Edge-Enabled Multimodal Clinical Workflows

Under DIL Operational Constraints

Machine Learning & AI in Military Health, Readiness & Performance

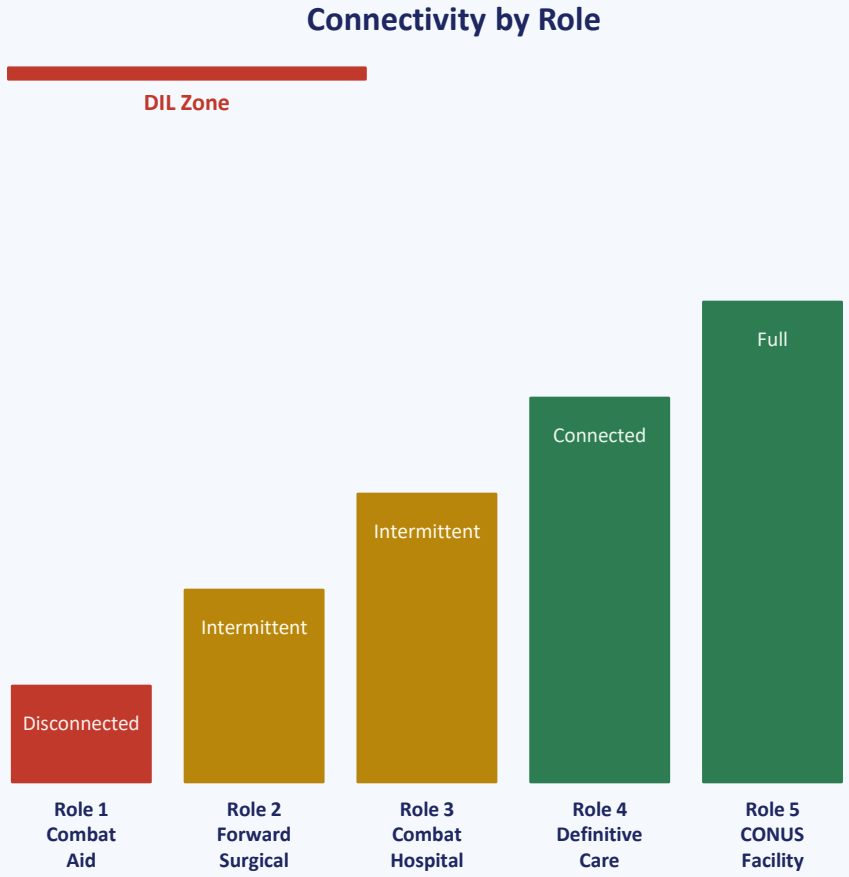
John Killcommons
CEO, ZuluCare, LLC.
Abstract ID: MHSRS-26-5698

Disclosure: The presenter reports no relevant financial relationships with ineligible entities.

Problem Definition — DIL Constraints and Workflow Fragmentation

Clinical AI deployment advances in fixed-facility environments — but breaks down at the operational edge.

1. **Latency variability**
   Unpredictable round-trip delays disrupt real-time clinical decision support
2. **Intermittent connectivity**
   Synchronization windows are narrow, unreliable, or absent
3. **Disconnected imaging**
   DICOM workflows stall when cloud inference endpoints are unreachable
4. **Edge compute limits**
   Resource-constrained hardware cannot run full cloud model stacks
5. **Workflow fragmentation**
   Care continuity breaks at the point of network disruption



Environmental Constraints — Why Cloud-Dependent Architectures Fail

Conventional AI deployment assumes persistent, low-latency network connectivity. Operational environments invalidate this assumption.

Cloud-Dependent Architecture

- ✕ Inference requests require external API connectivity
- ✕ DICOM routing depends on cloud-hosted endpoints
- ✕ Report generation stalls on network disruption
- ✕ No local fallback — workflow stops entirely
- ✕ Data synchronization assumes persistent uplink
- ✕ Edge node becomes inert when disconnected

