SecureMed - HIPAA Compliance Management System

Cybersecurity Capstone Project 2025 Knight Foundation School of Computing and Information Sciences (KFSCIS)
Florida International University

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Executive Summary

SecureMed is a comprehensive healthcare security and compliance management system designed to address the critical challenge of maintaining HIPAA compliance while actively detecting and preventing security breaches in healthcare organizations.

Healthcare organizations face increasing cybersecurity threats, with the average breach costing $10M and affecting thousands of patients. Many small to medium healthcare facilities lack the resources for enterprise-grade security solutions, leaving them vulnerable to violations and unable to properly train staff on HIPAA requirements.

SecureMed solves this by providing an integrated platform that:

- Encrypts Protected Health Information (PHI) using AES-128 encryption
- Provides interactive HIPAA training with real-time compliance scoring
- Automatically detects and logs privacy violations
- Simulates security breaches with detailed incident response playbooks
- Generates audit-ready compliance reports

The system successfully demonstrates that comprehensive healthcare cybersecurity and compliance can be achieved through thoughtful design, combining regulatory requirements (HIPAA), technical security controls (encryption, audit trails), and human-centered training.

Key results: 100% encryption coverage of sensitive data, complete audit trail of all system activities, automated violation detection with 0 false negatives in testing, and interactive training system with measurable compliance scoring.

Problem & Requirements

Context

Healthcare data breaches affect millions of patients annually, with organizations facing:

- Average breach costs of $10 million per incident
- Mandatory HIPAA compliance requirements under 45 CFR Part 164
- Staff training gaps leading to privacy violations
- Lack of affordable security solutions for small/medium facilities
- No standardized incident response procedures

Stakeholders

1. Healthcare Organizations: Small to medium clinics (5-50 staff) needing affordable compliance solutions
2. Healthcare Staff: Nurses, medical assistants requiring HIPAA training and PHI access
3. Compliance Officers: Need violation tracking and audit report generation
4. Patients: Require privacy protection and breach notification
5. Regulatory Bodies: HHS Office for Civil Rights (OCR) requiring compliance evidence

Functional Requirements

Priority	Requirement	HIPAA Section
P0	Encrypt all PHI at rest (SSN, medical records)	§164.312(a)(2)(iv)
P0	Maintain complete audit trail of all PHI access	§164.312(b)
P0	Unique user identification and authentication	§164.312(a)(2)(i)
P1	Interactive HIPAA training system	§164.308(a)(5)
P1	Automated violation detection and logging	§164.308(a)(1)(ii)(A)
P1	Security incident response procedures	§164.308(a)(6)
P2	Compliance report generation	§164.308(a)(8)
P2	Session timeout for unattended workstations	§164.312(a)(2)(iii)

Non-Functional Requirements

- Security: Zero tolerance for unencrypted PHI, SQL injection prevention
- Performance: Page load < 2 seconds, PDF generation < 3 seconds

- Usability: Intuitive interface requiring < 5 minutes training
- Compliance: Adherence to HIPAA Security, Privacy, and Breach Notification Rules
- Portability: Cross-platform (macOS, Windows, Linux)

Success Criteria

1. All PHI encrypted in database with 100% coverage
2. Complete audit trail with 0 missing entries for critical actions
3. Training system with measurable compliance scores (0-100%)
4. Automated breach simulation with response playbooks
5. Report generation in under 3 seconds

Constraints

- Educational/demonstration project (not production-ready without hardening)
- 12-week development timeline
- No budget for external services (AWS, cloud databases)
- Must run locally without internet connectivity

Risks

Risk	Likelihood	Impact	Mitigation
Database corruption	Low	Critical	Regular backups, demo reset function
Performance degradation	Medium	Medium	SQLite optimization, indexed queries
Training adoption	High	High	Gamification with compliance scoring
Key management	Medium	Critical	Separate key storage, documented in production guide

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System Overview & Architecture

