Project Design Phase

Solution Architecture

Date	06 November 2025
Team ID	F529277D47452DB9E7447BD087E08E5E
Project Name	Medical Inventory Management
Maximum Marks	4 Marks

Goals & requirements (short)

- Accurate real-time stock levels for medicines & supplies (batch, expiry, lot, serial).
- Automated reorder (min/max, EOQ, safety stock) + vendor integration.
- Traceability: receiving → storage → dispensing → disposal (audit trail).
- Integration with EHR/EMR, procurement, billing, and lab systems.
- Support barcode / RFID / IoT sensors (temperature, humidity).
- Secure + compliant (HIPAA/GDPR where applicable), role-based access.
- Scalable, highly-available, observable.

High-level architecture (summary)

1. Client layer: Web UI (inventory managers, pharmacists), Mobile apps (scanning), Kiosk/terminal UI.
2. API layer: Gateway + REST/GraphQL services.
3. Core services: Inventory service, Ordering/Replenishment service, Lot/Expiry service, Audit service, Supplier service.
4. Data layer: Relational DB for transactional data, Time-series DB for sensors, Data warehouse for analytics.
5. Integration & messaging: Event bus (Kafka/RabbitMQ), API adapters for EHR / suppliers, HL7/FHIR adapter.
6. Physical devices: Barcode/RFID readers, IoT sensors, smart shelves.
7. Cross-cutting: Auth/ZTNA, encryption, logging, monitoring, CI/CD.

(Architecture mapped to cloud on AWS/Azure/GCP is included below.)

Component breakdown

1. Client layer

- Web app (React/TS) for inventory management dashboards, inbound/outbound workflows.
- Mobile app (iOS/Android or PWA) for scanning barcodes/RFID and offline mode.
- Handheld scanners / kiosks — integrate via Bluetooth/USB or MQTT gateway.

2. API Gateway & Edge

- API Gateway (Auth enforcement, rate limiting).
- Protocols: REST for operational APIs, GraphQL for the UI if desired, gRPC for internal microservices.

3. Core microservices

- **Inventory Service** — core ledger of stock transactions (receipts, issues, transfers). Keeps per-location, per-lot, expiry, and status.
- **Lot & Expiry Service** — tracks lot numbers, expiry, recalls.
- **Replenishment / Procurement Service** — reorder rules (min/max, periodic review), PO creation, supplier selection.
- **Receiving Service** — checks inbound shipments against POs, QC, quarantine.
- **Dispense Service** — fulfill requests (ward, patient), supports barcode scanning for 2FA.
- **Audit & Compliance Service** — immutable log of all transactions (append-only).
- **Inventory Forecasting / ML** — demand forecasting and expiry risk; uses time-series and historical usage.
- **Integration Service / EHR Adapter** — transforms to/from HL7 / FHIR, syncs orders / patient medication needs.
- **Notification Service** — low stock alerts, expiry alerts, recall notifications (email/SMS/Push).

4. Data stores

- **Primary DB**: PostgreSQL/Cloud SQL / Azure SQL — ACID for transactions.
- **Cache**: Redis for hot lookups and locks.
- **Event Store / Stream**: Kafka or managed pub/sub for events (stock changed, PO created).
- **Timeseries DB**: InfluxDB / Prometheus / AWS Timestream for sensor data.
- **Data Warehouse**: Snowflake / BigQuery / Redshift for BI.
- **Object storage**: S3/GCS/Azure Blob for attachments, invoices, certificates.

5. Device & Edge connectivity

- Local gateway for barcode/RFID → forwards events to API (MQTT/HTTPS).

- IoT sensors stream to edge gateway → time-series DB / monitoring.

Data model (simplified ER)

- Item (item_id, sku, name, description, uom, category)
- Location (location_id, name, type:warehouse/ward/fridge)
- Lot (lot_id, item_id, lot_number, manufacture_date, expiry_date, quantity, status)
- StockTransaction (tx_id, item_id, lot_id, from_location, to_location, qty, tx_type, timestamp, user_id, reference_id)
- PurchaseOrder (po_id, supplier_id, items[], status)
- Supplier (supplier_id, name, contact)
- ReorderRule (item_id, location_id, min, max, reorder_qty, rule_type)
- AuditLog (log_id, entity, action, prev_state, new_state, user, timestamp)

Key flows (sequence)

Receiving & Putaway

1. Supplier sends shipment → Warehouse receiving clerk scans shipment.
2. System matches against PO (Receiving Service).
3. If mismatch → create exception task. If OK → create Lot record and StockTransaction (RECEIPT).
4. Putaway: move to location (shelf, cold chain) → StockTransaction (TRANSFER).

Dispensing to Ward/Patient

1. Ward places requisition (EHR or Inventory UI).
2. Dispense Service confirms availability by lot/expiry and reserves stock.
3. Pharmacist scans item & patient ID (2-factor verification), system records StockTransaction (ISSUE).
4. If partial, system updates lot quantities and triggers reorder if below threshold.

Replenishment

- Replenishment service periodically evaluates ReorderRules and forecasts. Generates PO and notifies procurement. Events published on event bus.

APIs (example endpoints)

- `POST /api/v1/receive` — submit received shipment (body: po_id, items[{sku, lot, qty}])
- `POST /api/v1/stock/transfer` — move stock between locations
- `POST /api/v1/dispense` — issue item to ward/patient (requires auth & patient_id)
- `GET /api/v1/stock?item_id=&location_id=` — current stock snapshot
- `GET /api/v1/lot/{lot_id}` — lot details (expiry, quantity)
- `POST /api/v1/reorder/trigger` — force reorder for item/location
- FHIR endpoints for medication supply: `POST /fhir/MedicationRequest` (adapter transforms)

All endpoints behind API Gateway with JWT/OAuth2 scopes.

