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1 Technical Design Document

1.1 1. Document Control

- **Version:** 2.1
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- **Date:** 2025-11-3
- **Reviewers:** Prof. Arnold Lau, T.A. Sneh Bhandari

1.2 2. Introduction

This TDD specifies the technical implementation details for the Gym Membership Management System (“FitDB”). The design emphasizes the database layer: RBAC (SQL roles), auditable transactions, and denormalized reporting views.

(See `README.md` for MVP and roadmap, and `MVP_SCOPE.md` for detailed MVP clarification.)

1.2.1 2.1 MVP Scope

Current Phase (MVP): The MVP focuses exclusively on core account and access card management:

- User account creation (username, email, password)
- Member account registration by front desk managers
- Access card issuance by front desk managers
- Audit logging for all operations
- RBAC infrastructure (front desk manager role enabled)

Future Phases: While the database schema supports the full feature set, the following will be implemented post-MVP:

- Session management and bookings
- Check-in system
- Equipment management
- Reporting and analytics
- Advanced member management

The database schema is designed to support all future features without requiring schema changes.

1.3 3. High-Level Architecture

- **Application Layer:** Flask (Python) web framework
- **Database Layer:** MySQL (system of record)
- **Services:** Auth/RBAC, Membership, Audit
- **Storage:** Static assets and member photos stored locally in development
- **Future:** AWS S3 for production photo storage, optional load balancing

1.3.1 3.1 Three-Tier Architecture

Layer	Description / Responsibilities
Presentation	Flask Templates, HTML/CSS <i>User Interface</i>
Business Logic	Flask App (Python): — Authentication & Authorization — Business Rules Enforcement — Transaction Management — Audit Logging
Data Layer	MySQL+: — Tables, Views, Procedures — Triggers, Indexes — RBAC via SQL Roles — Audit Tables

1.4 4. Detailed Design

1.4.1 4.1 Data Model

ER Diagram Overview with audit tables. For separated diagrams (overview *without* audits, plus three clearer ERDs), see `ERDs.md`.

1.4.1.1 4.1.0 Database Design Decisions **Normalization Level:** - **Chosen:** Third Normal Form (3NF) - **Rationale:** - Eliminates redundancy without sacrificing query performance - Maintains data integrity through proper foreign key relationships - Allows for efficient updates and joins - Balance between normalization and practical considerations

Strategic Denormalization: - **Audit Tables:** Use `after_json` field to store complete snapshots (allows for quick state reconstruction without joins) - **Reporting Views:** Denormalized views aggregate data

for fast queries (utilization, equipment demand) - **Rationale:** Performance optimization for read-heavy operations while maintaining single source of truth in base tables

Indexing Strategy: - **Primary Keys:** All tables have auto-incrementing BIGINT primary keys - **Foreign Keys:** Automatically indexed in MySQL - **Unique Constraints:** Username, email, card_uid, composite keys for business rules - **Composite Indexes:** Created on frequently queried combinations (e.g., (gym_id, starts_at), (member_id, session_id)) - **Covering Indexes:** Audit tables indexed for common query patterns

Data Type Choices: - **BIGINT for IDs:** Supports scaling to millions of records - **VARCHAR for text:** Appropriate lengths to prevent waste and overflow - **DATETIME for timestamps:** Precise to second granularity (sufficient for business needs) - **DATE for dates:** Used where time-of-day is irrelevant (membership dates, availability) - **ENUM considered but rejected:** Status values stored via foreign keys to indicator tables (more flexible, easier to add/modify values)

Referential Integrity: - **Foreign Keys:** Enforced on all relationships - **ON DELETE Behavior:** - CASCADE for audit tables (deleting a record should remove its audit trail) - RESTRICT for core relationships (prevent deletion that would orphan records) - **ON UPDATE:** Default CASCADE for ID propagation

Constraint Enforcement: - **Check Constraints:** Column-level validation (status codes, date ranges, quantities 0) - **Triggers:** Business rule enforcement that cannot be expressed via simple constraints - **Application Layer:** Additional validation for complex business logic

