Leveraging Open Standards to Create Mixed Reality Medical Simulations

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ABSTRACT: *Medical training for Tactical Combat Casualty Care (TCCC) requires both tactile realism and scenario flexibility, yet traditional solutions—high-fidelity manikins and fully virtual environments—each fall short. High-fidelity manikins provide hands-on practice but are costly and difficult to reconfigure, while virtual simulations lack the physical interaction essential for procedural competence. To address this gap, we developed a Mixed Reality Trainer (MRT) that integrates physical manikins with augmented reality (AR) overlays, virtual anatomical visualization, and real-time performance feedback. This approach enhances lower-fidelity manikins with dynamic instructional content, reducing reliance on expensive simulators and instructor intervention.*

The MRT architecture implements a Modular Open Systems Approach (MOSA) [12] using open standards including the Modular Healthcare Simulation & Education System (MoHSES) [1], Data Distribution Service (DDS), Joint Emergency Trauma Simulation (JETS) [9], and clinical ontologies such as the Foundational Model of Anatomy (FMA) and SNOMED-CT [7]. This standards-based design enables interoperability across vendors, scenario portability, and integration with existing simulation infrastructure. Validation through eight Soldier Touchpoints with military medical personnel demonstrated strong acceptance and successful multi-vendor interoperability in mass casualty, paired integration, and patient handoff scenarios. We present lessons learned and propose a roadmap for extending these standards to additional healthcare domains through the SISO Medical Simulation Multi-Modality Data Transfer Study Group.

1. Introduction

Medical simulation training for Tactical Combat Casualty Care (TCCC) faces a persistent challenge in balancing realism, cost, and training effectiveness. Traditional approaches rely on either physical manikins or fully virtual environments, each with distinct limitations that impact training outcomes.

Physical manikins provide tactile feedback essential for developing procedural competence in interventions such as tourniquet application, needle decompression, and airway management. However, high-fidelity manikins capable of presenting realistic injuries and physiological responses are costly and difficult to reconfigure, while lower-fidelity manikins require significant instructor supplementation. Virtual simulations offer flexibility and lower per-student cost but lack the hands-on interaction required to build procedural confidence under operational conditions.

Mixed Reality (MR) systems bridge this gap by combining physical manikins with augmented reality (AR) overlays. Virtual content—anatomical visualization, injury presentation, instructional guidance, and performance feedback—enhances lower-fidelity manikins while maintaining critical hands-on practice.

This paper describes a Mixed Reality Trainer (MRT) for female combat casualty care, developed through a Combat Casualty Care (CCT) Small Business Innovation Research (SBIR) award from the Army Applications Lab. The MRT integrates a physical manikin with AR instructional overlays, virtual anatomical models, and real-time physiological simulation using open standards to ensure interoperability and extensibility.

Key objectives of this paper:

- Describe the MRT system architecture and open standards implementation
- Present the interoperability framework enabling multi-vendor integration
- Provide a roadmap for extending these approaches through the SISO Medical Simulation Multi-Modality Data Transfer Study Group

2. System Architecture and Open Standards Implementation

2.1 Integration Challenges in Mixed Reality Medical Simulation

The interoperability challenges addressed by the MRT system are ones that are faced by all modern medical simulations. The architecture integrates multiple components: a physical manikin (MATTi female trauma trainer from TacMed Solutions) with embedded sensors detecting interventions, AR head-mounted displays (Meta Quest 3) presenting virtual overlays aligned with physical components, a physiology engine (BioGears) modeling patient state and response to treatment, and a compact compute system (Raspberry Pi 5) running MoHSES core software coordinating all components.

This multi-modal architecture creates significant interoperability requirements. Intervention data must flow from physical sensors to physiology models to visual displays, with all components potentially from different vendors. Patient state must be shared across systems for distributed training. Clinical terminology must be consistent to enable meaningful data exchange. Performance requirements are stringent—AR rendering requires sub-20ms latency for visual registration, while physiology updates occur at 1-50 Hz depending on fidelity requirements.

Traditional proprietary integration would require custom interfaces for each component combination, creating a maintenance burden that grows exponentially with system complexity. The standards-based approach described in this section addresses these challenges through layered integration: component-level integration via MoHSES, federation-level coordination via JETS, and semantic interoperability via clinical ontologies.

