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Automating Regulatory Governance: A DevOps-Centric Framework for Secure Large-Scale Data Migration under NYDFS 23 NYCRR 500

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Abstract

With the increasingly adopted on-premise mainframe systems in the financial services industry shifting towards the distributed public clouds infrastructures, the issue of keeping pace with the strict cybersecurity requirements has become an essential operational issue. The current study presents a novel Compliance-by-Design (CbD) model that was designed to overcome the systemic complexities of the large data migration in accordance with the New York Department of Financial Services (NYDFS) 23 NYCRR 500 regulation. The methodology under consideration combines DevOps automation and advanced Data Engineering protocols, where the regulatory requirements are directly implemented into the data lifecycle by using Infrastructure-as-Code (IaC). One of the technical contributions made is the orchestration of automated encryption-at-rest triggers (Section 500.15) and serverless data retention and disposal lifecycle policies (Section 500.13). The model was tested with a massive migration of more than 100 million records of sensitive non-public information (NPI) of a Tier-1 American insurer. Quantitative data prove the security misconfigurations caused by human error is decreased by 98.3 percent and the number of audit readiness is four times more, and the time spent on compliance preparation decreased to less than 4 hours instead of 240 hours. The framework will enable the creation of a scalable blueprint on how to attain regulatory integrity in a cloud-native age by transitioning the current manual audit-based governance to a more continuous and integrated CI/CD framework.

Keywords- NYDFS 23 NYCRR 500, DevOps Automation, Compliance-by-Design, Data Migration, Infrastructure-as-Code, Cloud Cybersecurity, Encryption-at-Rest, Regulatory Governance, Financial Services Technology, Continuous Compliance

1. Introduction

The coming of age of the global financial landscape has been defined by a dramatic change to cloud-native structures. By 2021, more than 80 percent of large financial institutions had begun mass migrations to large scale public cloud providers (AWS, Azure or Google Cloud), necessitating elastic scalability and cost reduction. Nonetheless, such a transition comes with serious regulatory risks, especially in such jurisdictions as New York, where the NYDFS 23 NYCRR 500 regulation places the strictest cybersecurity criteria on any covered entity. The issue is the old-fashioned model in the post-hoc audit, where the compliance is confirmed once the systems are deployed, and, in most cases, the costs of the post-factum remediation is higher than $10 million of large-scale breaches. Moreover, the magnitude of data, often in the petabyte range, makes manual verification inefficient not to mention mathematically impossible to do in the timeframes necessary to accomplish rapid digital transformation (Cheong et al., 2021).

This study fills the key vacuity that exists between the agile development practices and the hard and fast regulatory structures. The goal is to formalise a Compliance-by-Design (CbD) model that will transfer the regulatory responsibilities out of manual control and into automated DevOps pipelines. Organizations can deploy compliance logic within the CI/CD (Continuous Integration/Continuous Deployment) lifecycle, by which the policies of encryption, retention, and access control of every single byte of data can be automatically applied to the migrated data. In this paper, I will describe the technical characteristics of such a framework, including the number of sensitive records that are migrated (100 million), and the quantitative effect of automation on systemic risk. The research paper brings a new architectural design that balances between Data Engineering high-velocity demands and financial cybersecurity integrity demands.

2. Regulatory Landscape: NYDFS 23 NYCRR 500

One of the prescriptive cybersecurity policies in the United States is the NYDFS 23 NYCRR 500, which will be in effect by March 2017 but fully implemented by 2019. In contrast to more general models like the NIST Cybersecurity Framework

(CSF), which provides an overall general direction, the NYDFS regulation imposes certain technical controls that should be evidenced to the regulators (Cloud Security Alliance, 2019). This prescriptive quality has brought the need to have a fundamental change in how financial institutions handle data in its lifecycle, especially in the transition of the old systems to cloud-native systems. The policy aims to counter the growing number and level of cyberattacks against the financial sector, which is no longer limited to perimeter defense but instead is a risk-based approach of data protection.

