



Digital Twin Training Workshop
Industry 17-18 September 2025

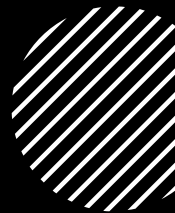
Perspectives on Digital Twin in Healthcare

Practical Case Study & Implementation
Guide

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Presentat ion Outline



Industry drivers & definition

Value propositions across stakeholders

Technical and non-technical enablers

Barriers, risks & regulatory considerations

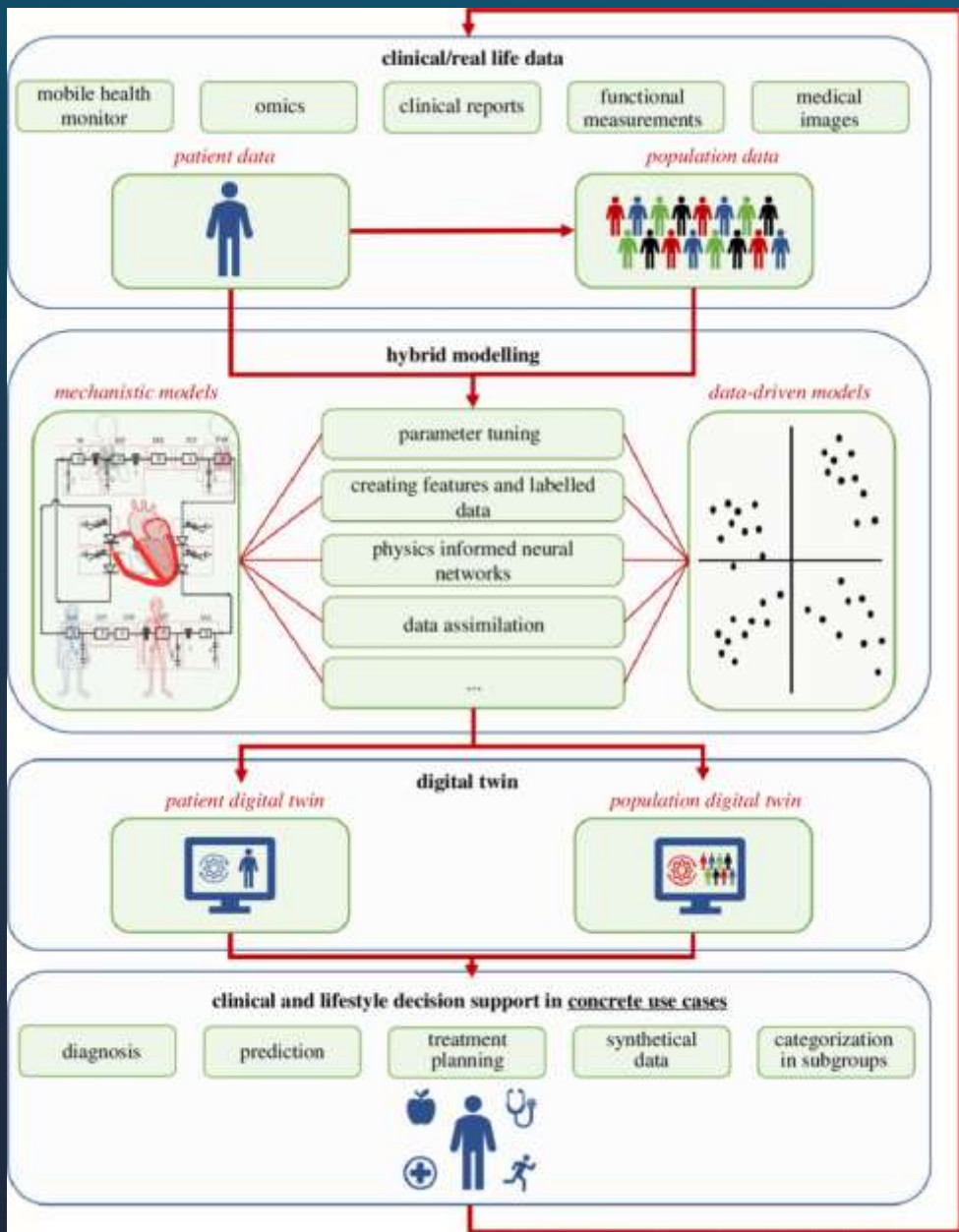
ROI, KPIs, and implementation roadmap

Practical case study: Patient-specific digital twin in ICU

Lessons learned, recommendations, and references

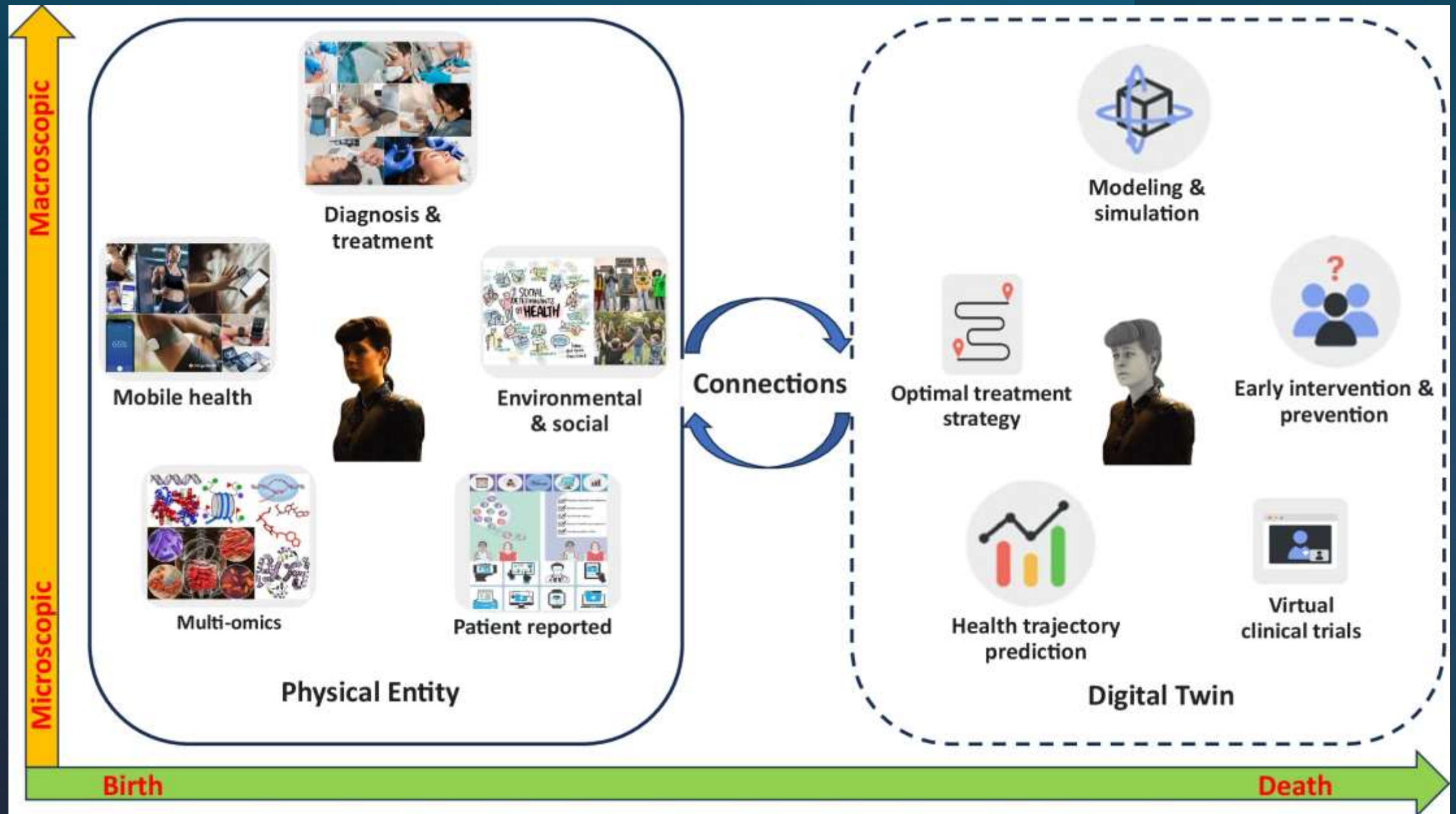
What is a Digital Twin in Healthcare?