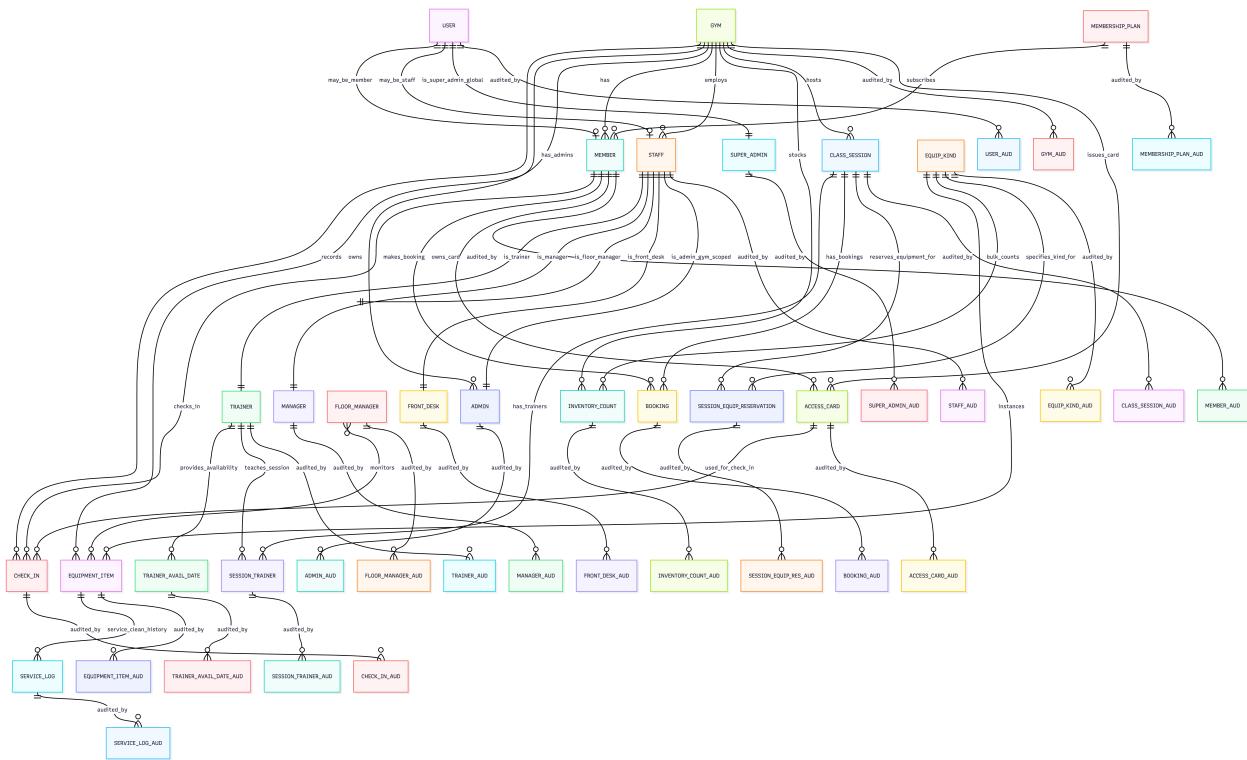


Figure 1: TDD ERD Diagram 1: Data Model

1.4.1.2 4.1.1 Cardinality

- **1:1**
 - USER MEMBER (optional specialization per user)
 - USER STAFF (optional specialization per user)

- STAFF ADMIN / TRAINER / MANAGER / FLOOR_MANAGER / FRONT_DESK (each role maps to exactly one STAFF)
- 1:N
 - GYM → STAFF, ADMIN, CLASS_SESSION, CHECK_IN, EQUIPMENT_ITEM, INVENTORY_COUNT, MEMBER
 - EQUIP_KIND → EQUIPMENT_ITEM, INVENTORY_COUNT
 - TRAINER → TRAINER_AVAIL_DATE
 - CLASS_SESSION → BOOKING
 - MEMBER → BOOKING, CHECK_IN, ACCESS_CARD
 - GYM → ACCESS_CARD
- M:N
 - CLASS_SESSION TRAINER (through SESSION_TRAINER)
 - FLOOR_MANAGER EQUIPMENT_ITEM (monitoring)
 - CLASS_SESSION EQUIP_KIND (through weak SESSION_EQUIP_RESERVATION)
 - MEMBER GYM (through CHECK_IN)

1.4.1.3 4.1.2 Participation Constraints

- Total participation (mandatory)
 - every TRAINER, MANAGER, FLOOR_MANAGER, FRONT_DESK, ADMIN must be a STAFF.
 - every CLASS_SESSION belongs to a GYM.
 - every BOOKING references one CLASS_SESSION and one MEMBER.
 - SESSION_TRAINER, SESSION_EQUIP_RESERVATION, INVENTORY_COUNT, CHECK_IN, and ACCESS_CARD cannot exist without their parents
- Partial participation (optional)
 - a USER may be a MEMBER and/or STAFF (not required to be either).
 - a GYM may have zero CLASS_SESSIONS or EQUIPMENT_ITEMS at initialization.
 - a MEMBER may have zero BOOKINGS or CHECK_INS.

