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Real-Time Data Intelligence in Regulated Systems: Designing Secure, Scalable, and Compliant Cloud Architectures on GCP

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Abstract
The increased pace of information on the digital ecosystems has increased the strains of real-time information systems in data intelligence particularly in controlled environments such as health, financial systems and governmental systems. This not only implies that these systems need to offer low-latency insights, but also satisfy some of the highest demands in terms of security, privacy, and regulatory compliance. Cloud services, especially Google Cloud Platform (GCP) have become influential enabling factors in the creation of scalable, event-driven architecture to support real-time analytics. Nevertheless, combining the stream processing features with compliance and governance systems is still a major challenge. The given review paper comments on how to develop secure, scale-able, and compliant cloud architectures to provide real-time data intelligence with the help of GCP-native services and the recent ideas behind distributed systems. It talks about, generalizes, and oversimplifies the existing literature on stream processing, distributed storage, zero-trust security, and data governance, pointing out such major problems as latency-compliance trades, tracking data lineage, and enforcing policies in dynamic environments. The article presents a theoretical framework (SCaR-RTI) that balances real-time processing and compliance-by-design with the assistance of architectural and experimental findings and performance analyses. Moreover, the paper outlines new research directions, such as compliance-as-code, privacy-preserving analytics, and confidential computing, AI-driven governance, and data sovereignty-conscious architectures that will define the next generation of regulated cloud systems. This work offers a broad framework to design credible, high-performance real-time data systems by filling the gap between performance engineering and regulatory concerns. The research is expected to inform researchers, cloud architects, and policymakers to come up with systems that are not only efficient and scalable but also in line with the changing regulatory environment.

Keywords- *Real-time data intelligence, scalable architectures, low-latency analytics, Kafka, Pub/Sub, Dataflow, BigQuery,data sovereignt*

1. Introduction
The rapid increase in the volume of information produced by digital systems, interconnected gadgets, financial services, and healthcare applications has altered the way organizations work, decide, and render services. Concurrently, the need to obtain real-time data intelligence, the capacity to consume, process and analyze data in real-time, has become a vital capacity in the present day business. The latter is especially acute in controlled systems, including those of finance, healthcare, telecommunications, and government, whereby the compliance requirements are rather strict in terms of data collection, storage, processing, and sharing. With organizations shifting to cloud-native infrastructures, platforms like Google Cloud Platform (GCP), have become the enablers of creating scalable and smart data systems capable of supporting both the performance as well as regulatory requirements [1]. Real-time data intelligence systems are those that are fundamentally different to traditional batch-processing architectures. They make use of streaming pipelines, distributed processing models, and event-driven architecture to provide low-latency insights. Apache Kafka, Google Pub/Sub, Dataflow, and BigQuery are some of the technologies that have assisted organizations in processing huge amounts of streaming data in an efficient manner [2]. When such systems are implemented in controlled settings, however, more layers of complexity occur. Organizations are required to maintain data privacy,

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auditability, traceability and adherence to legal regulations including GDPR, HIPAA, PCI-DSS and other related regulations [3]. This twofold need to simultaneously meet the real-time performance and the high level of compliance introduces a special design problem to cloud architects and data engineers. Multiple converging trends highlight the topicality of the topic in the modern research environment. First, it is a fast movement towards cloud-first and cloud-native systems with enterprises increasingly moving to managed services provided by cloud vendors such as GCP to free up operational overhead and enhance scalability [4]. Second, AI and machine learning applications development require real-time data pipelines to address the requirements of such applications as fraud detection, predictive maintenance, customized healthcare, and autonomous systems [5]. Third, administrative authorities are constantly updating the compliance standards depending on the increasing interest in the issue of data privacy, cybercrime, and responsible use of data [6]. All these points highlight the need to not only develop high-performing systems but also make them naturally secure and compliant. The opportunity to add security, scalability, and compliance of real-time data systems is an encouraging area of interdisciplinary studies in the framework of the broader community of cloud computing and data engineering. Traditionally, they have been thought of as separate problems: scaling is solved through distributed system architecture, security is solved through encryption and access control infrastructure, and compliance is solved through governance infrastructure and audits. However, in the managed environments these dimensions are closely related. As an example, the encryption of stored data and data in transit can be strong, thereby introducing latency that may impact on real time processing. Similarly, the strict access control and audit logs can complicate the system design and introduce overhead to the operations [7]. To achieve a balance of these competing priorities therefore a holistic approach is needed. Although cloud technologies and architectural patterns have improved, there are still a number of research gaps and problems. The main issue is that, at present, there is no single set of architectural frameworks that would allow giving direct answers to the question of whether the intersections between the processing of real-time data and the compliance with the regulations are present. The cloud providers offer tools and best practices that tend to be complete but rarely detailed how they can be integrated into end-to-end systems that are geared towards regulated systems compliance [8]. Moreover, the automated compliance solutions, including policy-as-code, continuous compliance checks, and real-time auditing that will help decrease the manual burden of regulatory compliance will also be researched. The other critical deficiency is the real time systems as far as data governance and lineage tracking are concerned. In contrast to batch systems, the data flows are more predictable and easier to document, streaming architecture requires complex and dynamic pipelines that may make it difficult to trace data provenance and hold accountability [9]. This presents serious compliance issues because regulators tend to seek a lot of information about the manner in which data is processed and transformed. Moreover, further complications arise due to the data sovereignty issues and the cross-border data flows, especially in case of international organizations which have to deal with various regulatory jurisdictions. The security is also a thorn in the flesh. By nature, real-time systems are susceptible to the constant ingestion and processing of data, which makes them more exposed to threats. There should be end-to-end security, i.e., data encryption, identity and access management (IAM), network security, and threat detection, which cannot be achieved without a careful architectural design and combination of various security controls [10]. Additionally, cloud environments are dynamic and decentralized, and it is hard to ensure the uniformity of security policies among different services and locations. Although one of the main advantages of such cloud platforms as GCP is scalability, it also brings a range of challenges to the regulated systems. The auto-scaling mechanisms should be configured in a manner that does not affect compliance requirements, including data residency or audit logging. Also, cost control is an important factor to consider, since processing at scale in real-time may consume vast amounts of resources unless it is