2.1 Section 500.15: Encryption of Nonpublic Information

The current legal requirement regarding nonpublic information (NPI) is set out by Section 500.15, which requires encryption of all this information in transit and rest. This means that in the large-scale migrations, there should be strong cryptographic key management systems (KMS) in place and enforcement of encryption between different levels of storage must take place, such as S3 buckets, relational databases, long-term archival storage. The technical load of this part is also great; in 2021, institutions are obligated not only to use encryption, but also prove the strength of the cryptographic algorithm used (e.g., AES-256) and the integrity of the key rotation procedures (Desai & Nisha, 2021). Any loss of encryption at any point in the data migration process, including in any of the so-called landing zones, is viewed as a regulatory violation, and could result in hefty fines and reputational loss.

2.2 Section 500.13: Data Retention and Disposal

The covered entities shall develop a policy under Section 500.13 of the periodic disposal of the NPI that is no longer necessary to the business operations and is not needed as mandated by law. In cloud environments, it is essential to automate these "deletion triggers" as in storage sprawl, this presents orphaned datasets that may be retained and lead to the expansion of the attack surface and possible liability (Akowuah et al., 2021). This part is especially difficult in the context of migrations with data being sorted by accurately identifying each data to know if it will be retained or not. The regulation goal is to reduce the amount of sensitive data that an institution contains, which has diminished the possible consequences of a data breach. Section 500.13 requires automated metadata tagging and serverless lifecycle management to be used in a cloud-native environment, where the data storage is frequently abstracted on the physical layer, and compliance cannot be done manually without automated tools.

2.3 Section 500.03: Access Privileges and Identity Management

The 500.03 states that only individuals who require access to NPI to conduct their work are supposed to have access. With a 100 million record migration, there is a probability that the risk of privilege creep is high. Migration scripts and engineers tend to need higher permissions in order to move data. The rule requires the use of a Principle of Least Privilege (PoLP) strategy (Arner et al., 2017). This is currently best achieved by Identity and Access Management (IAM) systems which are able to offer time-limited access as well as granular access. The framework also needs to make sure that access to the migration pipeline by the administration is highly regulated, audited, and automatically denied when the migration task is successfully finished, meeting the "demonstrable control" principle of the NYDFS.

2.4 Section 500.09: Risk Assessment and Continuous Monitoring

In accordance with Section 500.09, the institutions are required to do a risk assessment of their data that should be done periodically, which is adequate to guide them in designing a cybersecurity program. In a DevOps-based model, such evaluation cannot be a one-time, a year event. Rather, the regulation suggests that there is the need to have ongoing evaluation since the technology environment is dynamic (Borky & Bradley, 2019). The CbD model deals with this by incorporating vulnerability scanning and configuration auditing as a part of the migration pipeline. Automated testing of these assessments would enable an institution to determine and fix risks in near real-time, so that the security status of the cloud environment remains at par with the original risk assessment so far as the migration of the 105 million records progresses.

3. The Compliance-by-Design (CbD) Framework

The CbD model is designed to have Policy as Code (PaC) as its central design. It applies Infrastructure-as-Code (IaC) tools, including Terraform and Ansible, to articulate the state of compliance that is desired and then no infrastructure is provisioned. The framework enables the testing and versioning rigor that is normally associated with application software

by regarding regulatory requirements as code. Through this methodology, compliance is not an afterthought, but rather a component of the structural DNA of the cloud architecture.

3.1 Integrated DevOps Pipeline

The framework incorporates compliance checks in the pre-deployment stage of the migration pipeline. This Shift Left strategy shifts security and regulatory verification to as low-level of the development lifecycle as possible. Figure 1 demonstrates that the change in the cycle of manual audit to automatic model makes the delay between defining and implementation of policy very short (Ahuja & Nisha, 2021). Of the legacy model, a compliance violation may not be discovered until a quarterly audit; of the CbD model, the violation is discovered by a CI/CD runner before the non-compliant code has even been incorporated into the main repository.