2.2 Open Standards Framework

Table 2.1 summarizes the open standards implemented in the MRT architecture, showing how each standard addresses specific integration challenges.

Table 2.1: Standards Implementation in MRT Architecture

Standard	Layer	Integration Challenge Addressed	MRT Implementation
MoHSES	Component	Vendor-specific APIs, real-time data exchange	DDS pub/sub with clinically relevant topics, up to 50 Hz update rate
JETS	Federation	Site-to-site coordination, patient ownership	HLA gateway with patient ownership transfer protocol
FMA	Semantic	Anatomical location mapping across vendors	Anatomical terms standardized across 5 vendors
SNOMED-CT	Semantic	Intervention and physical finding terminology	Procedure codes agreed upon by cohort
DDS	Transport	Real-time publish-subscribe messaging	OMG DDS 1.4 with custom QoS profiles

2.3 Modular Healthcare Simulation & Education System (MoHSES)

MoHSES is an open standard developed through collaboration between the University of Washington, Vcom3D, and other partners, with oversight from the Army's Simulations Training and Technology Center (STTC). MoHSES defines a modular architecture where individual components (modules) communicate through a standardized data bus using the Data Distribution Service (DDS) protocol [1].

In the MRT implementation, MoHSES modules include:

- **Physiology Engine Module**: Manages patient physiological state, publishes vital signs (heart rate, blood pressure, SpO2, respiratory rate) and responds to intervention messages

- **Manikin Module**: Publishes intervention detection events (tourniquet placement, needle decompression, catheter insertion), utilizes physiology to present synchronized breathing/pulse rates
- **AR Student Display Modules**: Subscribe to patient state and publish user interactions
- **AR Instructor Interface Module**: Publishes scenario control commands and subscribes to all data for assessment
- **Virtual Patient Monitor Display Module**: Subscribes to vital signs and displays patient monitor interface

Each module operates independently, publishing or subscribing to relevant message topics on the MoHSES data bus. This loose coupling enables component replacement without system redesign. For example, when we demonstrated the system with an IDL manikin instead of the MATTi manikin, only the interface to the manikin required modification—all other modules continued operating without changes.

The MRT uses Vcom3D's Compact Core™, a MoHSES core software components implementation running on a Raspberry Pi 5. The Compact Core manages the DDS data bus, coordinates module communication, and provides a web-based control and configuration interface. The compact form factor (10cm × 7cm × 3cm) enables portable deployment while maintaining full MoHSES functionality.

2.4 Joint Emergency Trauma Simulation (JETS)

JETS is a High-Level Architecture (HLA) federation that enables interoperability across military medical training simulations [9]. JETS defines object classes, interactions, and attributes for representing patients, medical personnel, interventions, and facilities in distributed training exercises. While MoHSES focuses on component-level integration within a single system and represents a single patient, JETS operates at a higher level of abstraction enabling information sharing across geographically distributed sites.

JETS supports critical training scenarios that span multiple systems:

- **Mass casualty exercises** where multiple patients are managed simultaneously by different teams
- **Echelon of care progression** where patients move from point-of-injury through Role 1, Role 2, and Role 3 facilities
- **Multi-site training** where geographically distributed learners participate in coordinated scenarios
- **After-action review** with aggregated data from all participating systems

To enable MRT participation in JETS federations while maintaining the benefits of MoHSES modular architecture, we developed a MoHSES/JETS Gateway that operates as both a MoHSES module and a JETS federate. This gateway represents a key technical contribution by providing a reusable pattern for integrating component-based systems with federation-level coordination. This gateway is described in more detail in Section 4.

2.5 Clinical Ontologies for Semantic Interoperability

Technical connectivity alone is insufficient for meaningful interoperability—systems must share common vocabulary for anatomical locations, injuries, interventions, and physiological findings. The MRT interoperability framework leverages two established clinical ontological standards:

Foundational Model of Anatomy (FMA) [6] is a structured ontology containing over 75,000 anatomical entities and 120,000 relationships. FMA provides a detailed framework for anatomical knowledge, enabling precise specification of injury locations and intervention sites. For example, rather than ambiguous terms like "upper leg," FMA provides specific codes for femoral artery (FMA:70248), vastus lateralis muscle (FMA:22432), and other anatomical structures.