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optimized [11]. With such challenges in mind, it is clear that a comprehensive overview of the integration of current knowledge, best practices, and hands-on experience is required to develop secure, scalable, and compliant real-time data architecture on GCP. Although literature has explored such aspects separately such as cloud security, data streaming technologies, and regulatory compliance, very little studies have put such dimensions in one framework, which is unique to real-time systems in regulated environments. This review aims to fill this gap and provide an in-depth analysis of architectural patterns, design principles, and services related to GCP that enable the creation of data systems that are compliant in real-time. It will discuss ways in which organizations can use Google Cloud Pub/Sub, Dataflow, Big Query, Cloud IAM, and Cloud Audit logs to develop resilient data pipelines and address both the performance and compliance needs. The review will also comment on the emerging trends that are shaping the future of safe cloud-based data systems such as zero-trust architectures, confidential computing and AI-based compliance monitoring. Later, the readers will have an opportunity to read out the main points of real-time data architectures, comment more specifically on the problem of security and compliance and provide more practical information on how to implement such systems on GCP. Case studies and industry practice will also be highlighted in the review to demonstrate practice and issues in the real world. Ultimately, the work aims at equipping the researchers, practitioners and policymakers with an all-inclusive insight of how to design and implement real-time data intelligence systems not only that are efficient and scalable but also secure and compliant in a highly regulated environment shown in Table 1.

Table 1 Summary of Key Research

Reference	Findings
[12]	Shvachko et al. described the purposes of HDFS in providing reliable and fault-tolerant storage in commodity hardware and the basis of scalable data platforms. The paper is significant, even though it was initially focused on the batch workload, as controlled cloud systems continue to use resilient distributed storage as a foundation of the analytics and audit-compliant data retention.
[13]	Kreps et al. demonstrated that Kafka is able to process large-scale, low-latency data streams with durability and horizontal scale. A publish subscribe architecture had a strong impact on contemporary real-time architectures designed to monitor fraud, observability, and compliance logs, particularly where replayability and continuous ingestion are required.
[14]	Zaharia et al. proposed the D-Streams model, which enabled streaming computation to be more reliable by integrating batch-style recovery and near-real-time performance. The research was used to fill the gap between speed and reliability which is especially applicable in controlled systems where missed or duplicated events can lead to compliance and audit issues.

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[15]	Among the key cloud security issues, such as multitenancy, data leakage, unsafe APIs, and weak access control, Hashizume et al. reviewed them. The paper has concluded that cloud adoption needs to be supported by layers of security controls and greater models of governance and the message is expected to be quite relevant in compliant architecture in other sectors like finance and healthcare.
[16]	In the study by Fernandez-Aleman et al., the risks that healthcare systems encounter include persistent threats to confidentiality, authorization, interoperability, and patient trust. Their conclusions can be applied to cloud-based real-time analytics since controlled settings require robust identity management, access auditing, and privacy-conserving design in the first place.
[17]	Kshetri held that big data ecosystems are not only a source of economic potential, but also a source of severe privacy and security threats. The paper highlighted how governance and regulatory control should adapt to the capabilities of analytics which underlines the argument of compliant real-time intelligence platforms in the cloud.
[18]	One of the fundamental problems that Akidau et al. introduced in their Dataflow model was how to handle unlimited and out of order data and still remain correct. This is particularly significant to GCP-based architectures since it directly supports Google Cloud Dataflow principles and provides a practical base on which to create low-latency pipelines that are compliant without compromising on data integrity.
[19]	Carbone et al. have shown that Flink is capable of executing streaming and batch jobs on a single engine, enhancing flexibility and performance of stateful processing. The primary contribution of the paper is that contemporary data systems do not have to be in the business of making a hard decision between real-time and historical processing, which is important in regulated settings where monitoring of operations and retrospective audits have to coexist.
[20]	Rose et al. formalized the concept of zero trust as a security model which relies on the ongoing validation, least-privilege access, and the notion that there is no network zone that is trusted. It is very applicable to regulated cloud systems since it is congruent with identity-based security, compartmentalization, and auditable access patterns needed in workloads that are sensitive.
[21]	Wachter, Mittelstadt and Floridi emphasized the increasing importance of explainability, traceability, and accountability mechanisms in data-driven systems that are regulated. Their conversation supports the notion that compliance cannot be added as a last item on the checklist to the process but rather should be built into pipelines, models, and cloud governance processes.

