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Readiness & Supportability Programs

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Albuquerque, NM 87185

8th Annual NDIA Systems Engineering Conference

October 24-27, 2005

San Diego, CA

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LOCKHEED MARTIN

Sandia National Laboratories

New Mexico

California

"Helping secure a peaceful and free world through technology"

- **8,000 employees in New Mexico, California, Nevada, and Hawaii**
- **Responsible for research, development, engineering, and maintenance of U.S. nuclear weapons**
- **Responsible for all non-nuclear subsystems; the primary systems integration and engineering lab**
- **$2B annual budget**
- **$550M from other federal agencies**
- **$50M from private industry through R&D partnerships**

Major Readiness/Supportability Initiatives

Army's FCS Supportability

JSF Autonomic Logistics

Army's Recapitalization (RECAP)

Navy CVN 21 Manpower

Future Combat Systems

Sandia National Laboratories (SNL)
UA System-of-Systems (SoS)
Supportability Modeling & Simulation

FUTURE COMBAT SYSTEMS

FCS

One Team—The Army/DARPA/Industry

What is a System-of-Systems?

FUTURE COMBAT SYSTEMS
FCS
One Team – The Army/DARPA/Industry

Key to understanding a System-of-Systems (SoS) is the notion that a SoS performs a function not possible with any of the individual parts (systems) acting alone

- In this context, a SoS can be viewed as a collection of interdependent systems that are integrated to provide a prescribed capability
- The loss of individual systems within the SoS will degrade the performance or capabilities of the SoS
- However, individual systems within the SoS can provide a capability or function independent of the other systems within the SoS

A SoS can be viewed as multiple systems, each capable of independent operations, but must interact in order to fulfill a global mission.

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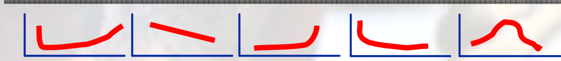
SNL SoS M&S Framework

FUTURE COMBAT SYSTEMS
One Team – The Army/DARPA/Industry

State Models

- Single model for multiple MOEs/MOPs
- Multiple states (not just functional or failed)
- Incorporates complex interdependencies
- Includes external factors (weather, terrain, threats)
- Able to incrementally add new components

State Model Objects



Uncertainty Characterization

Optimization Analyses

Simulated Campaigns

- Scalability to large numbers of platforms
- Can include multiple pulses throughout campaigns
- Includes integrated logistics support during campaign
- Tracks dynamic changes in force structure during campaign
- Includes complex communications & data networks

- **Utilizes:**
  - Unique State Modeling Concepts
  - State-of-Art SoS Simulation Framework
  - Customized Optimization Algorithms
- **Provides Capability for Analyzing:**
  - Systems as well as Systems-of-Systems
  - Warfight capabilities (pre, post, during campaigns)
  - Spiral integration of technologies
- **Flexibility to Include:**
  - Complex supply & support networks
  - Stochastic treatment of combat damage
  - Human performance (maintainers, warfighters, …)
- **Allows Analyst to Assess Impacts of:**
  - PHM
  - Asset visibility
  - Commonality & complex functional redundancies

- *Time-Dependent Warfight Capability*
- *UA/SoS MOE's/TPM's*
- *Sensitivity Trades*
- *Optimization Analyses*

Integrated methodology provides unique capabilities for SoS analysis

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State Model Concepts

- **State modeling attributes**
  - Multiple functions/operations
    - Mobility
    - Communications
    - Sensing
    - Lethality/Firepower
  - Multiple States (not just functional or failed)
  - Models interdependencies
  - Can include external factors (weather, terrain, combat, …)
  - Able to incrementally add new components
- **Model system behavior by defining:**
  - States for all subsystems/components/functions
  - How transitions are made between states
- **States can change through:**
  - Normal processes (failure, repair,…)
  - External conditions (weather, terrain, combat,…)
  - Changes in functional states of other systems

NLOS-C State Model Object

NLOS-C Model

Example Elements
- 105 mm Cannon
- M240 Machine Gun
- Sandstorm

Example Operations
- Operability
- Lethality
- Mobility

Intuitive Environment for Capturing System Behavior

Soldier Performance Modeling

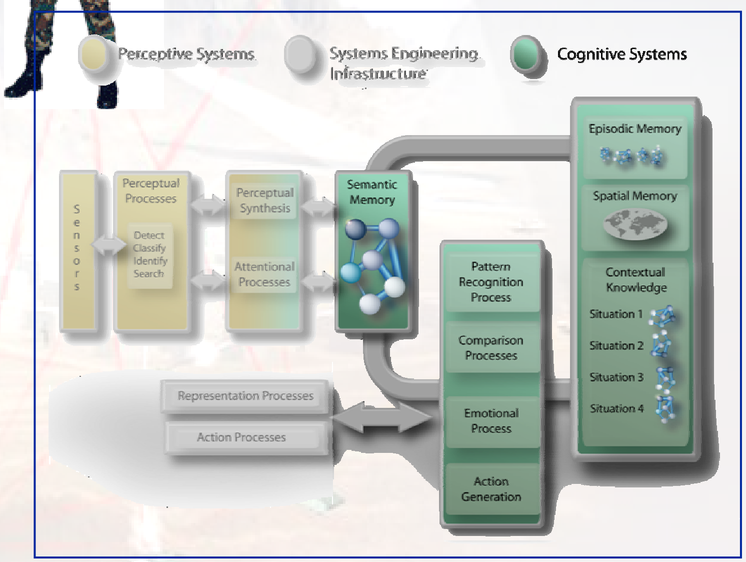
- **Multiple Functions/Operations**
  - Navigate
  - Communicate
  - Combat
  - Maintain . . .
- **Multiple States**
  - Not just functional or failed
- **Model soldier behavior by defining:**
  - All possible states
  - How transitions are made between states
- **States can change through:**
  - Fatigue
  - Stress
  - Sleep deprivation
  - Training . . .

