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Evaluating Communications System Performance Effects at a System of Systems Level

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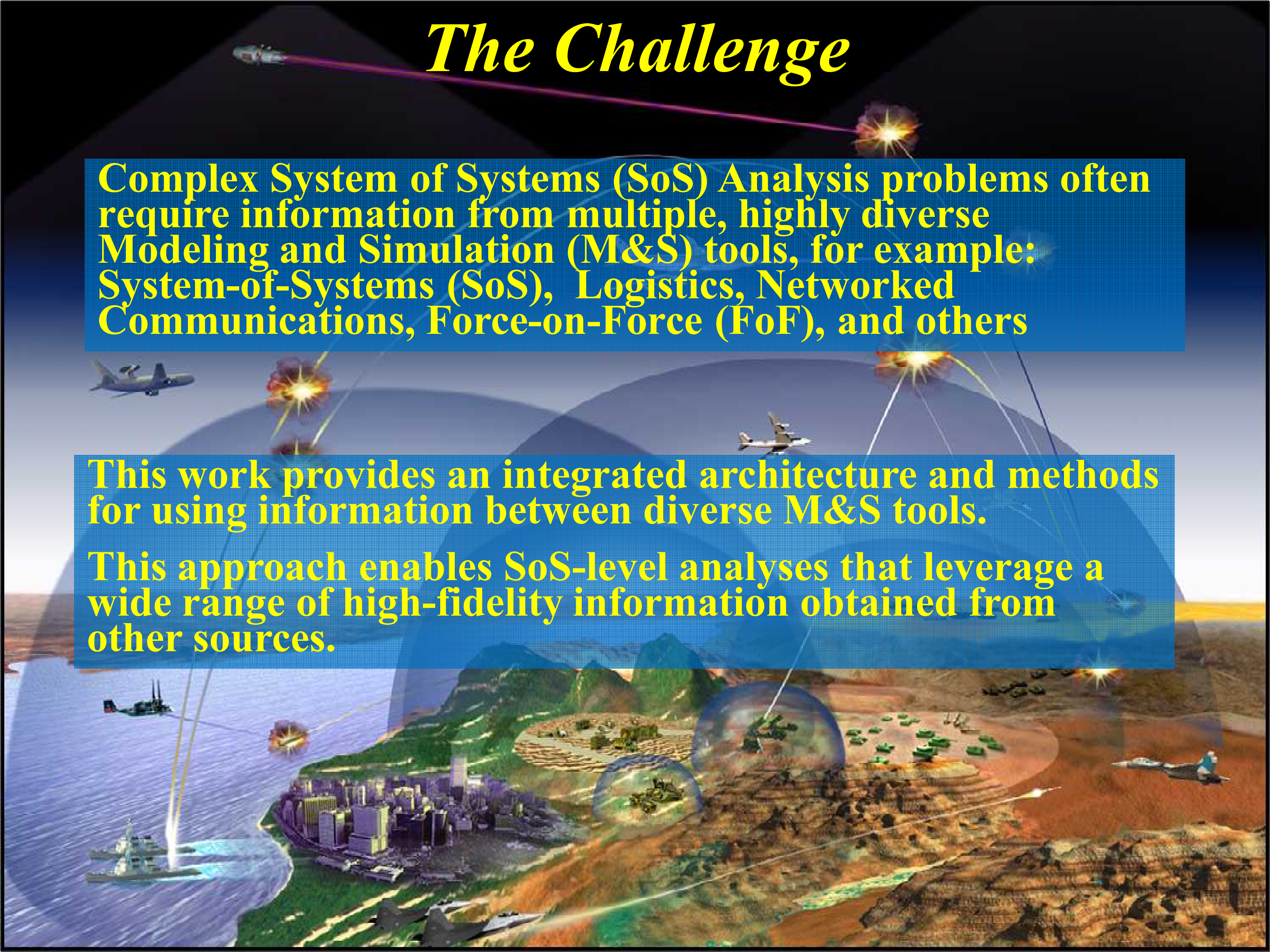
The Challenge