Systematized Nomenclature of Medicine - Clinical Terms (SNOMED-CT) [7] is a comprehensive clinical terminology system standardizing medical concepts for documentation and information sharing. SNOMED-CT includes codes for injuries, diseases, procedures, and findings. For TCCC training, we use SNOMED-CT codes for interventions such as tourniquet application (SNOMED:225369003) and needle decompression (SNOMED:91602002).

By integrating FMA and SNOMED-CT into the MoHSES/JETS Gateway, the MRT ensures accurate, interoperable representation of injuries and procedures. When publishing intervention data to a JETS federation, the gateway includes both MoHSES internal representation and corresponding FMA/SNOMED-CT codes, allowing other systems to interpret interventions correctly regardless of internal data models.

2.6 Modular Open Systems Approach (MOSA) and Composability

The MRT architecture implements Modular Open Systems Approach (MOSA) principles—a DoD strategy emphasizing modular design, open interfaces, and competitive sourcing to reduce vendor lock-in and enable continuous technology insertion [12].

A key MOSA concept is **composability**: combining independently developed components into larger systems with predictable emergent behavior. The MRT demonstrates composability at multiple levels:

- **Module-level**: Individual MoHSES modules compose into complete training systems
- **System-level**: MoHSES systems compose with other platforms through the JETS gateway
- **Hardware-level**: Commercial Off-The-Shelf (COTS) hardware (Meta Quest 3, Raspberry Pi 5) integrates through standardized interfaces

Clear interfaces at each integration point enable mix-and-match composition addressing specific training requirements. Demonstrated configurations included:

- **Multi-manikin instructor integration**: Single instructor interface controlling multiple manikins from different vendors
- **Cross-vendor intervention detection**: ATCorp computer vision detecting interventions on TacMed manikin
- **Multi-patient mass casualty coordination**: Five vendors' systems coordinated via JETS
- **Patient state transfer across echelons**: Handoff from Exonicus point-of-injury system to Vcom3D Role 2 system

This composability demonstrates the MOSA principle of "severability"—the ability to replace individual components without redesigning the entire system.

3. Mixed Reality Training System

3.1 System Overview

The MRT integrates physical and virtual components to create a comprehensive TCCC training environment. Physical components include the MATTi female trauma trainer manikin with embedded sensors detecting tourniquet application, needle decompression, and catheter insertion; Meta Quest 3 AR headsets providing mixed reality displays; and Compact Core running on Raspberry Pi 5 coordinating all components via MoHSES.

Virtual components include underlying anatomy visualization showing thoracic and pelvic anatomical structures aligned with the physical manikin, a virtual casualty (homunculus) replicating injuries and tracking interventions, instructional overlays providing procedural guidance, a digital DD Form 1380 (TCCC Card) for documentation training, and an instructor interface with automated performance assessment.

This multi-modal architecture creates significant interoperability challenges. Intervention data must flow from physical sensors to physiology models to visual displays. Patient state must be shared across systems for distributed training. Documentation must follow patients through handoffs. All components must maintain synchronization despite potentially being from different vendors.

The standards-based architecture described in Section 2 addresses these challenges. MoHSES enables component integration through publish-subscribe messaging. JETS enables federation-level coordination for distributed scenarios. Clinical ontologies ensure semantic consistency across vendors. The following subsections briefly describe key capabilities to provide context for the interoperability demonstrations in Section 4.

3.2 Key Training Capabilities

3.2.1 Underlying Anatomy (UA) Visualization

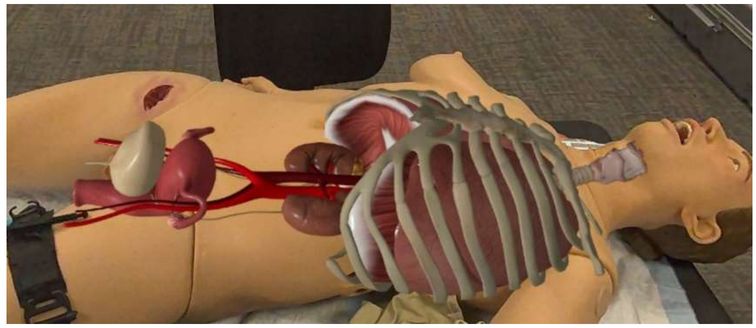

Figure 3.1 Views of UA, including thoracic and pelvic cavities.