Architecture Overview

SecureMed follows a three-tier architecture with React-based frontend, Flask REST API backend, and SQLite database with field-level encryption.

```
┌──────────────────────────────────────────────────────────┐
│                    Presentation Layer                      │
│  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐  │
│  │ Admin        │  │ User/Nurse   │  │ Training     │  │
│  │ Dashboard    │  │ Dashboard    │  │ Simulator    │  │
│  │ (React)      │  │ (React)      │  │ (React)      │  │
│  └──────────────┘  └──────────────┘  └──────────────┘  │
└──────────────────────────────────────────────────────────┘
                         ↕ HTTPS/REST API
┌──────────────────────────────────────────────────────────┐
│                    Application Layer                       │
│  ┌────────────────────────────────────────────────────┐ │
│  │         Flask Web Server (Python 3.x)              │ │
│  │  ┌──────────┐  ┌──────────┐  ┌──────────────────┐ │ │
│  │  │ Auth     │  │ Patient  │  │ Compliance       │ │ │
│  │  │ Module   │  │ Mgmt     │  │ Engine           │ │ │
│  │  └──────────┘  └──────────┘  └──────────────────┘ │ │
│  │  ┌──────────┐  ┌──────────┐  ┌──────────────────┐ │ │
│  │  │ EDR/     │  │ Audit    │  │ Report           │ │ │
│  │  │ Security │  │ Trail    │  │ Generator        │ │ │
│  │  └──────────┘  └──────────┘  └──────────────────┘ │ │
│  └────────────────────────────────────────────────────┘ │
└──────────────────────────────────────────────────────────┘
                         ↕ Encryption Layer
┌──────────────────────────────────────────────────────────┐
│                      Data Layer                            │
│  ┌────────────────────────────────────────────────────┐ │
│  │         SQLite Database (securemed.db)             │ │
│  │  ┌──────────┐  ┌──────────┐  ┌──────────────────┐ │ │
│  │  │ users    │  │ patients │  │ audit_results    │ │ │
│  │  │ (auth)   │  │ (PHI)    │  │ (violations)     │ │ │
│  │  └──────────┘  └──────────┘  └──────────────────┘ │ │
│  │  ┌──────────┐  ┌──────────┐                        │ │
│  │  │activity_ │  │directory │                        │ │
│  │  │log       │  │(approved)│                        │ │
│  │  └──────────┘  └──────────┘                        │ │
│  └────────────────────────────────────────────────────┘ │
└──────────────────────────────────────────────────────────┘
```

Key Technologies

Component	Technology	Version	Purpose
Backend Framework	Flask	3.1.2	REST API server

Component	Technology	Version	Purpose
Frontend UI	React	18 (CDN)	Interactive dashboards
Database	SQLite	3.x	Lightweight data storage
Encryption	Cryptography (Fernet)	46.0.3	AES-128 CBC PHI encryption
Password Hashing	hashlib (SHA-256)	Built-in	Secure credential storage
PDF Generation	ReportLab	4.4.4	Compliance reports
CORS	Flask-CORS	6.0.1	API access control

Data Model

Main Tables:

- users: User accounts with roles (admin/user), hashed passwords
- patients: PHI with encrypted SSN, MRN, demographics
- audit_results: Security violations, HIPAA findings
- activity_log: Complete audit trail (login, PHI access, changes)
- directory: Pre-approved PHI transmission destinations
- assignments: Staff tasks with directory validation

API Overview

The system exposes 25+ REST endpoints:

Endpoint Pattern	Methods	Purpose
/api/patients	GET, POST, PUT, DELETE	Patient CRUD operations
/api/violations	GET, POST	Violation tracking
/api/audit-trail	GET	Activity log retrieval
/api/training/*	POST	Training progress tracking
/api/directory	GET	Approved contact lookup
/api/assignments	GET, POST	Task management
/generate_pdf	GET	Compliance report generation

Discipline-Specific Depth (Cybersecurity)

Threat Model & Risk Analysis

Assets

1. Protected Health Information (PHI)
   - Patient names, SSNs (encrypted)
   - Medical Record Numbers (MRN)
   - Diagnosis and treatment data

2. Authentication Credentials
    - User passwords (SHA-256 hashed)
    - Session tokens
3. System Infrastructure
    - Database files
    - Encryption keys
    - Application code

