A Large Scale Enterprise Level Systems of Systems Simulation Tool

Gio K. Kao, PhD & Steven M. Handy

gkkao@sandia.gov  smhandy@sandia.gov

Sandia National Laboratories
Albuquerque, NM 87135

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Outline

• Motivation

• The Simulation Tools

• Features

• Summary
Motivation

The beginning:

– Simulation capability motivated by the US Army’s need to analyze a brigade-level System of Systems (SoS)
  • SoS analysis is necessary to capture interrelationships in a complex large-scale logistics and sustainment environment
  • Analysis support provide to
    – US Army Program Manager Future Combat Systems Brigade Combat Team (PM FCS (BCT))
  • Analyzes focused on quantify impacts to changes in reliability, maintenance, and supply requirement and CONOPS

– SoSAT (System of Systems Analysis Toolset)
  • System of Systems State Model tool
  • Stochastic simulation tool
  • Advanced data visualization tools
  • Optimization tools

SoSAT provides modeling capabilities for sustainment and logistic analysis of a large system of systems
SoSAT Overview

- SoSAT provides analysis capability:
  - SoSAT is a SoS tool that can simulate detailed organizational operation over a defined mission or set of missions
  - Simulates any or all of a system of systems organizational structure
- Typical Problem Dimensions
  - Force structure consisting of over 1500 platforms organized at company level
  - Average of more than 200 elements per platform
  - Multiple day mission
  - Includes fuel, water, ammo utilization, storage and distribution
  - Includes spares and supplies optimization analyses
- Features
  - Element reliability failures, consumable depletion
  - Maintenance modeled with repair time distributions and any spares or services required for the repair
  - Supply reorder for consumables and spare inventories
  - Combat damage modeling
  - Network modeling
  - Prognostics and health management
  - External conditions and external references
System of Systems Analysis Toolset (SoSAT) Enterprise

The evolution:

- Capability motivated by the US Army's need to assess long-term life-cycle operations and support (O&S) metrics and cost beyond the brigade level

- Enterprise expansion (SoSAT Enterprise)
  - Built on top of SoSAT simulation
  - Expanded analysis scope to multiple brigades (entire fleet) and support infrastructure
  - Supply and repair-chain logistics simulation tool
  - Inventory management
  - O&S cost constraints
  - Resources and personnel workflow

- Enhanced simulation performance
  - New architecture coupling SoSAT
  - Multi-layered discrete event queue
  - Performance tuning
Enhanced Simulation Performance: The Event Queue

- **Combination of a Calendar Queue and Lazy Queue**
  - Adaptive: Adjusting number of buckets and width
  - Multi-layers to help with multi-modal distribution of events
  - Hand-tuned for performance

- **Dumping**
  - Only a single sorted list of *near* events
  - *Far* events are “dumped” to different data structures as time advances

- **Rebinning**
  - Adjust the number of buckets and barrels
  - Design to help handle skewed distributions (surges of events)
  - Barrels cover most events
  - Buckets sized to limit the number of sorted elements

Event Queue Data Structures

- Glacier
- Plug
- Cistern
- Barrels
- Buckets
- Cup
- Fired event

Time Covered

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SoSAT Enterprise Expansion

- **SoSAT Enterprise** provides analysts the capability to:
  - Support business decisions at a global logistics scale
  - Determine cost drivers for life-cycle analysis
  - Perform trade studies with various performance metrics
  - Assess impacts of architecture changes on performance metrics

- **Basic modeling features** include the simulation of:
  - Global logistics infrastructure including transportation
  - Support structure
    - Supply and repair chain management
    - Resource usage at multiple echelons
  - OEM capabilities with build models
  - Detailed task modeling

- **SoSAT Enterprise Problem Scale**
  - Multiple Brigades
  - Thousands of systems
  - Hundreds of sites worldwide
  - Hundreds of types of support equipment
  - Multiple personnel skill types
  - Simulate multiple years of operation

Arbitrary multi-echelon support structure
Global Enterprise Model

- Sites Definition
  - Resource Model
  - Workflow Model
  - OEM Build Capability
- Repair Chain Management
- Supply Chain Management
- Transportation Model
- Enterprise Cost

Simulation Parameters

<table>
<thead>
<tr>
<th>Settings</th>
<th>Value</th>
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<tbody>
<tr>
<td>Number of Simulation Trials</td>
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<td>Random Seed</td>
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<td>Simulation Duration (hr)</td>
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<td>Simulation Time Step (hr)</td>
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<tr>
<td>Details Interval</td>
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Options

- Enable Network
- Save Parts Inventory Details
- Save Consumables Inventory Details
- Enable Enterprise Model
- Save Summary Output
- Save Event Output
Sites Definitions

- **Types**
  - Base (repair, supply)
  - Supply Depot
  - Repair Depot
  - OEM (repair, supply, build)

