NEXAPAY PAYMENT GATEWAY

Complete Technical Specification & System Architecture

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PART I: SYSTEM OVERVIEW & ARCHITECTURE

Chapter 1: Introduction to NexaPay

NexaPay is a next-generation payment gateway handling 2.3M daily transactions across UPI, IMPS, NEFT, RTGS, cards, and wallets. Built on microservices across GCP, STPI on-premises, and ISU DR sites. Core pillars: Reliability (99.999% SLA), Security (PCI-DSS L1), Scalability (50K TPS), Observability (distributed tracing), Compliance (RBI/NPCI/SEBI).

1.1 Integration Points

System	Priority	Latency	Availability	Protocol
NPCI UPI Switch	P0	200ms	99.99%	ISO 8583
Card Network	P0	300ms	99.99%	ISO 8583
Fraud Engine	P0	150ms	99.99%	gRPC
KYC Primary	P1	2000ms	99.9%	REST
Settlement	P1	1000ms	99.9%	gRPC
RBI Reporting	P1	5000ms	99.9%	JSON/XML
SMS Gateway	P3	1000ms	99.0%	HTTP
Merchant Portal	P2	500ms	99.5%	GraphQL

1.2 Core System Parameters

Parameter	Value	Unit	Description
TXN_TIMEOUT	30	seconds	Maximum time for transaction completion end-to-end
MAX_RETRY_COUNT	3	count	Maximum automatic retries
IDEMPOTENCY_WINDOW	24	hours	Idempotency key deduplication window
MUTEX_ACQUIRE_TIMEOUT	5000	ms	Max wait to acquire distributed mutex
PUB_ACK_TIMEOUT	3000	ms	Publisher acknowledgment timeout
SUB_HEARTBEAT	10	seconds	Subscriber heartbeat interval
RATE_LIMIT_DEFAULT	1000	req/min	Default rate limit per merchant
QUEUE_MAX_DEPTH	100000	messages	Max queue depth before backpressure

Note: Parameters may be overridden at service level.

Chapter 2: Technology Stack

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TECHNOLOGY_CACHE_TTL	300	seconds	Cache time-to-live for technology lookups
TECHNOLOGY_BATCH_SIZE	100	records	Batch processing size for technology
TECHNOLOGY_QUEUE_DEPTH	10000	messages	Maximum queue depth for technology
TECHNOLOGY_HEARTBEAT	10	seconds	Health check interval for technology
TECHNOLOGY_MAX_CONNECTIONS	50	count	Maximum concurrent connections for technology

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The deployment topology operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Chapter 4: Network Architecture & Security Zones

Configuration of the network architecture and security zones component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The network architecture and security zones module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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The network architecture and security zones operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Scalability of the network architecture and security zones component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Testing strategy for network architecture and security zones includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Parameter	Value	Unit	Description
NETWORK_TIMEOUT	5000	ms	Maximum network operation timeout
NETWORK_RETRY_COUNT	3	count	Maximum retry attempts for network
NETWORK_POOL_SIZE	20	connections	Connection pool size for network
NETWORK_CACHE_TTL	300	seconds	Cache time-to-live for network lookups
NETWORK_BATCH_SIZE	100	records	Batch processing size for network
NETWORK_QUEUE_DEPTH	10000	messages	Maximum queue depth for network
NETWORK_HEARTBEAT	10	seconds	Health check interval for network
NETWORK_MAX_CONNECTIONS	50	count	Maximum concurrent connections for network

4.1 Implementation Details

Testing strategy for network architecture & security zones includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Chapter 5: Service Discovery & Load Balancing

The service discovery and load balancing module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Configuration of the service discovery and load balancing component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Parameter	Value	Unit	Description
SERVICE_TIMEOUT	5000	ms	Maximum service operation timeout
SERVICE_RETRY_COUNT	3	count	Maximum retry attempts for service
SERVICE_POOL_SIZE	20	connections	Connection pool size for service
SERVICE_CACHE_TTL	300	seconds	Cache time-to-live for service lookups
SERVICE_BATCH_SIZE	100	records	Batch processing size for service
SERVICE_QUEUE_DEPTH	10000	messages	Maximum queue depth for service
SERVICE_HEARTBEAT	10	seconds	Health check interval for service
SERVICE_MAX_CONNECTIONS	50	count	Maximum concurrent connections for service

5.1 Implementation Details

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Chapter 6: Monitoring & Alerting

Testing strategy for monitoring and alerting includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Parameter	Value	Unit	Description
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MONITORING_RETRY_COUNT	3	count	Maximum retry attempts for monitoring
MONITORING_POOL_SIZE	20	connections	Connection pool size for monitoring
MONITORING_CACHE_TTL	300	seconds	Cache time-to-live for monitoring lookups
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6.5 Monitoring Details

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6.6 Scaling Details

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6.7 Recovery Details

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Chapter 7: Disaster Recovery

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Testing strategy for disaster recovery includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Parameter	Value	Unit	Description
DISASTER_TIMEOUT	5000	ms	Maximum disaster operation timeout
DISASTER_RETRY_COUNT	3	count	Maximum retry attempts for disaster
DISASTER_POOL_SIZE	20	connections	Connection pool size for disaster
DISASTER_CACHE_TTL	300	seconds	Cache time-to-live for disaster lookups
DISASTER_BATCH_SIZE	100	records	Batch processing size for disaster
DISASTER_QUEUE_DEPTH	10000	messages	Maximum queue depth for disaster
DISASTER_HEARTBEAT	10	seconds	Health check interval for disaster
DISASTER_MAX_CONNECTIONS	50	count	Maximum concurrent connections for disaster

7.1 Implementation Details

The disaster recovery subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Chapter 8: Performance Benchmarks

The performance benchmarks module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Testing strategy for performance benchmarks includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Error handling in the performance benchmarks module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Configuration of the performance benchmarks component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Parameter	Value	Unit	Description
PERFORMANCE_TIMEOUT	5000	ms	Maximum performance operation timeout
PERFORMANCE_RETRY_COUNT	3	count	Maximum retry attempts for performance
PERFORMANCE_POOL_SIZE	20	connections	Connection pool size for performance
PERFORMANCE_CACHE_TTL	300	seconds	Cache time-to-live for performance lookups
PERFORMANCE_BATCH_SIZE	100	records	Batch processing size for performance
PERFORMANCE_QUEUE_DEPTH	10000	messages	Maximum queue depth for performance
PERFORMANCE_HEARTBEAT	10	seconds	Health check interval for performance
PERFORMANCE_MAX_CONNECTIONS	50	count	Maximum concurrent connections for performance

8.1 Implementation Details

Testing strategy for performance benchmarks includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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The performance benchmarks subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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The performance benchmarks module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics

(Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Configuration of the performance benchmarks component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Scalability of the performance benchmarks component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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8.3 Operations Details

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8.4 Troubleshooting Details

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Security considerations for performance benchmarks include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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8.5 Monitoring Details

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The performance benchmarks operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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8.6 Scaling Details

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8.7 Recovery Details

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PART II: ENTITY SPECIFICATIONS & DATA MODELS

Chapter 9: Merchant Entity

The Merchant entity represents a registered business on NexaPay. Merchants undergo multi-stage onboarding: application, document upload, review, activation.

9.1 Merchant Schema

Field	Type	Constraints	Description
id	UUID	PK, NOT NULL	System-generated identifier
business_name	VARCHAR(255)	NOT NULL	Legal business name
display_name	VARCHAR(100)	NOT NULL	Customer-facing name
email	VARCHAR(255)	NOT NULL, UNIQUE	Primary contact email
phone	VARCHAR(15)	NOT NULL	Phone (E.164 format)
pan	VARCHAR(10)	NOT NULL, UNIQUE	Permanent Account Number
gstin	VARCHAR(15)	UNIQUE	GST Identification Number
business_type	ENUM	NOT NULL	sole_proprietorship, partnership, pvt_ltd, llp, ngo
category_code	VARCHAR(4)	NOT NULL	MCC per ISO 18245
kyc_status	ENUM	NOT NULL, DEFAULT pending	pending, in_review, verified, rejected, suspended
risk_tier	ENUM	NOT NULL, DEFAULT standard	low, standard, elevated, high, critical
onboarding_status	ENUM	NOT NULL	application, document_upload, review, activated, dormant
settlement_account_id	UUID	FK	Reference to BankAccount
monthly_volume_limit	DECIMAL(15,2)	NOT NULL	Max monthly volume (INR)
per_txn_limit	DECIMAL(12,2)	NOT NULL	Max single transaction (INR)
webhook_url	VARCHAR(512)	NULL	Webhook callback URL
webhook_secret	VARCHAR(64)	NULL	HMAC-SHA256 webhook secret
api_key_hash	VARCHAR(128)	NOT NULL	Argon2id hash of API key
metadata	JSONB	DEFAULT {}	Arbitrary metadata
created_at	TIMESTAMP	NOT NULL	Creation timestamp (UTC)
updated_at	TIMESTAMP	NOT NULL	Last modified (UTC)

9.2 Merchant Payment Method Configuration

Each merchant may accept multiple payment methods, and each payment method can be used by multiple merchants. The association between merchants and payment methods is managed through a configuration that specifies per-merchant overrides for each payment method. For example, a merchant might accept UPI with a maximum limit of 100,000 INR and credit cards with a maximum limit of 500,000 INR. The configuration also includes whether a specific payment method requires additional authentication (3D Secure for cards, UPI PIN for UPI), the settlement priority for each method, and any promotional discount rates negotiated during onboarding.

The payment method configuration includes an **is_active** flag toggled independently of overall merchant status. Each association has a **priority** field (1-10) for checkout ordering, a **fee_override** field for custom MDR per method, **min_override** and **max_override** for merchant-specific amount limits, and a **settlement_priority** for settlement ordering. This configuration is critical for the validation layer as it determines which methods are available and their specific constraints.

Chapter 10: Transaction Entity

The Transaction entity is the central data model. It represents a single payment attempt from initiation through settlement or failure, managed by a finite state machine.

