a

portfolio of 20,000 arrangements assessed against 30 rules, generating 600,000 rule-arrangement pairs, with a base rate of deficiency of 15 percent giving 90,000 true deficiencies. A system at 0.85 precision and 0.85 recall produces 13,500 missed deficiencies and 15,882 false alarms. The false alarms cost roughly 5,300 reviewer hours at twenty minutes each; the missed deficiencies cost whatever a supervisory finding costs, multiplied by 13,500. Reporting an F1 of 0.85 tells the reader nothing about whether this system should be deployed. Fraud analytics abandoned symmetric metrics for the same reason (Atakpa, 2021; Atakpa & Abetoh, 2022).

Several additional measures are therefore worth reporting alongside conventional metrics. Recall at fixed reviewer budget asks, given a budget of H reviewer hours, what fraction of true deficiencies the system surfaces, which directly measures the deployment-relevant quantity and makes systems comparable across confidence-threshold settings. Cost-weighted error, $\sum_j w_j (\alpha \cdot FN_j + \beta \cdot FP_j)$, should use α and β elicited from the compliance function rather than assumed, and publishing the elicited ratio is itself informative. Grounding rate is the proportion of findings whose cited evidence validates against source, which should be near unity by construction if mechanical verification is implemented, so any shortfall indicates a pipeline defect. Laziness rate, as introduced in the ContractEval benchmark, is the rate of incorrect no-relevant-clause responses, which isolates the Type 1 false negative and should be reported per rule rather than aggregated, because it concentrates in specific rule types. Calibration error over the confidence distribution matters because routing depends on it. Abstention quality compares accuracy on the abstained subset if forced to decide against accuracy on the non-abstained subset, since a well-functioning abstention mechanism abstains where it would have been wrong. Positional robustness measures accuracy as a function of the location of ground-truth evidence within the document, detecting lost-in-the-middle degradation directly rather than by inference. And drift robustness measures accuracy after a rule base version change without retraining, confirming that rule knowledge is genuinely externalised rather than memorised. CUAD-derived benchmarks remain the workhorse and carry known biases. The corpus is drawn from public filings, which skews toward larger transactions and English-language United States practice. The annotation targets provisions of interest to a reviewer generally rather than provisions mandated by a specific regulation. And no public benchmark covers Types 4 through 6. The pattern reported across recent evaluations is that models handle categories with explicit lexical signals far better than categories requiring judgement, which is exactly what the Type 1 versus Type 2 distinction predicts, so benchmark performance should be disaggregated by liability type before it is used to justify a deployment decision. For an organisation validating a deployment rather than publishing research, a workable protocol comprises stratified sampling across counterparty size, document age, and rule type, since accuracy varies substantially along all three; dual independent annotation by qualified lawyers with reported inter-annotator agreement, because a system cannot be shown to exceed human consistency that was never measured; adversarial perturbation testing in which known-compliant clauses are minimally edited to introduce Type 2 defects, which isolates threshold-reading capability; and negative controls consisting of arrangements with no applicable rules, to measure the false-positive rate under conditions where the model has an incentive to find something. Structured user acceptance testing methodology provides a workable template for the validation stage (Eyetsemitan et al., 2023b), and breach-and-attack simulation offers the closest existing precedent for adversarial perturbation as a routine assurance practice (Dosunmu & Ogundele, 2024a).

6. Discussion

Economics. At 600,000 rule-arrangement pairs, per-pair cost dominates everything. A cascade in which a cheap model resolves the large majority and a reasoning model handles the residue changes total cost by roughly an order of magnitude relative to uniform use of the expensive model. Aggressive caching also helps, since many arrangements share templated language and provision-level embedding deduplication across the portfolio can eliminate a substantial share of redundant adjudication. Capacity planning and cost optimisation research in enterprise IT supplies established methods for modelling this trade-off before commitment (Edivri & Oteri, 2022; Tonoyan et al., 2022c).