- **Activation/Deactivation**
  - Initiation/Termination of sites

- **Shipping/Delivery Time**

- **Operational Hours**

- **Time Zone/Location**

- **Cost Multiplier**

---

**Site Definitions**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Activation Time</th>
<th>Deactivation Time</th>
<th>Supply Chain</th>
<th>Repair Chain</th>
<th>Schedule</th>
<th>Pay Multiplier</th>
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</thead>
<tbody>
<tr>
<td>EU Base</td>
<td>Base</td>
<td>1/1/2050 12:00 AM</td>
<td>1/1/2100 12:00 AM</td>
<td>Supply base-to</td>
<td>Repair base-to</td>
<td>Daily-24/7</td>
<td>1</td>
</tr>
<tr>
<td>OEM Electronic</td>
<td>OEM</td>
<td>1/1/2050 12:00 AM</td>
<td>1/1/2100 12:00 AM</td>
<td>Supply base-to</td>
<td>Repair base-to</td>
<td>Daily-24/7</td>
<td>1</td>
</tr>
<tr>
<td>OEM Mechanical</td>
<td>OEM</td>
<td>1/1/2050 12:00 AM</td>
<td>1/1/2100 12:00 AM</td>
<td>Supply base-to</td>
<td>Repair base-to</td>
<td>Daily-24/7</td>
<td>1</td>
</tr>
<tr>
<td>Repair Depot Electronic</td>
<td>Repair</td>
<td>1/1/2050 12:00 AM</td>
<td>1/1/2100 12:00 AM</td>
<td>Repair</td>
<td></td>
<td>Daily-24/7</td>
<td>1</td>
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<tr>
<td>Repair Depot Mechanical</td>
<td>Repair</td>
<td>1/1/2050 12:00 AM</td>
<td>1/1/2100 12:00 AM</td>
<td>Repair</td>
<td></td>
<td>Daily-24/7</td>
<td>1</td>
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<td>Supply Depot Electronic Supply</td>
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<td>1/1/2100 12:00 AM</td>
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<td>Supply</td>
<td>Daily-24/7</td>
<td>1</td>
</tr>
</tbody>
</table>

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Sites: Resource Model

• Use of resources to perform work
  – Build, supply, repair, maintenance
  – Schedule/shift dependent

• Support Equipment (Hourly)
  – Lifecycle with replacement
  – Scheduled/Unscheduled*

• Maintenance
  • Operational Age*, Times Used, Calendar Hour

• Personnel
  – Employee (Salaried)
  – Contractor (Hourly)
Sites: Workflow Model

- Workflows (sequences of tasks)
  - build (parts/consumables), supply, repair, maintenance

- Task Details
  - Time distribution
  - Resource(s) needs
  - Penalty
  - Cost
Sites: OEM Build Model

- Parts and consumables can be built/generated at OEM(s)
- Depleted inventory → generates build order for parts/consumables
- Batch quantity
- Detailed build workflows
- Excess parts/consumables are stored at OEM for future supply requisitions
Repair Chain Management

- System Failure Requiring Spares
  - Flow of failed parts defined by the repair chain
  - Repair levels (probability)
    - Disposal (system level), Test Serviceable, Site Levels
  - Repair workflow(s)
- Repaired Parts
  - Re-enter system via supply chain (based on originating platform)
- Multi-echelon repair chains
Supply Chain Management

- **Supply flow**
  - Spare parts and consumables
  - Demand generated from Systems

- **Inventory control**
  - Standard (s,S) re-order strategy
  - Stock levels, overstock rule
  - Supply type workflow
    - Requisition processing, Issue Spares, Restock, Order placement, Return Item

- **Flexible, multi-echelon supply chains**
- Transportation of parts & consumables
- Transport activities for items occur:
  - From system to site
  - Between sites
  - From site to system
- Transportation parameters
  - Delivery windows
  - Cargo type/volume/priorities
  - Shipping time (distribution)
  - Time zone/location zone
- Transportation Rules
  1. Cheapest cost within defined standard
  2. Shortest transport time
Dynamic Simulation Changes

- **Model attributes can be changed over time**
  - **Inventory Rules**
    - Modification of re-order strategy
    - Capability to model surges in demand, changes in operating strategy, etc.
  - **Activation/Deactivation of Sites**
    - Sites can be interrupted/disabling transportation
    - Capability to model attacks, transpiration cut-offs, worker strikes, closing of a plant, etc.
  - **Resource Changes**
    - Modification to the type and number of support equipment and personnel at a site.
    - Capability to model worker strikes, deployment of resources, site specific scenarios, resource constraints, etc.
  - **Inventory Changes**
    - Inventory levels of specific parts can be add or removed between sites
    - Capability to model shortages, surges, deployment, etc.
Enterprise Cost

- **Support Equipment Cost**
  - Initial SE Invest
  - SE Usage Cost
  - SE Maintenance
  - Replace SE Invest
- **Parts Related Cost**
  - Initial Part Invest
  - Initial Consumable Invest
  - Replenish Part & Consumable
- **Labor Cost**
  - Task Cost
  - Employee Pay
  - Contractor Pay
- **Transportation & Storage Cost**
  - Inventory Storage
  - In-Bound Transport
  - Out-Bound Transport

Enterprise Cost By Site for 5 Sites

- SE Initial: 45.32%
- SE Replacement: 0.75%
- SE Scheduled Maintenance: 0.15%
- SE Unscheduled Maintenance: 0.12%
- SE Usage: 12.42%
- Initial Part Invest: 5.12%
- Initial Consumable Invest: 6.78%
- Replenish Part & Consumable: 4.60%
- Task Cost: 3.08%
- Employee Pay: 0.75%
- Contractor Pay: 0.15%
- Inventory Storage: 1.26%
- In-Bound Transport: 1.00%
- Out-Bound Transport: 1.00%

Total: 707,547.00
Results

Multiple Systems Roll-up Availability vs. Time

Individual Systems Details

Sustainment - Provider Services Details
Summary

• **High fidelity simulation**
  – Repair and supply chain simulation
  – Resource contentions
  – Multi-echelon distribution structure
  – Dynamic simulation changes
  – Detail workflow modeling

• **Efficiency**
  – Custom novel architecture
  – Hybrid of an adaptive calendar queue and lazy queue

• **Future Development**
  – Modeling overhaul/recap/reset of systems
  – Higher fidelity for repair and supply chain (SRU level)
  – Integrated optimization capabilities
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