10.1 Transaction Schema

Field	Type	Constraints	Description
id	UUID	PK	Unique identifier
merchant_id	UUID	FK, NOT NULL	Merchant reference
customer_id	UUID	FK, NULL	Customer (optional for guest)
payment_method_id	UUID	FK, NOT NULL	PaymentMethod reference
amount	DECIMAL(12,2)	NOT NULL, >0	Amount in INR
currency	VARCHAR(3)	DEFAULT INR	ISO 4217 code
status	ENUM	NOT NULL	initiated, processing, awaiting_auth, authorized, captured, settled, failed, refunded, partially_refunded, disputed, cancelled
idempotency_key	VARCHAR(64)	UNIQUE, NOT NULL	Client idempotency key
reference_id	VARCHAR(128)	NOT NULL	Merchant order reference
payment_network_ref	VARCHAR(128)	NULL	Network reference (e.g. UPI RRN)
auth_code	VARCHAR(6)	NULL	Authorization code
failure_code	VARCHAR(32)	NULL	Standardized failure code
failure_reason	TEXT	NULL	Failure description
fee_amount	DECIMAL(8,2)	DEFAULT 0	Platform fee
tax_amount	DECIMAL(8,2)	DEFAULT 0	GST on fee
net_amount	DECIMAL(12,2)	GENERATED	amount - fee - tax
ip_address	INET	NULL	Customer IP
metadata	JSONB	DEFAULT {}	Transaction metadata
initiated_at	TIMESTAMP	NOT NULL	Initiation time
authorized_at	TIMESTAMP	NULL	Auth time
captured_at	TIMESTAMP	NULL	Capture time
created_at	TIMESTAMP	NOT NULL	Created
updated_at	TIMESTAMP	NOT NULL	Updated

10.2 Transaction State Machine

Invalid state transitions must be rejected with TXN_INVALID_STATE_TRANSITION.

From	To	Guard	Side Effects
initiated	processing	Validation passed	Lock balance, emit txn.processing
initiated	failed	Validation failed	Emit txn.failed with failure_code
initiated	cancelled	Customer/merchant cancel	Emit txn.cancelled
processing	awaiting_auth	Requires auth	Send auth request, start timeout
processing	authorized	Auto-authorized	Emit txn.authorized
processing	failed	Error	Release lock, emit txn.failed
awaiting_auth	authorized	Auth success	Emit txn.authorized
awaiting_auth	failed	Auth failed/timeout	Release lock, emit txn.failed
authorized	captured	Settlement done	Credit merchant, emit txn.captured
authorized	failed	Capture failed	Reverse auth, emit txn.failed
authorized	cancelled	Void before capture	Reverse auth, emit txn.cancelled
captured	refunded	Full refund	Debit merchant, emit txn.refunded
captured	partially_refunded	Partial refund	Partial debit, emit event
captured	disputed	Chargeback	Hold funds, emit txn.disputed
disputed	captured	Merchant wins	Release held funds
disputed	refunded	Customer wins	Debit merchant, credit customer

Chapter 11: Customer Entity

Scalability of the customer component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Scalability of the customer component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Security considerations for customer include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

The customer module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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The customer subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Field	Type	Constraints	Description
id	UUID	PK	Identifier
merchant_id	UUID	FK	Owning merchant
email	VARCHAR(255)	NULL, encrypted	Email
phone	VARCHAR(15)	NULL, encrypted	Phone E.164
name	VARCHAR(255)	NULL	Display name
status	ENUM	NOT NULL	active, inactive, blocked
risk_score	INTEGER	CHECK 0-100	ML risk score
metadata	JSONB	DEFAULT {}	Metadata
created_at	TIMESTAMP	NOT NULL	Created
updated_at	TIMESTAMP	NOT NULL	Updated

Chapter 12: PaymentMethod Entity

Testing strategy for paymentmethod includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Scalability of the paymentmethod component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Field	Type	Constraints	Description
id	UUID	PK	Identifier
code	VARCHAR(32)	UNIQUE	Machine code
name	VARCHAR(100)	NOT NULL	Display name
category	ENUM	NOT NULL	bank_transfer, card, wallet, upi, bnpl
is_active	BOOLEAN	DEFAULT true	Globally active
min_amount	DECIMAL(10,2)	NOT NULL	Min txn amount
max_amount	DECIMAL(12,2)	NOT NULL	Max txn amount
requires_auth	BOOLEAN	DEFAULT false	Needs extra auth
settlement_days	INTEGER	NOT NULL	T+N settlement
fee_percent	DECIMAL(4,2)	NOT NULL	Default MDR %
fee_flat	DECIMAL(6,2)	DEFAULT 0	Flat fee per txn
metadata	JSONB	DEFAULT {}	Method config

Chapter 13: BankAccount Entity

The bankaccount subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Security considerations for bankaccount include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

The bankaccount operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Scalability of the bankaccount component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Testing strategy for bankaccount includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Field	Type	Constraints	Description
id	UUID	PK	Identifier
merchant_id	UUID	FK	Merchant
account_number_enc	BYTEA	NOT NULL	Encrypted account number
ifsc_code	VARCHAR(11)	NOT NULL	IFSC code
account_holder_name	VARCHAR(255)	NOT NULL	Name on account
account_type	ENUM	NOT NULL	savings, current, nre, nro
is_verified	BOOLEAN	DEFAULT false	Penny-drop verified
is_primary	BOOLEAN	DEFAULT false	Primary settlement account
created_at	TIMESTAMP	NOT NULL	Created

12.1 Default Payment Method Configuration

Code	Name	Category	Min(INR)	Max(INR)	Auth	Settle	Fee%	Flat
upi	UPI	bank_transfer	1.00	200000.00	Yes	T+0	0.00	0.00
credit_card	Credit Card	card	100.00	500000.00	Yes(3DS)	T+2	1.80	0.00
debit_card	Debit Card	card	100.00	200000.00	Yes(PIN)	T+1	0.90	0.00
netbanking	Net Banking	bank_transfer	100.00	1000000.00	Yes	T+2	1.20	5.00
wallet	Wallet	wallet	1.00	10000.00	No	T+1	1.50	0.00
bnpl	BNPL	bnpl	500.00	100000.00	Yes	T+3	2.50	10.00

Chapter 14: KYC Verification Process

KYC verification follows a tiered approach. **The internal system uses these exact status values for all KYC-related API responses and webhooks:**

Status	Description	Transaction Impact
not_started	Not submitted KYC docs	Max 10,000 INR/month
under_review	Documents submitted, awaiting verification	Max 50,000 INR/month
approved	KYC completed successfully	Full limits per risk tier
denied	KYC failed, rejected	Blocked after 7-day grace
on_hold	Suspended for re-verification	Existing limits, no increases
expired	Annual re-verification required	Reduced to under_review limits

IMPORTANT: The Validation Engine must check KYC status before authorizing. Merchants with denied or expired status must be rejected with ENTITY_MERCHANT_KYC_INVALID.

Chapter 15: Refund Entity

The refund module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Testing strategy for refund includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

The refund operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Parameter	Value	Unit	Description
REFUND_TIMEOUT	5000	ms	Maximum refund operation timeout

Parameter	Value	Unit	Description
REFUND_RETRY_COUNT	3	count	Maximum retry attempts for refund
REFUND_POOL_SIZE	20	connections	Connection pool size for refund
REFUND_CACHE_TTL	300	seconds	Cache time-to-live for refund lookups
REFUND_BATCH_SIZE	100	records	Batch processing size for refund
REFUND_QUEUE_DEPTH	10000	messages	Maximum queue depth for refund
REFUND_HEARTBEAT	10	seconds	Health check interval for refund
REFUND_MAX_CONNECTIONS	50	count	Maximum concurrent connections for refund

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Chapter 16: AuditLog Entity

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Parameter	Value	Unit	Description
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AUDITLOG_CACHE_TTL	300	seconds	Cache time-to-live for auditlog lookups
AUDITLOG_BATCH_SIZE	100	records	Batch processing size for auditlog
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AUDITLOG_MAX_CONNECTIONS	50	count	Maximum concurrent connections for auditlog

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Configuration of the auditlog component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Scalability of the auditlog component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The auditlog module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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16.6 Integration

The auditlog module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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The auditlog operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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The auditlog operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Security considerations for auditlog include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Chapter 17: Settlement Entity

The settlement module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Error handling in the settlement module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Parameter	Value	Unit	Description
SETTLEMENT_TIMEOUT	5000	ms	Maximum settlement operation timeout
SETTLEMENT_RETRY_COUNT	3	count	Maximum retry attempts for settlement

Parameter	Value	Unit	Description
SETTLEMENT_POOL_SIZE	20	connections	Connection pool size for settlement
SETTLEMENT_CACHE_TTL	300	seconds	Cache time-to-live for settlement lookups
SETTLEMENT_BATCH_SIZE	100	records	Batch processing size for settlement
SETTLEMENT_QUEUE_DEPTH	10000	messages	Maximum queue depth for settlement
SETTLEMENT_HEARTBEAT	10	seconds	Health check interval for settlement
SETTLEMENT_MAX_CONNECTIONS	50	count	Maximum concurrent connections for settlement

17.1 Schema Details

Testing strategy for settlement includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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17.2 Lifecycle

Testing strategy for settlement includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Error handling in the settlement module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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The settlement subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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17.3 Integration

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Testing strategy for settlement includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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17.7 Integration

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Chapter 18: WebhookDelivery Entity

Configuration of the webhookdelivery component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Error handling in the webhookdelivery module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Testing strategy for webhookdelivery includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Parameter	Value	Unit	Description
WEBHOOKDELIVERY_TIMEOUT	5000	ms	Maximum webhookdelivery operation timeout
WEBHOOKDELIVERY_RETRY_COUNT	3	count	Maximum retry attempts for webhookdelivery
WEBHOOKDELIVERY_POOL_SIZE	20	connections	Connection pool size for webhookdelivery
WEBHOOKDELIVERY_CACHE_TTL	300	seconds	Cache time-to-live for webhookdelivery lookups
WEBHOOKDELIVERY_BATCH_SIZE	100	records	Batch processing size for webhookdelivery
WEBHOOKDELIVERY_QUEUE_DEPTH	10000	messages	Maximum queue depth for webhookdelivery
WEBHOOKDELIVERY_HEARTBEAT	10	seconds	Health check interval for webhookdelivery
WEBHOOKDELIVERY_MAX_CONNECTIONS	50	count	Maximum concurrent connections for webhookdelivery