Mobility

Lethality

Survivability

Communication



Human Performance is Key to Modeling Complex SoS's

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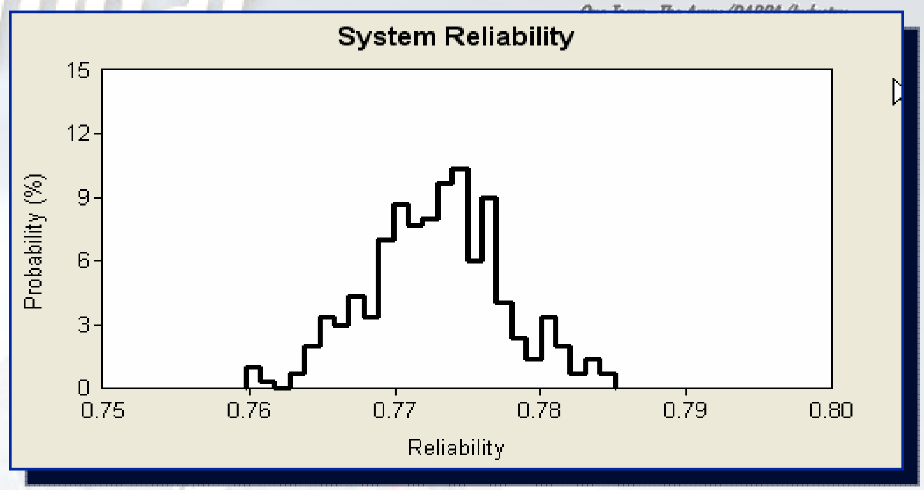
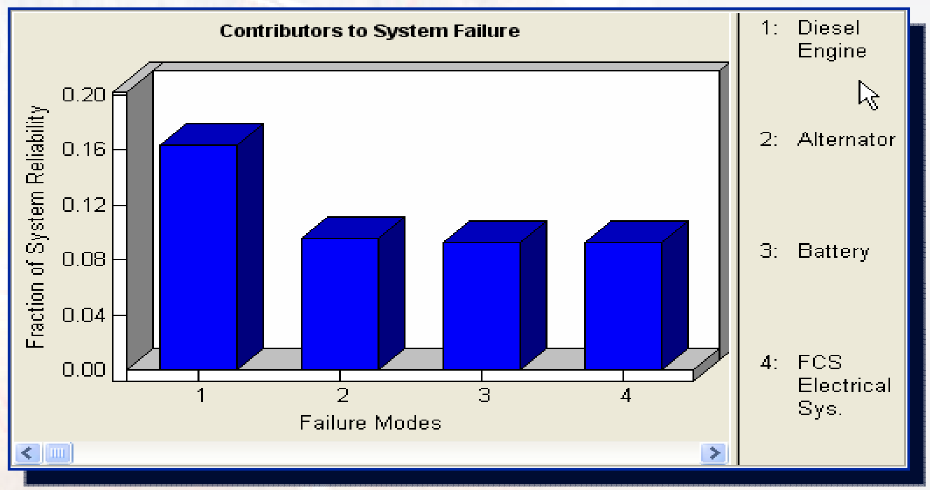
State Model Results

- System Performance Analyses
  - Reliability
  - MTBF
  - Availability …
- Sensitivity Analyses
- Optimization Analyses
  - Spares
  - Performance trades
  - Resource allocation





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1 Summary | 2 Details

Performance Measure	Baseline	Limit	Objective	Value
Fitness	0.00461			0.758
NLOS-C : Reliability	0.535	0.580	0.600	0.594
C2 : Reliability	0.773	0.800	0.820	0.807
Cost 1	0	2.00E+7	1.20E+7	1.23E+7

FUTURE COMBAT SYSTEMS

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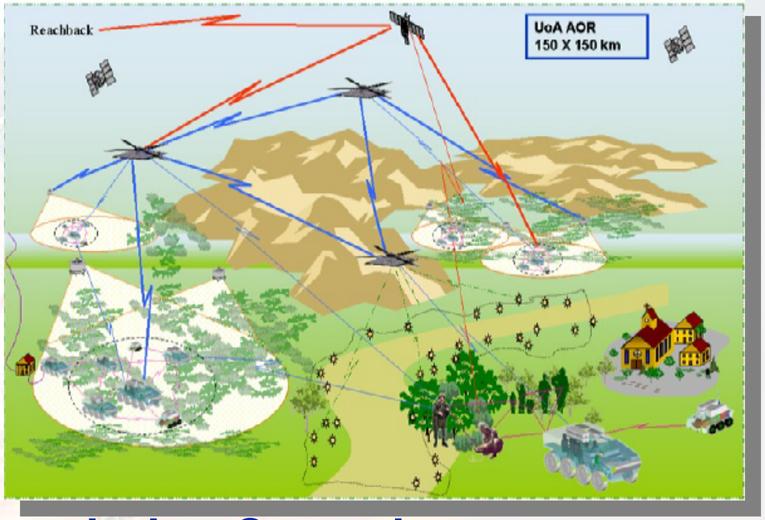
Time Simulation

Incorporates State Model Objects (SMOs) to dynamically represent a given scenario for a defined force structure

- Creates and duplicates platforms and platform types (Defines Force Structure)
- Describes Scenario/Campaign
- Describes Functions for Each Platform Type
- Describes System/Elements Properties
- Describes External Conditions



- Evaluates/tracks Functionality of Force Structure during Campaign
- Tracks Supplies & Services (Logistics Footprint)