AR overlays present three-dimensional anatomical models registered to the manikin's position, including detailed models of the thoracic cavity (lungs, vessels, airways) and female genitourinary system (bladder, urethra, reproductive organs). The anatomy responds dynamically to injuries and interventions—for example, in a pneumothorax scenario, the affected lung collapses as pressure builds in the pleural cavity, then re-expands following needle decompression. This visualization addresses a fundamental medical training challenge: students must develop mental models of three-dimensional anatomy and understand how interventions affect internal structures.

3.2.2 Virtual Casualty (Homunculus)

The system includes a virtual casualty (homunculus) replicating injuries, tracking interventions, and exhibiting physiological changes throughout scenarios. Visible to both the instructor and students during instructional scenarios and visible only to the instructor during training scenarios to avoid learner distraction, it serves as a visual aid to provide patient cues not provided by the physical manikin. The MoHSES architecture allows the homunculus module to subscribe to all intervention and physiology data, maintaining a complete record without separate data collection mechanisms.

3.2.3 Performance Tracking and Assessment

The instructor AR display includes an automated intervention checklist configured based on training scenarios and TCCC guidelines. As learners perform procedures, the checklist automatically populates with completion indicators and time stamps by subscribing to intervention messages on the MoHSES data bus. This reduces instructor cognitive load and provides objective performance records for after-action review. This interface also provides the ability to register observable treatment events that the manikin is not capable of sensing.

Figure 3.2 View from the AR headset of the female homunculus exhibiting injuries and treatments.

3.2.4 Documentation Training

A digital DD Form 1380 (TCCC Card) appears as a virtual panel in the AR display, manipulated using hand gestures. Completed forms publish to the JETS federation, enabling documentation to follow patients through handoffs—a critical capability for training the full continuum of care.

3.3 Standards-Enabled Modularity

These capabilities demonstrate MoHSES modular architecture benefits. Individual capability modules (anatomy visualization, documentation, performance tracking, physiology modeling) operate independently while sharing data through the standardized bus, enabling flexible composition.

Portability demonstrated: The underlying anatomy module successfully operated with both the MATTi manikin and an IDL manikin by simply updating registration parameters. This demonstrates portability enabled by open standards—training content developed for one manikin transfers to another manufacturer's manikin without module redesign.

Multi-level integration: The digital DD Form 1380 module publishes completed documentation to either MoHSES internal data structures or externally to a JETS federation. This illustrates how standard interfaces enable integration at multiple levels without requiring module redesign.

These examples validate the MOSA principle that well-defined interfaces enable component reuse and system extensibility. The following section demonstrates how this architecture enables practical multi-vendor interoperability in operational training scenarios.

4. Interoperability Demonstrations

A distinguishing feature of the Casualty Care Training SBIR program was the emphasis on interoperability among the five awardees' systems. Rather than developing entirely independent solutions, a 'cohort' of participating companies was challenged to create systems that could work together to provide enhanced training capabilities. This section describes the multi-vendor integration approach and presents three types of interoperability demonstrations conducted at Soldier Touchpoint evaluations.

4.1 Multi-Vendor Integration Approach

Successful interoperability among systems from different vendors requires not only technical standards but also organizational processes for coordination and integration. The CCT SBIR cohort established several mechanisms to facilitate collaboration.

An **Interoperability Working Group** met regularly throughout the project to discuss technical approaches, share development progress, and coordinate integration activities. These meetings were instrumental in establishing standardized vocabulary for anatomical locations and interventions, defining the integration points in the composability framework, and scheduling hands-on integration sessions for testing.

Several **hands-on integration events** were held where cohort members brought their systems together for direct testing. These events identified technical issues that could not be discovered through documentation review alone, provided opportunities for knowledge transfer among development teams, and built confidence that interoperability was achievable.