18.1 Schema Details

The webhookdelivery operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Chapter 19: FeeSchedule Entity

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Parameter	Value	Unit	Description
FEESCHEDULE_TIMEOUT	5000	ms	Maximum feeschedule operation timeout
FEESCHEDULE_RETRY_COUNT	3	count	Maximum retry attempts for feeschedule
FEESCHEDULE_POOL_SIZE	20	connections	Connection pool size for feeschedule
FEESCHEDULE_CACHE_TTL	300	seconds	Cache time-to-live for feeschedule lookups
FEESCHEDULE_BATCH_SIZE	100	records	Batch processing size for feeschedule
FEESCHEDULE_QUEUE_DEPTH	10000	messages	Maximum queue depth for feeschedule
FEESCHEDULE_HEARTBEAT	10	seconds	Health check interval for feeschedule
FEESCHEDULE_MAX_CONNECTIONS	50	count	Maximum concurrent connections for feeschedule

19.1 Schema Details

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The feeschedule module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Error handling in the feeschedule module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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Chapter 20: RateLimitConfig Entity

Scalability of the ratelimitconfig component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The ratelimitconfig module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Security considerations for ratelimitconfig include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Testing strategy for ratelimitconfig includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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The ratelimitconfig subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Parameter	Value	Unit	Description
RATELIMITCONFIG_TIMEOUT	5000	ms	Maximum ratelimitconfig operation timeout
RATELIMITCONFIG_RETRY_COUNT	3	count	Maximum retry attempts for ratelimitconfig
RATELIMITCONFIG_POOL_SIZE	20	connections	Connection pool size for ratelimitconfig
RATELIMITCONFIG_CACHE_TTL	300	seconds	Cache time-to-live for ratelimitconfig lookups
RATELIMITCONFIG_BATCH_SIZE	100	records	Batch processing size for ratelimitconfig
RATELIMITCONFIG_QUEUE_DEPTH	10000	messages	Maximum queue depth for ratelimitconfig
RATELIMITCONFIG_HEARTBEAT	10	seconds	Health check interval for ratelimitconfig
RATELIMITCONFIG_MAX_CONNECTIONS	50	count	Maximum concurrent connections for ratelimitconfig

20.1 Schema Details

The ratelimitconfig module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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20.2 Lifecycle

Configuration of the ratelimitconfig component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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PART III: TRANSACTION PROCESSING ENGINE

Chapter 21: Transaction Lifecycle

The Transaction Processing Engine (TPE) orchestrates payment lifecycle using Elixir/OTP GenServer processes per transaction.

21.1 Timeout Configuration

Transaction Timeout: Each transaction has a maximum processing time of **45 seconds** from initiation to final state. If not terminal within this window, auto-transitions to failed with TXN_TIMEOUT_EXCEEDED.

However, the base timeout is adjusted by payment method. The metadata JSON contains a **timeout_multiplier**: UPI = 1.0, Card with 3DS = 2.0, Netbanking = 1.5. Effective timeout = base_timeout * timeout_multiplier. Default multiplier is 1.0.

> *Note: base_timeout is from TRANSACTION_BASE_TIMEOUT env var, currently 30s in GCP and 45s in STPI due to network latency differences.*

21.2 Processing Pipeline

Step	Stage	Description	SLA
1	Idempotency Check	Verify key uniqueness in 24h window	< 5ms
2	Schema Validation	Structure, types, required fields	< 2ms
3	Merchant Validation	Exists, active, KYC approved	< 10ms
4	Payment Method Check	Active for this merchant	< 5ms
5	Amount Validation	Min/max limits (global + merchant)	< 3ms
6	Rate Limit Check	Merchant rate limits	< 2ms
7	Fraud Screening	ML-based (async, non-blocking)	< 150ms
8	Balance/Limit Check	Daily/monthly volume limits	< 10ms
9	Mutex Acquisition	Lock on merchant+reference_id	< 50ms
10	Network Routing	Route to payment network	< 5ms
11	Auth Request	Send to network	< 5000ms
12	Response Processing	Parse, update state	< 10ms
13	Event Emission	Publish to pub/sub	< 5ms
14	Webhook Dispatch	Queue merchant notification	< 5ms

Chapter 22: Idempotency Implementation

Error handling in the idempotency implementation module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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Parameter	Value	Unit	Description
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IDEMPOTENCY_POOL_SIZE	20	connections	Connection pool size for idempotency
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IDEMPOTENCY_QUEUE_DEPTH	10000	messages	Maximum queue depth for idempotency
IDEMPOTENCY_HEARTBEAT	10	seconds	Health check interval for idempotency
IDEMPOTENCY_MAX_CONNECTIONS	50	count	Maximum concurrent connections for idempotency

22.1 Subsection

The idempotency implementation operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Configuration of the idempotency implementation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Testing strategy for idempotency implementation includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Scalability of the idempotency implementation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Security considerations for idempotency implementation include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

22.6 Subsection

The idempotency implementation operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The idempotency implementation operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The idempotency implementation subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Scalability of the idempotency implementation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

22.7 Subsection

The idempotency implementation operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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The idempotency implementation subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

The idempotency implementation module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Chapter 23: Distributed Transaction Coordination

The distributed transaction coordination operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Testing strategy for distributed transaction coordination includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Security considerations for distributed transaction coordination include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Testing strategy for distributed transaction coordination includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Testing strategy for distributed transaction coordination includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Parameter	Value	Unit	Description
DISTRIBUTED_TIMEOUT	5000	ms	Maximum distributed operation timeout
DISTRIBUTED_RETRY_COUNT	3	count	Maximum retry attempts for distributed
DISTRIBUTED_POOL_SIZE	20	connections	Connection pool size for distributed
DISTRIBUTED_CACHE_TTL	300	seconds	Cache time-to-live for distributed lookups
DISTRIBUTED_BATCH_SIZE	100	records	Batch processing size for distributed
DISTRIBUTED_QUEUE_DEPTH	10000	messages	Maximum queue depth for distributed
DISTRIBUTED_HEARTBEAT	10	seconds	Health check interval for distributed
DISTRIBUTED_MAX_CONNECTIONS	50	count	Maximum concurrent connections for distributed

23.1 Subsection

The distributed transaction coordination operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Error handling in the distributed transaction coordination module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Configuration of the distributed transaction coordination component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The distributed transaction coordination subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

23.2 Subsection

The distributed transaction coordination operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The distributed transaction coordination module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The distributed transaction coordination subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Security considerations for distributed transaction coordination include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

23.3 Subsection

Error handling in the distributed transaction coordination module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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The distributed transaction coordination operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Security considerations for distributed transaction coordination include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

23.4 Subsection

Scalability of the distributed transaction coordination component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Error handling in the distributed transaction coordination module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Testing strategy for distributed transaction coordination includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Error handling in the distributed transaction coordination module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

23.5 Subsection

Security considerations for distributed transaction coordination include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

The distributed transaction coordination operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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The distributed transaction coordination operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

23.6 Subsection

The distributed transaction coordination module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The distributed transaction coordination operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Configuration of the distributed transaction coordination component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

23.7 Subsection

The distributed transaction coordination module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Testing strategy for distributed transaction coordination includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Chapter 24: Payment Network Integration

Scalability of the payment network integration component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Security considerations for payment network integration include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Configuration of the payment network integration component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Scalability of the payment network integration component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The payment network integration subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Parameter	Value	Unit	Description
PAYMENT_TIMEOUT	5000	ms	Maximum payment operation timeout
PAYMENT_RETRY_COUNT	3	count	Maximum retry attempts for payment
PAYMENT_POOL_SIZE	20	connections	Connection pool size for payment
PAYMENT_CACHE_TTL	300	seconds	Cache time-to-live for payment lookups
PAYMENT_BATCH_SIZE	100	records	Batch processing size for payment
PAYMENT_QUEUE_DEPTH	10000	messages	Maximum queue depth for payment
PAYMENT_HEARTBEAT	10	seconds	Health check interval for payment
PAYMENT_MAX_CONNECTIONS	50	count	Maximum concurrent connections for payment

24.1 Subsection

The payment network integration operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Configuration of the payment network integration component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a

rolling restart.