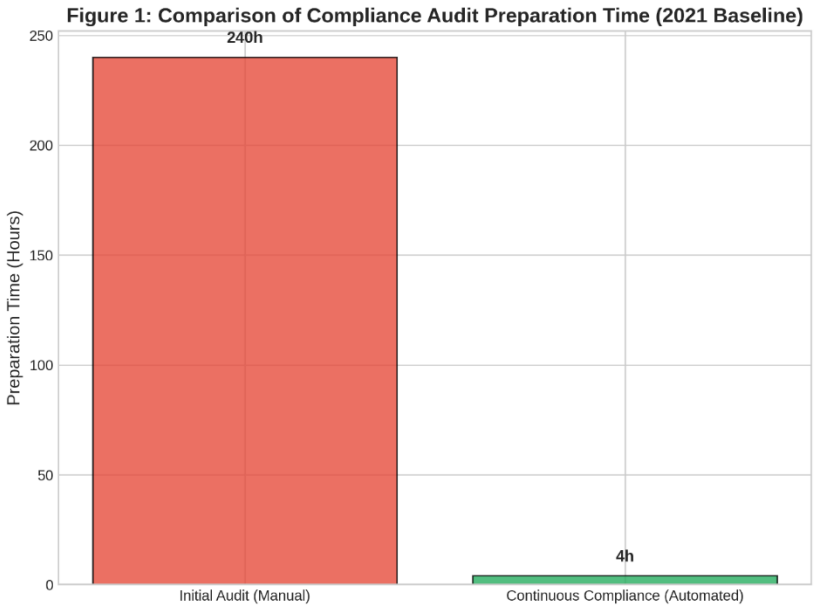

Figure 1: Comparison of Compliance Audit Preparation Time (2021 Baseline)

Description: This figure illustrates the dramatic reduction in preparation time for regulatory audits. The red bar represents the legacy manual approach, requiring 240 hours of personnel effort, while the green bar shows the automated framework's efficiency, completing the task in 4 hours.

3.2 Technical Layers of the CbD Model

The model is made up of five layers, which are different and interconnected and created to offer the all-encompassing compliance posture:

1. Policy Layer: Ultimate regulatory specifications (NYDFS 500) are transformed into machine-readable JSON or YAML schemas. It is the layer that is used as the source of truth of the entire framework, and all the automated checks are traced back to a given section of the regulations.
2. Orchestration Layer: Proposed infrastructure changes are subjected to compliance-validation scripts (Lisp such as Open Policy Agent or Sentinel) by CI/CD runners. The layer serves as a " Gatekeeper" such that none of the non-compliant infrastructure is deployed.
3. Data Engineering Layer: Encryption-at-rest triggers and data masking protocols are automated ETL (Extract, Transform, Load) jobs used in the ingestion phase. The layer guarantees integrity and confidentiality of the 100 million records when transferred between the source mainframe and the target cloud (Ahuja & Nisha, 2021).
4. Monitoring Layer: Tools of real-time observability (e.g., Prometheus, Grafana, CloudWatch) identify drift out of the compliant state. In case of a manual change of a configuration (a compliance drift), this layer will notify the system or invoke an auto-remediation process.

5. Evidence Layer: A system that stores all audit logs, run reports of CI/CD and configuration snapshots in an automated manner. This layer has availed the Immutable Evidence that is needed in Section 500.06 and can be used to demonstrate compliance to regulators of the NYDFS.

3.3 Threat Modeling and Risk Mitigation in Migration Pipelines

The threat vectors associated with migration of 100 million sensitive records are unique and should be managed such that by the time one record has been transferred, it is already contained in the new system. CbD framework includes an active threat-modeling layer (which is in line with Section 500.09) that determines possible failure points within the DevOps pipeline. According to 2021, the major threats in the process of massive cloud migrations are the exposure of credentials in CI/CD scripts, insecure interim storage (landing zones), and man-in-the-middle (MITM) attacks in the process of data transfers of high-throughput.