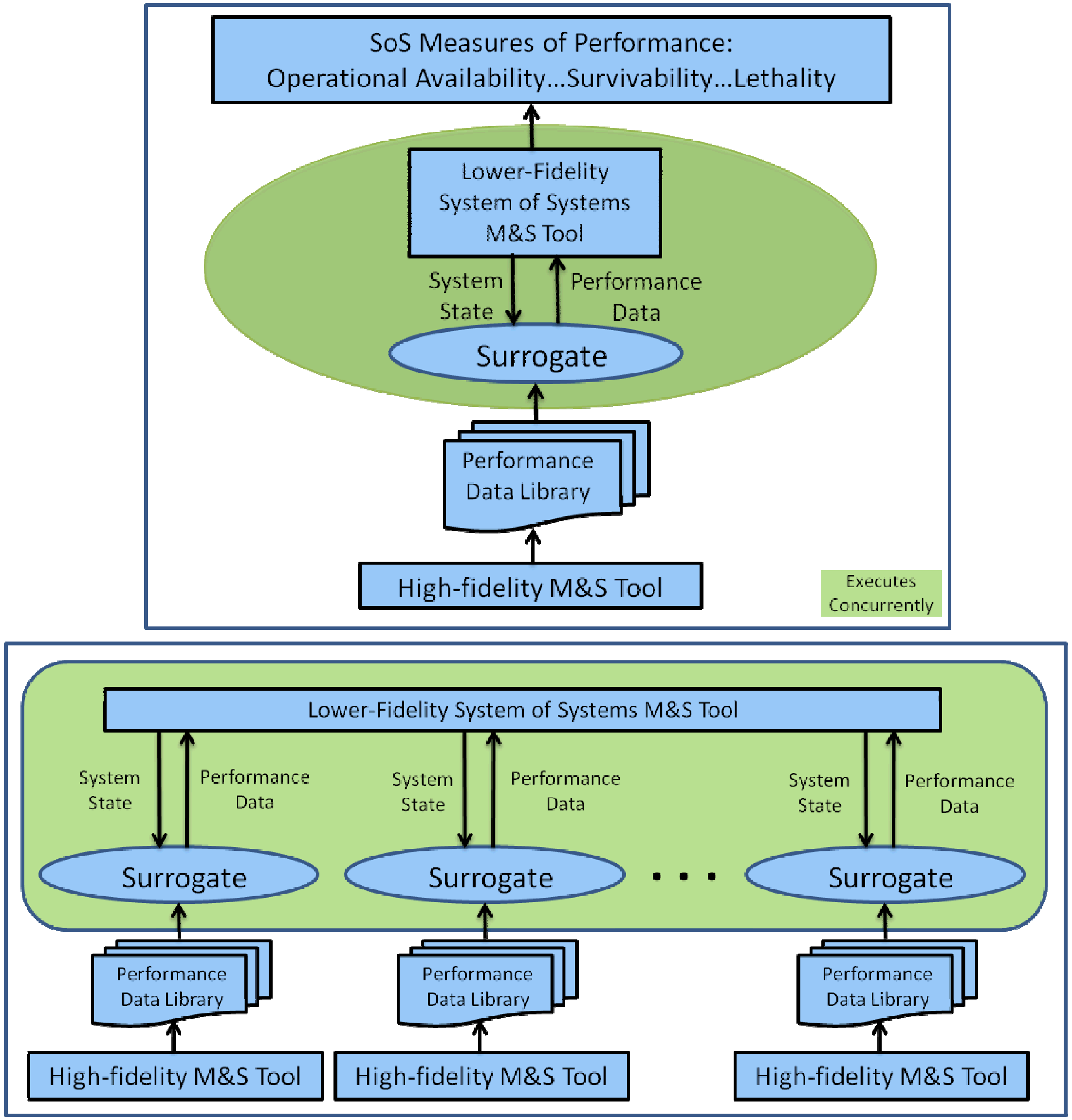


Complex System of Systems (SoS) Analysis problems often require information from multiple, highly diverse Modeling and Simulation (M&S) tools, for example: System-of-Systems (SoS), Logistics, Networked Communications, Force-on-Force (FoF), and others

This work provides an integrated architecture and methods for using information between diverse M&S tools.