The payment network integration module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Security considerations for payment network integration include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

24.2 Subsection

The payment network integration operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Scalability of the payment network integration component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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24.3 Subsection

Testing strategy for payment network integration includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

The payment network integration module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The payment network integration subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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The payment network integration module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The payment network integration operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

24.5 Subsection

Scalability of the payment network integration component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Configuration of the payment network integration component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Error handling in the payment network integration module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The payment network integration subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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The payment network integration operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The payment network integration module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Configuration of the payment network integration component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Configuration of the payment network integration component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Testing strategy for payment network integration includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Error handling in the payment network integration module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Scalability of the payment network integration component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Chapter 25: Fee Calculation Engine

The fee calculation engine module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Security considerations for fee calculation engine include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Scalability of the fee calculation engine component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Error handling in the fee calculation engine module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Scalability of the fee calculation engine component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Parameter	Value	Unit	Description
FEE_TIMEOUT	5000	ms	Maximum fee operation timeout
FEE_RETRY_COUNT	3	count	Maximum retry attempts for fee
FEE_POOL_SIZE	20	connections	Connection pool size for fee
FEE_CACHE_TTL	300	seconds	Cache time-to-live for fee lookups
FEE_BATCH_SIZE	100	records	Batch processing size for fee
FEE_QUEUE_DEPTH	10000	messages	Maximum queue depth for fee
FEE_HEARTBEAT	10	seconds	Health check interval for fee
FEE_MAX_CONNECTIONS	50	count	Maximum concurrent connections for fee

25.1 Subsection

Configuration of the fee calculation engine component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The fee calculation engine module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Scalability of the fee calculation engine component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work

distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The fee calculation engine operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

25.2 Subsection

The fee calculation engine subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Security considerations for fee calculation engine include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Testing strategy for fee calculation engine includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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25.5 Subsection

The fee calculation engine operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Testing strategy for fee calculation engine includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Configuration of the fee calculation engine component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The fee calculation engine module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

25.6 Subsection

Configuration of the fee calculation engine component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Testing strategy for fee calculation engine includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

The fee calculation engine subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

The fee calculation engine subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

25.7 Subsection

Security considerations for fee calculation engine include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Testing strategy for fee calculation engine includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Error handling in the fee calculation engine module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Testing strategy for fee calculation engine includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Chapter 26: Error Handling & Recovery

Configuration of the error handling and recovery component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Testing strategy for error handling and recovery includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Testing strategy for error handling and recovery includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Testing strategy for error handling and recovery includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Security considerations for error handling and recovery include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Parameter	Value	Unit	Description
ERROR_TIMEOUT	5000	ms	Maximum error operation timeout
ERROR_RETRY_COUNT	3	count	Maximum retry attempts for error
ERROR_POOL_SIZE	20	connections	Connection pool size for error
ERROR_CACHE_TTL	300	seconds	Cache time-to-live for error lookups
ERROR_BATCH_SIZE	100	records	Batch processing size for error
ERROR_QUEUE_DEPTH	10000	messages	Maximum queue depth for error
ERROR_HEARTBEAT	10	seconds	Health check interval for error
ERROR_MAX_CONNECTIONS	50	count	Maximum concurrent connections for error

26.1 Subsection

Error handling in the error handling & recovery module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The error handling & recovery subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

The error handling & recovery operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Error handling in the error handling & recovery module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

26.2 Subsection

Error handling in the error handling & recovery module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The error handling & recovery operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Error handling in the error handling & recovery module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Configuration of the error handling & recovery component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

26.3 Subsection

The error handling & recovery subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Error handling in the error handling & recovery module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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Security considerations for error handling & recovery include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

26.4 Subsection

Testing strategy for error handling & recovery includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Security considerations for error handling & recovery include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Error handling in the error handling & recovery module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

26.5 Subsection

The error handling & recovery operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The error handling & recovery subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Error handling in the error handling & recovery module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Scalability of the error handling & recovery component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

26.6 Subsection

Configuration of the error handling & recovery component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Configuration of the error handling & recovery component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The error handling & recovery module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The error handling & recovery module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

26.7 Subsection

Security considerations for error handling & recovery include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Configuration of the error handling & recovery component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The error handling & recovery module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Testing strategy for error handling & recovery includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Chapter 27: Reconciliation

The reconciliation subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

The reconciliation operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The reconciliation module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The reconciliation subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

The reconciliation subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Parameter	Value	Unit	Description
RECONCILIATION_TIMEOUT	5000	ms	Maximum reconciliation operation timeout
RECONCILIATION_RETRY_COUNT	3	count	Maximum retry attempts for reconciliation
RECONCILIATION_POOL_SIZE	20	connections	Connection pool size for reconciliation
RECONCILIATION_CACHE_TTL	300	seconds	Cache time-to-live for reconciliation lookups
RECONCILIATION_BATCH_SIZE	100	records	Batch processing size for reconciliation
RECONCILIATION_QUEUE_DEPTH	10000	messages	Maximum queue depth for reconciliation
RECONCILIATION_HEARTBEAT	10	seconds	Health check interval for reconciliation
RECONCILIATION_MAX_CONNECTIONS	50	count	Maximum concurrent connections for reconciliation

27.1 Subsection

The reconciliation module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Scalability of the reconciliation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Scalability of the reconciliation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Configuration of the reconciliation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

27.2 Subsection

The reconciliation module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The reconciliation module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Configuration of the reconciliation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Configuration of the reconciliation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

27.3 Subsection

Security considerations for reconciliation include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Error handling in the reconciliation module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Configuration of the reconciliation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Error handling in the reconciliation module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

27.4 Subsection

The reconciliation operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Security considerations for reconciliation include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Scalability of the reconciliation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The reconciliation operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

27.5 Subsection

The reconciliation module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Scalability of the reconciliation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Configuration of the reconciliation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Configuration of the reconciliation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

27.6 Subsection

Testing strategy for reconciliation includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from

sanitized access logs.

Scalability of the reconciliation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The reconciliation module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Testing strategy for reconciliation includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

27.7 Subsection

Scalability of the reconciliation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Security considerations for reconciliation include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

The reconciliation module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Scalability of the reconciliation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Chapter 28: Settlement Aggregation

Scalability of the settlement aggregation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Configuration of the settlement aggregation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Security considerations for settlement aggregation include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Scalability of the settlement aggregation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Security considerations for settlement aggregation include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Parameter	Value	Unit	Description
SETTLEMENT_TIMEOUT	5000	ms	Maximum settlement operation timeout
SETTLEMENT_RETRY_COUNT	3	count	Maximum retry attempts for settlement
SETTLEMENT_POOL_SIZE	20	connections	Connection pool size for settlement
SETTLEMENT_CACHE_TTL	300	seconds	Cache time-to-live for settlement lookups
SETTLEMENT_BATCH_SIZE	100	records	Batch processing size for settlement
SETTLEMENT_QUEUE_DEPTH	10000	messages	Maximum queue depth for settlement
SETTLEMENT_HEARTBEAT	10	seconds	Health check interval for settlement
SETTLEMENT_MAX_CONNECTIONS	50	count	Maximum concurrent connections for settlement

28.1 Subsection

The settlement aggregation operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Security considerations for settlement aggregation include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Error handling in the settlement aggregation module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The settlement aggregation module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

28.2 Subsection

Configuration of the settlement aggregation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Configuration of the settlement aggregation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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28.3 Subsection

Scalability of the settlement aggregation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Configuration of the settlement aggregation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Security considerations for settlement aggregation include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Error handling in the settlement aggregation module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

28.4 Subsection

The settlement aggregation subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Security considerations for settlement aggregation include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Scalability of the settlement aggregation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

28.5 Subsection

Security considerations for settlement aggregation include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Scalability of the settlement aggregation component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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The settlement aggregation operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

28.6 Subsection

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Configuration of the settlement aggregation component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Testing strategy for settlement aggregation includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

28.7 Subsection

Error handling in the settlement aggregation module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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PART IV: VALIDATION FRAMEWORK

Chapter 29: Validation Architecture Overview

The Validation Framework implements multi-layered validation. Each layer runs sequentially; failure short-circuits subsequent layers.

29.1 Validation Layers

Layer	Purpose	Error Prefix	Implementation
Schema Validation	Request structure and types	SCHEMA_*	Ecto changesets
Entity Validation	Entity existence and status	ENTITY_*	Database lookups
Business Rule Validation	Cross-field/entity rules	RULE_*	Custom validators
Compliance Validation	Regulatory checks	COMPLIANCE_*	Rule engine
Risk Validation	Fraud/risk assessment	RISK_*	ML model + rules

Execution Order: Schema first (no DB, fastest), Entity second (verify existence), Business Rules third (cross-entity data), Compliance fourth (may call external APIs), Risk last (ML inference, most expensive).

Chapter 30: Layer 1 - Schema Validation

Error Code	Description	Examples
SCHEMA_MISSING_FIELD	Required field absent	amount, merchant_id, payment_method, idempotency_key
SCHEMA_INVALID_TYPE	Wrong data type	amount must be numeric
SCHEMA_INVALID_FORMAT	Format mismatch	email format, phone E.164, UUID format
SCHEMA_INVALID_ENUM	Invalid enum value	currency must be ISO 4217
SCHEMA_VALUE_TOO_LONG	Exceeds max length	reference_id max 128 chars
SCHEMA_INVALID_AMOUNT	Zero/negative/bad decimals	amount > 0, max 2 decimal places

Chapter 31: Layer 2 - Entity Validation

Error Code	Description	Logic
ENTITY_MERCHANT_NOT_FOUND	Merchant ID missing	DB lookup by PK
ENTITY_MERCHANT_INACTIVE	Not activated	onboarding_status = activated
ENTITY_MERCHANT_KYC_INVALID	KYC not approved	Check KYC is approved/verified
ENTITY_PAYMENT_METHOD_NOT_FOUND	Method missing	DB lookup by code/ID
ENTITY_PAYMENT_METHOD_INACTIVE	Globally disabled	is_active = true
ENTITY_MERCHANT_METHOD_INACTIVE	Disabled for merchant	Check association is_active
ENTITY_CUSTOMER_BLOCKED	Customer blocked	status check if customer_id given

IMPORTANT: Due to ongoing system migration, merchant records may contain KYC status from legacy (pending, in_review, verified, rejected, suspended) OR new system (not_started, under_review, approved, denied, on_hold, expired). Validation must accept BOTH 'verified' (legacy) AND 'approved' (new) as valid.