Confidentiality and privilege. Beyond data residency, two issues recur. Contracts frequently contain confidentiality terms restricting disclosure to third parties, and whether an API call constitutes disclosure is a question counsel must answer before the pipeline is designed rather than after. And where the compliance assessment is conducted under privilege, the audit trail becomes a privileged artefact whose retention and access controls must be designed accordingly. Access control policy research grounded in privacy requirements is directly applicable to that retention design (Ladapo, Jooda, et al., 2023b; Okoruwa et al., 2020).

Reviewer workflow. The most common deployment failure is not model accuracy but reviewer interface. Findings presented without in-place evidence force reviewers to search the document themselves, which eliminates the time saving. Findings presented in arbitrary order prevent reviewers from working down a risk gradient. And systems offering no mechanism for a reviewer to correct a finding and have that correction feed back into evaluation waste the most valuable labelled data the organisation will ever generate. Human-centred annotation research with generative AI addresses precisely this feedback loop (Ladapo, Jooda, et al., 2024), and workflow and cycle-time studies show how much of the realised benefit depends on process design rather than model quality (Oyeleye et al., 2022; Eyetsemitan et al., 2024a).

Trust and adoption. Lawyers are trained to be sceptical of unsourced assertions, which is a professional virtue rather than an obstacle. Systems that show evidence in context, state confidence honestly, and abstain visibly earn adoption faster than systems presenting higher headline accuracy without provenance. The 2025 empirical finding that vendor hallucination claims were overstated has made legal buyers appropriately harder to convince, and architectures that make grounding mechanically verifiable are the credible response. Research on user trust and regulatory compliance in telehealth adoption documents the same relationship between transparency and professional uptake in another regulated profession (Akintola et al., 2025), and change management research explains why technically sound deployments still fail organisationally (Eyetsemitan et al., 2023a).

Governance of the system itself. A system deployed to manage regulatory risk is itself an AI system operating in a regulated context. Under the EU AI Act framework, classification depends on use rather than on technology. A contract analytics system producing informational findings for lawyer review sits differently from one whose output automatically determines whether a counterparty relationship is terminated or whether a regulatory register entry is filed, and as automation increases and human review decreases, the classification question becomes live rather

than academic. Work on automated decision-making and anti-discrimination compliance, and on algorithmic accountability where model internals are protected as trade secrets, maps the contours of that question directly (Annan, 2025a; Annan, 2024). Organisations deploying these systems should document their classification analysis contemporaneously. Regardless of classification, several obligations follow from good practice and from the general direction of the Act's requirements: technical documentation of design, data, and known limitations; logging sufficient to reconstruct individual determinations; meaningful human oversight, which means oversight with genuine capacity to override rather than nominal sign-off on volumes no human could actually review; and transparency to downstream consumers about what the system does and does not detect. Comparative governance research on AI-driven management in healthcare describes the same oversight architecture in a sector that adopted it earlier (Afrihyia, Akinse, et al., 2024), and cybersecurity compliance research argues that mature compliance posture functions as a competitive asset rather than a pure cost (Annan, 2025b). The AI literacy requirement that took effect in February 2025 has a practical corollary: a compliance function relying on model output needs enough understanding of the system's failure modes to know which findings warrant scepticism, and a lawyer who does not know that the system performs worse on Type 2 defects than Type 1, or worse on evidence located mid-document, cannot exercise meaningful oversight. Organisational readiness research on generative AI integration addresses how that capability is actually built (Afrihyia et al., 2025), and questions of authorship and ownership in AI-generated work remain unsettled where system output is incorporated into professional deliverables (Annan, 2023). Professional responsibility, finally, is not delegable: where the output informs legal advice, the supervising lawyer owns the advice, and the system's role is to allocate attention rather than to produce conclusions.