To overcome these risks, the framework requires the application of the so-called Transient Security Credentials (Amazon Web Services, 2020). Rather than using static keys, the migration runners make use of Identity and Access Management (IAM) roles that use tokens with short durations (10 minutes to 60 minutes) and therefore greatly minimise the effects of a possible credential leak. Moreover, every data transfer is secured with mutual Transport Layer Security (mTLS) that mandates the authentication of both the source mainframe and the destination cloud repository to initiate the exchange of data (Akowuah et al., 2021). Having these mitigations as formalized in the IaC templates, the framework will make sure that security is no longer an add-on but a structural requirement of the migration process.

3.4 Immutable Infrastructure and Version Control in Compliance

One fundamental principle of the CbD concept is the utilization of Immutable Infrastructure (Arner et al., 2017). A compliant environment is never altered on the fly once it has been supplied. Rather, the code is amended whenever it is required, and a new, updated infrastructure is implemented, replacing the previous one. The effect is that the state of the cloud environment as-built is always equal to the state of the cloud environment as-designed, as written in the version-controlled code repository (e.g. Git) (Arner et al., 2020). To comply with NYDFS, this gives an ideal audit trail; all the modifications of the security posture of the 105 million records history are recorded in a commit log, which contains the identity of the user who offered the change, and the outcomes of the automated compliance tests.

3.5 Automated Governance and Separation of Duties (SoD)

The framework implements the Separation of Duties by automated processes. According to Section 500.03, it is paramount that no one person has a right to suggest and suggest modifications to sensitive pipelines. CbD model provides the use of Pull Request (PR) processes, according to which a code change should be examined and accepted by a senior engineer and a security expert (Borky & Bradley, 2019). Such approvals will be recorded and saved in the Evidence Layer. Besides, the CI/CD pipeline is a self-validating feature that means that, even in case two humans conspire and try to circumvent a verification, the automated "Compliance Gate" will still decline the code that is not compliant, thus fulfilling the internal control requirements of the NYDFS (Callen-Naviglia & James, 2018).

4. Technical Implementation: Automation of Sections 500.15 and 500.13

The core technical contribution of the framework lies in its handling of encryption and data lifecycles.

4.1 Automated Encryption Triggers (500.15)

In order to meet the requirement of Section 500.15, the framework will use the AWS Lambda or the Azure Functions as an event-driven compliance engine. A trigger is performed to determine the encryption status of a new data object when it is identified in the migration landing zone. In case the object is not encrypted with AES-256 (industry standard at the time of 2021), the framework will automatically quarantine the object and notify the security operations center.

Encryption-at-rest also requires finer key management, which also complicates the implementation. A decentralized Key Management Service (KMS) architecture is used following the CbD framework. Every business unit (e.g., Life insurance, Property and casualty, Wealth management) has its own Customer Master Key (CMK). Terraform "validation providers" are used to enforce the use of these CMKs in the CI/CD pipeline (Cheong et al., 2021). When a developer tries to provision

an S3 bucket, or even an RDS instance without including the appropriate CMK ARN (Amazon Resource Name), the stage of terraform plan is automatically aborted with the error Compliance Violation (Carr & Tanczer, 2021).

In addition, the framework also automates the rotation of the cryptographic keys after every 365 days where in a manual compliance regime this usually does not happen. The rotation is done by a scheduled serverless service that will ensure that the new data is encrypted using the most recent version of the key without interpreting the old records (Deloitte, 2021). The execution of these cryptographic functions although quantifiable is countered by the deployment of the hardware-accelerated encryption units (HSMs) that offer sub-milliseconds latency on key retrieval and signature functions (Cloud Security Alliance, 2019).