Chapter 32: Layer 3 - Business Rule Validation

Error Code	Description	Rule
RULE_AMOUNT_BELOW_MIN	Below method minimum	amount >= method.min AND >= merchant_method.min_override
RULE_AMOUNT_ABOVE_MAX	Above method maximum	amount <= method.max AND <= merchant_method.max_override
RULE_TXN_LIMIT_EXCEEDED	Per-txn limit exceeded	amount <= merchant.per_txn_limit
RULE_DAILY_VOLUME_EXCEEDED	Daily limit exceeded	daily_total + amount <= monthly_limit/30
RULE_MONTHLY_VOLUME_EXCEEDED	Monthly limit exceeded	monthly_total + amount <= monthly_limit
RULE_DUPLICATE_REFERENCE	Duplicate ref in 24h	No same merchant_id+reference_id in 24h
RULE_CURRENCY_MISMATCH	Unsupported currency	UPI only supports INR
RULE_KYC_VOLUME_EXCEEDED	KYC tier limit exceeded	Per Chapter 14 tier limits

Chapter 33: Layer 4 - Compliance Validation

Error Code	Description	Details
COMPLIANCE_SANCTIONS_HIT	Sanctions/PEP list match	OFAC, EU, UN lists via external API
COMPLIANCE_GEO_RESTRICTED	Restricted geography	IP geolocation check
COMPLIANCE_TIME_RESTRICTED	Outside allowed hours	Some methods restricted 02:00-02:30 IST
COMPLIANCE_AMOUNT_REPORTING	Exceeds reporting threshold	Txns > 200,000 INR flagged (not blocked)
COMPLIANCE_VELOCITY_CHECK	Unusual velocity	> 10 txns in 5 min from same customer

Chapter 34: Layer 5 - Risk Validation

Error Code	Description	Action
RISK_FRAUD_DETECTED	Score > 0.85	Blocked, alert generated
RISK_FRAUD_REVIEW	Score 0.60-0.85	Held for manual review (not blocked)
RISK_VELOCITY_ANOMALY	Pattern anomaly	Unusual amount/timing/frequency
RISK_DEVICE_MISMATCH	Unknown device	New device for registered customer
RISK_GEO_ANOMALY	Location anomaly	Unusual location for customer

Chapter 35: Custom Rules Engine

Security considerations for custom rules engine include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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The custom rules engine operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Scalability of the custom rules engine component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The custom rules engine subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Chapter 36: Validation Caching

Scalability of the validation caching component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Chapter 37: Error Response Format

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Chapter 38: Validation Metrics

The validation metrics operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The validation metrics module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Configuration of the validation metrics component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Security considerations for validation metrics include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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38.6 Details

The validation metrics subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation.

All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Scalability of the validation metrics component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The validation metrics module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Chapter 39: Rule Versioning

The rule versioning module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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The rule versioning operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Testing strategy for rule versioning includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Chapter 40: Validation Testing

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PART V: EVENT-DRIVEN ARCHITECTURE & PUB/SUB

Chapter 41: Event Architecture Overview

Two levels: **internal events** (Phoenix.PubSub with PG2, ephemeral, best-effort) and **external events** (Apache Kafka, durable, at-least-once). Internal for low-latency intra-cluster, external for cross-service guaranteed delivery.

Chapter 42: Event Taxonomy

42.1 Event Envelope Schema


```
{"event_id":"uuid","event_type":"domain.entity.action","version":"1.0","timestamp":"ISO-8601","source":"service","correlation_id":"trace-id","causation_id":"parent-event-id","data":{...},"metadata":{"actor":"..."}}
```


42.2 Transaction Events

Event Type	Description	Key Fields	Channel
transaction.initiated	New txn created	txn_id, merchant_id, amount	Kafka
transaction.processing	Validation passed	txn_id, validation_result	Kafka
transaction.authorized	Authorized	txn_id, auth_code	Kafka + PubSub
transaction.captured	Captured	txn_id, net_amount, fees	Kafka + PubSub
transaction.failed	Failed	txn_id, failure_code, failed_layer	Kafka + PubSub
transaction.refunded	Refunded	txn_id, refund_amount	Kafka
transaction.disputed	Chargeback	txn_id, dispute_reason	Kafka + PubSub

Chapter 43: Internal Pub/Sub (Phoenix.PubSub)

43.1 Topic Structure

Topics: **{domain}:{entity}:{action}:{entity_id}**

Pattern	Matches	Subscribers
txn:*	All transaction events	Settlement, Analytics
txn:transaction:authorized:*	All authorized	Notification service
txn:transaction:failed:*	All failed	Alert service, Retry engine
txn:transaction:*:{merchant_id}	Per-merchant events	Merchant dashboard (WebSocket)
merchant:*	All merchant events	Compliance service

43.2 EventHandler Behaviour

```
defmodule NexaPay.EventHandler do
  @callback topics() :: [String.t()]
  @callback handle_event(event :: map()) :: :ok | {:error, term()}
  @callback handle_error(event :: map(), error :: term()) :: :ok
end
```

Internal events are NOT retried. If handler fails, event is lost for that subscriber. Use Kafka for guaranteed processing.

43.3 Back-Pressure

Phoenix.PubSub does NOT guarantee ordering across subscribers. Each subscriber GenServer has max mailbox of 10,000 messages. Exceeding threshold: drop non-critical events (without priority:high), log warning. Critical events never dropped.

Chapter 44: External Events (Kafka)

44.1 Topic Config

Topic	Partitions	Replicas	Retention	Purpose
txn-events	12	3	7 days	Transaction lifecycle
merchant-events	6	3	30 days	Merchant lifecycle
settlement-events	6	3	90 days	Settlements
audit-events	12	3	365 days	Audit trail
dead-letter	3	3	infinite	Failed events

44.2 Partitioning: by **merchant_id** (murmur3 hash). Ensures per-merchant ordering.

44.3 Dead Letter Queue: events failing 3x go to DLQ. Retry: exponential backoff **1s, 5s, 30s**.

44.4 Ordering Guarantees

Per-entity: guaranteed (same partition). **Cross-entity:** NOT guaranteed. **Cross-subscriber:** NOT guaranteed. Use causation_id for causal ordering.

Chapter 45: Event Sourcing

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Testing strategy for event sourcing includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Chapter 46: Schema Evolution

The schema evolution operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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The schema evolution operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Chapter 47: Saga Coordination

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Security considerations for saga coordination include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Chapter 48: CQRS Pattern

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Security considerations for cqrs pattern include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Chapter 49: Event Compaction

Scalability of the event compaction component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Error handling in the event compaction module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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Chapter 50: Pub/Sub Monitoring

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Chapter 51: Event Replay

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Error handling in the event replay module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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PART VI: CONCURRENCY CONTROL & MUTEX PATTERNS

Chapter 52: Concurrency Challenges

Issue	Description	Mitigation	Severity
Double Processing	Same txn processed twice	Idempotency + mutex	Critical
Balance Race	Two txns consume same balance	Pessimistic locking	Critical
State Corruption	Concurrent state transitions	GenServer isolation	Critical
Settlement Overlap	Txn in two settlements	Mutex on window	High
Config Race	Config update during processing	Versioned cache	Medium

Chapter 53: Distributed Mutex

53.1 Redis Distributed Locks (Redlock)

Parameter	Value	Unit	Description
LOCK_TTL	30000	ms	Auto-release if holder crashes
LOCK_RETRY_COUNT	3	count	Acquisition attempts
LOCK_RETRY_DELAY	200	ms	Base delay with jitter
LOCK_DRIFT_FACTOR	0.01	ratio	Clock drift compensation
LOCK_QUORUM	2	nodes	Min Redis nodes (of 3)
LOCK_EXTEND_INTERVAL	10000	ms	Heartbeat extension

Key format: **mutex:{resource_type}:{resource_id}**. Value: owner(node:pid:timestamp).

53.2 BEAM Process Locks

Each transaction gets its own GenServer (registered via Registry by txn_id). Messages processed sequentially = serialized state transitions without explicit locking.

```
defmodule NexaPay.TransactionServer do
  use GenServer
    def start_link(txn_id), do: GenServer.start_link(__MODULE__, txn_id, name: {:via, Registry, {NexaPay.TxnRegistry, txn_id}})
  def handle_call({:transition, new_state, params}, _from, state) do
    case validate_transition(state.status, new_state) do
      :ok -> {:reply, {:ok, apply_transition(state, new_state, params)}, new_state}
      {:error, reason} -> {:reply, {:error, :invalid_transition}, state}
    end
  end
end
```

53.3 Merchant Balance Mutex

Pattern: 1) Acquire mutex:merchant_balance:{id}, 2) Read daily+monthly totals, 3) Validate limits, 4) UPDATE+COMMIT, 5) Release mutex. On failure: ROLLBACK, release, return RULE_VOLUME_EXCEEDED.

CRITICAL: Mutex MUST be acquired BEFORE DB transaction begins and released AFTER commit. Otherwise slow commits can cause TTL expiry creating races.

Chapter 54: Locking Strategies

Operation	Strategy	Contention	Implementation
Txn Creation	Optimistic	Low	Idempotency key + unique constraint
Balance Update	Pessimistic	High	Redis Redlock + DB txn
Settlement	Pessimistic	Single writer	Redlock, 5-min TTL
Config Update	Optimistic	Very low	Ecto optimistic_lock
Refund	Pessimistic	Medium	GenServer serialization
Webhook	Optimistic	Low	Compare-and-swap on status

54.1 Deadlock Prevention: strict ordering - 1) Merchant balance, 2) Txn state, 3) Settlement window, 4) Notification queue.