Defining Force Structure

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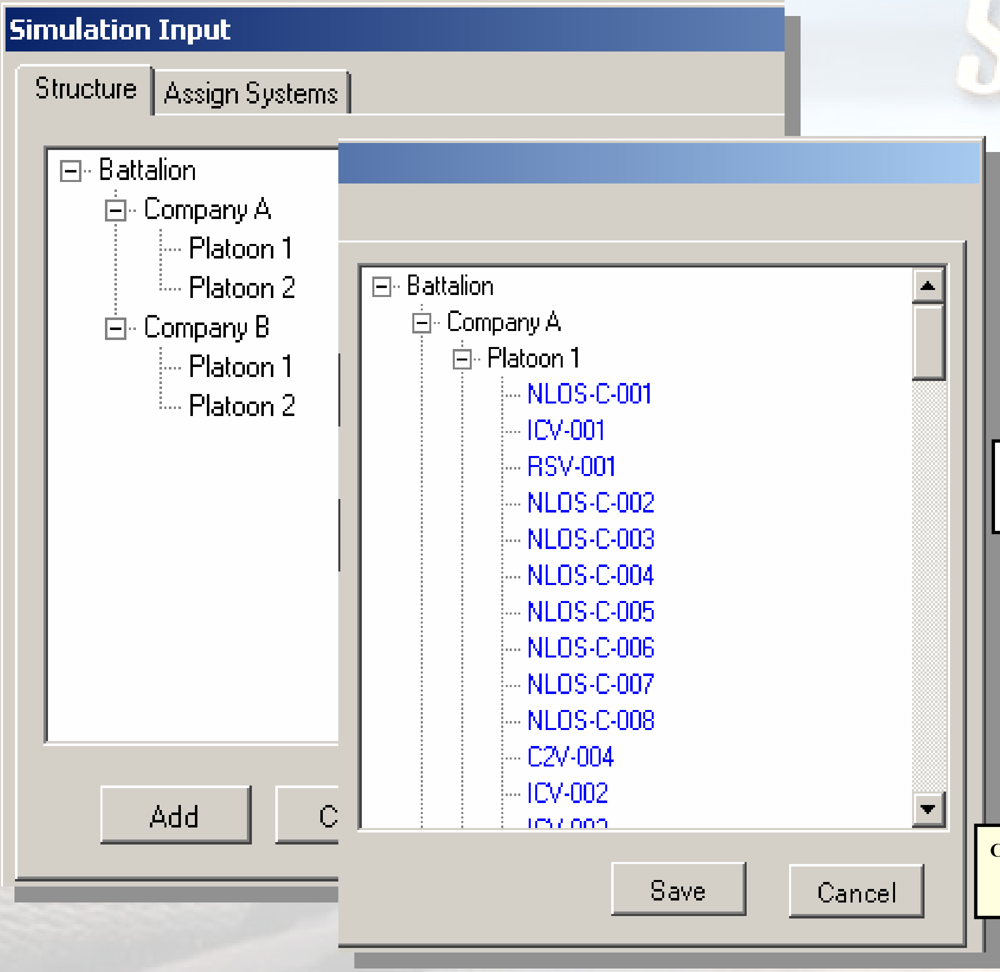
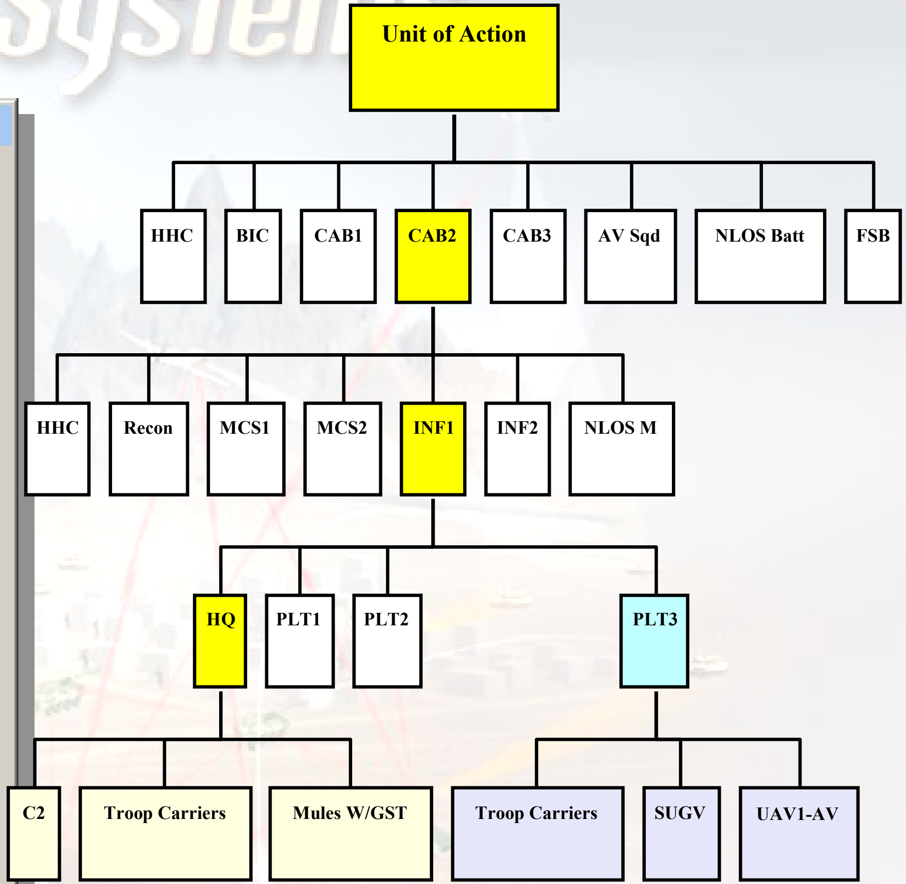
Example Battalion Structure for Simulation





Force Structure is established in Simulation Software by creating and duplicating platforms and platform types