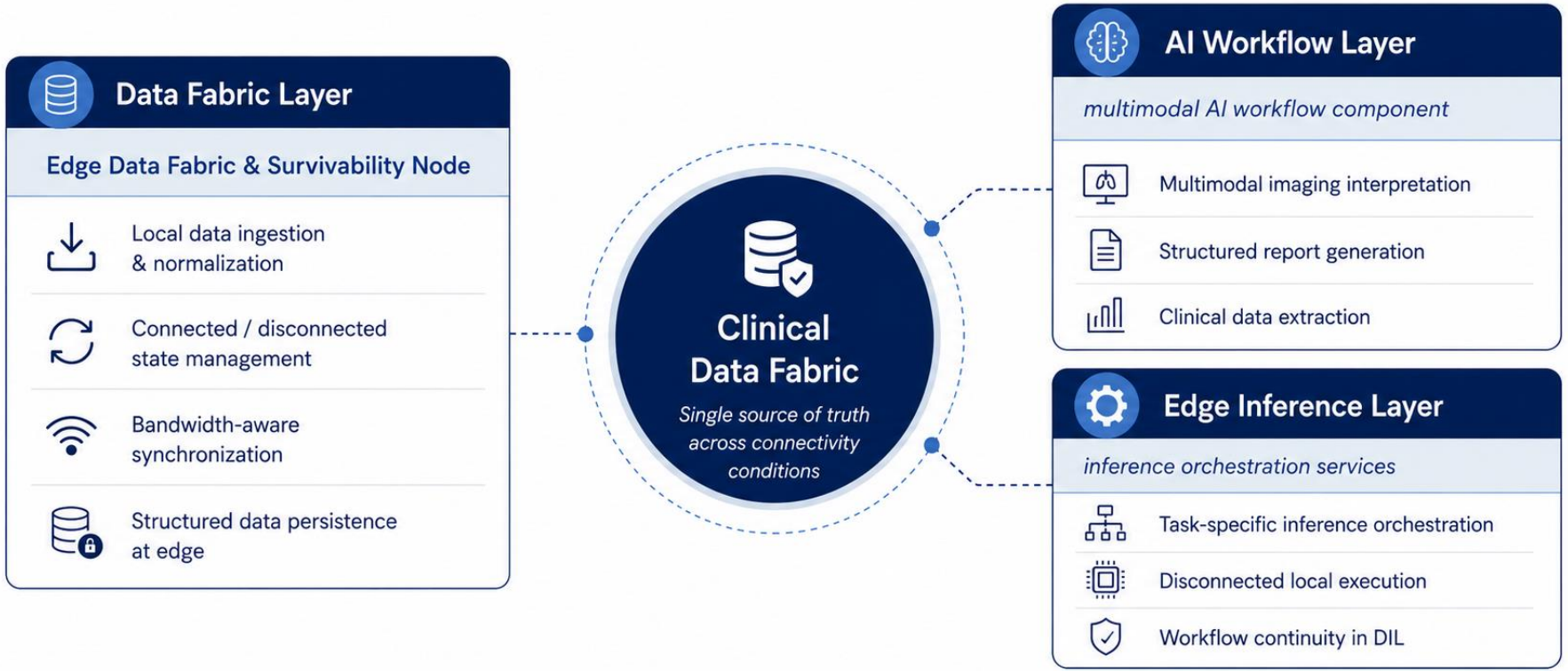
vs

Local Survivability Node

- ✓ Local inference execution — no uplink required
- ✓ Edge-resident imaging and DICOM processing
- ✓ Disconnected report generation and structured output
- ✓ Graceful degradation with defined failure modes
- ✓ Bandwidth-aware synchronization on reconnect
- ✓ State consistency maintained across connectivity gaps

Distributed Edge Clinical Architecture — Integrated Workflow Layer

Three interdependent functional layers operating across connected and disconnected environments.



Edge-Based Survivability Node (LSN) — Connected vs. Disconnected State

The LSN maintains full clinical workflow continuity during network disruption by sustaining local execution of critical functions.

● CONNECTED STATE

- ✓ **Real-time inference**
  Cloud + edge pipelines available; optimal model selection
- ✓ **Live synchronization**
  Bidirectional data sync with central clinical systems
- ✓ **Full DICOM routing**
  All imaging workflows active; remote consultation enabled
- ✓ **Report generation**
  Structured output via full local workflow pipeline
- ✓ **State management**
  Continuous state consistency maintained centrally