This approach enables SoS-level analyses that leverage a wide range of high-fidelity information obtained from other sources.

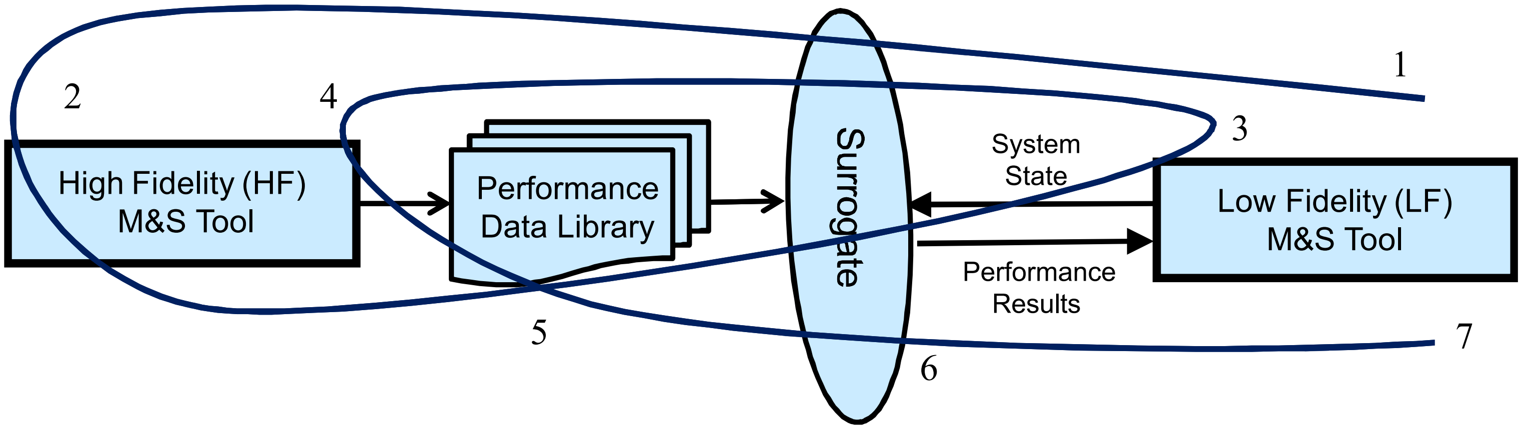
M&S Information Linkage Architecture



- General purpose methodology uses intermediate surrogate model to bridge the information gap between diverse modeling and simulation tools
- Decoupled architecture allows M&S tools to run asynchronously, enabling statistical characterization of high-fidelity performance information
- Intermediate surrogate model provides real-time, dynamic access to high-fidelity performance characterizations as SoS state changes
- Approach allows for linkage between many diverse M&S tools simultaneously – only limited by compute power

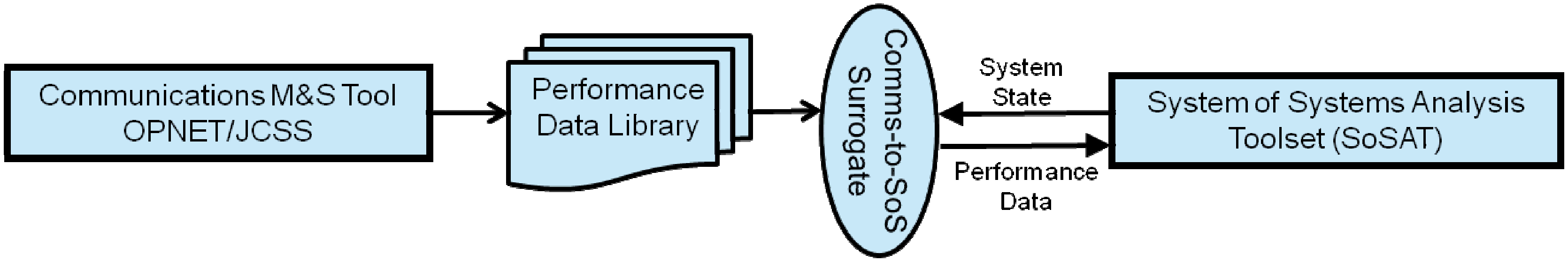
Multi-Step M&S Linkage Process

Process employs an iterative, systems engineering approach where the driving force is the customer question