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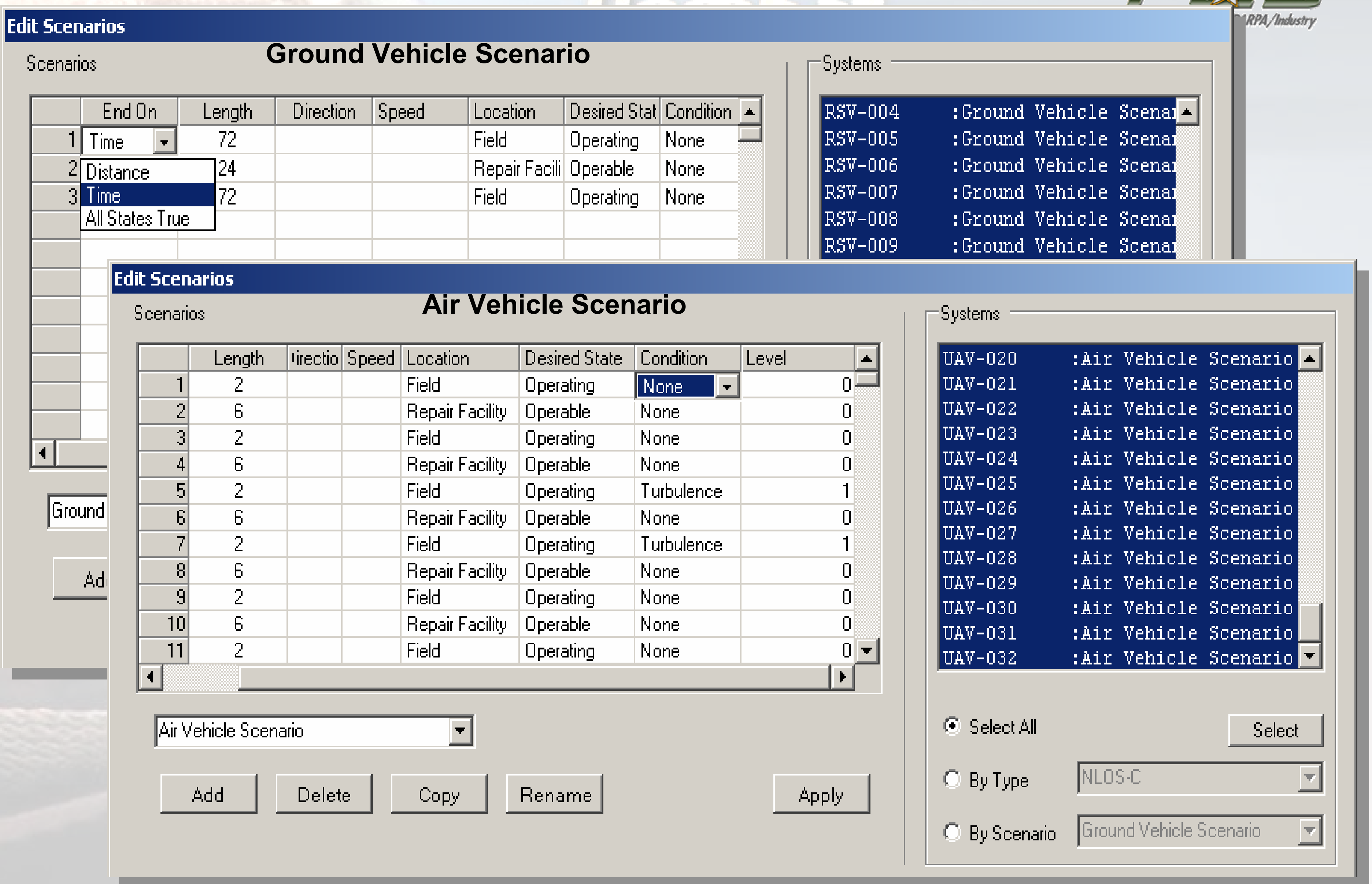
Simulation Scenario Structure



Edit Scenarios

Scenarios

Ground Vehicle Scenario

	End On	Length	Direction	Speed	Location	Desired Stat	Condition
1	Time	72			Field	Operating	None
2	Distance	24			Repair Facili	Operable	None
3	Time	72			Field	Operating	None
	All States True						

Systems

RSV-004 :Ground Vehicle Scenar
RSV-005 :Ground Vehicle Scenar
RSV-006 :Ground Vehicle Scenar
RSV-007 :Ground Vehicle Scenar
RSV-008 :Ground Vehicle Scenar
RSV-009 :Ground Vehicle Scenar

Ground

Ad

Edit Scenarios

Scenarios

Air Vehicle Scenario

	Length	irectio	Speed	Location	Desired State	Condition	Level
1	2			Field	Operating	None	0
2	6			Repair Facility	Operable	None	0
3	2			Field	Operating	None	0
4	6			Repair Facility	Operable	None	0
5	2			Field	Operating	Turbulence	1
6	6			Repair Facility	Operable	None	0
7	2			Field	Operating	Turbulence	1
8	6			Repair Facility	Operable	None	0
9	2			Field	Operating	None	0
10	6			Repair Facility	Operable	None	0
11	2			Field	Operating	None	0