Adversaries & Attack Surfaces

Threat Actor	Motivation	Capability	Attack Surface
External Attacker	Financial gain, ransom	High (organized cybercrime)	Network, web application
Insider Threat	Curiosity, revenge, profit	Medium (authorized access)	Direct database, patient records
Opportunistic Hacker	Challenge, reputation	Low-Medium	Web vulnerabilities, default credentials
Nation-State APT	Intelligence gathering	Very High	All surfaces (theoretical)

STRIDE Analysis

Category	Threat	Mitigation
Spoofing	Credential theft via phishing	Password complexity, training simulator
Tampering	Unauthorized PHI modification	Audit trail, access controls
Repudiation	Denial of PHI access	Complete activity logging with timestamps
Information Disclosure	Database theft exposing PHI	Fernet encryption, access controls
Denial of Service	System unavailability	Session management, rate limiting (future)
Elevation of Privilege	Nurse accessing admin functions	Role-based access control (RBAC)

Controls & Assurance

Administrative Safeguards (HIPAA §164.308)

Control	Implementation	Standard Mapping
Security Officer	Admin role with full system access	§164.308(a)(2)
Workforce Training	Interactive training simulator with scoring	§164.308(a)(5)
Risk Assessment	Vulnerability scanner, EDR panel	§164.308(a)(1)(ii)(A)
Sanction Policy	Automated violation logging	§164.308(a)(1)(ii)(C)

Technical Safeguards (HIPAA §164.312)

Control	Implementation	Standard Mapping
Unique User ID	Username-based authentication	§164.312(a)(2)(i)
Encryption	Fernet (AES-128) for SSN, PHI	§164.312(a)(2)(iv)
Audit Controls	Complete activity_log table	§164.312(b)
Automatic Logoff	2-minute session timeout	§164.312(a)(2)(iii)
Access Control	Admin vs. User role separation	§164.312(a)(1)

Physical Safeguards (HIPAA §164.310)

Control	Implementation	Standard Mapping
Workstation Security	Session timeout for unattended terminals	§164.310(b)
Device Controls	Directory system for approved PHI destinations	§164.310(d)(1)

Security Testing

Static Analysis (SAST)

Test Type	Tool/Method	Findings	Remediation
SQL Injection	Manual testing with malicious inputs	0 vulnerabilities	Parameterized queries throughout
XSS Prevention	Input validation testing	0 vulnerabilities	HTML escaping, React auto-escaping
Password Storage	Code review	Secure (SHA-256 hashing)	No plaintext passwords
Hardcoded Secrets	Manual code inspection	1 finding (encryption key)	Documented for production Key Management System (KMS)

Dynamic Analysis (DAST)

Test Type	Scenarios	Results	Status
Authentication Bypass	15 login attempts with malformed data	0 successful bypasses	PASS
Session Management	Session fixation, timeout validation	Proper timeout enforcement	PASS
Encryption Validation	100 encrypt/decrypt cycles	100% success rate, 0 plaintext leaks	PASS
Audit Trail Completeness	50 test actions across all features	50 log entries created	PASS

Vulnerability & Dependency Scanning

Component	Scanner	Critical	High	Medium	Status
Python Dependencies	pip-audit (manual)	0	0	2	Acceptable for demo
SQLite	Version check	0	0	0	Current version
Frontend Libraries	CDN integrity check	0	0	0	Verified SRI hashes

Penetration Test Summary

Attack Vector	Test Result	Notes
SQL Injection	BLOCKED	Parameterized queries effective
XSS (Reflected)	BLOCKED	Input sanitization effective
XSS (Stored)	BLOCKED	React escaping + validation
CSRF	PARTIAL	Mitigated by session validation (recommend tokens)
Brute Force	LIMITED	No rate limiting (recommend implementation)
Session Hijacking	BLOCKED	Timeout enforced, secure cookies

Incident Response & Business Continuity

Breach Simulation Playbooks

The system includes 5 comprehensive incident response procedures:

1. Ransomware Attack (20 steps)
    - Phase 1 (0-1 hr): Containment, isolation
    - Phase 2 (1-24 hr): Forensics, evidence preservation
    - Phase 3 (24-72 hr): Recovery, notification
    - Phase 4 (60 days): HHS reporting, remediation
2. Insider Data Theft (24 steps)
3. Phishing Attack (23 steps)
4. Database Exposure (23 steps)
5. Laptop Theft - Unencrypted (25 steps)

Each playbook follows HIPAA Breach Notification Rule timelines (60-day reporting requirement).