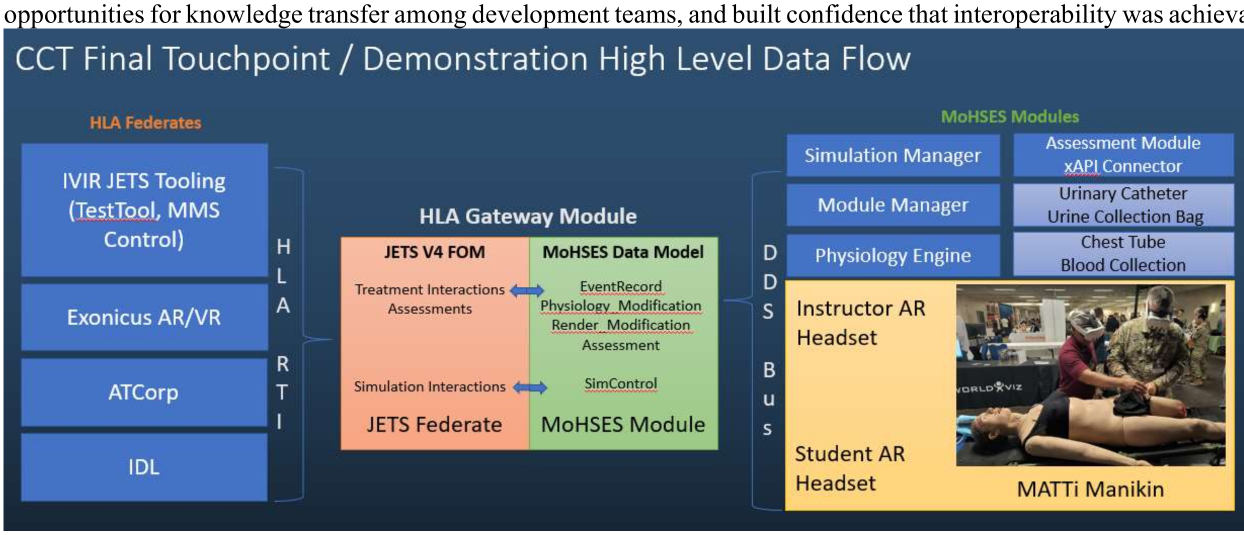

Figure 4.1 High level overview of the MoHSES/JETS integration and data flow.

Figure 4.1 illustrates the high-level overview of the MoHSES/JETS integration and data flow, showing how MoHSES modules connect to the MoHSES Data Bus, which connects through the MoHSES/JETS Gateway to the JETS Federation and other JETS Federates.

4.2 Demonstrated Interoperability Scenarios

The final CCT Soldier Touchpoint at Fort Hood in September 2025 included three types of interoperability demonstrations showcasing different aspects of multi-vendor integration. Each demonstration involved active-duty Army combat medics and medical officers as learners, with systems operated by vendor personnel.

4.2.1 Mass Casualty Demonstration

All five cohort members (ATCorp, Exonicus, IDL, IVIR, Vcom3D) operated independently, each managing a separate patient instance coordinated by the JETS Federation. Each organization ran their version of the CCT Exemplar Case simultaneously while IVIR's TestTool aggregated and displayed patient states and interventions from all five systems. Vcom3D published a completed TCCC Card (DD Form 1380) which IVIR successfully displayed, demonstrating end-to-end data flow through the federation.

Interoperability Validation: This demonstration validated federation-level coordination with multiple simultaneous patient instances, semantic interoperability across five vendors with different internal architectures, real-time data exchange meeting performance requirements, and documentation sharing through standardized JETS interactions.

4.2.2 Paired Integration Demonstrations

Two paired demonstrations showcased component-level interoperability, demonstrating the MOSA principle of "composability"—the ability to mix and match components from different vendors:

MATTi with ATCorp Computer Vision: ATCorp's computer vision successfully detected tourniquet placement on the MATTi manikin, with results displayed in the Vcom3D instructor interface. This demonstrated that intervention detection from one vendor could integrate with another vendor's assessment tools.

Figure 4.2 Vcom3D anatomical overlay placed on the IDL manikin

IDL Manikin with Vcom3D AR: Vcom3D registered underlying anatomy overlays and virtual casualty onto the IDL manikin using AI computer vision. Despite integration challenges, the demonstration validated that AR content developed for one manikin could transfer to another manufacturer's manikin, proving the portability enabled by open standards.

Interoperability Validation: These paired demonstrations validated component-level mixing across vendors, content portability protecting training investment, and standardized interfaces enabling rapid integration.

4.2.3 Patient Handoff Demonstrations

Two handoff demonstrations simulated patient movement through echelons of care, a critical capability for training the full continuum of combat casualty care.