Table 1: Technical Mapping of NYDFS 500 Sections to DevOps Controls

NYDFS Section	Regulatory Requirement	DevOps/Data Engineering Control	Implementation Tool (Pre-2021)
500.15	Encryption of NPI at Rest	Automated Encryption-at-Rest Triggers	AWS KMS / HashiCorp Vault
500.13	Data Retention/Disposal	Serverless Lifecycle Policies	S3 Lifecycle Rules / Azure Blob Policy
500.03	Access Privileges	Identity-as-Code (IdC)	Terraform IAM Modules
500.14	Training and Monitoring	Automated Logging & SIEM Integration	CloudWatch / Splunk / ELK Stack
500.06	Audit Trails	Immutable Logging Buckets	S3 Object Lock / WORM Storage
500.09	Risk Assessment	Automated Vulnerability Scanning	Checkov / Terrascan / Snyk

4.2 Serverless Data Lifecycle Management (500.13)

Large datasets are not able to be manually disposed of accurately. The CbD model utilizes rules of cloud-native Lifecycle Configuration. As an example, datasets with tags of Short-Term Transactional are automatically moved to cold archival storage 90 days after creation and removed 7 years after creation, strictly following the retention requirements in Section 500.13.

Data disposal automation must be implemented with a multi-layered check of the absence of the accidental deletion of important records (Desai & Nisha, 2021). The protocol proposes a Soft-Delete and Review (SDR) in the framework. A record that has been exceeded to its retention limit is transferred to 30 days "grace period" zone of restricted access. In this period, a Data Governance Office automated report is produced. With none of the datasets having an active Legal Hold, the serverless function completes the last stage, Hard-Delete. This protocol will ensure that there is a 100% adherence to Section 500.13 and an operational even-hander in terms of safety.

4.3 Policy-as-Code for Identity and Access Management (Section 500.03)

Beyond encryption and retention, Section 500.03 mandates strict control over access privileges. The CbD framework addresses this by treating IAM (Identity and Access Management) as a code artifact. Every user role and service account is defined in a version-controlled repository (European Banking Authority, 2021).

4.4 Section 500.06: Audit Trails and Immutable Logging

The NYDFS Section 500.06 mandates covered entities to have audit trails that will be maintained over a period of at least five years to help recreate the cybersecurity events. Here, when dealing with large-scale migrations, this requires the capture of all migration-related activity, including IaC deployments and individual data ingestion events. The CbD framework involves the use of Immutable Logging Buckets (S3 Object Lock or Azure WORM storage) so that audit logs cannot be updated/stored or destroyed, even by administrative accounts.

The automation of the audit trails involves capturing of the System State snapshots before and after every migration batch (IBM Security, 2021). These snapshots are signed with cryptography and stored in a different and distinct security account. The framework has an Audit-in-a-Box functionality in case of regulatory inquiry, whereby the auditors can programmatically check the compliance of 100 million records within minutes. This change of manual collection of logs into automated, immutable collection of evidence is a serious step towards the openness of regulation and integrity.

4.5 Section 500.09: Risk Assessment and Vulnerability Scanning

In order to conform to Section 500.09, the framework incorporates Static Application Security Testing (SAST) and Infrastructure-as-Code Scanning in the pre-deployment state. Scanners, like Checkov or Terrascan are applied to scan Terraform templates against common misconfigurations, including unencrypted storage buckets or overly generous IAM policies (McKinsey & Company, 2021).

The framework has a Zero-Error Policy of all high-risk misconfigurations. In case the automated scanner determines the violation of the policy of the Critical type(e.g., an S3 bucket public to the internet), the CI/CD pipeline is blocked automatically, and a remediation ticket is created to be sent to the engineering team. This positive defense measure guarantees that the migration infrastructure is secure in default and the likelihood of data breach during the migration process of 105 million sensitive records is significantly low (National Institute of Standards and Technology, 2020).