Note: indexes, attribute typing (key/derived/multi-valued/composite), and the detailed audit schema will be documented in **ERDs.md**.

1.4.2 4.2 API Design (Post-MVP)

- Auth: POST /api/auth/register (user account creation), POST /api/auth/login, GET /api/me
- Front Desk: POST /api/front-desk/members (create member account), POST /api/front-desk/access-cards (issue access card)
- Sessions & Booking: GET /api/sessions, POST /api/bookings, DELETE /api/bookings/{id}
- Trainer: GET/POST /api/trainer/availability (AM/PM per date)
- Manager: POST /api/manager/sessions (create/cancel/assign trainer)
- Equipment: GET /api/equipment/items, POST /api/equipment/service-logs
- Reports: GET /api/reports/class-utilization, GET /api/reports/equipment-demand

1.4.3 4.3 Entitlements Summary

- r_member: Can view personal profile/bookings/check-ins/available sessions; check in.
- r_plus_member: All r_member rights plus booking sessions, cancel own bookings, view bookable sessions.
- r_trainer: Can view personal profile (trainer version), trainer schedule, class rosters; set availability.
- r_front_desk: Can view member lookup; issue/revoke access cards; check in.
- r_floor_manager: Can view equipment status; log equipment service; snapshot inventory.
- r_manager: Can view everything above plus utilization/equipment demand reports; manage sessions, trainers, access cards, register/ban members, cancel bookings.
- r_admin_gym: All r_manager functions plus view audit logs; create user accounts.
- r_super_admin: All functions, including gym/role management.

Special notes: - Trainers see their own info in a trainer-specific format. - Members can check in only when membership is valid.

1.4.4 4.4 Application Logic

Booking Workflow (transactional) 1. verify role = plus_member; session is scheduled and within bookable window 2. capacity check + equipment sufficiency (per-attendee requirements × seats) 3. insert Booking; write audit; commit or rollback on any failure

Publish Sessions (manager) 1. expand TrainerAvailability into sessions for date range 2. validate conflicts and equipment availability; create ClassSession rows; write audit transactionally

Check-In - validate active membership; insert CheckIn; write audit

1.4.4.1 Stored Procedures

- `sp_book_session(p_member_id, p_session_id)`: validates plus membership, capacity, status; inserts BOOKING; writes BOOKING_AUD.
- `sp_cancel_booking(p_member_id, p_booking_id, p_reason)`: ensures staff/admin; updates status; writes BOOKING_AUD.
- `sp_check_in(p_member_id, p_gym_id, p_card_uid)`: validates membership/card; inserts CHECK_IN; writes CHECK_IN_AUD.
- `sp_set_availability(p_trainer_id, p_gym_id, p_for_date, p_period) / sp_remove_availability(...)`: upsert/delete TRAINER_AVAIL_DATE; write TRAINER_AVAIL_DATE_AUD.
- `sp_publish_sessions(p_gym_id, p_start_date, p_end_date)`: creates CLASS_SESSION batches from availability; writes CLASS_SESSION_AUD.
- `sp_assign_trainer(p_session_id, p_trainer_id, p_role) / sp_unassign_trainer(...)`: maintains SESSION_TRAINER; writes SESSION_TRAINER_AUD.
- `sp_reserve_session_equipment(p_session_id, p_equip_kind_id, p_qty)`: upsert SESSION_EQUIP_RESERVATION; validates stock; writes SESSION_EQUIP_RES_AUD.
- `sp_log_equipment_service(p_item_id, p_action, p_staff_id, p_notes)`: inserts SERVICE_LOG; updates flags; writes SERVICE_LOG_AUD.
- `sp_snapshot_inventory(p_gym_id)`: recomputes INVENTORY_COUNT for dashboards; writes INVENTORY_COUNT_AUD.
- `sp_member_register(p_user_id, p_plan_id, p_home_gym_id)`: creates MEMBER; assigns role; writes MEMBER_AUD.
- `sp_access_card_issue(p_member_id, p_gym_id, p_card_uid) / sp_access_card_revoke(...)`: maintains ACCESS_CARD; writes ACCESS_CARD_AUD.