- **Digital Twin (DT) :**
 - A virtual model of a physical system (patient, organ, device, workflow)
- **Digital Twin Types:**
 - Patient-specific DT (PSDT)
 - Organ-specific DT
 - Device/Asset DT
 - Process/Workflow DT



Why Industry Cares: Key Market Drivers

- Personalization of care and precision medicine
- Regulatory pressure to improve outcomes and reduce readmissions
- Cost containment and operational efficiency
- Growth in connected medical devices & IoT
- Faster drug and device development via in-silico trials



Industry Driver

**Personalization of care /
precision medicine**

**Regulatory pressure to improve
outcomes & reduce readmissions**

**Cost containment & operational
efficiency**

**Growth in connected medical
devices & IoT**

Faster drug/device development

Linked Business KPI(s)

↑ Treatment success rates, ↓
adverse events, ↑ patient
satisfaction scores

↓ 30-day readmission rate, ↑
compliance score, ↓ penalties
from payers/regulators

↓ Average Length of Stay (LoS),
↓ resource utilization per
patient, ↑ throughput per
bed/unit

↑ Data availability for
predictive analytics, ↓ device
downtime (predictive
maintenance), ↑ asset
utilization rate

↓ Time-to-market (TtM), ↓ cost
per clinical trial phase, ↑

Stakeholder Value Map

- **Clinicians:** accurate prognosis, treatment planning, decision support
- **Hospital Ops:** bed/ICU forecasting, asset utilization
- **Patients:** tailored therapies, remote monitoring, better outcomes
- **Payers:** cost reduction, risk stratification
- **Device manufacturers:** predictive maintenance, performance modeling
- **Regulators & researchers:** simulation-based evidence



Core Technical Enablers



Data sources: EHR, medical images (DICOM), monitoring devices (ECG, SpO2), genomics, labs



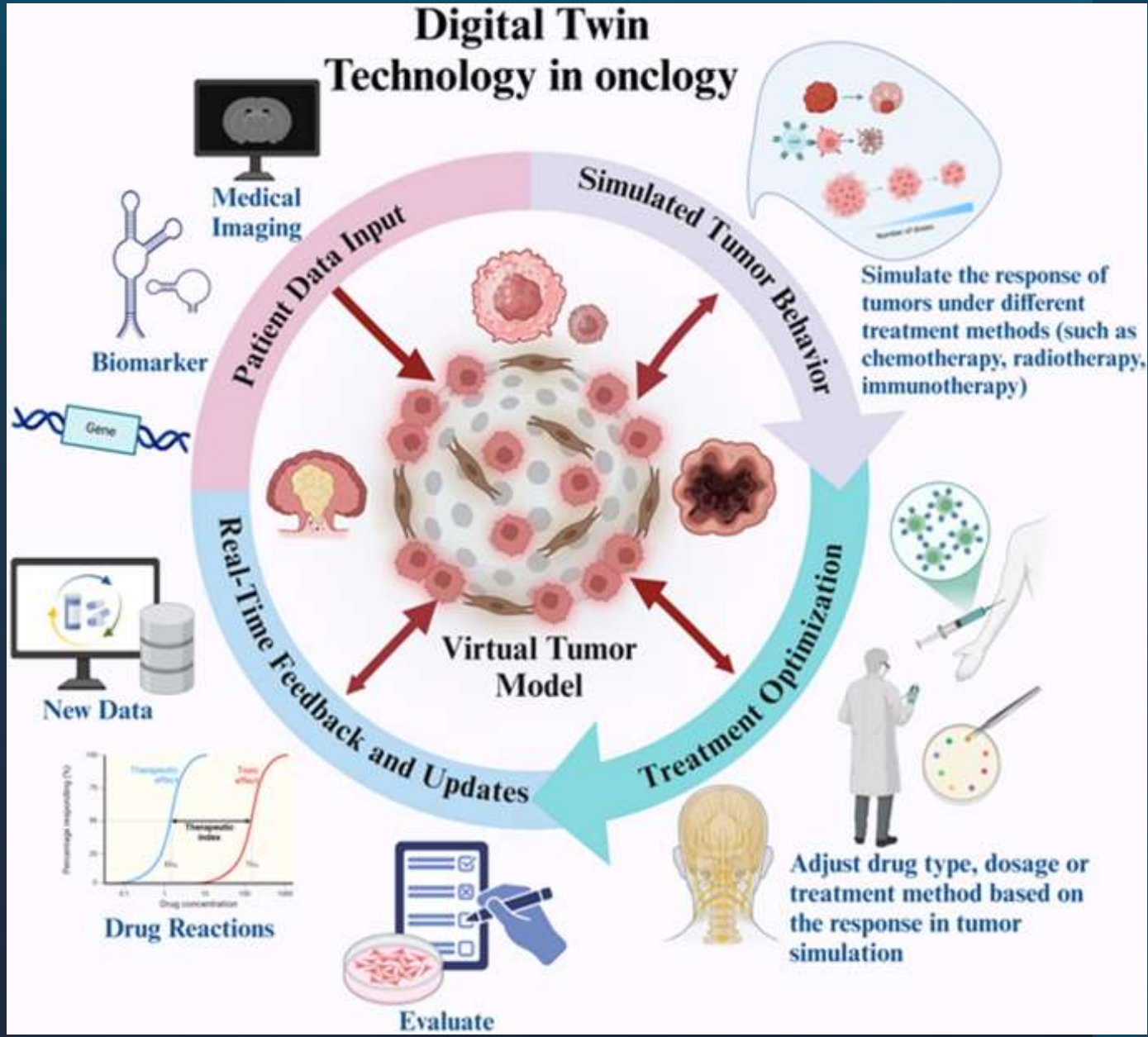
Models: Mechanistic models (physiology), statistical/ML models, hybrid (physics + ML)