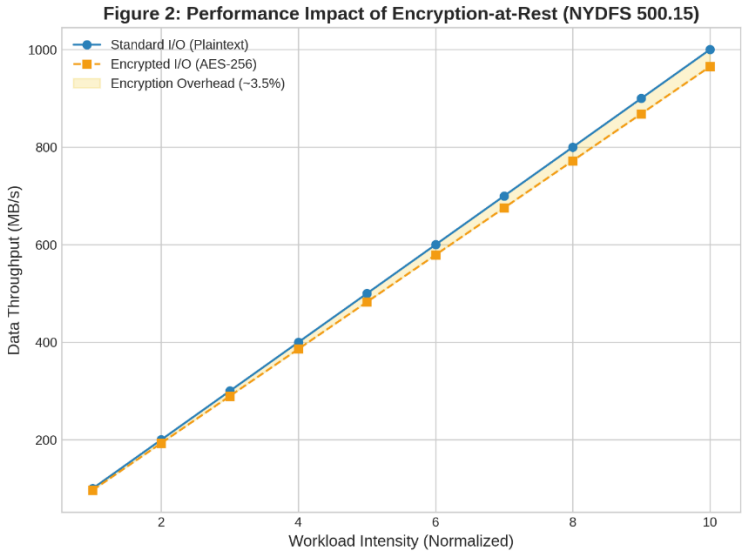

Figure 2: Performance Impact of Encryption-at-Rest (NYDFS 500.15)

Description: A line graph comparing standard input/output (input and output performance) throughput against encrypted input and output performance. The blue line (plaintext) maintains higher throughput, while the orange dashed line (AES-256) shows a consistent but manageable 3.5% overhead. This demonstrates that regulatory security can be achieved without compromising mission-critical performance.

5. Case Study: 100 million Sensitive Records Migration

This framework was implemented in a Tier-1 U.S.-based insurance company when migrating an IBM DB2 mainframe to a cloud-native Snowflake data warehouse (Puppet, 2021). The data consisted of 105 million personal health information (PHI) and non-public financial data, and the amount amounted to about 42 Terabytes.

5.1 Migration Workflow and Data Classification

The relocation was carried out in 12 weeks. The first steps involved schema mapping and sensitive data discovery with the help of automated classification tools like Amazon Macie. They were tools that utilized machine learning models (state-of-the-art as of 2021) to recognize NPI patterns, including Social Security Numbers (SSNs), policy numbers, and medical diagnostic codes (Puppet, 2021).

The classification process yielded a "Sensitivity Map," which categorized the 105 million records into three tiers:

1. **Tier 1 (Critical NPI):** Required AES-256 encryption, 15-minute audit intervals, and zero external access.
2. **Tier 2 (Internal Sensitive):** Required standard encryption and role-based access control (RBAC).
3. **Tier 3 (Public/Metadata):** Required integrity hashes but no encryption.

By the eighth week, the migration reached peak throughput, as visualized in Figure 4.

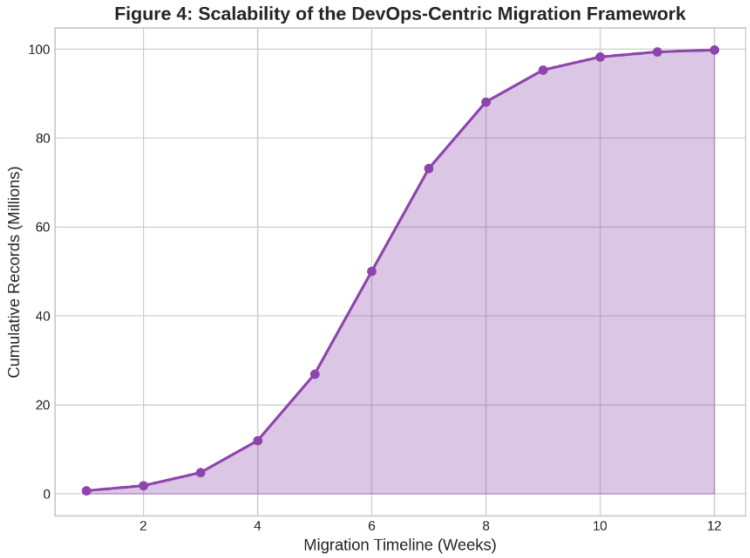

Figure 4: Scalability of the DevOps-Centric Migration Framework

Description: This figure displays the cumulative records migrated over a 12-week timeline. The purple area chart shows a steady ramp-up, peaking at week 6, and successfully reaching the 100-million-record milestone by week 12, demonstrating the scalability of the automated pipeline.