1. Define Question to be answered by Low Fidelity(LF) M&S tool
2. Scenario Definition: What are scenario(s) that apply to this specific question?
3. Define LF information parameters needed to answer the question and the subset of dynamic parameters that comprise the System State
4. Define High Fidelity (HF) parameters and measures of effectiveness (MOEs) needed supply surrogate and LF tool with necessary information
5. Define information to be stored in data library and required data processing/transformations
6. Specifications of information that surrogate will provide to LF (SoS) tool
7. Define LF (SoS) experiments and outputs

Example Linkage Using this Approach: High-Fidelity Communications-to-SoS



- Driver of this study is the System of Systems level (SoS-level) analysis
- Situational Awareness (SA) applications depend on communication system performance
- Driving Question: ***What is SA availability at a SoS-level with various communication technologies and operating conditions?***
  - Varying network configurations: 1) wireless, ground-based military radio 2) Unmanned Aerial Vehicle (UAV) with comms relay, 3) satellite
  - Vary node densities and number of relay points available
  - UAV available or not
  - Varying background traffic, terrain and mission conditions

Provide quantitative SoS-level assessment of communications application performance under different operating conditions

Communications Modeling: OPNET Modeler™ with JCSS

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- OPNET Modeler provides communication network modeling and simulation with detailed protocol modeling and analysis
- Joint Communication Simulation System (JCSS) provides military network and radio/protocol models
- Use case employs notional OPNET/JCSS MITRE developed scenario
  – company-level deployment, mobility pattern that includes non-line-of-site, 20 platforms, 20x20 km area, random seed
- Approach can employ various military radio configurations (used CSMA and High-Data Rate (HDR))
  - Issues impacting platform-to-platform connectivity: line-of-sight(LOS) between source-destination pairs, LOS to relay platform, network or relay node congestion, offered load
- Performance Data Library created by capturing comms measures of performance (MoPs) over multiple simulation runs
  – Variations: networks, # relay points, background traffic, etc.
  – MoPs: Comms application availability (mean up time) and mean time to repair (mean down time)