Infrastructure: Cloud & edge computing, containerization, APIs

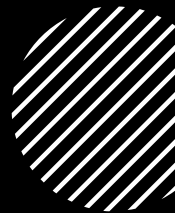


Standards & interoperability: HL7 FHIR, DICOM, IEEE 11073





Non- Technical Enablers



Clinical workflow
integration & **clinician
buy-in**

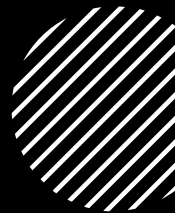
Data governance & patient
consent frameworks

Reimbursement models and
payer incentives

Partnerships among
hospitals, medtech, AI
companies, Contract
Research Organizations
(CROs)



Regulatory , Privacy & Ethical Considerations



Medical device
classification (could be
regulated as SaMD)

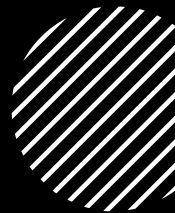
Data privacy governed by
HIPAA, GDPR-equivalents
local laws in Pakistan

Explainability & model
transparency for clinical
decisions

Bias & equity for ensuring
model validity across
populations



Security & Data Governanc e



End-to-end encryption, role-based access control, secure APIs



Audit trails, provenance, model versioning



De-identification vs. re-identification risk for research datasets



Architectures & Deployment Models

Cloud-native vs edge (on-prem) vs hybrid

Microservices + Kubernetes for scaling

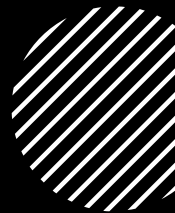
Real-time stream processing (Kafka) for ICU-grade latency