Disaster Recovery

- Full Demo Reset: Wipes all data while preserving user accounts
- Database backup procedure documented in operations guide
- Recovery Time Objective (RTO): < 5 minutes for demo environment
- Recovery Point Objective (RPO): Last manual backup

Implementation Notes

Repository Structure

```
Cap_Finaldev/
├── webapp.py                 # Main Flask application (REST API)
├── generate_report.py        # PDF compliance report generator
├── requirements.txt          # Python dependencies
├── securemed.db             # SQLite database (auto-generated)
├── templates/               # HTML templates with embedded React
│   ├── login.html
│   ├── dashboard_react.html      # Admin dashboard
│   ├── user_dashboard_react.html # Nurse dashboard
│   ├── edr.html                  # EDR/security panel
│   ├── training_simulator.html   # HIPAA training
│   ├── patients.html
│   └── audit_trail.html
├── docs/                    # Documentation (appendices)
│   ├── INSTALL.md          # Installation guide
│   ├── HOW_TO_USE.md       # User manual
│   ├── TROUBLESHOOTING.md  # Common issues
│   ├── TESTING.md          # Test suite documentation
│   ├── FEATURES.md         # Feature reference
│   ├── CAPSTONE_QA.md      # Q&A for presentations
│   └── TEAM_CONTRIBUTIONS.md
└── seed_*.py               # Database seeding scripts
```

Coding Conventions

- PEP 8 compliance for Python code
- Parameterized SQL queries exclusively (security requirement)
- Modular function design (authentication, encryption, logging separated)
- Comprehensive error handling with try/except blocks
- Inline comments for complex security logic

Notable Design Patterns

1. Encryption Abstraction: Centralized encrypt/decrypt functions prevent inconsistent implementation
2. Audit Logging Decorator: Could be implemented for automatic action tracking
3. Role-Based Access Control: Session-based role checking on all protected routes
4. Fail-Safe Defaults: Session timeout, conservative permissions

Key Tradeoffs

Decision	Alternative	Rationale
SQLite	PostgreSQL/MySQL	Portability, zero-config, sufficient for demo scale
Fernet	AES-256 GCM	Fernet includes authentication, simpler API

Decision	Alternative	Rationale
Session-based auth	JWT tokens	Simpler implementation, adequate for demo
2-minute timeout	15-30 minutes	Demonstrates security feature quickly in demos
Hardcoded key	KMS/Vault	Documented limitation, acceptable for educational use

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Testing & Evaluation

Testing Strategy

1. Unit Testing: Individual function validation (encryption, hashing, scoring)
2. Integration Testing: API endpoint verification, database operations
3. Security Testing: SQL injection, XSS, authentication bypass attempts
4. Compliance Testing: Audit trail completeness, HIPAA requirement coverage
5. User Acceptance Testing: Workflow validation by team members

Test Suite

The system includes 20 automated tests covering:

Test Category	Count	Coverage
Encryption/Decryption	2	SSN encryption, uniqueness
Password Security	6	Hashing, complexity validation
Database Operations	3	CRUD, SQL injection prevention
Authentication	5	Login, session management, authorization
Compliance Scoring	3	Score calculation, bounds checking
Audit Logging	1	Activity recording

Test Results

All 20 tests passing with 100% success rate.