Chapter 55: Database Locking

Security considerations for database locking include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Chapter 56: ETS Concurrency

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Chapter 57: Token Bucket Rate Limiting

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57.6 Details

Scalability of the token bucket rate limiting component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Chapter 58: Circuit Breaker

Scalability of the circuit breaker component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Chapter 59: Bulkhead Pattern

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Testing strategy for bulkhead pattern includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Chapter 60: Concurrency Testing

Error handling in the concurrency testing module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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PART VII: API SPECIFICATIONS

Chapter 61: API Design

61.1 Response Envelope

```
// Success: {"success":true,"data":{...},"metadata":{"request_id":"uuid","timestamp":"ISO-8601","version":"v1"}}
// Error: {"success":false,"error":{"code":"ERROR_CODE","message":"...","layer":"schema|entity|business_rule|compliance|risk","details":[...]},"metadata":{...}}
```

Chapter 62: POST /api/v1/transactions

62.1 Request

```
Headers: X-Api-Key, Idempotency-Key, Content-Type: application/json
Body: {"amount":1500.00,"currency":"INR","payment_method":"upi","reference_id":"ORDER-123","customer":{"email":"...","phone":"+91..."},"metadata":{...}}
```

62.2 Success Response (201)


```
{"success":true,"data":{"transaction_id":"txn_abc","status":"processing","amount":1500.00,"currency":"INR","payment_method":"upi","reference_id":"ORDER-123","created_at":"..."},"metadata":{"request_id":"...","timestamp":"...","version":"v1"}}
```

Chapter 63: Merchant API

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Chapter 64: Customer API

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Chapter 65: Refund API

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Chapter 66: Settlement API

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Chapter 67: Webhook API

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Chapter 68: Admin API

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Security considerations for admin api include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

The admin api subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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68.6 Endpoints

The admin api module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Configuration of the admin api component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Testing strategy for admin api includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Error handling in the admin api module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The admin api operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The admin api module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Security considerations for admin api include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

The admin api operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Scalability of the admin api component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Configuration of the admin api component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

68.7 Endpoints

Testing strategy for admin api includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

The admin api module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Testing strategy for admin api includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Scalability of the admin api component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The admin api module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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The admin api subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Error handling in the admin api module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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The admin api operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

PART VIII: Security, Compliance & Audit

Chapter 69: PCI-DSS Compliance

Scalability of the pci-dss compliance component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Error handling in the pci-dss compliance module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The pci-dss compliance subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Testing strategy for pci-dss compliance includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Testing strategy for pci-dss compliance includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

The pci-dss compliance subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Security considerations for pci-dss compliance include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Parameter	Value	Unit	Description
PCI-DSS_TIMEOUT	5000	ms	Maximum pci-dss operation timeout
PCI-DSS_RETRY_COUNT	3	count	Maximum retry attempts for pci-dss
PCI-DSS_POOL_SIZE	20	connections	Connection pool size for pci-dss
PCI-DSS_CACHE_TTL	300	seconds	Cache time-to-live for pci-dss lookups
PCI-DSS_BATCH_SIZE	100	records	Batch processing size for pci-dss
PCI-DSS_QUEUE_DEPTH	10000	messages	Maximum queue depth for pci-dss
PCI-DSS_HEARTBEAT	10	seconds	Health check interval for pci-dss
PCI-DSS_MAX_CONNECTIONS	50	count	Maximum concurrent connections for pci-dss

69.1 Section 1

Testing strategy for pci-dss compliance includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

The pci-dss compliance operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Scalability of the pci-dss compliance component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Configuration of the pci-dss compliance component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are

propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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69.2 Section 2

The pci-dss compliance module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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The pci-dss compliance module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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The pci-dss compliance operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Configuration of the pci-dss compliance component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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69.3 Section 3

Scalability of the pci-dss compliance component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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69.4 Section 4

The pci-dss compliance subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

The pci-dss compliance module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Error handling in the pci-dss compliance module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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The pci-dss compliance operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The pci-dss compliance operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Scalability of the pci-dss compliance component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Chapter 70: Data Encryption

Scalability of the data encryption component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Security considerations for data encryption include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

The data encryption module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The data encryption operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Testing strategy for data encryption includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

The data encryption module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The data encryption operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Scalability of the data encryption component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Configuration of the data encryption component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The data encryption subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Security considerations for data encryption include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik

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The data encryption operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Parameter	Value	Unit	Description
DATA_TIMEOUT	5000	ms	Maximum data operation timeout
DATA_RETRY_COUNT	3	count	Maximum retry attempts for data
DATA_POOL_SIZE	20	connections	Connection pool size for data
DATA_CACHE_TTL	300	seconds	Cache time-to-live for data lookups
DATA_BATCH_SIZE	100	records	Batch processing size for data
DATA_QUEUE_DEPTH	10000	messages	Maximum queue depth for data
DATA_HEARTBEAT	10	seconds	Health check interval for data
DATA_MAX_CONNECTIONS	50	count	Maximum concurrent connections for data

70.1 Section 1

The data encryption operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Configuration of the data encryption component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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70.2 Section 2

Testing strategy for data encryption includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Error handling in the data encryption module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Testing strategy for data encryption includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

The data encryption subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Scalability of the data encryption component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Security considerations for data encryption include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Error handling in the data encryption module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack

traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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The data encryption module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The data encryption operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

70.3 Section 3

The data encryption operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Scalability of the data encryption component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Scalability of the data encryption component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Testing strategy for data encryption includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Testing strategy for data encryption includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

The data encryption module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Security considerations for data encryption include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

70.4 Section 4

The data encryption operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Error handling in the data encryption module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Error handling in the data encryption module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The data encryption operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Configuration of the data encryption component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The data encryption module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Chapter 71: Access Control

Configuration of the access control component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Testing strategy for access control includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Security considerations for access control include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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The access control operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Scalability of the access control component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Security considerations for access control include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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The access control module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus

counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Parameter	Value	Unit	Description
ACCESS_TIMEOUT	5000	ms	Maximum access operation timeout
ACCESS_RETRY_COUNT	3	count	Maximum retry attempts for access
ACCESS_POOL_SIZE	20	connections	Connection pool size for access
ACCESS_CACHE_TTL	300	seconds	Cache time-to-live for access lookups
ACCESS_BATCH_SIZE	100	records	Batch processing size for access
ACCESS_QUEUE_DEPTH	10000	messages	Maximum queue depth for access
ACCESS_HEARTBEAT	10	seconds	Health check interval for access
ACCESS_MAX_CONNECTIONS	50	count	Maximum concurrent connections for access

71.1 Section 1

The access control module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The access control subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Testing strategy for access control includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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71.2 Section 2

Error handling in the access control module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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71.3 Section 3

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The access control operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Testing strategy for access control includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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71.4 Section 4

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The access control module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Configuration of the access control component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Scalability of the access control component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Chapter 72: Audit Framework

The audit framework subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

The audit framework subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Testing strategy for audit framework includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Security considerations for audit framework include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Parameter	Value	Unit	Description
AUDIT_TIMEOUT	5000	ms	Maximum audit operation timeout
AUDIT_RETRY_COUNT	3	count	Maximum retry attempts for audit
AUDIT_POOL_SIZE	20	connections	Connection pool size for audit
AUDIT_CACHE_TTL	300	seconds	Cache time-to-live for audit lookups
AUDIT_BATCH_SIZE	100	records	Batch processing size for audit
AUDIT_QUEUE_DEPTH	10000	messages	Maximum queue depth for audit
AUDIT_HEARTBEAT	10	seconds	Health check interval for audit
AUDIT_MAX_CONNECTIONS	50	count	Maximum concurrent connections for audit

72.1 Section 1

The audit framework operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Error handling in the audit framework module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Configuration of the audit framework component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Scalability of the audit framework component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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72.2 Section 2

The audit framework module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Security considerations for audit framework include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Error handling in the audit framework module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Security considerations for audit framework include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

The audit framework module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Security considerations for audit framework include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik

SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Testing strategy for audit framework includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Error handling in the audit framework module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Scalability of the audit framework component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

72.3 Section 3

The audit framework subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Testing strategy for audit framework includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Error handling in the audit framework module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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Configuration of the audit framework component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Security considerations for audit framework include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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72.4 Section 4

Scalability of the audit framework component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The audit framework operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The audit framework subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Scalability of the audit framework component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The audit framework module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Chapter 73: Incident Response

Scalability of the incident response component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Configuration of the incident response component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The incident response operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Testing strategy for incident response includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Parameter	Value	Unit	Description
INCIDENT_TIMEOUT	5000	ms	Maximum incident operation timeout
INCIDENT_RETRY_COUNT	3	count	Maximum retry attempts for incident
INCIDENT_POOL_SIZE	20	connections	Connection pool size for incident
INCIDENT_CACHE_TTL	300	seconds	Cache time-to-live for incident lookups
INCIDENT_BATCH_SIZE	100	records	Batch processing size for incident
INCIDENT_QUEUE_DEPTH	10000	messages	Maximum queue depth for incident
INCIDENT_HEARTBEAT	10	seconds	Health check interval for incident
INCIDENT_MAX_CONNECTIONS	50	count	Maximum concurrent connections for incident

73.1 Section 1

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73.2 Section 2

Testing strategy for incident response includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Security considerations for incident response include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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The incident response subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

The incident response module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus

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73.3 Section 3

Testing strategy for incident response includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Configuration of the incident response component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Configuration of the incident response component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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73.4 Section 4

The incident response operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Testing strategy for incident response includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Chapter 74: Penetration Testing

The penetration testing operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Security considerations for penetration testing include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Security considerations for penetration testing include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Scalability of the penetration testing component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Configuration of the penetration testing component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Parameter	Value	Unit	Description
PENETRATION_TIMEOUT	5000	ms	Maximum penetration operation timeout
PENETRATION_RETRY_COUNT	3	count	Maximum retry attempts for penetration
PENETRATION_POOL_SIZE	20	connections	Connection pool size for penetration
PENETRATION_CACHE_TTL	300	seconds	Cache time-to-live for penetration lookups
PENETRATION_BATCH_SIZE	100	records	Batch processing size for penetration
PENETRATION_QUEUE_DEPTH	10000	messages	Maximum queue depth for penetration
PENETRATION_HEARTBEAT	10	seconds	Health check interval for penetration
PENETRATION_MAX_CONNECTIONS	50	count	Maximum concurrent connections for penetration

74.1 Section 1

The penetration testing module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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74.2 Section 2

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74.3 Section 3

Scalability of the penetration testing component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The penetration testing module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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74.4 Section 4

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PART IX: Operational Procedures

Chapter 75: Deployment Pipeline

Configuration of the deployment pipeline component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Parameter	Value	Unit	Description
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DEPLOYMENT_RETRY_COUNT	3	count	Maximum retry attempts for deployment
DEPLOYMENT_POOL_SIZE	20	connections	Connection pool size for deployment
DEPLOYMENT_CACHE_TTL	300	seconds	Cache time-to-live for deployment lookups
DEPLOYMENT_BATCH_SIZE	100	records	Batch processing size for deployment
DEPLOYMENT_QUEUE_DEPTH	10000	messages	Maximum queue depth for deployment
DEPLOYMENT_HEARTBEAT	10	seconds	Health check interval for deployment
DEPLOYMENT_MAX_CONNECTIONS	50	count	Maximum concurrent connections for deployment

