
The Unified Modeling Gap

Why No Single Environment Spans
Transport, Tracking & Kill-Chain



Three Domains — Three Incompatible Worlds

Each domain evolved its own formalisms, data models, and temporal assumptions — making integration non-trivial.



DOMAIN 01

Transport

- Route & schedule optimization
- Continuous spatial-temporal state
- Physics-driven kinematics
- Platform lifecycle & logistics

01



DOMAIN 02

Tracking

- Probabilistic state estimation
- Sensor fusion across modalities
- Intermittent observation windows
- Track association under uncertainty

02



DOMAIN 03

Kill-Chain

- Decision-theoretic sequencing
- Find-Fix-Track-Target-Engage-Assess
- Policy & rules of engagement logic
- Effect assessment feedback loops

03



No shared state representation, temporal model, or composition theory bridges these three worlds — the structural root of the modeling gap.

Root Causes of the **Modeling Gap**



SEMANTIC HETEROGENEITY

01

Continuous kinematics vs. discrete event sequences vs. probabilistic belief states — incompatible data models cannot share a common state representation.



TEMPORAL MISMATCH

02

Transport runs on continuous real-time simulation; Tracking on asynchronous sensor events; Kill-Chain on decision epochs with variable latency — three irreconcilable clocks.



FORMALISM FRAGMENTATION

03

ODE solvers, Bayesian filters, and state-machine planners evolved independently — no common composition theory exists to bridge these technical lineages.



CLASSIFICATION BARRIERS

04

Kill-chain models carry classification levels that prevent integration with unclassified transport or civil tracking environments — a hard institutional firewall.



INSTITUTIONAL SILOS

05

Acquisition programs fund domain-specific tools in isolation. No program of record exists for cross-domain integration — organizational incentives perpetuate the gap.



SCALABILITY TRADEOFFS

06

Unified full-fidelity simulation across all three domains simultaneously creates computational intractability at operational scale — the physics of the problem resist unification.

How Current Tools Fall Short



DOMAIN-SPECIFIC TOOLS (STATUS QUO)

INSUFFICIENT



STK / AGI

Excellent orbital & trajectory fidelity — but no decision logic or kill-chain sequencing



JMASS / OneSAF

Kill-chain capable — but lacks sensor fusion and probabilistic tracking pipelines



AFSIM

Engagement modeling well-supported — but limited transport fidelity and logistics state



Custom Bayesian Filters

Tracking-only solutions — no platform dynamics, no transport state, no kill-chain hook

vs



WHAT A UNIFIED ENVIRONMENT REQUIRES

TARGET STATE



Common Event-Based State Representation

Single shared event schema spanning kinematics, detections, and decisions across all three domains



Composable Model Interfaces

Well-defined coupling semantics — domain components exchange events without exposing internal state



Multi-Resolution Support

Seamless zoom from individual entity physics to theater-level aggregate behavior in one run



Explicit Uncertainty Propagation

Probability distributions tracked continuously through transport, tracking, and kill-chain effect assessment



Interoperable Time Management

Heterogeneous clocks — continuous, asynchronous event-driven, and decision-epoch — composed under a single time advance protocol

DEVS: A Candidate Unifying Formalism

1

ATOMIC DEVS MODEL

Discrete Event State Machine

Encapsulates **any domain behavior** — kinematic, probabilistic, or decision-theoretic — as a discrete event state machine with well-defined **internal & external transitions** and **time advance functions**.

 $\delta_{\text{int}} \cdot \delta_{\text{ext}} \cdot \text{ta}(s)$

2

COUPLED DEVS

Port-Based Composition

Composes atomic models through **explicit input/output port coupling** — enabling Transport, Tracking, and Kill-Chain components to exchange events **without sharing internal representations**.



Closure under Coupling

3

DEVS Interoperability MIDDLEWARE

Dynamic coupling, model substitution, and multi-resolution hierarchy — the **critical bridge between domain silos**.



Transport · Tracking · Kill-Chain

 $M = \langle X, S, Y, \delta_{\text{int}}, \delta_{\text{ext}}, \lambda, \text{ta} \rangle$ · Coupled = $\langle X, Y, D, \{\text{Md}\}, \text{EIC}, \text{EOC}, \text{IC} \rangle$ · PWSA: $\forall \text{Md} \mapsto \text{EventBus}(\text{topic})$

The DEVS Interoperability Framework: Bridging the Gap

DOMAIN COVERAGE



Single Event Bus



UNIFIED EVENT ONTOLOGY

Kill-Chain

Transport

Tracking



MODULAR MODEL SUBSTITUTION

Any domain model can be swapped at runtime without restructuring — replace a kinematic tracker with a Kalman filter without touching kill-chain logic. Ports decouple implementation from interface.



HIERARCHICAL RESOLUTION CONTROL

DEVS hierarchy lets analysts zoom from entity-level physics to theater-level aggregation within a single simulation run — multi-resolution without model duplication or hand-off seams.



EXPLICIT COUPLING SEMANTICS

All inter-domain dependencies are declared at coupling time — making the integration contract visible, inspectable, and verifiable. No hidden shared state; every connection is a typed port binding.



REPRODUCIBILITY & VERIFICATION & VALIDATION

DEVS formal semantics enable model verification independent of domain — each atomic model's behavior is provable from its transition functions alone, directly addressing accreditation gaps in current M&S practice.

ENABLES

Formal Verification
per atomic model

M&S Accreditation
cross-domain

Path Forward

1

Accept the Gap Is Structural

Not a technology failure — a consequence of **incompatible domain formalisms** and institutional incentives baked in at program inception.

2

Adopt DEVS as Integrating Theory

Its **closure-under-coupling property** is the only proven mechanism for composing heterogeneous M&S components across domain boundaries.

3

Develop Interoperability Middleware

A **Distributed DEVS protocol** implementing DEVS coupling semantics bridges domains without forcing model homogenization or rearchitecting existing tools.

4

Drive a Cross-Domain Ontology Standard

Transport, Tracking, and Kill-Chain communities must **co-author a shared event vocabulary** before any tool integration effort can reach production fidelity. Standards precede software.

5

Pursue Incremental Integration

Instrument **STK**, **AFSIM**, **custom trackers** with DEVS wrappers as a near-term path — defer full unification to a second generation.