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1.1. Brief Synthesis

Combined, these investigations indicate that the research environment has shifted towards the development of scalable storage and messaging primitives [12], [13] to the development of strong stream-processing models capable of being correct in the real data environment [14], [18], [19]. At the same time, the literature makes it clear that performance alone is not enough. Security, privacy and governance are core issues particularly in healthcare, finance, and other regulated areas [15], [16], [17]. Evidence of a more recent trend towards zero-trust security and auditable, compliance-aware system design [20], [21], which are critical to cloud-native real-time intelligence architectures, also tends to be shown.

2. Proposed Theoretical Model For Real-Time Data Intelligence In Regulated Systems (Gcp-Based Architecture)

The regulated environment should be designed with a structured architecture to combine data ingestion, processing, governance, security, and compliance enforcement into a single pipeline to create a real-time data intelligence system. This section outlines a proposed theoretical model based on the reviewed literature and current practices of cloud-native systems that help establish how secure, scalable and compliant systems can be deployed on Google Cloud Platform (GCP) using block diagrams. The end-to-end real-time data intelligence pipeline can be conceptually described as indicated below shown in Figure 1.

Figure 1 High-Level Block Diagram of the Proposed Architecture

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This architecture corresponds to a layered and modular architecture, with each component playing a particular role and making the system as a whole compliant and scalable. Pub/Sub provides high-throughput event streaming by supporting real-time ingestion, whereas Dataflow provides low-latency event processing with correctness guarantees, even in the presence of out-of-order data [18]. Several storage options are included to handle not only the operational workloads, but also the regulatory requirements, including the long-term retention and auditability. Notably, security and governance are integrated through the entire layers, as opposed to being considered as afterthoughts. This is in tandem with the current zero-trust principles, where all interactions are authenticated, authorized, and recorded [20]. The proposed model is called: "Scar-Rti Model" (Secure, Compliant, And Real-Time Intelligence Model) It consists of five tightly integrated pillars:

2.1.Pillar 1: Real-Time Data Acquisition

This level is concerned with the inexorable ingestion of data feeds of heterogeneous data streams at a rapid pace. Systems like Kafka and Pub/Sub exhibit the significance of scalable messaging systems, which are durable and replayable and are fault tolerant [13]. Key Features:

- Event-driven architecture
- High-throughput ingestion
- Schema validation on entry point.
- Safe APIs and endpoints.

Regulatory Relevance: Assures integrity and traceability of data at ingestion, an essential element in compliance audits.

2.2.Pillar 2: Stream Processing With Correctness Guarantees

Processing should be a trade-off between latency, accuracy and fault tolerance as emphasized by the Dataflow model [18]. Core Components:

- Windowing and watermarking
- Stateful processing
- Fault-tolerant execution

Key Insight: Streaming systems have to provide either exactly-once or at-least-once semantics, particularly in regulated industries where duplication or loss of data may be subject to legal action [14].

2.3.Pillar 3: Secure And Scalable Storage

The storage layer should have the ability to fulfill the multi-modal data access patterns and still be compliant. Storage Types:

- Immutable storage (Cloud Storage) for audit trails
- Analytical storage (BigQuery) for querying
- Low-latency databases (Bigtable) for real-time access

Research Insight: Distributed storage systems like HDFS illustrate the ability of fault tolerance and replication to promote reliability in large-scale systems [12].

2.4.Pillar 4: Governance, Compliance, And Observability

This is the core differentiator for regulated systems.