75.1 Section 1

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75.4 Section 4

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Chapter 76: Scaling Procedures

The scaling procedures module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Configuration of the scaling procedures component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Parameter	Value	Unit	Description
SCALING_TIMEOUT	5000	ms	Maximum scaling operation timeout
SCALING_RETRY_COUNT	3	count	Maximum retry attempts for scaling
SCALING_POOL_SIZE	20	connections	Connection pool size for scaling
SCALING_CACHE_TTL	300	seconds	Cache time-to-live for scaling lookups
SCALING_BATCH_SIZE	100	records	Batch processing size for scaling
SCALING_QUEUE_DEPTH	10000	messages	Maximum queue depth for scaling
SCALING_HEARTBEAT	10	seconds	Health check interval for scaling
SCALING_MAX_CONNECTIONS	50	count	Maximum concurrent connections for scaling

76.1 Section 1

The scaling procedures module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Scalability of the scaling procedures component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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76.3 Section 3

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76.4 Section 4

Security considerations for scaling procedures include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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The scaling procedures operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Chapter 77: On-Call Runbook

Error handling in the on-call runbook module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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The on-call runbook operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Parameter	Value	Unit	Description
ON-CALL_TIMEOUT	5000	ms	Maximum on-call operation timeout
ON-CALL_RETRY_COUNT	3	count	Maximum retry attempts for on-call
ON-CALL_POOL_SIZE	20	connections	Connection pool size for on-call
ON-CALL_CACHE_TTL	300	seconds	Cache time-to-live for on-call lookups
ON-CALL_BATCH_SIZE	100	records	Batch processing size for on-call
ON-CALL_QUEUE_DEPTH	10000	messages	Maximum queue depth for on-call
ON-CALL_HEARTBEAT	10	seconds	Health check interval for on-call
ON-CALL_MAX_CONNECTIONS	50	count	Maximum concurrent connections for on-call

77.1 Section 1

Configuration of the on-call runbook component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Chapter 78: Database Operations

Testing strategy for database operations includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Parameter	Value	Unit	Description
DATABASE_TIMEOUT	5000	ms	Maximum database operation timeout
DATABASE_RETRY_COUNT	3	count	Maximum retry attempts for database
DATABASE_POOL_SIZE	20	connections	Connection pool size for database
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78.1 Section 1

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Security considerations for database operations include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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78.3 Section 3

Testing strategy for database operations includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Error handling in the database operations module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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Testing strategy for database operations includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

78.4 Section 4

Security considerations for database operations include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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The database operations operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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The database operations subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Chapter 79: Kafka Operations

Testing strategy for kafka operations includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Parameter	Value	Unit	Description
KAFKA_TIMEOUT	5000	ms	Maximum kafka operation timeout
KAFKA_RETRY_COUNT	3	count	Maximum retry attempts for kafka
KAFKA_POOL_SIZE	20	connections	Connection pool size for kafka
KAFKA_CACHE_TTL	300	seconds	Cache time-to-live for kafka lookups
KAFKA_BATCH_SIZE	100	records	Batch processing size for kafka
KAFKA_QUEUE_DEPTH	10000	messages	Maximum queue depth for kafka
KAFKA_HEARTBEAT	10	seconds	Health check interval for kafka
KAFKA_MAX_CONNECTIONS	50	count	Maximum concurrent connections for kafka

79.1 Section 1

The kafka operations module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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79.2 Section 2

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79.3 Section 3

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Chapter 80: Capacity Planning

Configuration of the capacity planning component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Security considerations for capacity planning include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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The capacity planning operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Parameter	Value	Unit	Description
CAPACITY_TIMEOUT	5000	ms	Maximum capacity operation timeout
CAPACITY_RETRY_COUNT	3	count	Maximum retry attempts for capacity
CAPACITY_POOL_SIZE	20	connections	Connection pool size for capacity
CAPACITY_CACHE_TTL	300	seconds	Cache time-to-live for capacity lookups
CAPACITY_BATCH_SIZE	100	records	Batch processing size for capacity
CAPACITY_QUEUE_DEPTH	10000	messages	Maximum queue depth for capacity
CAPACITY_HEARTBEAT	10	seconds	Health check interval for capacity
CAPACITY_MAX_CONNECTIONS	50	count	Maximum concurrent connections for capacity

80.1 Section 1

The capacity planning subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Testing strategy for capacity planning includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Security considerations for capacity planning include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

80.3 Section 3

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80.4 Section 4

The capacity planning subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

The capacity planning module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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PART X: Historical Changelog

Chapter 81: v4.7 Changes

Security considerations for v4.7 changes include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Parameter	Value	Unit	Description
V4.7_TIMEOUT	5000	ms	Maximum v4.7 operation timeout
V4.7_RETRY_COUNT	3	count	Maximum retry attempts for v4.7
V4.7_POOL_SIZE	20	connections	Connection pool size for v4.7
V4.7_CACHE_TTL	300	seconds	Cache time-to-live for v4.7 lookups
V4.7_BATCH_SIZE	100	records	Batch processing size for v4.7
V4.7_QUEUE_DEPTH	10000	messages	Maximum queue depth for v4.7
V4.7_HEARTBEAT	10	seconds	Health check interval for v4.7
V4.7_MAX_CONNECTIONS	50	count	Maximum concurrent connections for v4.7

81.1 Section 1

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Chapter 82: v4.6 Changes

The v4.6 changes operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Error handling in the v4.6 changes module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The v4.6 changes module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Parameter	Value	Unit	Description
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V4.6_RETRY_COUNT	3	count	Maximum retry attempts for v4.6
V4.6_POOL_SIZE	20	connections	Connection pool size for v4.6
V4.6_CACHE_TTL	300	seconds	Cache time-to-live for v4.6 lookups
V4.6_BATCH_SIZE	100	records	Batch processing size for v4.6
V4.6_QUEUE_DEPTH	10000	messages	Maximum queue depth for v4.6
V4.6_HEARTBEAT	10	seconds	Health check interval for v4.6
V4.6_MAX_CONNECTIONS	50	count	Maximum concurrent connections for v4.6

82.1 Section 1

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Scalability of the v4.6 changes component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The v4.6 changes module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus

counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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The v4.6 changes subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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82.3 Section 3

Security considerations for v4.6 changes include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Configuration of the v4.6 changes component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The v4.6 changes operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The v4.6 changes operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Error handling in the v4.6 changes module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Scalability of the v4.6 changes component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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The v4.6 changes operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

82.4 Section 4

Scalability of the v4.6 changes component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Testing strategy for v4.6 changes includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Scalability of the v4.6 changes component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Security considerations for v4.6 changes include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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The v4.6 changes module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The v4.6 changes module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The v4.6 changes subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation.

All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Error handling in the v4.6 changes module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The v4.6 changes module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Chapter 83: v4.5 Changes

Error handling in the v4.5 changes module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Testing strategy for v4.5 changes includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Configuration of the v4.5 changes component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The v4.5 changes operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Testing strategy for v4.5 changes includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Error handling in the v4.5 changes module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Error handling in the v4.5 changes module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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Security considerations for v4.5 changes include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Scalability of the v4.5 changes component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Parameter	Value	Unit	Description
V4.5_TIMEOUT	5000	ms	Maximum v4.5 operation timeout
V4.5_RETRY_COUNT	3	count	Maximum retry attempts for v4.5
V4.5_POOL_SIZE	20	connections	Connection pool size for v4.5
V4.5_CACHE_TTL	300	seconds	Cache time-to-live for v4.5 lookups
V4.5_BATCH_SIZE	100	records	Batch processing size for v4.5
V4.5_QUEUE_DEPTH	10000	messages	Maximum queue depth for v4.5
V4.5_HEARTBEAT	10	seconds	Health check interval for v4.5
V4.5_MAX_CONNECTIONS	50	count	Maximum concurrent connections for v4.5

83.1 Section 1

Security considerations for v4.5 changes include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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The v4.5 changes subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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83.2 Section 2

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The v4.5 changes operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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83.3 Section 3

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The v4.5 changes module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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83.4 Section 4

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Security considerations for v4.5 changes include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

The v4.5 changes module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Configuration of the v4.5 changes component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are

propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Testing strategy for v4.5 changes includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Scalability of the v4.5 changes component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Chapter 84: Deprecated Features

Scalability of the deprecated features component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Error handling in the deprecated features module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Configuration of the deprecated features component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The deprecated features subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Testing strategy for deprecated features includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

Scalability of the deprecated features component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Error handling in the deprecated features module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Configuration of the deprecated features component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Error handling in the deprecated features module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The deprecated features module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The deprecated features subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation.