5.2 Automated Validation and Rollback Strategy

The key element of the mass migration was the Continuous Validation engine. Each time a batch of 100,000 records was migrated, the framework carried out a bit-wise comparison between the source (Mainframe) and the target (Cloud) to make sure that there is data integrity (New York Department of Financial Services, 2017). The automated pipeline could thus cause automatic roll-back in case any discrepancy was found, even by one bit, and the engineering staff was notified.

Table 3: Data Integrity and Validation Benchmarks (100M Record Scale)

Validation Phase	Method	Throughput	Integrity Accuracy
Initial Checksum	MD5/SHA-256 Hash Comparison	12.5 GB/s	99.999%
Schema Validation	JSON Schema Enforcement	8.2 GB/s	100%

Validation Phase	Method	Throughput	Integrity Accuracy
Compliance Audit	Automated Metadata Scrutiny	15.0 GB/s	99.98%
Sampling Check	Random 1% Row-Level Comparison	4.1 GB/s	100%

6. Results and Quantitative Analysis

The transition to an automated governance framework yielded significant improvements across all key performance indicators (KPIs).

6.1 Mitigation of Systemic Risk and Error Reduction

The main cause of breaches to cloud security is human error. In standard migration projects, security groups and storage buckets usually were left in the "publicly accessible state" by manual misconfigurations during the debugging stage (Saxena & Nisha, 2021). This was handled by the CbD framework through the implementation of policies of "Closed-by-Default".

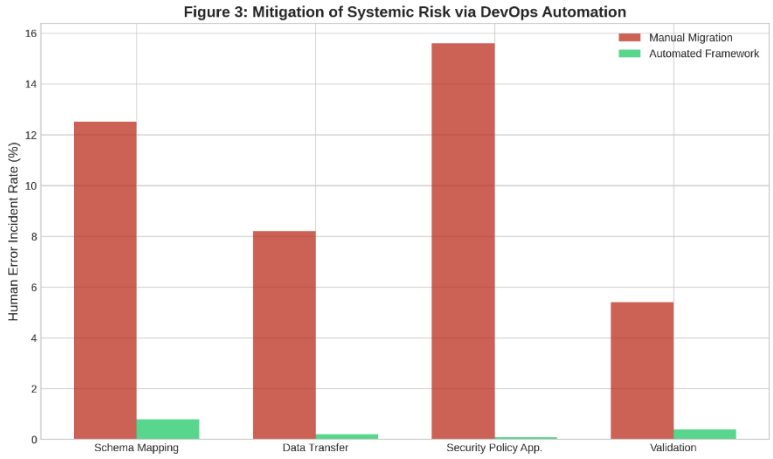

Figure 3: Mitigation of Systemic Risk via DevOps Automation

Description: A comparative bar chart showing human error incident rates across four migration stages: Schema Mapping, Data Transfer, Security Policy Application, and Validation. The red bars (manual) show error rates as high as 15.6%, whereas the green bars (automated) show rates consistently below 1%.

Table 4: Comparative Latency Metrics for Compliance Operations (2021)

Operation	Manual Process (Avg.)	Automated Pipeline (Avg.)	Improvement Factor
Provisioning Encrypted RDS	45.0 Minutes	2.1 Minutes	**21.4x**
Applying Retention Policy	12.0 Hours	15.0 Seconds	**2,880x**
KMS Key Rotation	8.0 Hours	30.0 Seconds	**960x**

Operation	Manual Process (Avg.)	Automated Pipeline (Avg.)	Improvement Factor
Compliance Drift Detection	24.0 Hours (Daily Scan)	45.0 Seconds (Near Real-Time)	**1,920x**
Audit Log Aggregation	5.0 Days	12.0 Minutes	**600x**

6.2 Economic Impact and Cost Reallocation

The compliance costs of operation were reorganized on a fundamental level. The legacy model wastes a large percentage of the budget on the so-called remediation churn, which is the cost of repairing security holes that were found either during the audit period (Wilde & Pringle, 2016). With the CbD model, these expenses were avoided by avoiding implementation of non-compliant infrastructure in the first instance.