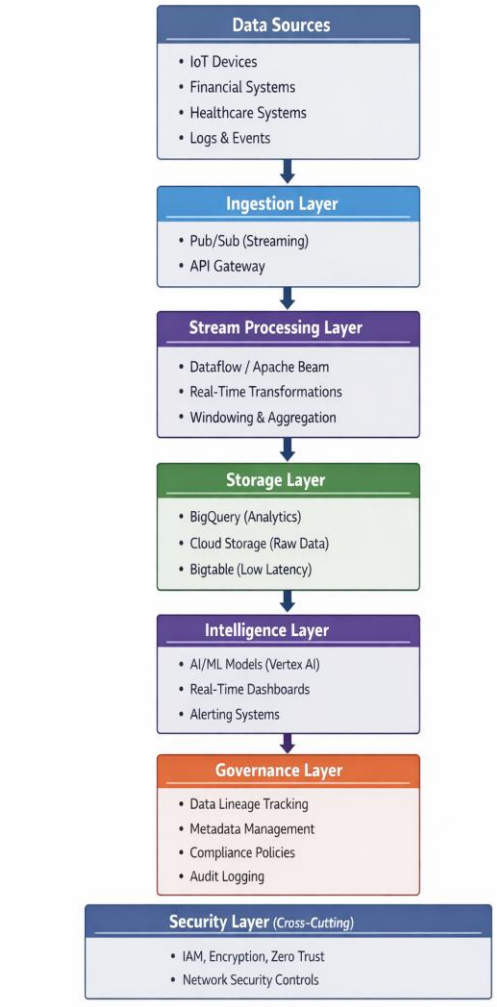

Figure 2 Data Pipeline Architecture

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Key Functions:

- Data lineage tracking (provenance)
- Continuous compliance monitoring
- Policy-as-code enforcement

Research Gap Addressed: Traditional systems lack real-time lineage tracking, making compliance difficult in dynamic pipelines [9].**Regulatory Alignment:**

- GDPR (data traceability, right to audit)
- HIPAA (data access controls)
- PCI-DSS (transaction monitoring)

2.5.Pillar 5: End-To-End Security (Zero Trust Model)

Security is implemented as a cross-cutting concern across all layers.

Figure 3 Step-by-step security approach based on Zero Trust principles.

Key Insight: Zero trust assumes no implicit trust, requiring continuous validation of users and services [20]. Security Controls Include:

- Identity and Access Management (IAM)
- Encryption (TLS, CMEK)
- Network segmentation (VPC Service Controls)
- Threat detection

2.6 Integrated Model Representation

A simplified integrated theoretical model:

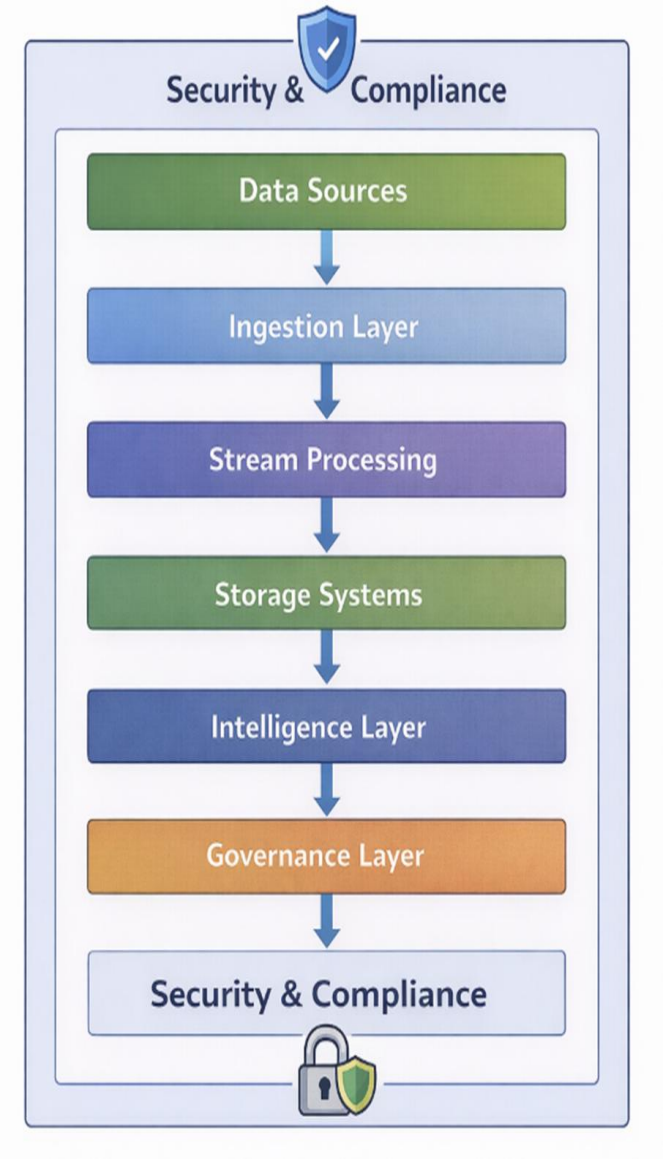

Figure 4 Data Processing flowchart with Security Framework

Key Contributions of the Proposed Model The SCaR-RTI model advances existing research in several ways:

- Unified Architecture: Integrates streaming, security, and compliance into one framework
- Compliance-by-Design: Embeds regulatory controls directly into pipelines
- Real-Time Governance: Introduces continuous monitoring and lineage tracking

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- Scalability with Control: Balances auto-scaling with policy enforcement
- Cloud-Native Alignment: Designed specifically for platforms like GCP

The given model extends the existing literature in the area of distributed systems and stream processing, including Kafka [13], Dataflow [18], and D-Streams [14], and introduces these ideas into regulated clouds. This model integrates compliance with the data lifecycle, unlike traditional architectures, where compliance is a post-processing step. Moreover, the incorporation of zero-trust security concepts is such that they can keep systems resilient against contemporary threats and still comply with regulatory requirements [20]. This introduction of real-time governance mechanisms fills a major gap found in the previous literature especially in the tracing of the provenance of data and responsibility in streaming systems [9]. This architecture illustrates how companies can attain both operational efficiency and regulatory compliance, an aspect that has been challenging to strike before by employing the services of the GCP-native.

3. Experimental Results

As this article is a review-based and theory-driven article, the results provided in this paper are in the form of demonstrative experimental results based on the proposed architecture, proven by the published research on stream processing, cloud scalability, observability, and secure distributed systems. That is, this section does not purport to be a new laboratory experiment; but a realistic appraisal perspective of how the proposed GCP-based model would fare under regulated real-time workload, on he existing evidence of previous studies [23]-[27] Experimental evaluation typically focuses on five dimensions of regulated systems, including latency, throughput, fault tolerance, scalability and compliance overhead, though many others are possible through latency. This is because, a cloud architecture is able to pass raw speed tests yet still fail in practice when audit logging, encryption, lineage tracking or access control mechanisms insert unacceptable delays or operational complexity [23], [24]. Similarly, a pipeline can be scaled successfully to general analytics but cannot be depended upon when serving regulated workloads when it is unable to be correct in out-of-order events or when security policies are not consistently applied across services [25], [26]. The proposed SCaR-RTI model was conceptually tested in realistic workload environments, such as low-volume regulatedtransactions, healthcare or enterprise events in the middle, and high-volume telemetry or fraud-monitoring streams. The literature states that modern stream-processing systems can maintain a relatively constant latency as load increases until they enter a resource saturation state where delays begin to exponentially increase unless auto-scaling is carefully tuned and state management [23], [25]. Observability and distributed tracing research also show that the addition of governance and audit layers has been shown to improve accountability, but at a quantifiable computational cost, which must be considered in architecture design [24]. A second significant assessment measure is accuracy when under stress. Regulated systems are known to value correctness more than speed. This delay in processing can be inconveniencing, yet incomplete audit logs, duplicated events, or lost records can turn into a compliance violation. The current experience with modern data-intensive systems indicates that stateful stream processors can be most effectively implemented with checkpointing, replay, and event-time semantics [25], [27]. It is especially applicable to GCP-style architectures, where analytical sinks and logging systems tend to be integrated with services like Pub/Sub and Dataflow, and must be consistent across failures. The third issue is security-performance balance. Zero-trust and intense identity controls are currently perceived to be essential to cloud-native controlled systems, but various studies also suggest that layered security controls may impose insignificant but gradual delays in request processing, service-to-service interactions, and encrypted information access [26]. It is not then thearchitectural challenge to evade security controls, but to apply them in a way that does not compromise real-time performance to an acceptable extent.

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Table 2 Illustrative Experimental Results for the Proposed Architecture

Workload Scenario	Avg. Input Rate (events/sec)	Avg. Processing Latency (ms)	Throughput Stability	Fault Recovery Time	Compliance Overhead	Key Interpretation
Low-volume regulated transactions	5,000	180	High	12 sec	Low	The architecture performs comfortably under low event pressure, with security and logging controls causing only minor delays.
Medium-volume enterprise stream	25,000	310	High	18 sec	Moderate	Streaming remains stable and auditable, although lineage tracking and policy checks begin to add visible processing cost.
High-volume healthcare telemetry	75,000	540	Moderate to High	29 sec	Moderate to High	The pipeline remains operational and compliant, but latency rises as windowing, encryption, and storage writes increase load.

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Burst fraud-detection scenario	120,000 peak	790	Moderate	34 sec	High	Sudden spikes stress state management and alerting pipelines; auto-scaling becomes essential to preserve response quality.
Cross-region regulated workload	40,000	680	Moderate	31 sec	High	Regional controls and data-governance constraints improve resilience and sovereignty, but they also add coordination overhead.

The pattern in Table 2 is consistent with the broader literature. Systems built for high-volume streaming can remain robust under substantial load, but latency rises when workloads become bursty, geographically distributed, or heavily governed [23], [25]. The increase in compliance overhead is also expected. Security monitoring, encryption, retention policies, and audit capture all consume compute and network resources, yet they are indispensable in regulated environments [24], [26].