Key metrics:

- Encryption success rate: 100% (1000 iterations tested)
- SQL injection attempts blocked: 15/15 (100%)
- Audit trail completeness: 50/50 actions logged (100%)
- Password validation accuracy: 25/25 test cases passed

Performance Testing

Operation	Target	Actual	Status
Page Load (Dashboard)	< 2 sec	0.8 sec	PASS

Operation	Target	Actual	Status
Database Query (Patient Lookup)	< 100 ms	45 ms	PASS
PDF Generation	< 3 sec	2.1 sec	PASS
Encryption/Decryption	< 50 ms	12 ms	PASS

Key Performance Indicators (KPIs)

Metric	Target	Actual
PHI Encryption Coverage	100%	100%
Audit Trail Completeness	100%	100%
Training Completion Rate	> 80%	95% (in testing)
Violation Detection Accuracy	> 95%	100%
System Uptime (Demo)	> 99%	100%

Defect Summary

Severity	Found	Fixed	Outstanding
Critical	2	2	0
High	5	5	0
Medium	8	7	1 (documented)
Low	12	10	2 (deferred)

Outstanding defects:

- Medium: Session timeout warning modal styling inconsistency (Safari)
- Low: PDF report footer alignment off by 2px
- Low: Training module completion animation delay

Security, Privacy, Accessibility & Compliance

Security Measures

1. Encryption at Rest
    - Fernet (AES-128 CBC) for all PHI
    - SHA-256 password hashing (one-way)
2. Access Controls
    - Role-based authorization (admin/user)
    - Session-based authentication
    - Automatic timeout (2 minutes demo, configurable)

3. Input Validation
    - SQL injection prevention via parameterized queries
    - XSS prevention via React auto-escaping
    - Password complexity enforcement
4. Audit & Monitoring
    - Complete activity logging
    - IP address tracking
    - Violation detection and alerting

Privacy Protections

- Minimum Necessary Principle: Directory system enforces limited PHI sharing
- Patient Consent: Documented in training modules
- Breach Notification: 60-day timeline in response playbooks
- Data Retention: Configurable audit log retention
- Access Logging: Every PHI access recorded with user/timestamp

Accessibility Considerations

- Keyboard navigation support for all forms
- High contrast mode compatible
- Screen reader friendly HTML structure
- Clear error messages and feedback
- Responsive design for various screen sizes

HIPAA Compliance Coverage

Requirement	Section	Implementation
Access Control	§164.312(a)(1)	RBAC, unique user IDs
Audit Controls	§164.312(b)	Complete activity_log
Integrity	§164.312(c)(1)	Encryption, validation
Transmission Security	§164.312(e)(1)	Directory system, approved destinations
Authentication	§164.312(d)	Password complexity, session management
Encryption/Decryption	§164.312(a)(2)(iv)	Fernet for SSN, PHI
Security Awareness Training	§164.308(a)(5)	Interactive training simulator
Risk Analysis	§164.308(a)(1)(ii)(A)	Vulnerability scanner, EDR
Sanction Policy	§164.308(a)(1)(ii)(C)	Automated violation logging
Breach Notification	§164.408	60-day timeline in playbooks

Ethical Considerations

- Educational Use Only: System clearly labeled as demonstration/training tool
- No Real PHI: All patient data is synthetic
- Responsible Disclosure: Security findings documented openly
- Privacy by Design: Encryption and access controls built from day one
- Transparency: Complete audit trail provides accountability

Legal & Societal Impact

- Reduces Healthcare Breach Risk: Training and monitoring prevent violations
- Affordable Compliance: Provides tools accessible to small organizations
- Patient Privacy Protection: Demonstrates proper PHI handling
- Regulatory Adherence: Maps directly to HIPAA requirements
- Workforce Education: Improves staff awareness of privacy rules

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Deployment & Operations

Quick Start

See docs/INSTALL.md (docs/INSTALL.md) for detailed installation instructions.

Basic setup:

```
cd Cap_Finaldev
python3 -m venv venv
source venv/bin/activate  # Windows: venv\Scripts\activate
pip install -r requirements.txt
python webapp.py
```

Access at: http://127.0.0.1:5000/login (http://127.0.0.1:5000/login)

Default credentials:

- Admin: admin / Admin123!
- User: stefan / Stefan123!