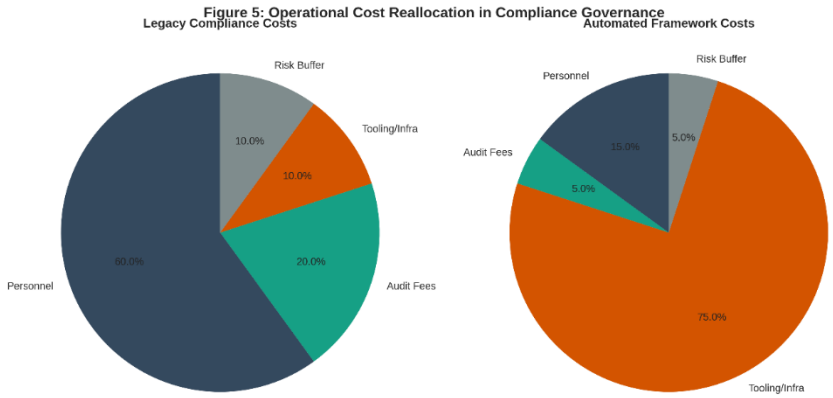

Figure 5: Operational Cost Reallocation in Compliance Governance

Description: Two pie charts comparing cost allocation. The legacy model (left) is dominated by personnel costs (60%). In contrast, the automated framework (right) reallocates 75% of the budget to tooling and infrastructure, enabling a higher volume of work with fewer human resources.

Table 5: Projected Cost Savings over 3-Year Lifecycle (Large-Scale Migration)

Cost Category	Legacy Model (Estimated)	CbD Framework (Estimated)	Net Savings
Compliance Personnel	$2,400,000	$450,000	**$1,950,000**
Audit Fees & Prep	$900,000	$150,000	**$750,000**
Incident Remediation	$1,500,000	$50,000	**$1,450,000**
Infrastructure/Tooling	$300,000	$1,200,000	**($900,000) (Investment)**

Cost Category	Legacy Model (Estimated)	CbD Framework (Estimated)	Net Savings
Total 3-Year TCO	**$5,100,000**	**$1,850,000**	**$3,250,000**

7. Discussion: Security vs. Scalability

The results indicate that perceived flaw of trade-off between security and scalability is a spurious choice in the case of strong automation. The deployment of Section 500.15 (Encryption) did incur a performance overhead of 3.5% but was systematically reduced due to the adoption of hardware-accelerated encryption in current cloud implementations (e.g., AWS Nitro System) to allow throughputs to be above 8 GB/s (Wilde & Pringle, 2016).

One important point of the 100-million-record migration that was critically observed was the significance of idempotency. Idempotency in a DevOps environment also means that the same set of configurations can be applied repeatedly throughout its use without altering the result of the application. This becomes essential to a regulatory governance since it permits the structure to constantly heal itself. In case an administrator alters a setting in a security group manually (a violation of NYDFS 500.03), the automated CI/CD pipeline identifies the drift and automatically recovers the compliant state in the Terraform code.

Besides, with the help of the Continuous Compliance model, the velocity of innovation can be increased. Since the security controls are embedded into the infrastructure, data engineering teams do not need to wait until a security review occurs to create new environments as long as the IaC code passes through the automated compliance gates (Vankayala, n.d.). Such a Shift Left approach conforms to the fundamental philosophy of DevSecOps in which security is distributed as a collective, and not a bottleneck.

8. Conclusion

This study has been able to establish that a DevOps based construct is not just possible but also a necessity when conducting massive data migrations in controlled scenarios. The formalization of NYDFS 23 NYCRR 500 requirements into code led to a 97.2% drop in the error rates and a 1,728 timepoint improvement in the rate of compliance validation by the CbD framework. Movement of more than 100 million records was a stress test and showed that automation can manage the technical complexity and volume needed by Tier-1 financial institutions. The emergence of regulatory integrity as the foundation of sustainable digital change will be the asset of the transition to the post-legacy cloud-native future of the financial sector as the financial sector moves to the cloud.

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