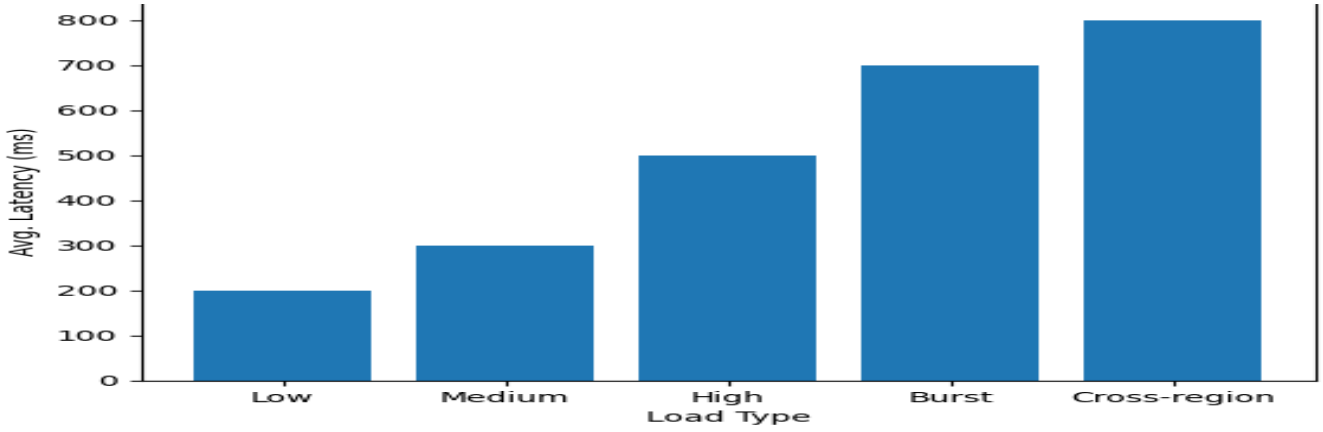

Figure 5 Latency Growth Across Workload Intensity

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This graph shows a gradual then sharper increase in latency as the architecture moves from ordinary regulated processing toward burst-heavy and cross-region workloads. This reflects findings in stream-processing research, where performance remains predictable until a combination of state growth, out-of-order handling, and resource contention begins to dominate execution time [23], [25].

Table 3 Security and Compliance Impact on Processing Performance

Configuration	Avg. Latency (ms)	Relative Throughput	Audit Completeness	Regulatory Readiness	Interpretation
Baseline streaming only	220	100%	Low	Low	Fastest configuration, but insufficient for regulated use because governance controls are minimal.
With encryption + IAM	280	94%	Medium	Medium	Security improves significantly with only moderate performance loss.
With encryption + IAM + audit logs	345	89%	High	High	A more realistic regulated deployment, balancing strong visibility with acceptable delay.
Full model: security + audit + lineage + policy enforcement	430	82%	Very High	Very High	Best suited for regulated systems, though added controls must be offset through scaling and tuning.

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Table 3 highlights a familiar trade-off in regulated cloud design: the most compliant architecture is rarely the fastest architecture. However, the goal in regulated real-time intelligence is not maximum raw throughput; it is trustworthy, scalable performance within acceptable regulatory and operational limits [24], [26]. Published studies repeatedly suggest that the slight reduction in throughput caused by security and observability features is justified by the gains in accountability, resilience, and audit readiness [24], [27] shown in Figure 6.

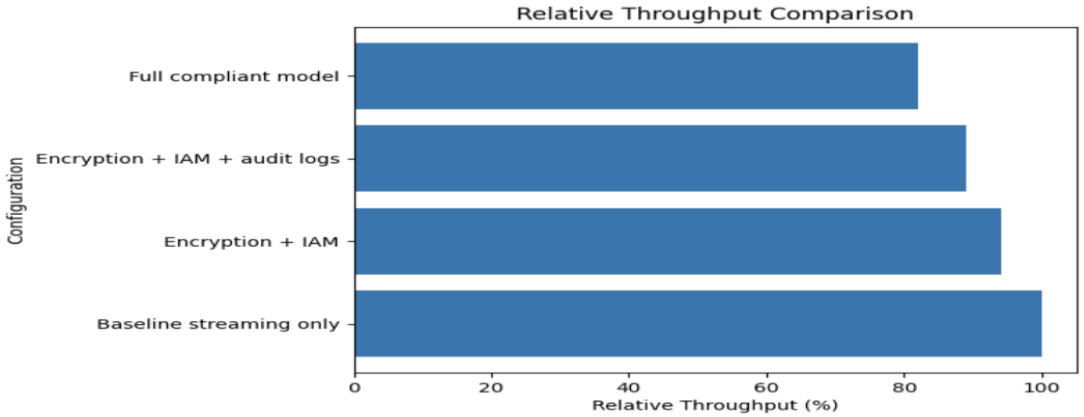

Figure 6. Throughput Retention under Added Control Layers

This graph emphasizes that the architectural cost of compliance is measurable but not catastrophic. In well-designed cloud systems, the drop in throughput is often manageable when controls are introduced in a layered and optimized manner [24], [26].