Air Vehicle Scenario

Add | Delete | Copy | Rename | Apply

Systems

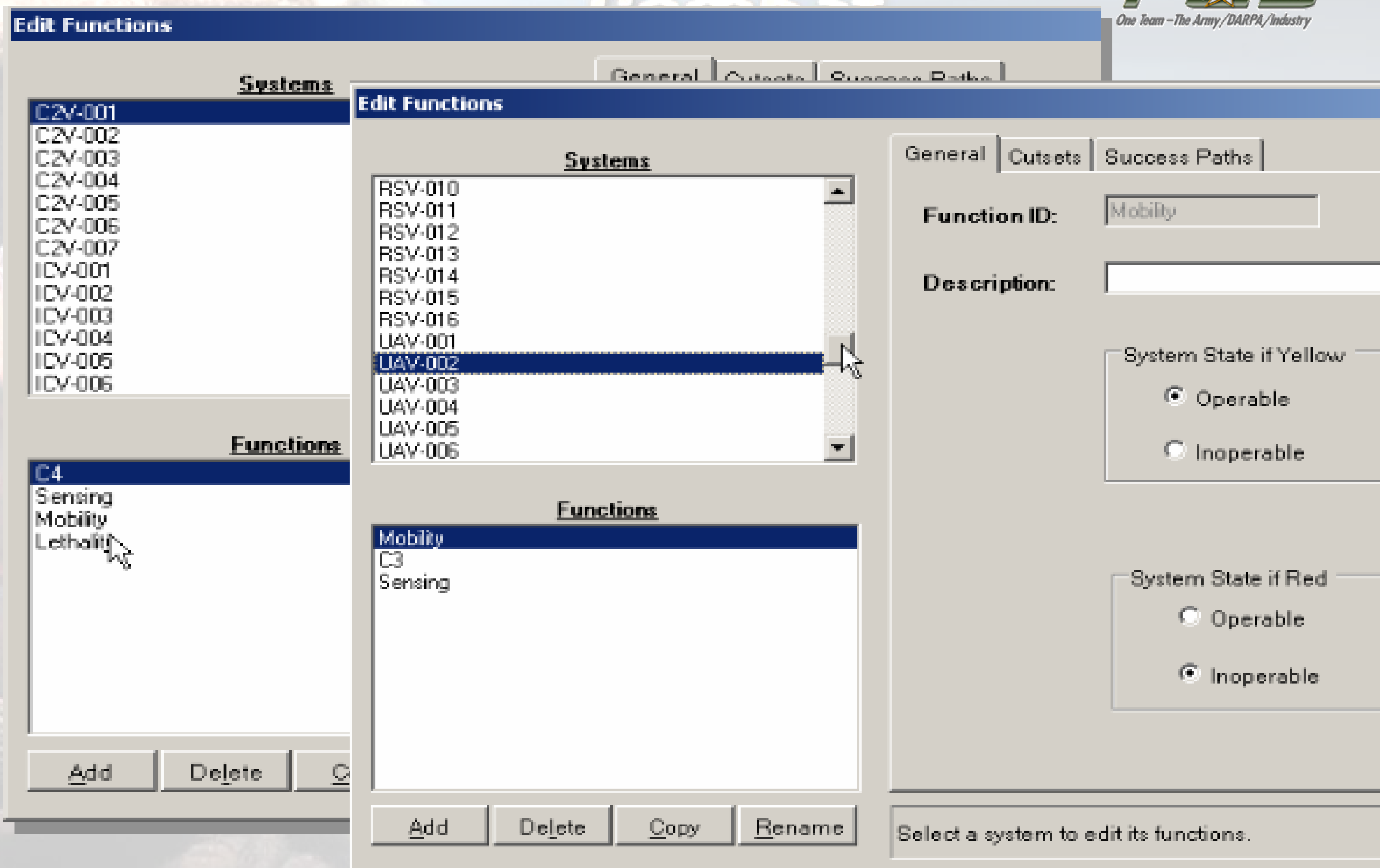
UAV-020 :Air Vehicle Scenario
UAV-021 :Air Vehicle Scenario
UAV-022 :Air Vehicle Scenario
UAV-023 :Air Vehicle Scenario
UAV-024 :Air Vehicle Scenario
UAV-025 :Air Vehicle Scenario
UAV-026 :Air Vehicle Scenario
UAV-027 :Air Vehicle Scenario
UAV-028 :Air Vehicle Scenario
UAV-029 :Air Vehicle Scenario
UAV-030 :Air Vehicle Scenario
UAV-031 :Air Vehicle Scenario
UAV-032 :Air Vehicle Scenario

Select All — Select

By Type — NLOS-C

By Scenario — Ground Vehicle Scenario

Functions for Each Platform Type



Example External Conditions

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External Conditions Can Include:

- Terrain
  - ✓Rough
  - ✓MOUT . . .
- Weather
  - ✓Sandstorm
  - ✓Turbulence . .
- Combat . . .

External Conditions Affect:

- Consumables
  - ✓Water/Fuel
  - ✓Ammo . . .
- Random Processes
  - ✓Time-to-failure (TTF)
  - ✓Time-to-repair (TTR) . . .
- System/Element State(s)
  - ✓Operable
  - ✓Inoperable . . .

Flexibility in Treatment of External Conditions

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System Functional Status

FUTURE COMBAT SYSTEMS
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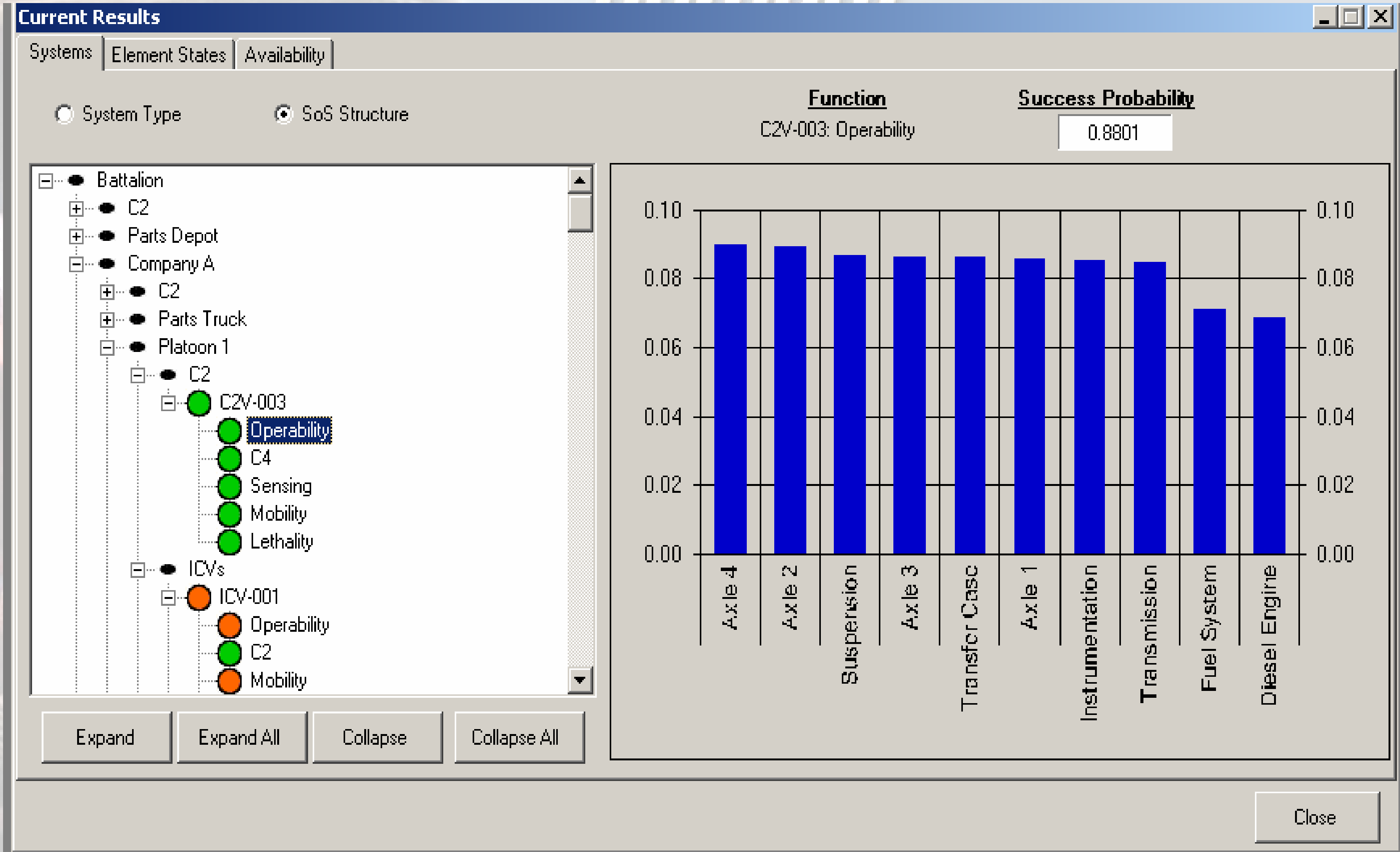