Limitations. Cross-instrument reasoning remains weak, and Type 5 liabilities are the most consequential in practice and the least supported by benchmarks or reported architectures; progress requires annotated arrangement-level data that does not publicly exist. Interpretation cannot be automated, since the rule base encodes legal judgement and automating its construction from statutory text would move the interpretive act into the model, which is neither technically reliable nor professionally appropriate. Corpus bias is unresolved, with English-language, United States-practice, large-transaction data underpinning nearly all public benchmarks, leaving performance on smaller commercial agreements, non-English contracts, and civil law traditions materially under-characterised. Evaluation and practice are decoupled: as the ACL Findings 2025 survey noted, there is limited visibility into large-organisation deployments, so the published record describes a laboratory version of a task whose production form may differ substantially. The cross-sector material in Section 2.3 partially compensates, but it is drawn largely from conceptual and review contributions rather than controlled deployment studies and should be read accordingly. Calibration under distribution shift is fragile, since confidence calibrated on one portfolio does not transfer reliably to another and recalibration requires labelled data from the new distribution, which is exactly the resource a new deployment lack. And the counterfactual is poorly measured: human contract reviewers make errors at rates that are rarely quantified, so claims that automated systems approach or exceed human performance rest on a baseline usually estimated from small samples under unrepresentative conditions.

Directions for further work. The field needs an expert-annotated dataset in which the unit of analysis is a set of related documents and the ground truth includes conflicts and supersessions; this is expensive to build and would be the single highest-value contribution available. Benchmarks framed around specific regulatory instruments, with rule bases published alongside annotations, would let systems be compared on the actual task rather than on a proxy. Once provisions are extracted into structured form, consistency checking can be handed to symbolic reasoners, and earlier legal reasoning work found symbolic solvers outperforming neural models on entailment in structured legal domains, so the neuro-symbolic combination is under-explored for contracts. Aviation and pharmaceutical regulation both quantify compliance capability as a graded organisational property with predictive value for audit outcomes (Adeyelu, Dagodzo, et al., 2024 [b]; Eze et al., 2022b), and importing that framing would let organisations forecast supervisory findings rather than merely count clause gaps. DORA's register obligation implies ongoing rather than periodic evaluation, so architectures that re-evaluate incrementally on rule base change or metadata change rather than reprocessing portfolios are the natural next step, and the continuous control validation literature provides a proven template (Dosunmu & Ogundele, 2024c; Aliliele et al., 2025a). Detecting liabilities before execution is strictly better than detecting them after, and work on clause-level revision generation and contract differencing points toward systems that propose compliant alternatives at drafting time, while smart contract automation research indicates how far that logic can eventually be pushed (Akomolafe et al., 2022). Finally, methods for calibrating confidence on a new portfolio using minimal labelled data would materially reduce deployment cost and are a well-defined research target.

7. Conclusion

The 2025 regulatory environment created genuine demand for automated detection of regulatory liabilities in contract portfolios, and the technical capability available at the end of that year is substantially better than what was available two years earlier. Context windows exceed contract lengths. Retrieval is measurable against legal-specific benchmarks. Reasoning models can walk statutory tests. Structured output makes grounding mechanically verifiable. Open-weight models make confidential on-premises deployment feasible.

The honest assessment is nonetheless that this is a capable assistant and not an autonomous reviewer. The published evidence characterises frontier model performance on clause-level legal risk identification as comparable to that of a junior legal assistant, finds meaningful gaps between proprietary and open-weight models, and shows sharp degradation on issue types lacking explicit lexical signals. Empirical work on commercial legal AI tools has found vendor reliability claims overstated. Cross-instrument liabilities, which dominate real portfolios, remain largely outside what current systems detect or benchmarks measure.

The cross-sector evidence surveyed in Section 2.3 supports a specific reading of that gap. The architectural problems, which include risk-weighted assurance allocation, continuous rather than periodic verification, provenance as a first-class requirement, and maturity-graded rather than binary compliance state, have already been solved in financial audit, cybersecurity governance, critical infrastructure protection, procurement, and aviation oversight. What has not been solved anywhere is the construction of a reliable normative signal from unstructured contractual language, and that is where the remaining research effort belongs.

The correct framing is therefore attention allocation rather than replacement. A well-designed system reads the whole portfolio, which no team can, and directs finite expert attention to the

places where it produces the most risk reduction per hour. That is a large and legitimate contribution. It also means the design priorities that matter most are not the ones that raise headline accuracy but the ones that make output verifiable: evidence grounding, calibrated confidence, honest abstention, and an audit trail that survives supervisory scrutiny. The rule base and the reviewer interface will determine whether a deployment succeeds more often than the choice of model will.

RPST

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