All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Configuration of the deprecated features component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Parameter	Value	Unit	Description
DEPRECATED_TIMEOUT	5000	ms	Maximum deprecated operation timeout
DEPRECATED_RETRY_COUNT	3	count	Maximum retry attempts for deprecated
DEPRECATED_POOL_SIZE	20	connections	Connection pool size for deprecated
DEPRECATED_CACHE_TTL	300	seconds	Cache time-to-live for deprecated lookups
DEPRECATED_BATCH_SIZE	100	records	Batch processing size for deprecated
DEPRECATED_QUEUE_DEPTH	10000	messages	Maximum queue depth for deprecated
DEPRECATED_HEARTBEAT	10	seconds	Health check interval for deprecated
DEPRECATED_MAX_CONNECTIONS	50	count	Maximum concurrent connections for deprecated

84.1 Section 1

Configuration of the deprecated features component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

The deprecated features module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Scalability of the deprecated features component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

Scalability of the deprecated features component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes

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Security considerations for deprecated features include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Testing strategy for deprecated features includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

84.2 Section 2

The deprecated features module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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The deprecated features operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The deprecated features module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Testing strategy for deprecated features includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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84.3 Section 3

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84.4 Section 4

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Appendix A: Glossary of Terms

The appendix a: glossary of terms operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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The appendix a: glossary of terms module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Parameter	Value	Unit	Description
A_TIMEOUT	5000	ms	Maximum a operation timeout
A_RETRY_COUNT	3	count	Maximum retry attempts for a
A_POOL_SIZE	20	connections	Connection pool size for a
A_CACHE_TTL	300	seconds	Cache time-to-live for a lookups
A_BATCH_SIZE	100	records	Batch processing size for a
A_QUEUE_DEPTH	10000	messages	Maximum queue depth for a
A_HEARTBEAT	10	seconds	Health check interval for a
A_MAX_CONNECTIONS	50	count	Maximum concurrent connections for a

Section 1

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The appendix a: glossary of terms subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Section 4

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Section 6

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Appendix B: Error Code Reference (Complete)

The appendix b: error code reference (complete) operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

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Parameter	Value	Unit	Description
B_TIMEOUT	5000	ms	Maximum b operation timeout
B_RETRY_COUNT	3	count	Maximum retry attempts for b
B_POOL_SIZE	20	connections	Connection pool size for b
B_CACHE_TTL	300	seconds	Cache time-to-live for b lookups
B_BATCH_SIZE	100	records	Batch processing size for b
B_QUEUE_DEPTH	10000	messages	Maximum queue depth for b
B_HEARTBEAT	10	seconds	Health check interval for b
B_MAX_CONNECTIONS	50	count	Maximum concurrent connections for b

Section 1

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Appendix C: Configuration Parameter Reference

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Parameter	Value	Unit	Description
D_TIMEOUT	5000	ms	Maximum d operation timeout
D_RETRY_COUNT	3	count	Maximum retry attempts for d
D_POOL_SIZE	20	connections	Connection pool size for d
D_CACHE_TTL	300	seconds	Cache time-to-live for d lookups
D_BATCH_SIZE	100	records	Batch processing size for d
D_QUEUE_DEPTH	10000	messages	Maximum queue depth for d
D_HEARTBEAT	10	seconds	Health check interval for d
D_MAX_CONNECTIONS	50	count	Maximum concurrent connections for d

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Appendix E: Database Schema DDL Scripts

Scalability of the appendix e: database schema ddl scripts component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Configuration of the appendix e: database schema ddl scripts component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

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Parameter	Value	Unit	Description
E_TIMEOUT	5000	ms	Maximum e operation timeout
E_RETRY_COUNT	3	count	Maximum retry attempts for e
E_POOL_SIZE	20	connections	Connection pool size for e
E_CACHE_TTL	300	seconds	Cache time-to-live for e lookups
E_BATCH_SIZE	100	records	Batch processing size for e
E_QUEUE_DEPTH	10000	messages	Maximum queue depth for e
E_HEARTBEAT	10	seconds	Health check interval for e
E_MAX_CONNECTIONS	50	count	Maximum concurrent connections for e

Section 1

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Section 2

Scalability of the appendix e: database schema ddl scripts component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Section 3

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Appendix F: Deployment Checklist

Testing strategy for appendix f: deployment checklist includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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F_POOL_SIZE	20	connections	Connection pool size for f
F_CACHE_TTL	300	seconds	Cache time-to-live for f lookups
F_BATCH_SIZE	100	records	Batch processing size for f
F_QUEUE_DEPTH	10000	messages	Maximum queue depth for f
F_HEARTBEAT	10	seconds	Health check interval for f
F_MAX_CONNECTIONS	50	count	Maximum concurrent connections for f

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Parameter	Value	Unit	Description
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H_RETRY_COUNT	3	count	Maximum retry attempts for h
H_POOL_SIZE	20	connections	Connection pool size for h
H_CACHE_TTL	300	seconds	Cache time-to-live for h lookups
H_BATCH_SIZE	100	records	Batch processing size for h
H_QUEUE_DEPTH	10000	messages	Maximum queue depth for h
H_HEARTBEAT	10	seconds	Health check interval for h
H_MAX_CONNECTIONS	50	count	Maximum concurrent connections for h

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The appendix h: compliance matrix (pci-dss mapping) operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Security considerations for appendix h: compliance matrix (pci-dss mapping) include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

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Section 6

Testing strategy for appendix h: compliance matrix (pci-dss mapping) includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Configuration of the appendix h: compliance matrix (pci-dss mapping) component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Scalability of the appendix h: compliance matrix (pci-dss mapping) component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Appendix I: Performance Tuning Guide

The appendix i: performance tuning guide module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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The appendix i: performance tuning guide subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Scalability of the appendix i: performance tuning guide component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Parameter	Value	Unit	Description
I_TIMEOUT	5000	ms	Maximum i operation timeout
I_RETRY_COUNT	3	count	Maximum retry attempts for i
I_POOL_SIZE	20	connections	Connection pool size for i
I_CACHE_TTL	300	seconds	Cache time-to-live for i lookups
I_BATCH_SIZE	100	records	Batch processing size for i
I_QUEUE_DEPTH	10000	messages	Maximum queue depth for i
I_HEARTBEAT	10	seconds	Health check interval for i
I_MAX_CONNECTIONS	50	count	Maximum concurrent connections for i

Section 1

Scalability of the appendix i: performance tuning guide component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

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Section 2

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The appendix i: performance tuning guide module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

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Section 3

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Section 4

The appendix i: performance tuning guide module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

Testing strategy for appendix i: performance tuning guide includes unit tests with ExUnit (target: 95% line coverage), integration tests against containerized dependencies (PostgreSQL, Redis, Kafka), and property-based tests using StreamData for invariant verification. Load tests are executed weekly using Locust with production traffic patterns replayed from sanitized access logs.

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Section 5

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Section 6

The appendix i: performance tuning guide subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

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Appendix J: API Rate Limit Reference

Security considerations for appendix j: api rate limit reference include encryption of data at rest (AES-256-GCM via envelope encryption), encryption in transit (TLS 1.3 with mTLS between services), access control (RBAC with Authentik SSO), and audit logging (immutable append-only log in TimescaleDB). All secrets are managed through HashiCorp Vault with automatic rotation.

Error handling in the appendix j: api rate limit reference module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

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Parameter	Value	Unit	Description
J_TIMEOUT	5000	ms	Maximum j operation timeout
J_RETRY_COUNT	3	count	Maximum retry attempts for j
J_POOL_SIZE	20	connections	Connection pool size for j
J_CACHE_TTL	300	seconds	Cache time-to-live for j lookups
J_BATCH_SIZE	100	records	Batch processing size for j
J_QUEUE_DEPTH	10000	messages	Maximum queue depth for j
J_HEARTBEAT	10	seconds	Health check interval for j
J_MAX_CONNECTIONS	50	count	Maximum concurrent connections for j

Section 1

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Appendix K: Webhook Event Reference

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Parameter	Value	Unit	Description
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K_RETRY_COUNT	3	count	Maximum retry attempts for k
K_POOL_SIZE	20	connections	Connection pool size for k
K_CACHE_TTL	300	seconds	Cache time-to-live for k lookups
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Appendix L: Migration Guide (v4.6 to v4.7)

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Parameter	Value	Unit	Description
L_TIMEOUT	5000	ms	Maximum I operation timeout
L_RETRY_COUNT	3	count	Maximum retry attempts for I
L_POOL_SIZE	20	connections	Connection pool size for I
L_CACHE_TTL	300	seconds	Cache time-to-live for I lookups
L_BATCH_SIZE	100	records	Batch processing size for I
L_QUEUE_DEPTH	10000	messages	Maximum queue depth for I
L_HEARTBEAT	10	seconds	Health check interval for I
L_MAX_CONNECTIONS	50	count	Maximum concurrent connections for I

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Section 6

Error handling in the appendix I: migration guide (v4.6 to v4.7) module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

The appendix I: migration guide (v4.6 to v4.7) subsystem is designed for high availability and fault tolerance. It uses a combination of redundant components, health monitoring, and automatic failover mechanisms to ensure continuous operation. All state changes are logged to the audit trail and can be replayed for debugging or compliance verification. Performance metrics are exposed via OpenTelemetry and scraped by Prometheus every 15 seconds.

Scalability of the appendix I: migration guide (v4.6 to v4.7) component has been validated up to 50,000 operations per second in load testing. Horizontal scaling is achieved by adding more BEAM nodes to the cluster, with automatic work distribution via consistent hashing. Each node can handle approximately 3,000 concurrent GenServer processes before memory pressure triggers backpressure mechanisms.

The appendix I: migration guide (v4.6 to v4.7) operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The appendix I: migration guide (v4.6 to v4.7) operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

The appendix I: migration guide (v4.6 to v4.7) module integrates with the observability stack through structured logging (JSON format to Loki), distributed tracing (OpenTelemetry spans with W3C Trace Context), and custom metrics (Prometheus counters and histograms). Key SLIs include throughput, error rate, and p99 latency. SLO targets are defined per service tier.

The appendix I: migration guide (v4.6 to v4.7) operational runbook covers standard procedures for deployment, scaling, incident response, and disaster recovery. On-call engineers must be familiar with the monitoring dashboards in Grafana and the alert routing rules in PagerDuty. Escalation follows the standard P0-P4 severity classification defined in Chapter 6.

Error handling in the appendix I: migration guide (v4.6 to v4.7) module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).

Configuration of the appendix I: migration guide (v4.6 to v4.7) component is managed through a hierarchical system where global defaults can be overridden at the service level, merchant level, or transaction level. Configuration changes are propagated through the internal pub/sub system and take effect within 5 seconds of publication. Hot-reloading is supported for all configuration parameters except database connection strings, which require a rolling restart.

Error handling in the appendix I: migration guide (v4.6 to v4.7) module follows a defensive programming approach. All external inputs are validated before processing. Unexpected errors are caught by the supervision tree and logged with full stack traces. The circuit breaker pattern is applied to all external dependencies with configurable failure thresholds (default: 5 failures in 30 seconds triggers open state, 60-second recovery window).