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System Functional Status

FUTURE COMBAT SYSTEMS

One Team – The Army/DARPA/Industry

Current Results

Systems | Element States | Availability

C2V-001
C2V-002
C2V-003
C2V-004
C2V-005
C2V-006
C2V-007
ICV-001
ICV-002
ICV-003
ICV-004
ICV-005
ICV-006
ICV-007
ICV-008
ICV-009
ICV-010
ICV-011
ICV-012
ICV-013
ICV-014
ICV-015
ICV-016
NLOS-C-001
NLOS-C-002
NLOS-C-003
NLOS-C-004
NLOS-C-005

States by System Type

	Name	State	Time-in-State	Expected TIS	Age Accel.
1	Diesel Engine	True	292.85	1,536.84	1.00
2	Fuel System	True	303.65	4,671.61	1.00
3	Instrumentation	True	301.26	7,481.27	1.00
4	MGV Batteries	True	292.65	2,715.61	1.00
5	MGV Elec. System	True	296.57	2,651.20	1.00
6	Steering System	True	304.51	2,616.73	1.00
7	Suspension	True	302.47	6,135.14	1.00
8	Transfer Case	True	300.05	5,732.35	1.00
9	Transmission	False	0.00	-	1.00
10	Axle 1	True	306.62	6,277.27	1.00
11	Axle 2	True	293.22	6,022.82	1.00
12	Axle 3	True	303.70	5,866.13	1.00
13	Axle 4	True	291.08	6,255.95	1.00
14	Wheel 1L	True	293.05	2,347.93	1.00

	Name	Capacity	Remaining	Projected Time	Request Replenish
1	Fuel	100.00	0.00	0.00	True
2	Water	20.00	0.00	0.00	True

Close

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FCS UA/BCT Analyses

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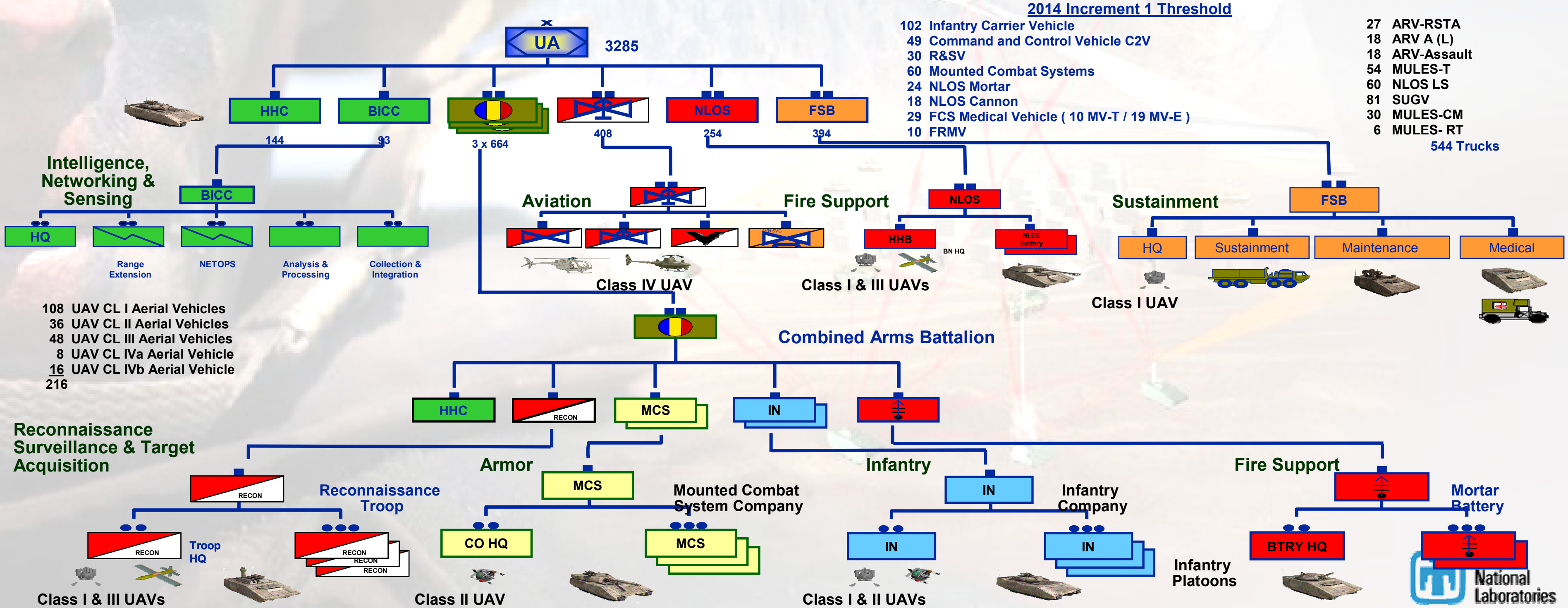
Example FCS UA/BCT Analysis