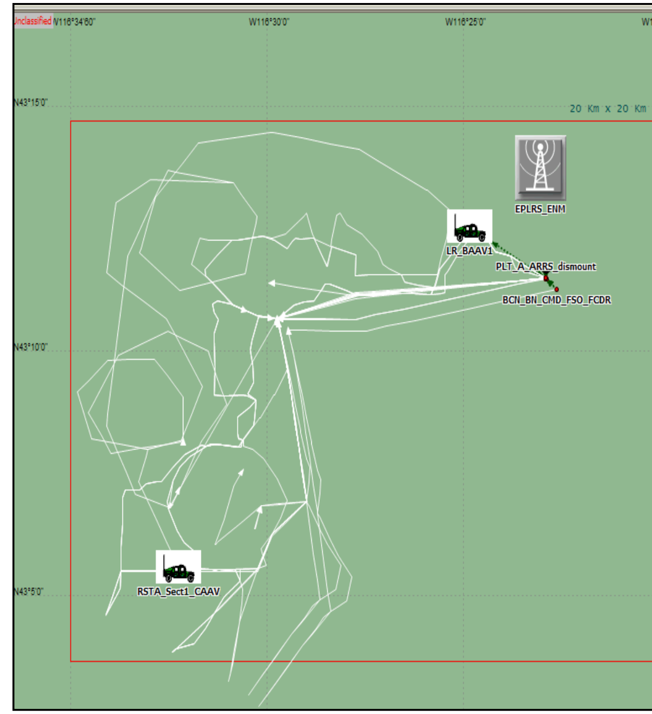
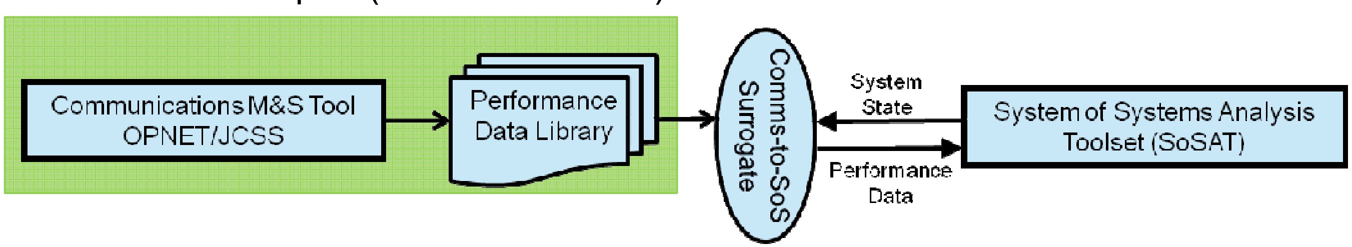
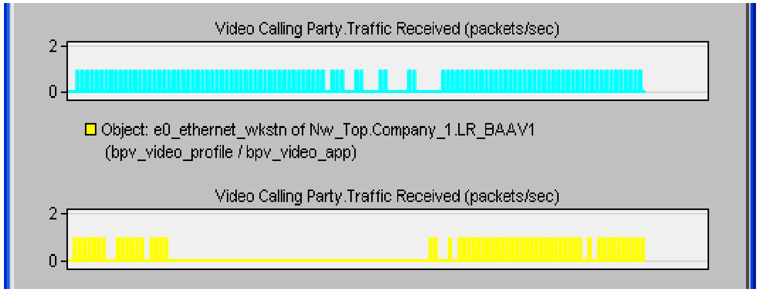


Figure depicts the initial platform locations and white traces illustrate the path taken by each node in the 20 km x 20 km area during the simulation.



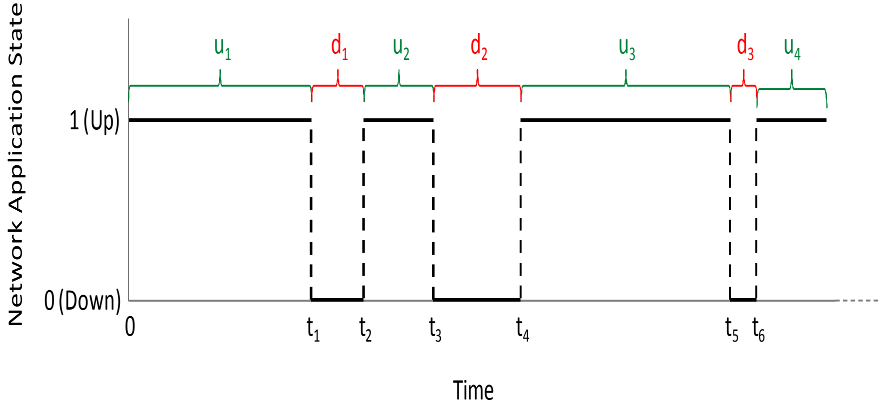
High-fidelity Comms Modeling

- Focus was on network protocol simulation, not high-fidelity wireless channel modeling (not considering multipath, fading effects)
- Periodic pings of network determined availability
  - Multiple simulations were run with different random seeds
  - Results were averaged since SoS availability does not consider specific platform location
  - Results were combined to create probability distribution for SoS MoPs



Example Up time and Down Time of a Military radio channel for a two-hour mobility pattern (scenario)

- Mean Up Time (MUT) and Down Time (MDT) calculations



$$MUT = \frac{1}{n_u}\sum_{i=1}^{n_u} u_i, \text{ where } n_u = \text{number of up periods}$$

