Lesson 42: Risk Management Systems

Module 4: Traditional Digital Finance

Digital Finance Course

2025

Learning Objectives

- Understand Value at Risk (VaR) methodologies and implementation
- Analyze stress testing and scenario analysis frameworks
- Examine Expected Shortfall (CVaR) and coherent risk measures
- Evaluate model risk management and validation processes
- Assess enterprise risk management systems and architecture

VaR Definition and Framework

Formal Definition:

Value at Risk (VaR) is the maximum loss over a target horizon at a given confidence level.

$$\Pr(L > \text{VaR}_\alpha) = 1 - \alpha$$

where L = portfolio loss, α = confidence level (typically 95% or 99%)

Standard Parameters:

- **Confidence Level:** 95% (regulatory: 99%)
- **Time Horizon:** 1 day (trading), 10 days (regulatory)
- **Currency:** Reporting currency (USD, EUR)
- **Scope:** Individual desk, portfolio, firm-wide

Interpretation Example:

- 1-day 99% VaR = \$10 million
- Interpretation: "We expect losses to exceed \$10M on 1% of trading days (2-3 days per year)"
- Not a worst-case measure (tail risk beyond VaR)

Applications:

- **Regulatory Capital:** Basel III market risk
- **Risk Limits:** Desk-level VaR limits
- **Performance Attribution:** Risk-adjusted returns
- **Client Reporting:** UCITS, hedge fund disclosures
- **Stress Testing:** Baseline for scenario comparison

VaR Methodologies

1. Parametric VaR (Variance-Covariance):

$$\text{VaR}_\alpha = \mu + z_\alpha \sigma \sqrt{t}$$

where μ = expected return, z_α = critical value (2.33 for 99%), σ = volatility, t = horizon

Assumptions:

- Normal distribution of returns
- Linear portfolio exposures
- Constant volatility and correlations

Pros: Fast, simple, transparent
Cons: Underestimates tail risk, poor for options

2. Historical Simulation:

- Apply past N days returns to current positions
- Sort simulated P&L outcomes
- VaR = α-quantile of distribution
- Typical lookback: 250-500 days

Pros: No distributional assumptions, captures fat tails
Cons: Backward-looking, sensitive to window choice

3. Monte Carlo Simulation:

- Generate 10,000+ random scenarios
- Price portfolio under each scenario
- Calculate VaR from simulated distribution
- Can model path-dependent options

Pros: Flexible, handles complex derivatives
Cons: Computationally intensive, model risk

VaR Backtesting and Model Validation

Backtesting Framework:

- Compare daily VaR forecasts to realized P&L
- Count exceedances (days where loss $>$ VaR)
- **Expected Exceedances:** 1% of days for 99% VaR
- Over 250 days: expect 2-3 exceedances

Statistical Tests:

- **Kupiec Test (1995):** Likelihood ratio test for correct number of exceedances
- **Christoffersen Test (1998):** Independence of exceedances
- **Traffic Light Approach:** Green (0-4), Yellow (5-9), Red (10+) zones for 250 days at 99%

Basel III Traffic Lights:

Zone	Exceedances (250 days)
Green	0-4
Yellow	5-9
Red	10+

Yellow/Red zones trigger capital multiplier increases

Common Failures:

- Clustered exceedances (volatility regime change)
- Underestimation during crisis periods
- Model drift due to changing market conditions
- Inadequate stress scenario coverage

2008 Crisis: Most banks had 20-40 VaR exceedances vs expected 2-3

Limitations of VaR and Alternatives

VaR Limitations:

- **Not Coherent:** Fails sub-additivity property
- **Ignores Tail:** No information beyond VaR level
- **Diversification Paradox:** Portfolio VaR can exceed sum of components
- **Model Risk:** Sensitive to assumptions (normality, correlation stability)
- **Procyclical:** VaR increases during stress, forcing deleveraging

Non-Subadditivity Example:

- Asset A: 99% VaR = $100M
- Asset B: 99% VaR = $100M
- Portfolio A+B: VaR could be $220M (if extreme correlation)
- Violates diversification intuition

Expected Shortfall (ES / CVaR):

$$\text{ES}_\alpha = \mathbb{E}[L \mid L > \text{VaR}_\alpha]$$

Average loss beyond VaR threshold

Advantages over VaR:

- Coherent risk measure (satisfies all axioms)
- Captures tail risk beyond VaR cutoff
- Subadditive: encourages diversification
- Basel III shift: ES replacing VaR for market risk (2023)

Challenges:

- Less intuitive for communication
- Harder to backtest (tail events rare)
- More sensitive to model assumptions
- Regulatory adoption still evolving

Stress Testing Framework

Types of Stress Tests:

- **Sensitivity Analysis:** Single risk factor shock (e.g., +100 bps rates)
- **Scenario Analysis:** Coherent multi-factor scenarios
- **Historical Scenarios:** Replay past crises (2008, COVID-19)
- **Hypothetical Scenarios:** Forward-looking extreme events
- **Reverse Stress Tests:** Find scenarios causing failure

Regulatory Stress Tests:

- **CCAR (US):** Comprehensive Capital Analysis and Review
- **EBA (EU):** European Banking Authority stress tests
- **PRA (UK):** Annual Cyclical Scenario, Biennial Exploratory

Scenario Design Principles:

- **Severity:** Plausible but extreme (1-in-30 year events)
- **Coherence:** Internally consistent macro narrative
- **Coverage:** All material risk factors
- **Granularity:** Regional and sectoral detail
- **Horizon:** Multi-year path (typically 3-5 years)

Example Scenario (CCAR 2024):

- Severely Adverse: Unemployment 10%, GDP -3.5%
- Equity markets down 40%
- Commercial real estate prices -35%
- Corporate bond spreads widen 400 bps

Historical Crisis Scenarios

2008 Global Financial Crisis:

- S&P 500: -38% (2008)
- VIX spike: 89 (Nov 2008)
- Investment-grade spreads: +500 bps
- High-yield spreads: +1700 bps
- Lehman bankruptcy: CDS spreads explode

COVID-19 Crash (March 2020):

- S&P 500: -34% in 23 days (fastest bear market)
- Oil: -50% (WTI negative pricing April 2020)
- Treasury volatility: MOVE Index to 165
- Credit markets freeze (Fed intervention)

1998 LTCM Crisis:

- Russia default + devaluation
- Flight to quality (Treasuries rally, spreads widen)
- Equity vol spike: VIX to 45
- Liquidity-driven correlations break models

European Sovereign Debt Crisis (2011-2012):

- Greek, Irish, Portuguese bond yields spike
- 2-year Greek yields exceed 100%
- Bank CDS correlate with sovereign risk
- EUR/USD volatility and basis blowouts

Key Lesson: Correlations increase to 1 during crises (diversification fails)

Reverse Stress Testing

Methodology:

- **Start with Outcome:** Failure point (insolvency, regulatory breach)
- **Work Backwards:** What scenarios lead to this outcome?
- **Assess Plausibility:** How realistic are these scenarios?
- **Identify Vulnerabilities:** Concentrations and weaknesses
- **Mitigants:** Risk limits, hedges, contingency plans

Example (Retail Bank):

- Failure: Tier 1 capital ratio below 4.5%
- Scenario 1: Residential mortgages default rate 15%
- Scenario 2: Wholesale funding freeze + deposit run
- Scenario 3: Major operational loss + cyber incident

Regulatory Requirements:

- **PRA (UK):** Annual reverse stress test mandatory
- **EBA (EU):** Recovery and Resolution Plans
- **Fed (US):** Resolution planning ("living wills")

Use Cases:

- Identify tail risks not covered in standard tests
- Challenge business model assumptions
- Inform risk appetite and limit frameworks
- Support recovery and resolution planning
- Board-level strategic discussions

"What would it take to break us?" – Common reverse stress test framing

Model Risk Framework

Model Risk Definition (SR 11-7):
"The potential for adverse consequences from decisions based on incorrect or misused model outputs and reports."

Sources of Model Risk:

- **Fundamental Error:** Incorrect theory or assumptions
- **Implementation Error:** Coding bugs, data errors
- **Misuse:** Application outside intended scope
- **Parameter Error:** Mis-calibration or estimation error
- **Data Quality:** Missing, stale, or incorrect inputs

Regulatory Guidance:

- **SR 11-7 (Fed, 2011):** Supervisory Guidance on Model Risk Management
- **SS1/23 (PRA, 2023):** Model risk management principles
- **BCBS 239:** Risk data aggregation and reporting

Model Governance Structure:

- **1st Line:** Model development and ownership
- **2nd Line:** Independent validation and risk oversight
- **3rd Line:** Internal audit
- **Model Risk Committee:** Senior governance forum

Model Validation Process

Validation Components:

1. **Conceptual Soundness:**
   - Review theoretical framework
   - Assess assumptions and limitations
   - Evaluate model design choices
   - Literature review and benchmarking
2. **Ongoing Monitoring:**
   - Backtesting and performance metrics
   - Sensitivity and stability analysis
   - Benchmark comparison
   - Process verification
3. **Outcomes Analysis:**
   - Compare predictions to actual outcomes
   - Statistical tests (e.g., VaR backtests)
   - Analyze forecast errors and bias
   - Identify model drift over time

Model Tiering (Risk-Based):

Tier	Risk	Validation Frequency
1	High	Annual
2	Medium	Biennial
3	Low	Triennial

High-Risk Model Examples:

- Capital calculation (Basel III, IFRS 9)
- Pricing of illiquid derivatives
- Stress testing and scenario models
- Credit risk scorecards
- Trading desk VaR models

Validation Report Contents:

- Executive summary and conclusions
- Scope and methodology
- Findings and recommendations
- Limitations and qualifications
- Model rating (e.g., satisfactory, needs enhancement,

Model Risk in Machine Learning

Additional ML Challenges:

- **Explainability:** Black-box models lack transparency
- **Overfitting:** High in-sample, poor out-of-sample
- **Regime Changes:** Models trained on past may fail in new regimes
- **Data Drift:** Input distributions shift over time
- **Adversarial Examples:** Susceptible to manipulation

ML-Specific Validation:

- Cross-validation and holdout sets
- Feature importance and SHAP analysis
- Robustness to input perturbations
- Comparison to simpler benchmark models
- Continuous monitoring of performance drift

Regulatory Concerns:

- ECB (2021): Guide on model risk for AI/ML
- Fed SR 11-7 applies to all models (including ML)
- Emphasis on documentation and explainability
- Need for human oversight and expert judgment

Emerging Practices:

- **Model Cards:** Standardized documentation
- **Champion-Challenger:** Continuous benchmarking
- **Ensemble Methods:** Reduce single-model risk
- **Explainable AI:** LIME, SHAP for interpretability
- **Fairness Testing:** Detect and mitigate bias

Industry trend: Hybrid models combining ML predictions with traditional risk frameworks

ERM System Architecture

Core Components:

1. **Data Aggregation Layer:**
   - Trade/position feeds from front office
   - Market data (prices, curves, volatilities)
   - Reference data (securities master, counterparties)
   - ETL processes and data quality checks
2. **Risk Calculation Engine:**
   - Sensitivities (Greeks, DV01, duration)
   - VaR and stress tests
   - Counterparty credit risk (CVA, PFE)
   - Aggregation across desks and entities
3. **Limit Monitoring and Alerting:**
   - Real-time limit checks
   - Breach notifications and escalation
   - Approval workflows for exceptions

4. Reporting and Analytics:

- Interactive dashboards (Tableau, Power BI)
- Regulatory reports (CCAR, FRTB)
- Ad-hoc analysis and drill-down
- Historical P&L and risk attribution

Leading Platforms:

- **Bloomberg AIM:** Multi-asset risk analytics
- **MSCI RiskMetrics:** Portfolio risk and performance
- **SunGard (FIS) Adaptiv:** Counterparty credit and CVA
- **Murex:** Front-to-risk integrated platform
- **Calypso:** Cross-asset trading and risk

Typical latency: Intraday VaR calculated every 15-30 minutes; EOD full suite in 2-4 hours

Risk Aggregation Challenges

Technical Challenges:

- **Data Latency:** T+1 positions from legacy systems
- **Reconciliation:** Front office vs risk systems breaks
- **Market Data:** Missing or stale prices (illiquid securities)
- **Calculation Performance:** Monte Carlo for large portfolios
- **Infrastructure:** Grid computing and cloud scaling

Organizational Challenges:

- Siloed data across business units
- Multiple risk systems (acquisitions)
- Inconsistent methodologies across desks
- Manual data adjustments and overrides

BCBS 239 Principles (2013):

1. Governance: Clear ownership and accountability
2. Data Architecture: Robust and flexible
3. Accuracy and Integrity: Automated controls
4. Completeness and Timeliness: Comprehensive and fast
5. Adaptability: Support ad-hoc requests
6. Distribution: Appropriate access and security

Modern Solutions:

- Data lakes and real-time streaming (Kafka)
- Cloud-based risk engines (AWS, Azure, GCP)
- In-memory computing (GridGain, Hazelcast)
- Standardized data models (FINOS, CDM)

Real-Time Risk Management

Intraday Risk Monitoring:

- **Pre-Trade Checks:** Order price/size limits (microseconds)
- **Incremental VaR:** Add/remove trade impact
- **Greeks Monitoring:** Real-time delta, gamma, vega
- **Stress Ladder:** Continuous recalculation
- **P&L Attribution:** Explain intraday P&L moves