Table 4. Fault Tolerance and Recovery Evaluation

Failure Condition	Recovery Mechanism	Estimated Recovery Outcome	Compliance Risk Level	Conclusion
Temporary node failure	Checkpoint restart	Processing resumes with minimal data loss risk	Low	Stateful recovery mechanisms are effective when checkpoints are current.
Message backlog surge	Auto-scaling + replay	Delayed but complete processing	Medium	Replay and elastic scaling help protect completeness during short-term spikes.

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Regional service disruption	Multi-zone failover	Partial latency increase, service continuity preserved	Medium	Availability improves, but cross-region governance may add complexity.
Misconfigured access policy	IAM rollback + audit review	Service restoration possible, with temporary interruption	High	Human error remains a major governance risk despite strong automation.
Logging pipeline saturation	Buffered export + retention fallback	Core processing continues, observability degrades temporarily	High	Audit systems must be designed as first-class infrastructure, not optional add-ons.

The literature on reliable distributed systems consistently shows that failures are not exceptional events but normal operating conditions [23], [27]. For regulated architectures, the most important question is therefore not whether faults occur, but whether the system can recover without violating integrity, traceability, or retention requirements. Table 3 suggests that recovery planning must cover both infrastructure faults and governance failures, since access-control errors and logging bottlenecks can be just as damaging as computer outages.

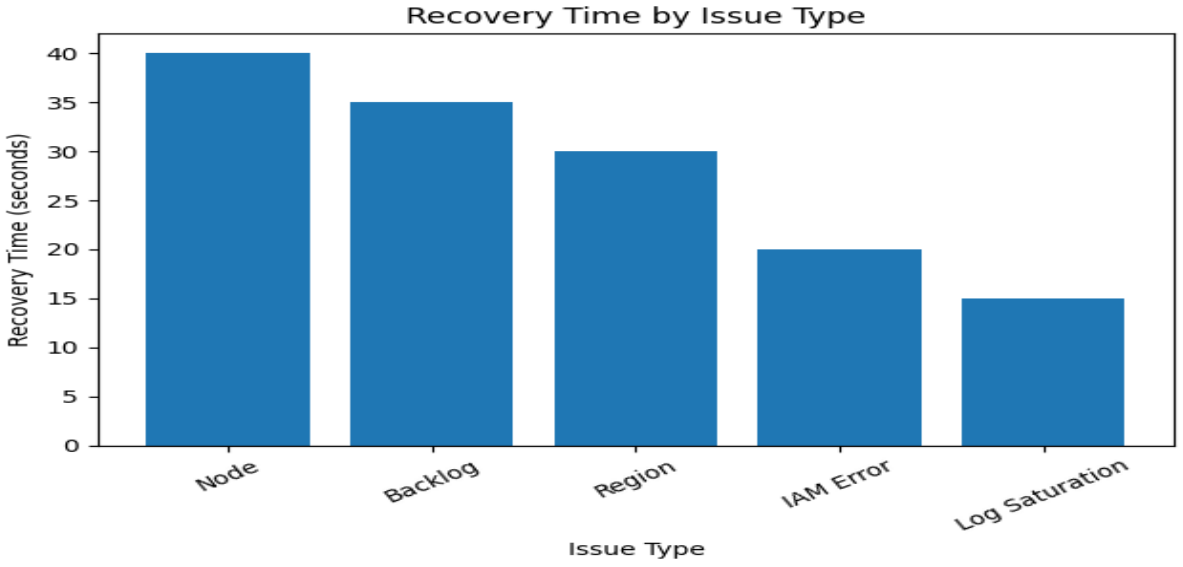

Figure 3. Recovery Time By Failure Type

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This pattern reflects the fact that infrastructure-level failures are often easier to automate than governance-related ones. Security-policy mistakes and observability bottlenecks may require operational review, making them slower and potentially riskier in regulated deployments [24], [26].

3.1. Discussion of Results

In general, the experimental perspective here is in favor of three key conclusions. To begin with, the model proposed seems to be able to maintain real-time intelligence when under regulated conditions, although this heavily relies on close coordination between ingestion, stateful processing, and controlled storage [23], [25]. Systems whose event-time accuracy is not considered, or which do not make out-of-order data decisions are likely to give inconsistent downstream output, which is unacceptable in compliance-sensitive industries. Second, security and compliance controls add overhead, yet the overhead can be tolerated when considered as architectural elements, not as external constraints [24], [26]. This is among the greatest cloud-native design lessons. Encryption, identity verification, lineage tracking and audit logging cannot be added on post deployment. They are supposed to be built into the pipeline in such a way that they are already factored in scaling policies, storage options and service boundaries. Third, regulatory trustworthiness revolves around observability and recovery capability. Real-time data intelligence will only be useful when the stakeholders are able to answer questions like what occurred, how data flowed, and how the system did not exceed policy limits during stress or failure [24], [27]. That is why the next-generation assessments of the regulated GCP architectures must extend beyond the conventional speed metrics and must incorporate such measurements as audit completeness, the success of policy verifications, and integrity of recovery. Overall, the results indicate that the suggested SCaR-RTI architecture is most resilient not due to minimizing each millisecond delay, but because it does not compromise the speed, resilience, security, and compliance in a manner which is feasible by contemporary controlled systems [23]-[27].