CI/CD for models (MLOps) with model rollback & A/B testing





Interoperability & Standards



HL7 FHIR for clinical data exchange



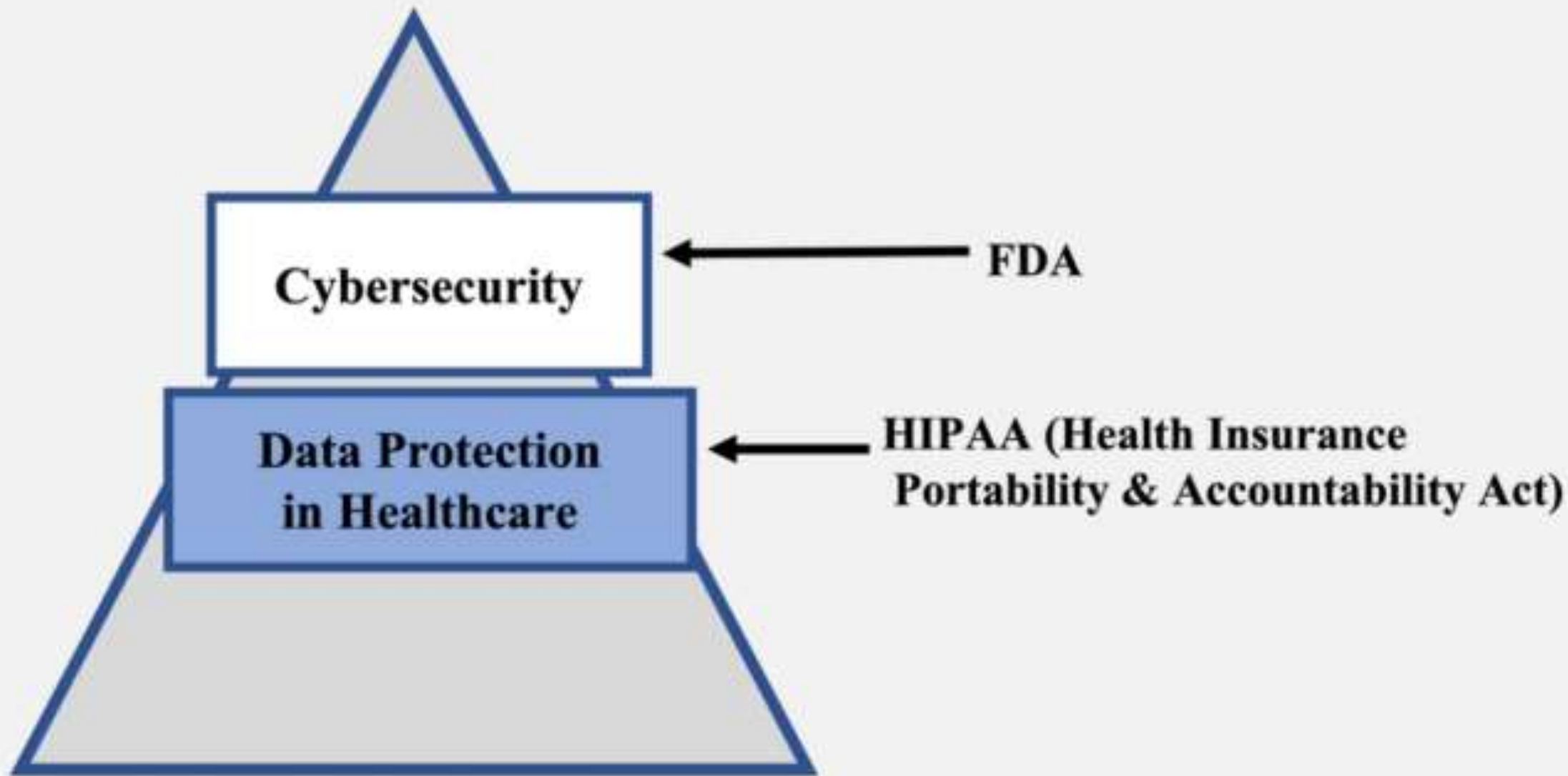
DICOM for imaging



IEEE 11073 for device data

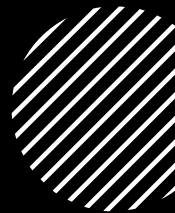


Use of open APIs & standardized data models for portability





Business Case & ROI Metrics



Clinical outcomes:

Mortality, readmissions,
complication rates

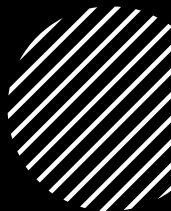
Operational: Bed-days (LoS)
saved, increased
throughput, reduction in
test utilization

Financial: Revenue uplift
(ROI), cost savings, time-
to-market for devices

Time horizon: Short-term
(6-12 months) for ops
gains; long-term for
clinical outcomes



Implementation Roadmap



Discovery & stakeholder alignment



Data audit & integration



Prototype model & validation



Pilot deployment (ICU/ward) +
clinician feedback



Scale & embed MLOps, governance



KPIs to Track



Clinical adoption rate
(users/clinicians)



Model performance gauged by
AUC, calibration,
sensitivity and specificity



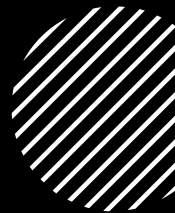
Operational metrics used in
alert fatigue, time-to-
action after alerts



Financial metrics for cost
per avoided adverse event



Mitigation of Common Pitfalls



Poor data quality →
mitigate with robust
ETL and data validation

No clinician
involvement → embed
clinicians from day 1

Overly complex models →
prefer
explainable/hybrid

models
Ignoring maintenance →
set up MLOps and
monitoring



Contracts & Commercial Models



SaaS subscription vs
licensing vs outcomes-
based contracts

Shared-risk models with
payers/hospitals (e.g.,
pay-per-improvement)