Audit note: procedures call a shared helper to append a *_AUD row with (seq_no, occurred_at, action, after_json, actor_user_id)

1.4.4.2 RBAC Mapping

- `r_member`
 - EXECUTE: `sp_check_in`, read-only helper procs
 - SELECT: views `vw_sessions_open`, `vw_member_profile`, `vw_member_checkins`, `vw_member_bookings`
- `r_plus_member` (inherits `r_member`)
 - EXECUTE: `sp_book_session`, `sp_cancel_booking`
 - SELECT: `vw_bookable_sessions`
- `r_trainer`
 - EXECUTE: `sp_set_availability`, `sp_remove_availability`
 - SELECT: `vw_trainer_schedule`, `vw_trainer_class_rosters`
- `r_manager`
 - EXECUTE: `sp_publish_sessions`, `sp_assign_trainer`, `sp_unassign_trainer`
 - SELECT: `vw_equipment_demand`, `vw_class_utilization`, `vw_all_rosters`

- **r_front_desk**
 - EXECUTE: sp_check_in, sp_access_card_issue, sp_access_card_revoke
 - SELECT: vw_member_lookup_minimal, vw_cards_by_gym
- **r_floor_manager**
 - EXECUTE: sp_log_equipment_service, sp_snapshot_inventory
 - SELECT: vw_equipment_status, vw_cleaning_due, vw_service_due
- **r_admin_gym**
 - EXECUTE: all above + maintenance procs
 - SELECT/INSERT/UPDATE/DELETE: on gym-scoped tables where needed
- **r_super_admin**
 - ALL PRIVILEGES incl. CREATE ROLE, GRANT

1.4.5 4.5 User Interface

1.4.5.1 4.5.1 Interface Types Web-Based Portal (Flask Application) - Primary Interface: Browser-based web application - Technology: Flask templates for server-side rendering - Responsive Design: Mobile-friendly CSS - No JavaScript Framework: Vanilla JavaScript for MVP simplicity

Database CLI Access - Direct Access: MySQL command-line for admins - **Read-Only**: Most users interact via application layer - **Procedures**: Business operations via stored procedures

1.4.5.2 4.5.2 MVP Interfaces (Post-MVP) User Account Creation Page

Registration Form:

- Username input
- Email input
- Password input
- Submit → Creates USER account

Front Desk Manager Console

Dashboard:

- Member Registration
 - User lookup (by username/ID)
 - Membership plan selection
 - Home gym selection
 - Create member account
- Access Card Management
 - Member lookup
 - Card UID input
 - Gym selection
 - Issue access card

1.4.5.3 4.5.3 Future Interfaces (Post-MVP) Member Portal (trial/basic/plus)

Dashboard:

- Profile View
 - Personal information
 - Membership plan details
 - Check-in history
 - Access card status
- Class Sessions
 - Available sessions list
 - Upcoming sessions (plus only)
- Bookings (plus only)
 - Current bookings

- Booking cancellation
- Check-In
 - Manual check-in option

Trainer Portal

Dashboard:

- Availability Management
 - View availability calendar
 - Set availability (date/period)
 - Remove availability
- Class Rosters
 - Assigned sessions
 - Member attendance lists

Manager Console

Dashboard:

- Session Management
 - View trainer availability
 - Publish sessions
 - Assign trainers
 - Cancel sessions
- Member Management
 - Member lookup
 - Register new members
 - Issue strikes/bans
 - Revoke access cards
- Reporting
 - Class utilization
 - Equipment demand
 - Member analytics

Front Desk Console

Dashboard:

- Member Lookup
 - Search by username/email
- Check-In Management
 - Manual check-in
 - Card-based check-in
- Access Card Management
 - Issue new cards
 - Revoke lost cards

Floor Manager Console

Dashboard:

- Equipment Status
 - By equipment type
 - By status (OK/Needs Service/Out of Order)
 - Cleaning due alerts
- Service Management
 - Log service actions
 - Update equipment status
- Inventory Snapshots
 - Manual inventory counts

Admin Console (Gym-SScoped)

Dashboard:

- Full Manager Access
- User Management
 - Create users
 - Assign roles
 - Deactivate accounts
- Audit Viewer
 - View all audit logs
- System Configuration
 - Gym-specific settings

Super Admin Console (Global)

Dashboard:

- All Admin Functions
- Multi-Gym Management
 - Create/edit gyms
 - Gym status management
- Global User Management
- Role Management
 - Grant/revoke roles
 - Role hierarchies
- System-Wide Reports

1.4.5.4 Interface Design Principles

- **Role-Based Dashboards:** Customized views per user role
- **Progressive Disclosure:** Show only relevant information
- **Responsive Tables:** Pagination for large datasets
- **Real-Time Updates:** Session capacity updates, booking confirmations
- **Error Handling:** Clear error messages with actionable guidance
- **Accessibility:** Semantic HTML, ARIA labels (MVP basic support)

1.4.6 SQL Views

- `vw_sessions_open`: sessions SCHEDULED & open_for_booking
- `vw_bookable_sessions`: `vw_sessions_open` + capacity remaining; hides full sessions
- `vw_trainer_schedule`: availability vs. assigned sessions for a trainer
- `vw_trainer_class_rosters`: roster with member display name
- `vw_class_utilization`: per-session capacity, seats taken, % utilization
- `vw_equipment_status`: item status, service/clean flags; by gym
- `vw_cleaning_due` / `vw_service_due`: items due by date, etc.
- `vw_equipment_demand`: SESSION_EQUIP_RESERVATION and frequency of use
- `vw_member_profile`: safe member profile (joins USER), photo path inherited from USER
- `vw_member_bookings` / `vw_member_checkins`: member-scoped history
- `vw_member_lookup_minimal`: front-desk-friendly lookup (username, plan, photo path)
- `vw_cards_by_gym`: active cards issued by gym

View Note - WHERE clauses enforce active status

1.5 Technology Stack

1.5.1 Core Technologies

- **Programming Language:** Python

- **Web Framework:** Flask
- **Database:** MySQL
 - Features used: Roles, Stored Procedures, Triggers, JSON support
 - Character set: UTF8MB4 with unicode collation
- **Frontend:** HTML, CSS (vanilla, no JS framework for MVP)
- **Testing:** manual SQL testing
- **Dependencies Management:** pip, requirements.txt

1.5.2 5.2 Python Dependencies

- Flask - Web framework
- mysql-connector-python - Database connectivity
- faker - Test data generation
- python-dotenv - Environment variable management (optional)

1.5.3 5.3 Development Tools

- **Make** - Build automation (Makefile)
- **MySQL CLI** - Database management
- **Git** - Version control
- **VS Code** - Development environment

1.6 6. Security & Compliance

1.6.1 6.1 Authentication

- **Password Storage:** Passwords are hashed using secure algorithms (stored in `USER.password_hash`)
- **Password Policy:** Never stored in plaintext; algorithm tracked in `USER.password_algo`
- **Password Updates:** Timestamp tracked in `USER.password_updated_at`
- **Last Login:** Tracked for security monitoring in `USER.last_login_at`

1.6.2 6.2 Authorization (RBAC)

Role Hierarchy and Inheritance:

```
r_super_admin (global admin, ALL PRIVILEGES)
    r_admin_gym (gym-scoped admin, full gym access)
        r_manager (session publishing, equipment, reporting)
            r_front_desk (check-ins, card management)
            r_floor_manager (equipment maintenance)
        r_trainer (availability, roster views)
r_member (basic access, profile viewing)
    r_plus_member (inherits r_member, adds booking permissions)
```

Grant Strategy: - Least privilege: roles only have access to necessary tables/views/procedures - Inheritance: `r_plus_member` inherits from `r_member` via MySQL role inheritance - Separation of concerns: Each role has distinct permissions - Super admin: Can grant/revoke roles and has ALL PRIVILEGES

1.6.3 6.3 SQL Injection Prevention

- **Parameterized Queries:** All SQL queries use parameter binding
- **Stored Procedures:** Business logic encapsulated in procedures with parameters
- **Input Validation:** Application layer validates all user inputs
- **Dynamic SQL:** Minimized; when used, inputs are sanitized

1.6.4 6.4 Data Protection

- **PII Handling:** User passwords, emails, photos protected
- **Profile Photos:** Stored as file paths (not BLOBs) for performance; default image when NULL
- **Encryption:** Passwords hashed; photos optionally encrypted in production

1.6.5 6.5 Audit & Compliance

- **Immutable Audit Trail:** All *_AUD tables are append-only (no UPDATE/DELETE allowed)
- **Audit Fields:** Every audit record contains:
 - seq_no - Sequential ordering
 - occurred_at - Precise timestamp
 - action - Operation type (insert/update/delete)
 - after_json - Complete state snapshot (JSON)
 - actor_user_id - Who performed the action
- **Audit Triggers:** Database triggers automatically write audit records
- **Compliance:** Audit trail enables regulatory compliance and forensic analysis