Events / Topics (event-driven)

- `stock.received`
- `stock.issued`
- `stock.transferred`
- `stock.threshold_breach`
- `po.created`
- `lot.expiry_near` (7/30/90 days)
- `recall.issued`

Consumers: Analytics, Notification Service, External Integrations, Audit Service.

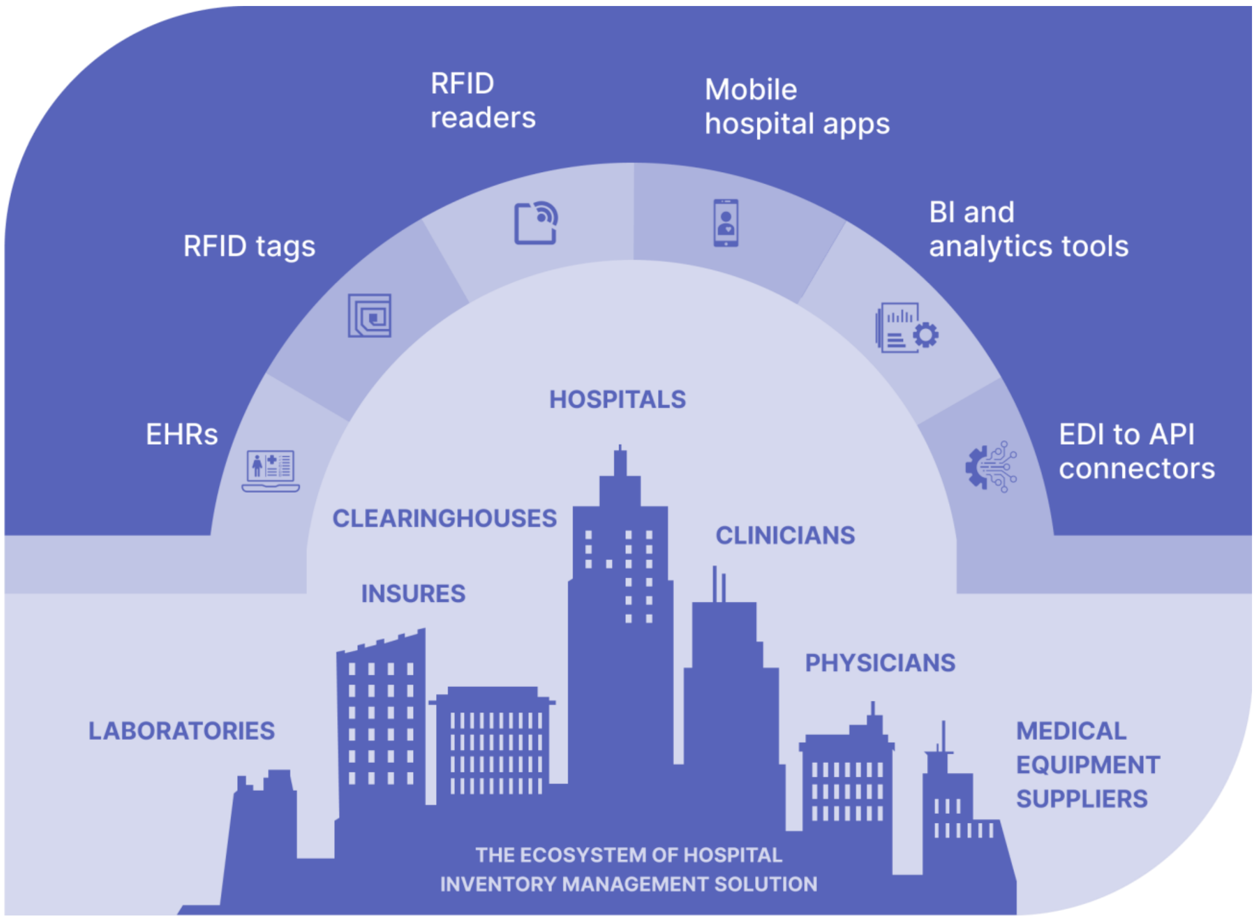
Security & Compliance

- Authentication: OAuth2 / OpenID Connect (Keycloak / Auth0 / AWS Cognito).
- Authorization: RBAC + attribute-based access (ABAC) for sensitive operations (dispense, write audits).
- Encryption: TLS in transit; database encryption at rest; HSM/KMS for key management.
- Auditability: Append-only audit logs with tamper-evident signatures (hash chaining).
- Data minimization: patient PHI separated; pseudonymize where possible.
- Access logging & SIEM integration (CloudWatch/ElasticSIEM/Splunk).
- Compliance checklist: HIPAA business associate agreements, data residency rules, retention & deletion policy.
- Physical security for cold-chain: signed logs + IoT sensor tamper detection.

Reliability, scaling & HA

- Stateless API services in Kubernetes with Horizontal Pod Autoscaling.

- PostgreSQL in multi-AZ with read replicas and automated failover (Patroni/RDS Multi-AZ).
- Kafka / managed pubsub for decoupling; compacted topics for stateful events.
- Redis cluster for caching & distributed locks (to prevent race conditions on inventory updates).
- Use optimistic concurrency control for stock updates plus idempotent operations (idempotency keys).
- Backup strategy: DB snapshots daily + WAL archiving; test restore monthly.
- Disaster recovery: RTO goal (e.g., 1-4 hours), RPO (e.g., 1 hour) depending on hospital SLAs.


RFID readers
Mobile hospital apps
RFID tags
BI and analytics tools
EHRs
EDI to API connectors
HOSPITALS
CLEARINGHOUSES
CLINICIANS
INSURES
PHYSICIANS
LABORATORIES
MEDICAL EQUIPMENT SUPPLIERS
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