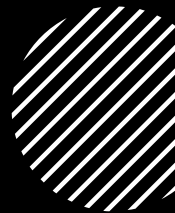
Regulatory/compliance
clauses, data
ownership, IP

Case Study – Overview

- Patient-Specific Digital Twin for Sepsis Management in ICU
 - **Setting:** Tertiary hospital ICU
 - **Objective:** Reduce time to appropriate antibiotics & predict hemodynamic collapse
 - **Partners:** Hospital, AI vendor, critical care team



Case Study – Data Sources



Continuous bedside monitors
(HR, BP, SpO₂) – streaming at
1 Hz

Ventilator data (where
applicable)

Lab results (CRP, WBC,
lactate)

EHR notes & medication orders

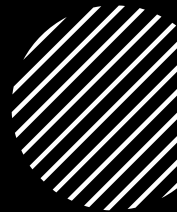
Microbiology reports and
prior patient history

Case Study — Model Design

- **Hybrid model:** physiological model of hemodynamics + ML-based risk estimator
- **Components:** state estimator (filtering), prediction engine (risk scores), treatment optimizer (counterfactual analysis)
- **Output:** real-time risk of deterioration, recommended interventions, simulated outcomes under alternative interventions



Case
Study –
Workflow
&
Integrati
on



Data ingestion →
normalization → feature
store

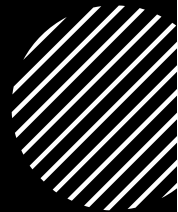
Real-time inference →
visualization in clinician
dashboard + alerts

Clinician review →
recommendations integrated
into order-entry

Feedback loop: outcomes
fed back for model
retraining



Case
Study –
Results
(Hypothet
ical /
Synthesiz
ed)



Pilot (n=120 ICU episodes):
18% reduction in time-to-
appropriate-antibiotics

Predicted deterioration AUC
= 0.87; sensitivity 0.82 at
0.25 FP rate

ICU length-of-stay reduced
by 10% in pilot subgroup

Clinician adoption rate:
68% used recommendations at
least once

Case Study – Lessons Learned

High-quality timestamps are critical (synchronization across devices)

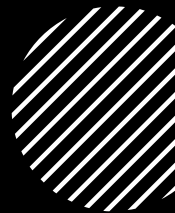
Clinician trust grew when the twin produced counterfactual 'what-if' scenarios

False positives drove alert fatigue – tuned thresholds and smart suppression rules helped

Data partnerships (microbiology, labs) were the hardest integrations



Risk Management & Ethics



Clinical
oversight
committee for
model release

Consent &
communication
to
patients/fami
lies (local
regulations)

Periodic bias
audits across
demographic
groups

Clear
escalation
paths for
model failure

Scaling Up — From Pilot to Hospital- Wide

Prioritize high-impact units
first (ICU, ED)

Build standardized ingestion &
feature pipelines

Use federated learning or
privacy-preserving analytics
where cross-site models needed

Continuous validation when
deploying to new demographics



Recommended Tech Stack

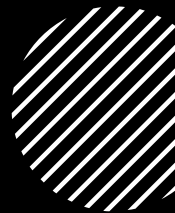
- **Data bus:** Kafka
- **Storage:** Object store (S3-compatible) + time-series DB
- **Compute:** Kubernetes + autoscaling; GPU nodes for heavy ML
- **Model infra:** MLflow or TFX for model registry & CI/CD
- **Integration:** FHIR server (HAPI FHIR) for EHR connectivity

Quick Playbook

1. Assemble cross-functional team
2. Conduct data readiness audit
3. Choose a narrow, measurable use case
4. Build an MVP with simple rules + one ML model
5. Validate retrospectively, then prospectively
6. Integrate into clinician workflow with clear UI
7. Run a limited pilot, capture feedback
8. Implement MLOps and monitoring
9. Plan for regulatory submission if required
10. Scale with governance & outcomes tracking



Suggested KPIs Dashboard



Model performance trend
(AUC over time)



Clinical adoption & action
rate



Operational gains (bed-days
saved)



Alerts per clinician per
day (alert fatigue)

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Thank You!

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