1.6.6 6.6 Network Security

- **Connection Encryption:** TLS for production (optionally enabled via MySQL SSL)
- **Access Control:** MySQL users restricted by host (@'%' for flexibility, can be '@localhost' for security)
- **Default Passwords:** Changed from defaults in production

1.6.7 6.7 Data Integrity

- **Referential Integrity:** Foreign keys enforce relationships
- **Check Constraints:** Column-level validation (status codes, date ranges)
- **Trigger-Based Validation:** Business rules enforced via triggers
- **Transaction Isolation:** ACID properties maintained via MySQL transactions

1.7 7. Performance Considerations

1.7.1 7.1 Database Performance

- **Indexing Strategy:**
 - Foreign keys automatically indexed in MySQL
 - Unique constraints indexed ((member_id, session_id), (card_uid))
 - Composite indexes for common queries (e.g., (gym_id, starts_at))
 - Covering indexes for audit tables (base_entity_id, seq_no)
- **Query Optimization:**
 - Stored procedures reduce network round-trips
 - Views denormalize data for reporting queries
 - EXPLAIN/ANALYZE used to optimize query plans
- **Partitioning:** Not needed for MVP but can partition audit tables by date in production
- **Connection Pooling:** Flask application uses connection pooling for efficiency

1.7.2 7.2 Application Performance

- **Pagination:** Large result sets (bookings, check-ins, audit logs) are paginated
- **Caching Strategy:**
 - Static assets (CSS, images) cached
 - Session data cached in Flask session
 - Views cached at database level
- **Target Response Times:**
 - Simple queries (< 500ms)

- Complex reports (< 3s)
- Booking transactions (< 1s)

1.7.3 7.3 Performance Testing

- Test with datasets: tiny (10 members), small (100), medium (1,000), large (10,000), huge (100,000)
- Measure: booking transaction time, session listing, utilization reports
- Document EXPLAIN/ANALYZE outputs for critical queries

1.8 8. Scalability Considerations

1.8.1 8.1 Current Scale (MVP)

- **Gym Count:** 1 (expandable to many)
- **Concurrent Users:** < 100
- **Data Volume:** 10,000-100,000 members feasible with proper indexing

1.8.2 8.3 Vertical Scaling

- **MySQL Configuration:** Buffer pool sizing, query cache (if applicable)
- **Server Resources:** CPU, RAM, SSD storage
- **Connection Limits:** Configure max_connections appropriately

1.8.3 8.4 Multi-Tenancy Support

- **Schema Design:** Already supports multiple gyms via `gym_id`
- **Data Isolation:** Gym-scoped admins ensure isolation
- **Future:** Could implement separate databases per gym if needed

1.8.4 8.5 Future Growth Considerations

- **Archival Strategy:** Archive old audit logs (> 2 years) to cold storage
- **Lazy Evaluation:** Defer heavy calculations until needed
- **Async Processing:** Background jobs for reporting generation
- **CDN:** Serve static assets via CDN in production

1.9 9. Risks & Mitigations

- **Overbooking or equipment conflicts** → DB constraints + transaction checks
- **RBAC misconfiguration** → explicit role grants
- **ERD conflicts** → ERD reviews
- **Scope considerations** → enforce MVP

1.10 10. Testing Strategy

- **Unit tests:** booking constraints, session publish logic, RBAC decorators
- **Integration tests:** transaction rollbacks on forced failures; seed users/roles
- **SQL tests:** views return expected utilization/equipment demand

1.11 11. Deployment & Monitoring

- **Runtime logging:** audit stored in DB as JSON snapshots
- **Metrics:** latency, error rates, booking success/failure counts
- **Backups:** DB snapshots/backups

1.12 12. GitHub Repository

Repository: <https://github.com/hah97/FitDB>

1.12.1 Repository Structure

- `/sql/` - Database schema files
- `/data/` - Seed data generation
- `/scripts/` - Automation and utilities
- `/docs/` - Comprehensive documentation
- `Makefile` - Build automation with targets
- `README.md` - Project overview, setup instructions, and current status
- `requirements.txt` - Python dependencies

1.12.2 Setup Instructions

See `README.md` for detailed setup instructions