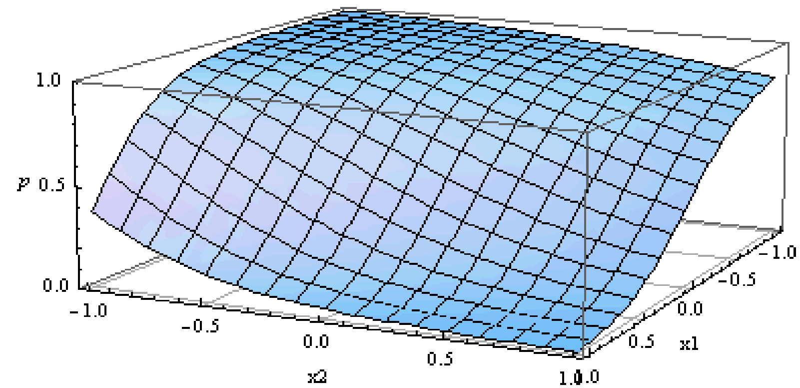
Used to derive Comms Application Availability in Surrogate

$$MDT = \frac{1}{n_d}\sum_{j=1}^{n_d} d_j, \text{ where } n_d = \text{number of down periods}$$

Used to derive Mean Time to Repair in Surrogate

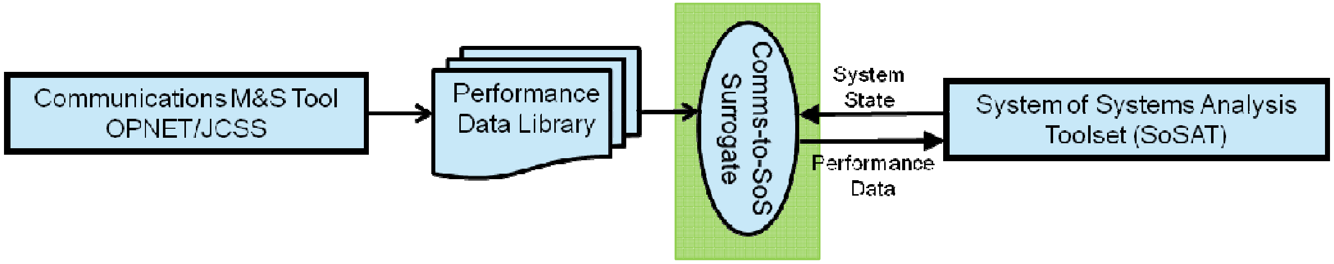
Intermediate Surrogate Model

- Objective of Surrogate: For a given set of inputs, produce an output that corresponds as closely as possible to the high-fidelity model output for the same inputs
- We used a multi-dimensional, best-fit response surface approach to develop the intermediate surrogate models for the ground-base radio and satellite networks



Example response surface depending on two parameters x_1 and x_2

- This approach
  - Provides rapid, intermediate estimates for states which do not have exact high-fidelity results
    - Running high-fidelity model for specific intermediate points is not feasible
  - Provides *dynamic* estimates based on current SoS system states
  - For this example, the communications surrogates provide SoSAT with:
    - Communications application failure rate (1/mean up time)
    - Average time to repair (equivalent to mean down time)



Experimental Design for Comms Surrogate

Experimental Design for Network Surrogate in JCSS				
Case	Network Type	Relay Node	Node Density	Offered Load
1	Ground-based	OFF	10	0%
2	Ground-based	OFF	10	45%
3	Ground-based	OFF	10	90%
4	Ground-based	OFF	20	0%
5	Ground-based	OFF	20	45%
6	Ground-based	OFF	20	90%
7	Ground-based	ON	10	0%
8	Ground-based	ON	10	45%
9	Ground-based	ON	10	90%
10	Ground-based	ON	20	0%
11	Ground-based	ON	20	45%
12	Ground-based	ON	20	90%
13	Satellite	N/A	N/A	0%
14	Satellite	N/A	N/A	45%
15	Satellite	N/A	N/A	90%