Production Deployment Considerations

Requirement	Demo Implementation	Production Recommendation
Web Server	Flask development server	Gunicorn/uWSGI with nginx reverse proxy
Database	SQLite	PostgreSQL with encrypted tablespaces

Requirement	Demo Implementation	Production Recommendation
Encryption Keys	Hardcoded in source	AWS KMS, HashiCorp Vault, or Azure Key Vault
HTTPS/TLS	HTTP only	Valid SSL/TLS certificates (Let's Encrypt)
Session Timeout	2 minutes	15-30 minutes
Multi-Factor Auth	Not implemented	TOTP, FIDO2, or SMS-based MFA
Rate Limiting	Not implemented	Flask-Limiter or nginx rate limiting
Logging	Local file	Centralized logging (Splunk, ELK Stack)
Monitoring	Manual	Prometheus + Grafana, Datadog
Backup	Manual	Automated daily backups with 30-day retention
High Availability	Single instance	Load balancer with multiple app servers

Operations Guide

See docs/TROUBLESHOOTING.md (docs/TROUBLESHOOTING.md) for detailed troubleshooting.

Common operations:

- Start application: `python webapp.py`
- Stop application: Ctrl+C
- Reset demo data: Click "Full Demo Reset" in admin dashboard
- Generate compliance report: Click "HIPAA Report" button
- View logs: Check Flask console output

Limitations & Future Work

Known Limitations

1. Not Production-Ready
   - Hardcoded encryption key (security risk)
   - No HTTPS/TLS (transmission security)
   - SQLite not suitable for high-concurrency environments
   - No multi-factor authentication
2. Scalability Constraints
   - Single-server architecture
   - No load balancing or horizontal scaling
   - SQLite performance degrades beyond ~10K records
3. Security Gaps

- No rate limiting (brute force vulnerability)
- No CSRF token protection
- Session timeout very short (demo purpose)
- No intrusion detection/prevention system (IDS/IPS)

4. Functional Limitations

- No integration with real EHR systems
- No mobile application
- No real-time notifications (email, SMS)
- No advanced analytics or dashboards

Technical Debt

Priority	Item	Effort	Impact
High	Externalize encryption key to config	2 hours	Security
High	Implement CSRF protection	4 hours	Security
Medium	Add rate limiting	3 hours	Security
Medium	Migrate to PostgreSQL	8 hours	Scalability
Low	Refactor frontend to separate React app	16 hours	Maintainability

Future Enhancements

Priority	Feature	Description	Effort
P0	Multi-Factor Authentication	TOTP or FIDO2 for enhanced login security	1 week
P0	HTTPS/TLS Deployment	SSL certificate integration, secure transmission	3 days
P1	Real SIEM Integration	Connect to Splunk, ELK Stack for advanced monitoring	2 weeks
P1	EHR Integration	Interface with Epic, Cerner for real patient data	4 weeks
P2	Mobile Application	iOS/Android app for on-the-go compliance checks	8 weeks
P2	Machine Learning Anomaly Detection	ML-based behavioral analytics for insider threats	6 weeks
P3	Automated Vulnerability Scanning	Integration with OWASP ZAP, Snyk	1 week
P3	Dark Web Monitoring	Credential leak detection	2 weeks

Roadmap

Quarter	Goals
Q1 2025	Production hardening: HTTPS, MFA, PostgreSQL migration, external key management

Quarter	Goals
Q2 2025	SIEM integration, advanced analytics, automated scanning
Q3 2025	Mobile application, EHR integration pilot
Q4 2025	ML-based anomaly detection, expanded breach scenarios

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Appendices

Appendix A: Installation Guide

See docs/INSTALL.md (docs/INSTALL.md)

Appendix B: User Manual

See docs/HOW_TO_USE.md (docs/HOW_TO_USE.md)

Appendix C: Operations Guide

See docs/TROUBLESHOOTING.md (docs/TROUBLESHOOTING.md)

Appendix D: Testing Documentation

See docs/TESTING.md (docs/TESTING.md)

Appendix E: Feature Reference

See docs/FEATURES.md (docs/FEATURES.md)

Appendix F: Presentation Q&A

See docs/CAPSTONE_QA.md (docs/CAPSTONE_QA.md)

Appendix G: Team Contributions

See docs/TEAM_CONTRIBUTIONS.md (docs/TEAM_CONTRIBUTIONS.md)

Appendix H: Login Credentials

See docs/LOGIN_CREDENTIALS.txt (docs/LOGIN_CREDENTIALS.txt)

License

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