↔

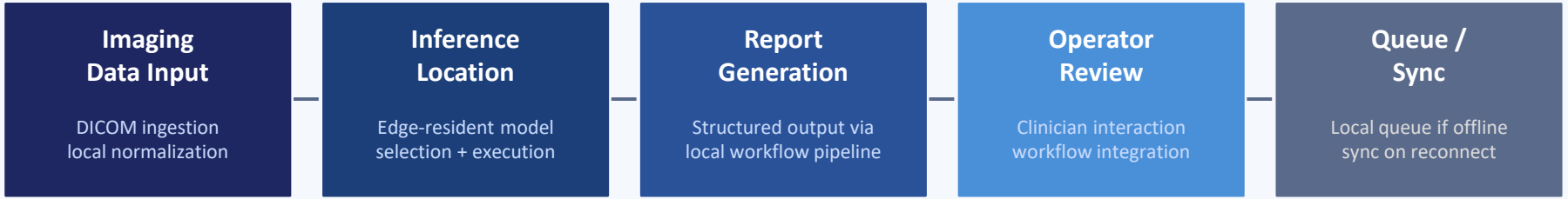
○ DISCONNECTED STATE

- **Local inference continues**
  Edge-resident models execute without uplink
- **Operations queue locally**
  Non-critical sync queued; prioritized on reconnect
- **Imaging workflows sustained**
  DICOM processing continues on local node
- **Structured output maintained**
  Report generation via local inference services
- **Graceful reconnect**
  State reconciled; conflicts resolved deterministically

Workflow execution state persists locally during connectivity interruption.

AI Workflow Integration — Inference Execution in Degraded Conditions

The clinical question: how does AI inference survive when the network does not?



Inference location

Task-specific models deployed directly on edge hardware. No external API call required for local execution.

Disconnected execution

Inference pipeline operates in full isolation. Network absence does not interrupt clinical decision support.

Structured output generation

Radiology reports and structured clinical data extracted locally and held for synchronization.

Operator interaction model

Clinician workflow unchanged regardless of connectivity state. Interface abstracts underlying network condition.

Interoperability Layer — Standards Integration and Edge Synchronization

Standards integration is treated as operational infrastructure — not compliance checkbox. Each layer handles a defined set of workflow functions.

DICOM standard	**Imaging Data Transport & Storage**	Modality ingestion, image normalization, local PACS routing, edge storage management, worklist management in disconnected mode
HL7 standard	**Clinical Messaging & Events**	Patient demographic exchange, order management, result delivery, ADT events, structured clinical messaging across care transitions
FHIR standard	**Structured Data Exchange & API Layer**	Resource-based clinical data exchange, RESTful API normalization, structured document generation, care coordination across roles
SYNC standard	**Edge Synchronization & Conflict Resolution**	Bandwidth-aware queuing, priority-based data movement, deterministic conflict resolution on reconnect, delta-sync for resource-constrained links

Operational Evaluation Metrics

Planned Measurement Framework

The proposed evaluation framework assesses whether edge-enabled AI workflows can maintain clinical continuity during disconnected, intermittent, and limited-bandwidth conditions.

Evaluation Focus

01 Clinical workflow continuity

02 Edge inference availability

03 Reconnect & sync recovery

04 Operator burden after disruption

A Workflow Timing

Image acquisition to structured output

Operator workflow continuity across states

B Function Availability

Functions available while disconnected

Inference availability during external network loss

C Sync Recovery

Queued transactions synchronized after reconnect

Manual reconciliation effort after reconnect

Final quantitative values will be reported after completion of the formal evaluation period.

Measurement framework only — not preliminary performance claims.

Metrics are designed to quantify operational continuity, synchronization reliability, and clinical workflow impact across DIL conditions.

Roles 1–5 Continuity — Sustained Clinical Functions Under DIL Conditions

The framework sustains defined clinical functions at each Role level regardless of connectivity state.

Role 1 Combat First Aid	Role 2 Forward Surgical	Role 3 Combat Hospital	Role 4 Definitive Care	Role 5 CONUS Facility
Disconnected	**Intermittent**	**Intermittent**	**Connected**	**Full**
Triage decision support (local)	DICOM imaging workflows	Full imaging pipeline (local)	Cloud + edge inference stack	Enterprise integration
Trauma imaging if available	Inference-assisted radiology workflow	Structured report generation	Full synchronization active	Full inference workflow services
Structured casualty data capture	Clinical messaging via HL7	HL7/FHIR-based data exchange	Longitudinal record access	Retrospective synchronization
✓	✓	✓	✓	✓

All functions above observed as sustained during DIL evaluation periods. Connectivity column reflects typical operational environment.

Technical Conclusions

01

Edge inference is operationally viable under DIL conditions

Local inference execution on resource-constrained hardware was demonstrated across disconnected, intermittent, and low-bandwidth environments without workflow interruption.

02

Integrated edge workflow architecture sustained structured clinical workflow execution

The combined data fabric, inference workflow services, and DICOM-native engine maintained structured clinical output generation independent of network state.

03

Measured workflow characteristics support Roles 1–5 continuity

Pilot observations indicate maintained triage support, imaging continuity, and structured reporting across the evaluated role spectrum under operational DIL constraints.