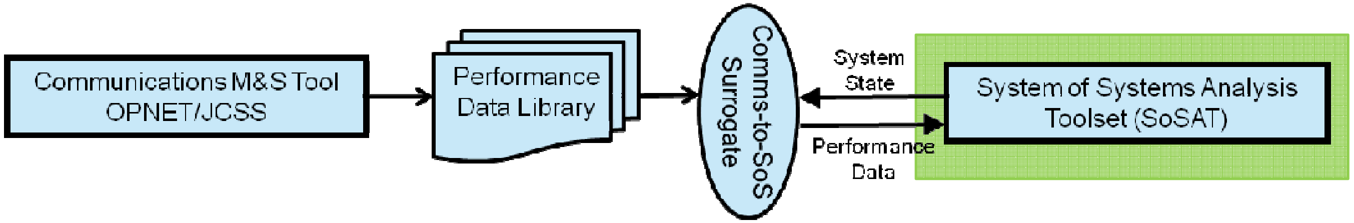
Definitions:

- Relay Node: State of relay node
- Node Density: Number of operating communication nodes distributed over 20km x 20km area
- Offered Load: Total traffic = Traffic for Application of interest + Background Traffic + ping traffic (fraction of link capacity)

- Surrogate Model Development:
  - High-fidelity comms simulations were conducted and best-fit, reduced, response surface models were developed to provide MUT and MDT response surface models for both the ground based military radios, with and without relay/UAV, and the satellite network.
  - The SoS tool required failure rate = 1/MUT ➔ application availability
  - MDT represents Mean Time to Repair (MTTR) needed by SoS tool

Sandia Laboratories-Developed SoS Analysis Toolset (SoSAT)

- Time-based, stochastic modeling and simulation tool that models multi-echelon activities and assesses SoS operations
- Simulate *any or all* of a SoS hierarchical organizational structure and multiple mission segments
- Basic Modeling Features
  - System element reliability failures
  - Consumable usage and depletion
  - Maintenance activities including any spares, services and supply reorder
- Advanced Modeling Features
  - Combat Damage Modeling
  - Network Modeling
  - Prognostics and Health Management
  - Time-Based changes to model attributes (External Conditions)
  - System Referencing (interdependencies)
- Provides data to assess key performance objectives
  - Operational Availability (Ao), Foot print reduction and trade-off decisions
- Formally Verification, Validation & Accreditation by AMSAA and NPGS

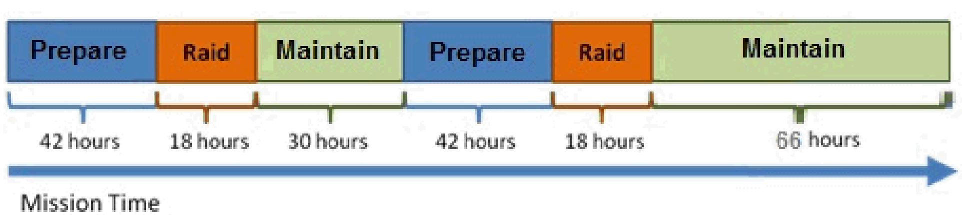


SoSAT Model Specifications

- System functions in SoSAT are defined by Boolean equations and measure the availability of specific system functionality:

System Functions	Definition	Description
Operability	System's availability to operate and communicate	System unavailable due to comms node failure, loss of line-of-sight, or combat damage. Operability fluctuates with node denisty.
Network Availability	Network's ability to support the comms application given current system state	Independent of comms hardware operability. Depends on failure rate and average down time. System state = node density, level of offered-load, and comms network type
SA Application Availability	SA application functionality, includes operabilty *and* network availability	Describes the availability of a comms application. Combination of comms hardware availability and network availability. Based on current system state.

- The functional SoS performance is simulated across a pre-defined scenario or mission. For this notional example, the high OPTEMPO segments are the Raids and the mission specification is as follows:



Example Performance Results of Comms-to-SoS Linkage

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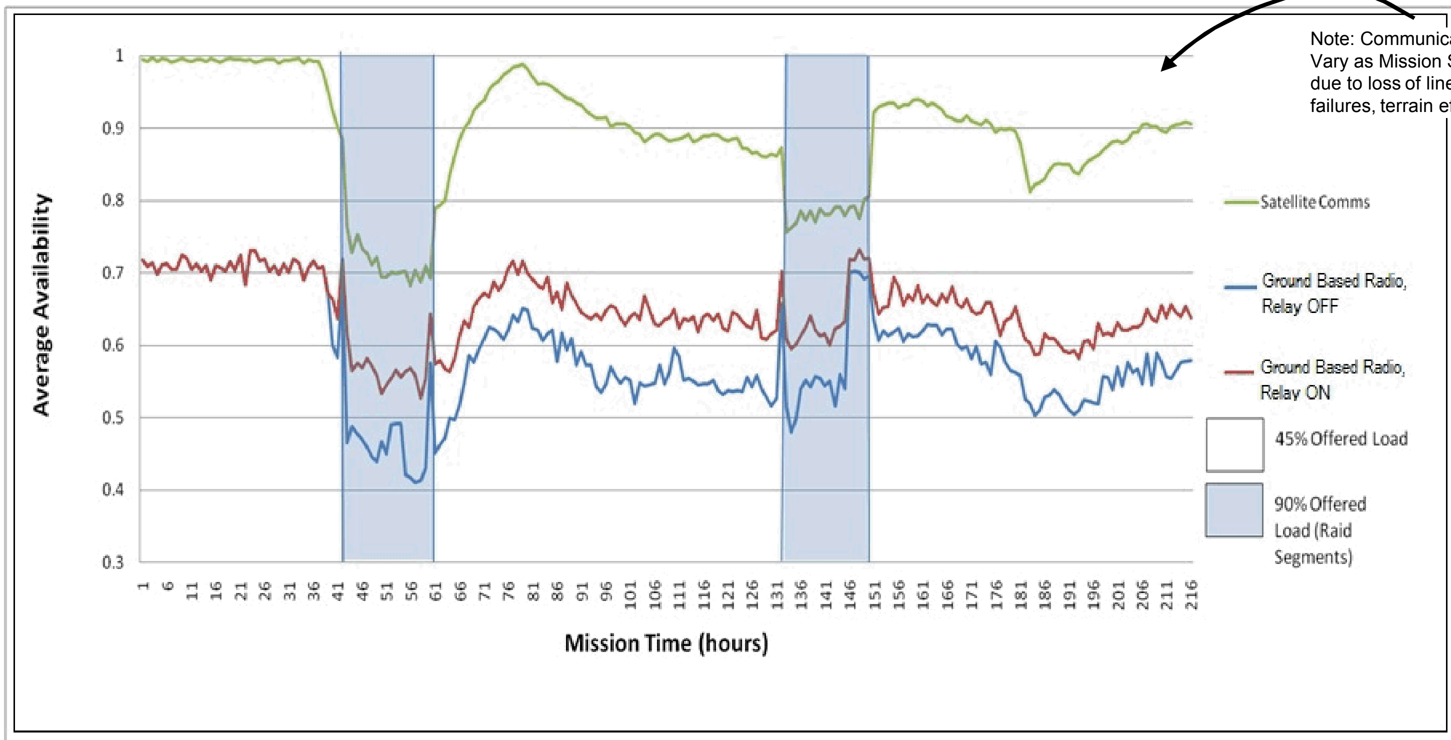
SoS-level Situational Awareness Availability
Network Type: Ground-based Radio versus Satellite
Varying Operating Conditions: OPTEMPO, node densities, background traffic and network type



Approach enables impacts of high-fidelity communication information to be explored at a SoS-level

Conclusions

- Benefits of this approach:
  - Allows information to be used between diverse M&S tools in a dynamic, efficient way
  - Increases fidelity of SoS results by incorporating high-fidelity, statistical performance information based on dynamic SoS state
  - Provides a useful alternative to expensive, brute-force, high-fidelity simulations that would be impossible to execute in parallel
- Future work includes
  - Exploring the general applicability of the methodology to a wider range of scenarios and M&S tools
  - Metric identification and mapping scenarios to dynamic parameters
  - Exploring alternative surrogate implementations, technologies and methodologies
- The methodology and approach are ready to be leveraged in new research and application projects – we are actively seeking partnerships

**** QUESTIONS? *** THANK YOU ****

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