- BCT force structure consisting of 1552 platforms
- Multiple pulses
- Level-5 subsystems – on average 265 elements
- Performed optimization and sensitivity analyses

FCS Equipped Brigade Combat Team (BCT)



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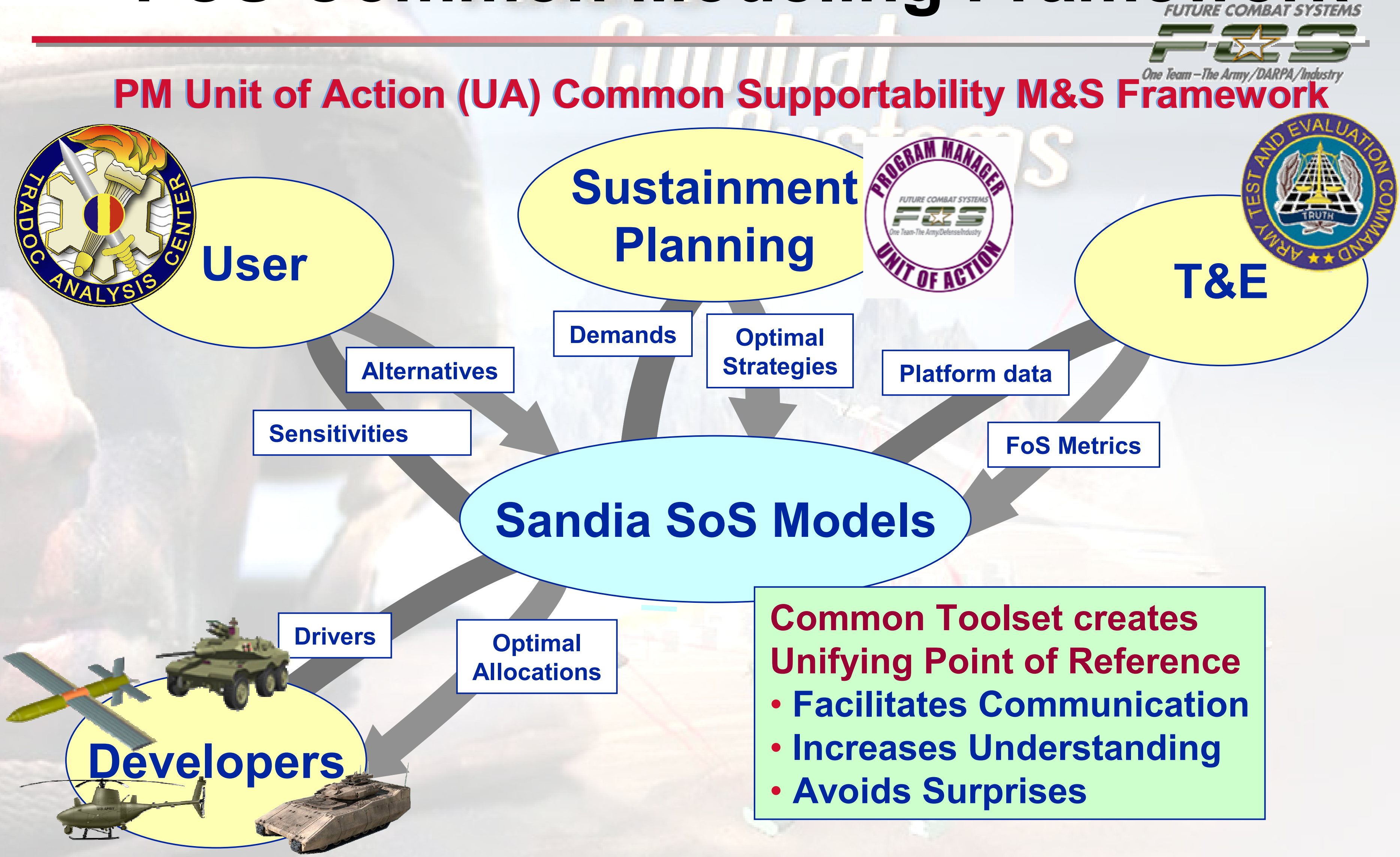
FCS Common Modeling Framework

PM Unit of Action (UA) Common Supportability M&S Framework



Common Toolset creates Unifying Point of Reference

- Facilitates Communication
- Increases Understanding
- Avoids Surprises

SNL tools being incorporated into PM UA Common M&S Framework for use in SoS Supportability Assessment Modeling.