Handoff Demonstration 1: Exonicus Point-of-Injury to Vcom3D Role 2
Exonicus ran the standard exemplar case in their Meta Quest 3 system. Upon scenario completion, the JETS federation transferred patient ownership from Exonicus to Vcom3D. Vcom3D then displayed patient vitals on the Virtual Patient Monitor while a student inserted a urinary catheter into the MATTi manikin, triggering the urine simulation interface and demonstrating continuity of care across systems.

Handoff Demonstration 2: Vcom3D Point-of-Injury to Exonicus Role 1
Vcom3D conducted the exemplar case using the MATTi manikin and instructor interface, with students completing a DD Form 1380 published to the JETS federation. Patient ownership transferred from Vcom3D to Exonicus, who continued the simulation as a Role 1 provider with full documentation continuity.

Interoperability Validation: The handoff demonstrations validated patient ownership transfer protocol, data continuity across system boundaries, documentation following patient through continuum of care, and training scenario portability across vendors.

4.3 Lessons Learned

The interoperability demonstrations revealed both successes and challenges that provide valuable guidance for future implementations. Table 4.2 structures these lessons learned by challenge category.

Challenge Category	Specific Issue	Root Cause	Solution Implemented	Reusable Pattern?	Standards Gap?
Semantic	Anatomical location ambiguity	No standard mapping between vendor terms and FMA	Working group establishing consensus vocabulary	Yes - vocabulary governance process	No - FMA exists, needs adoption
Semantic	Intervention terminology inconsistency	Different vendors used different SNOMED-CT granularity	Agreed upon specific SNOMED-CT codes for common procedures	Yes - procedure code standardization	No - SNOMED-CT exists, needs profiles

Technical	Real-time performance in AR	AR requires <20ms latency, federation adds 150-200ms	Tiered architecture: local high-frequency, federation low-frequency	Yes - performance tiering pattern	Yes - no latency requirements in standards
Technical	Patient ownership transfer	JETS doesn't specify handoff protocol details	Custom gateway protocol with state synchronization	Partially - needs standardization	Yes - JETS needs handoff specification
Process	Integration testing logistics	Coordinating 5 vendors across 3 sites	Quarterly hands-on integration events with structured agenda	Yes - integration event framework	No - process issue
Process	Version control across vendors	Different MoHSES/JETS versions caused incompatibilities	Agreed upon specific standard versions at project start	Partially – needs version management policy	No - process issue
Standards	Gateway pattern not documented	No reference implementation for MoHSES/JETS integration	Developed custom gateway, now available as reference	Yes - gateway reference implementation	Yes - needs documentation in standards

4.3.1 Key Insights from Lessons Learned:

1. **Semantic interoperability requires sustained effort**: Technical connectivity proved easier than semantic agreement. Establishing shared vocabularies using FMA/SNOMED-CT required working group coordination. Future projects should allocate time to vocabulary working groups established early in development. The governance process developed by the CCT cohort (bi-weekly meetings, consensus-based decision making, documented mappings) provides a reusable pattern.
2. **Real-time performance demands tiered architecture**: AR applications require very low latency (<20ms for visual registration), but federation coordination adds overhead (150-200ms in our implementation). The solution is tiered data architecture: high-frequency local data on MoHSES DDS, lower-frequency federation data on JETS. This pattern should be documented as a best practice. Additionally, medical simulation standards should include performance requirements for different modalities (VR, AR, physical, distributed).
3. **Standards maturity varies**: While MoHSES has an existing, open-source reference implementation and provided rapid component-level integration, JETS required custom gateway development because patient handoff protocols are not fully specified. Future standards work should focus on documenting gateway patterns as reference implementations and contributing handoff protocol specifications to JETS.
4. **Integration events are essential**: Hands-on integration events where vendors bring systems together for direct testing are critical for identifying issues, validating consistent use of standards, and building team relationships. The CCT cohort's quarterly integration schedule proved effective.
5. **Version management is critical**: Different versions of standards (MoHSES, JETS) have the potential to cause incompatibilities between vendors. Projects should establish version management policies at the outset, specifying which standard versions will be used and when upgrades are permitted.

5. Discussion and Future Directions

5.1 Demonstrated Benefits of Standards-Based Interoperability

The MRT development and multi-vendor demonstrations provide concrete evidence of the benefits of implementing open standards for medical simulation.