Technology Stack:

- **In-Memory Grids:** Apache Ignite, Hazelcast
- **Stream Processing:** Kafka, Flink, Spark Streaming
- **GPUs:** Massively parallel Monte Carlo
- **FPGA:** Ultra-low latency risk calculations

Use Cases:

- **Algorithmic Trading:** Real-time position limits
- **Market Making:** Inventory risk management
- **Prime Brokerage:** Client margin calculations
- **Treasury:** Intraday liquidity risk

Performance Requirements:

- Pre-trade checks: under 1 millisecond
- Incremental VaR: under 100 milliseconds
- Full portfolio VaR: under 5 minutes (10k+ positions)
- Stress tests: under 15 minutes

Leading trading firms: Full risk recalculation every 100-500 milliseconds for active portfolios

Basel III Market Risk Framework

Standardized Approach (SA):

- Risk-weighted buckets by asset class
- Sensitivity-based method (Delta, Vega, Curvature)
- Residual risk add-on (exotic options)
- Simple, transparent, less risk-sensitive

Internal Models Approach (IMA):

- Expected Shortfall (ES) replaces VaR
- 97.5% ES over 10-day horizon
- Stressed ES (calibrated to stress period)
- Default risk charge (jump-to-default)

IMA Formula:

$$\text{Capital} = \max(\text{ES}_t, mc \cdot \text{ES}_{avg}) + \text{SES} + \text{DRC}$$

where mc = multiplier (1.5+), SES = Stressed ES, DRC = Default Risk Charge

P&L Attribution Test:

- Compare theoretical P&L (risk system) to actual (front office)
- **Unexplained P&L:** Absolute difference
- **Threshold:** Exceed on max 12 days/year
- Failure $\rightarrow$ desk removed from IMA

Backtesting (ES):

- More challenging than VaR (tail events)
- Traffic light approach adapted for ES
- Greater reliance on P&L attribution

Implementation (FRTB):

- Fundamental Review of Trading Book
- Effective: January 2023 (extended to 2025 for some)
- Capital increase: 20-70% vs Basel II.5
- Driven by: tighter liquidity horizons, default risk, stressed calibration

Counterparty Credit Risk Metrics

Exposure Metrics:

- **Current Exposure (CE):** Replacement cost today
- **Potential Future Exposure (PFE):** High percentile (95%, 97.5%) of future exposure distribution
- **Expected Positive Exposure (EPE):** Average exposure over time
- **Effective EPE:** Non-decreasing EPE for capital

EPE Calculation:

$$\text{EPE}(t) = \mathbb{E}[\max(V(t), 0)]$$

where $V(t)$ = mark-to-market value at time t

CVA (Credit Valuation Adjustment):

$$\text{CVA} = (1 - R) \sum_{i=1}^{n} \text{EE}(t_i) \cdot \text{PD}(t_{i-1}, t_i)$$

where R = recovery rate, EE = expected exposure, PD = default probability

XVA Framework:

- **CVA:** Credit risk of counterparty
- **DVA:** Credit risk of own entity
- **FVA:** Funding cost of uncollateralized exposure
- **MVA:** Margin valuation adjustment (initial margin cost)
- **KVA:** Capital valuation adjustment

Calculation Challenges:

- Computationally intensive (nested Monte Carlo)
- Wrong-way risk (exposure-default correlation)
- Collateral modeling (CSA agreements)
- Netting set aggregation

Major banks: CVA desks actively hedge CVA exposure via CDS and equity positions

Summary and Key Takeaways

Value at Risk:

- 99% VaR: Maximum loss exceeded 1% of days
- Methodologies: Parametric, Historical, Monte Carlo
- Backtesting via traffic light approach
- Limitations: Non-coherent, ignores tail
- Expected Shortfall replacing VaR (Basel III)

Stress Testing:

- Sensitivity, scenario, and reverse stress tests
- Regulatory: CCAR (US), EBA (EU) stress tests
- Historical scenarios (2008, COVID-19) inform design
- Reverse stress tests identify failure points

Model Risk Management:

- SR 11-7: Independent validation mandatory
- Conceptual soundness, ongoing monitoring, outcomes analysis
- ML models: Explainability and drift challenges
- Model governance: 3 lines of defense

Enterprise Risk Systems:

- Real-time risk aggregation and limit monitoring
- BCBS 239: Data governance principles
- Cloud and in-memory computing for speed
- Basel III FRTB: ES replaces VaR, capital increase 20-70%