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JSF Autonomic Logistics
&
Enterprise Modeling & Simulation

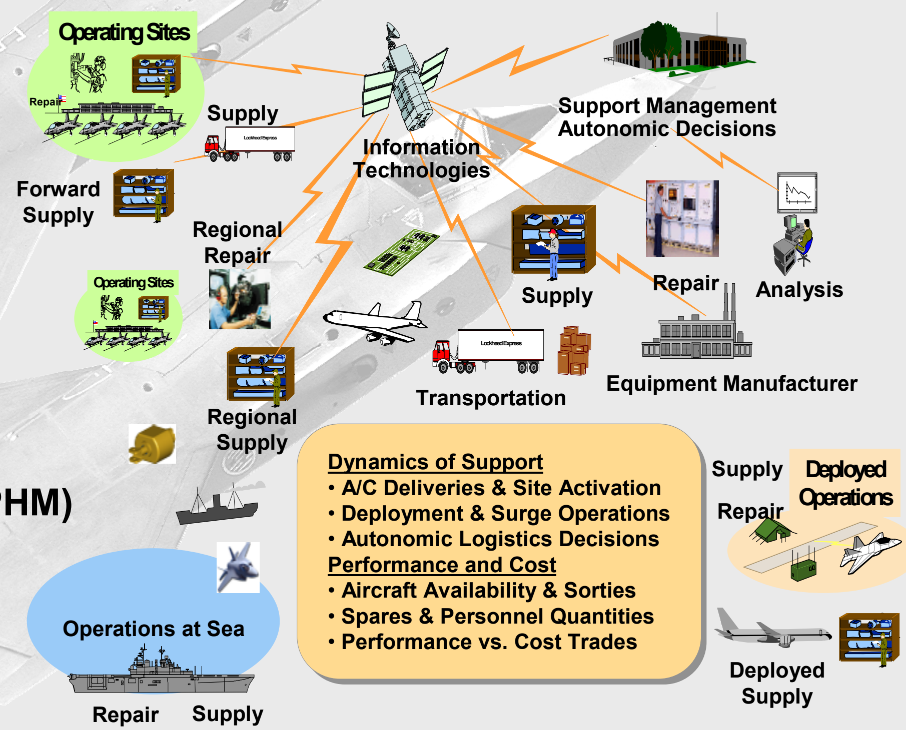
Support Enterprise Model (SEM)

A Unique Logistics Modeling, Analysis and Decision Support Tool

- **Features**
  - *Integrated* modeling of worldwide support system
    - Operations
    - Supply/Repair Chain
    - Transportation
  - *Dynamic* changes throughout life-cycle
    - Inventory/Fleet build up and retirement
    - Site activation/closure
    - Deployment/surge
  - *Total* support system performance & cost
    - Full on/off-system support activities
    - Prognostics and Health Management (PHM)
    - Global optimization across enterprise
- **Benefits**
  - Real-time strategic planning support
  - Dramatic risk mitigation
  - Unparalleled resource management flexibility to deal with changing conditions

Support System Analysis

Integration of Complex & Dynamic Support Processes



SEM is a Development Design Tool <u>and</u> a Decision/Planning & Management Tool

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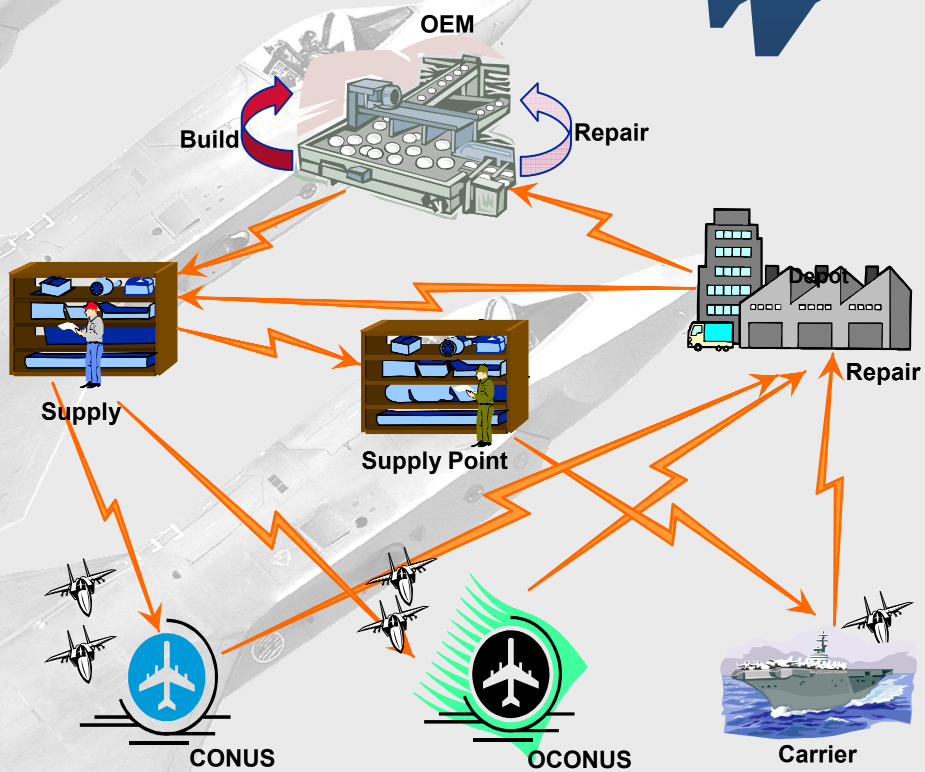
Typical Problem Scale (JSF)

- 3,000 aircraft
  - 5000+ LRC's
  - 10 configurations
- 250 sites worldwide
- 500 types of support equipment
- 50 personnel skill types
- 30 – 50 years of simulation
- ~4M data elements
- >> 1M part demands
- Arbitrary multi-echelon support structure



Unprecedented Data Integration Challenge

SEM Optimization Approach

- **Unique hybrid optimization process for SEM**
  - Heuristics:
  - Analytic Mixed Integer Programming:
  - Solution Refinement
- **Problem-Oriented Factors**
  - Unprecedented problem scale
    - Roughly 1 million site/part combinations
    - Roughly 20K site/resource combinations
    - *Per year* of the simulation
    - On the order of 50 million variables in all
  - SEM simulation is stochastic
- **Algorithmic Challenges**
  - Simultaneous optimization of inventory levels, resource levels, and location of repair facilities
    - Most approaches only consider one of these facets
  - Avoiding “brittle” solutions
    - Algorithms must generate robust solutions - insensitive to minor changes in operational parameters
    - Need to characterize the trade-offs between solution robustness and cost, quantify risk

Goal: Arrange spare parts, support equipment and personnel skills across the enterprise to meet target performance at lowest cost