5.1.1 Key Benefits Demonstrated

Reduction in integration time. MATTi manikin integrated in a few weeks vs. 3-6 months for proprietary approaches.

Proven multi-vendor interoperability. Five organizations successfully exchanged patient data.

Training Content Portability. Scenarios developed for the MATTi manikin successfully demonstrated on the IDL manikin with only registration parameter changes (approximately 1-2 minutes), protecting training content investment and ensuring content development is decoupled from hardware procurement.

Reduced Vendor Lock-In and Long-Term Supportability. Training organizations can select best-of-breed components from different vendors, creating competitive environments that drive innovation and cost reduction. Open standards ensure systems remain supportable even if original vendors exit the market.

5.2 Key Challenges and Solutions

While the benefits of standards-based interoperability are significant, achieving practical interoperability required addressing several critical challenges. This section expands on the lessons learned (Table 4.2) to provide detailed guidance for future implementers.

Semantic Interoperability. Technical connectivity proved easier than semantic agreement. Establishing shared vocabularies using FMA/SNOMED-CT required working group coordination and involvement from all interoperating parties.
Proposed Solution: Allocate project time to vocabulary working groups established early in development.

Real-Time Performance*:* AR applications require very low latency.
Proposed Solution: Establish performance budgets early, limit message sizes and tune Quality of Service (QoS) settings appropriately. Ensure all technologies using the open standards can meet the performance budgets.

Standards Maturity. While MoHSES provided excellent component-level integration, JETS required custom gateway development.
Proposed Solution: Document gateway patterns as reference implementations and contribute to standards organizations.

5.3 Roadmap for Healthcare Simulation Interoperability

The MRT project demonstrates that standards-based interoperability is achievable in complex, multi-modal medical simulation. However, significant work remains to extend these approaches to broader healthcare domains and mature the standards ecosystem. This section presents a roadmap for future development, organized by timeframe and explicitly identifying the role of the SISO Medical Simulation Multi-Modality Data Transfer Study Group.

Continued research and development, potentially guided by the Study Group, could include:
Near-term (1-2 years):

- Document MoHSES/JETS gateway patterns as reference implementation with example code
- Develop conformance test suite for MoHSES modules ensuring consistent implementation
- Extend FMA/SNOMED-CT mapping to additional procedures beyond TCCC
- Create best practices guide for AR content registration and alignment
- Establish interoperability profiles for common training scenarios
- Implement xAPI integration for learning analytics

Mid-term (2-4 years):

- Define interoperability profiles for civilian healthcare training domains (emergency medicine, surgical training, nursing)
- Standardize AR content registration and alignment methods across vendors
- Integrate learning management system interfaces
- Support adaptive training scenarios adjusting difficulty based on learner performance

- Establish cloud-based federation services for distributed training
- Develop certification programs for standards-compliant systems

Long-term (4+ years):

- Integrate with electronic health record systems for seamless documentation
- Support AI-driven adaptive training scenarios personalizing learning paths
- Enable large-scale distributed training exercises across multiple sites and services
- Investigate haptic feedback integration and physiological fidelity metrics
- Establish governance model for long-term standards maintenance
- Build international coalition of government, academic, and industry partners

5.4 Call for Community Engagement

The Study Group provides opportunities to extend these approaches to broader healthcare domains. We invite SISO community engagement on standardized approaches for AI/ML integration, AR/VR content registration best practices, interoperability profiles for specific domains, conformance testing methodologies, and gateway patterns for integration with existing standards.

The MRT project demonstrates that open standards can successfully enable interoperability in complex, multi-modal training systems. Through community collaboration, we can accelerate development of next-generation medical simulation capabilities that are interoperable, affordable, and effective across military and civilian healthcare domains.

5.5 How to Engage

Organizations interested in participating should:

1. Join the SISO Medical Simulation Multi-Modality Data Transfer Study Group
2. Attend SISO workshops (Simulation Innovation Workshop, Fall Simulation Innovation Workshop) to present work and collaborate
3. Contribute to open-source reference implementations (gateway code, conformance tests)
4. Participate in vocabulary working groups for specific domains
5. Provide feedback on draft standards and interoperability profiles

The standards-based approach validated in the MRT project provides a foundation for next-generation medical simulation systems that are interoperable, affordable, and effective across military and civilian healthcare domains. Through community collaboration, we can accelerate development of these capabilities and ensure that healthcare simulation training benefits from the same interoperability that has transformed other simulation domains.