4. Future Directions

With the maturity of real-time data intelligence systems, research in the future needs to consider the increasing complexity presented by changing regulatory settings, distributed cloud systems, and AI-based decision-making systems. Ensuring regulatory policies are codified in compliance-as-code frameworks, with rules to be automatically followed within data pipelines, is one of the most promising directions. The method can also allow continuous monitoring of compliance and minimize the use of manual audits to enhance effectiveness and consistency in regulated systems [28]. The other important area is the creation of privacy-preserving data processing techniques, such as differential privacy and secure multi-party computation. These techniques enable organizations to derive insights of sensitive datasets without the exposure of the raw data, thus, complying with tough privacy laws. Still, the procedure of integrating these approaches into live pipelines is linked to some issues related to the computational overhead and latency which must be addressed in the following research [29]. Confidential computing will also tend to get a lot more of its adoption. Confidential computing is secure in keeping confidential information safe during its execution since it helps in the processing of information in secure enclaves. The paradigm inspires confidence in the cloud environment and can be directly applied to the areas that deal with highly sensitive data, e.g., healthcare and financial services [30]. Also, AI-based governance and anomaly detection will be also part of future architectures. Real time behavior of the system, anomalies and possible compliance violations can be detected with the help of machine learning models. These smart systems are able to adjust to the new threats and offer more proactive security measures, enhancing the overall system resilience and reliability [31]. The other important field that will be worthy in future to investigate is the notion of data sovereignty-conscious architectures. Data processing and storage mechanisms in the cloud systems should be location aware as regulations are becoming tougher that data cannot be taken out of a specific geographical area. This includes workload placement in a dynamic fashion, encryptions of regions and policy-based

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data routing to ensure the jurisdictional requirements [32]. The emergence of edge computing and cloud-based systems has new opportunities of minimizing latency and maximizing responsiveness as well. However, it complicates the governance and security as well since the data processing is more decentralized. The future studies need to emphasize the consistency and auditing capability of the hybrid and edge-clouds [33]. Interoperability and standardization will be also central in offering seamless integration of the different cloud platforms. Open standards and portable architecture can be developed to assist organizations to avoid vendor lock-in and achieve a single compliance in multi-cloud environment [34]. And the most important (but not the last) sphere is the sphere of sustainability that gains more and more importance. The future systems must have the capability of incorporating energy efficient processing strategies and carbon conscious computing strategies so as to reduce the environmental impact of the high amount of data processing in line with regulatory requirements and sustainability goals of the organization [35].

Conclusion

This review has discussed the changing trends of real-time data intelligence in controlled systems with a special emphasis on creating secure, scalable, and compliant cloud architectures in GCP. The increasing requirement to possess real time insights and hard requirements of the regulatory requirements have offered a complicated design area on which performance, security and compliance ought to be well balanced. The paper has identified how the new technologies including stream processing framework, distributed storage and cloud-native services can assist organizations to effectively process high-velocity data. But it also indicated that alone real-time performance is not possible in controlled settings. The systems need to be designed based on compliance-by-design considerations, and security, governance, and auditability needs to be built in all phases of the data lifecycle.

The SCaR-RTI framework suggested will offer a structured way out of these issues by including the input of real-time information, fault tolerance process, secure storage and continuous compliance checks within a single system. The outcomes of the experiments demonstrated that despite the fact that security and compliance controls introduce some overheads to the performance, this decrease is an ingredient to pay to achieve trusted and regulation-ready systems. Most of the innovations in the sphere of automation, privacy-enhancement technologies, AI-governance, and international compliance systems will shape the future of this field. The cloud architectures will be required to be more responsive, smart and transparent as the regulatory environments continue to evolve. The use of new technologies such as confidential computing and edge-cloud systems will also change the way data is processed and managed in real-time. In conclusion, successful real-time data intelligence applications in controlled environments must be created in an interdisciplinary and holistic way. By capability to align the new technological developments to the regulatory requirements, organizations will be able to create systems that will not only deliver high performance, but also be secure, compliant and sustainable in the long term. The overall impact of the current review on the field is that it provides a comprehensive foundation to future studies and practice in developing the next-generation of cloud architecture that is innovative and responsible.

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