6. Conclusion

This paper demonstrates that open standards—MoHSES, JETS, and clinical ontologies—enable practical multi-vendor interoperability in complex, multi-modal medical simulation systems. Through eight Soldier Touchpoint evaluations involving five independent organizations, we validated that standards-based integration supports mass casualty coordination, component-level mixing, and patient handoff scenarios while maintaining training effectiveness.

The Mixed Reality Trainer for combat casualty care exemplifies the interoperability challenges facing modern medical simulation: physical manikins, AR displays, physiology models, and intervention detection systems must work together seamlessly, potentially from different vendors. Traditional proprietary integration creates vendor lock-in and prevents component reuse. The standards-based architecture presented in this paper addresses these challenges through layered integration—MoHSES for component-level coordination, JETS for federation-level interoperability, and clinical ontologies (FMA, SNOMED-CT) for semantic consistency.

Key contributions of this work include:

Proven gateway pattern for MoHSES/JETS integration: The gateway architecture enables component-based systems to participate in federation-level coordination while maintaining modular benefits. This pattern is reusable across medical simulation domains and should be documented as a reference implementation.

Standardized clinical vocabularies enabling semantic interoperability: The vocabulary standardization effort by the CCT cohort demonstrates that semantic interoperability is achievable but requires sustained collaborative effort. The resulting FMA/SNOMED-CT mappings provide a foundation for future interoperability profiles.

Documented lessons learned addressing critical challenges: Real-time performance requirements, patient ownership transfer protocols, and integration testing logistics present significant challenges for standards-based interoperability. The solutions developed in this project—tiered data architecture, explicit handoff protocol, structured integration events—provide guidance for future implementers.

Quantified benefits of standards-based approach: Integration time reduced significantly, content portability demonstrated across vendors, and successful multi-vendor coordination in operational training scenarios validate that open standards deliver concrete benefits without compromising training effectiveness.

The results at the Soldier Touchpoints demonstrate that standards-based interoperability is transparent to end users—participants did not distinguish between single-vendor and multi-vendor scenarios, indicating seamless integration. With 100% agreement that mixed reality added realistic training value and 94% support for operational deployment, the MRT validates that technical complexity can be hidden while providing flexible, interoperable training systems.

However, significant work remains to extend these approaches to broader healthcare domains. Critical near-term priorities include documenting gateway patterns as reference implementations, developing conformance test suites, and establishing interoperability profiles for specific training domains. Mid-term priorities include extending profiles to civilian healthcare, standardizing AR/VR content registration, and developing certification programs. Long-term priorities include establishing sustainable governance and building international coalitions.

We encourage the SISO community to build on this foundation through the Medical Simulation Multi-Modality Data Transfer Study Group. The standards-based approach validated in this project provides a roadmap for next-generation medical simulation systems that are interoperable, affordable, and effective across military and civilian healthcare training domains. Through continued community collaboration, we can ensure that healthcare simulation benefits from the same interoperability that has transformed other simulation domains, ultimately improving training outcomes and patient care.

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7.1 Author Biographies

DOUGLAS RAUM has been a Software Developer at Vcom3D, Inc. since 2014 and has been Senior Software Developer since 2020. Most recently at Vcom3D he has been the lead developer for the Modular Healthcare Simulation and Education System (MoHSES) specification and reference implementation software.

DAN SILVERGLATE is VP of Systems Architecture and Development at Vcom3D, Inc where he has led a team of artists and engineers for over 27 years in the development of cutting-edge, 3D character-based learning. He is the chief architect for Vcom3D's modular MedSim platform. He holds a Bachelor of Science degree in Computer Science from the University of Central Florida, where he graduated Magna Cum Laude, and a Bachelor of Arts degree from the University of Florida, where he graduated with High Honors.

EDWARD SIMS is Chief Technology Officer of Vcom3D, Inc. Most recently, his focus has been on developing multi-modal medical simulations that blend virtual and physical representations. Prior to co-founding Vcom3D, Ed held the positions of Chief Scientist and Technical Director for Lockheed Martin Information Systems Company. Ed received a BS degree in Mathematics from the College of William and Mary and MS and PhD degrees in Systems Engineering from Rensselaer Polytechnic Institute.