A Value Proposition for Applying MBSE to Discrete Manufacturing Systems

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BLUF: The goal of the Model Based Enterprise will not be fully realized without Model-Based Production Systems.

Model-based Industrial and Systems Engineering (MBISE) combines the principles, methods, and tools of model-based systems engineering with those of industrial engineering, et al.

- Domain-specific system knowledge and analysis methods and tools
Overview

• Production and Production System Lifecycles
• Stakeholders
  • **Product** Systems Engineers
  • **Production** Systems Engineers
• Value Proposition
  • Systems Engineering Methods
  • Model-based Methods
• What does MBISE look like?
• Realizing this Value Proposition
  • Model Libraries & Documentation
  • Playbook
  • Community of Interest
Product and Production System Lifecycles

**Life Cycle Stages**

**Exploratory**
- Investigate new opportunities
- Explore technology readiness
- Evaluate pre-concept match with users’ needs

**Concept**
- Identify stakeholders needs
- Evaluate alternate concepts
- Recommend possible solutions

**Development**
- Develop detailed planning
- Identify and manage risks and business opportunities
- Perform IV & V activities

**Production**
- Produce systems
- Inspect and Test

**Utilization**
- Operate system to satisfy users' needs

**Support**
- Provide sustained system capability

**Retirement**
- Store, archive or dispose of system

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**ALTERNATIVE DECISION GATE OUTCOMES**

- Proceed to next stage
- Proceed but open action items must be resolved
- Not ready; repeat the previous stage
- Terminate the project

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INCOSE Systems Engineering Handbook (INCOSE 2012) —
Product and Production System Lifecycles

Product and production system lifecycles intersect at the point of production (left), but are intertwined much earlier (right).

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Stakeholders: Product system engineers

- Design2Manufacturing or Design4Manufacturability
  - Product designs become requirements (constraints) on the production system
  - Validation of some product requirements requires feedback from production system design
    - Can I make this?
    - How much?
    - Durability, maintainability, lifespan? (Sustainment concerns)
    - How many can I make? (more of a CONOPS validation)
- MBSE methods applied to manufacturing system improves quality & timeliness of feedback cycle
- There’s blind spot for production systems, how do we mitigate this risk?
Contemporary practice is a combination of copying what has worked in the past and using improvement strategies to deal with shortcomings in design.

- Systems Engineering (SE) adds rigor to design process
  - Communication – Use Cases, Requirements, & Assumptions
  - Requirements and Validation
  - Lean is not a substitute for SE -- some mistakes can’t be fixed

- Model-Based Methods add rigor to the specification
  - Communication – specification of the artifact, formalized knowledge reuse
    - Integration of structural/behavioral specifications
  - Interoperability -- data and systems
  - Analysis integration (and accessibility)
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Value of Systems Engineering Methods

• Communication
  • Articulate use cases and requirements (constraints & assumptions)
  • Think about the system and its context

• Lifecycle awareness
  • Organization of what questions we should be asking and what models we should be building to answer those questions

• Requirements, Design, & Validation
  • Design comes before optimization
  • Need rigorous functional design and decomposition

• We need a better understanding (or articulation) of how we validate system designs for these kinds of systems.
  • Simulation is most likely the answer, but the current state-of-practice leaves much to be desired to address this role.
Value of Model-based Methods

• Value of “models” is to enable:
  • Greater clarity from precision of language
  • Shared understanding: structure, behavior, requirements, goals, constraints
  • Knowledge documentation and reuse
  • Traceability of assumptions
  • Decision support analyses: consistently, repeatably, creating, exercising analyses
  • Consistency, reliability: decision making best practices
  • Speed/cost: automating repetitive/reusable analyses
  • Bottom line—better, faster, cheaper decision making

• Standards: What does model-based offer above and beyond SE with standard information models?
  • Formalized harmonization
  • Computational models enable inference and automation
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What does MBISE look like? Product Definition
What does MBISE look like? Process Definition
What does MBISE look like? Resource/Facility Definition
A lot is going to change....

So, what this says is that practice will change dramatically. But this will take time, and practitioners will have to have some confidence about what they are changing “to”. Clearly, a lot of research, development, and education lies between where we are and where we need to be. How is that going to happen? And what are the consequences if it doesn’t happen?
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What are DELS?

**Discrete event logistics systems (DELS)** transform discrete flows through a network of interconnected subsystems.

- These systems share a common abstraction, i.e. *products* flowing through *processes* being executed by *resources* configured in a *facility* (PPRF).

**Examples include:**

- Supply chains
- Manufacturing systems
- Transportation
- Material handling systems
- Storage systems
- Humanitarian logistics
- Healthcare logistics
- Sustainment Logistics
- Reverse and Remanufacturing Logistics
- And many more ...
Overview: DELS-related Products

• Model Libraries
  • https://github.com/usnistgov/DiscreteEventLogisticsSystems
    • Email timothy.sprock@nist.gov for access (need github account)

• Documentation (DRAFT)
  • Overleaf: https://v2.overleaf.com/read/hhsmnkssjwcp

• Reference Implementation of SAI (Matlab)
  • https://github.com/usnistgov/dels-analysis-integration
    • Email timothy.sprock@nist.gov for access (need github account)

• MBISE Playbook – How to apply DELS model libraries
  • INCOSE Production and Logistics Systems Modeling Challenge Team
  • Overleaf (DRAFT): https://v2.overleaf.com/read/rsjqlqzwmxtxq
  • http://www.omgwiki.org/MBSE/doku.php?id=mbse:prodlog
SysML Model Libraries

Overview: Model library and ontology to support building conceptual and logical models of production and logistics systems.

Two libraries:
- Network Abstractions
- DELS Abstractions

https://github.com/usnistgov/DiscreteEventLogisticsSystems
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- Each element is elaborated with taxonomies and model libraries
- Draw upon standards such as ISO MANDATE (ISO 15531), EBC (ISO 16400), MTConnect, ISA-95 (IEC 62264), etc.
Examples – Process & Resource Taxonomy

- “Upper” abstractions help map to key analysis model libraries
- Domain-specific model libraries specialize these into more concrete elements
Overview: Description of the DELS modeling framework and model libraries. Includes SysML diagrams (views).

Documentation (Draft): https://v2.overleaf.com/read/hhsmnkssjwcp

1. Introduction
2. Modeling Framework
3. Network Abstractions
   3.1 Basic Networks
   3.2 Flow Networks
   3.3 Process Networks
4. Discrete Event Logistics Systems
   4.1 Resource
   4.2 Process
   4.3 Product
   4.4 Facility
   4.5 Task
   4.6 Interfaces
5. DELS Operational Control
   5.1 Operational Control Model Library
   5.2 DELS Controller
6. Extended DELS Definition
7. Specializing DELS
8. Composing Specialized DELS
Analysis Integration

- Integrate several analysis toolboxes (Matlab)
  - Optimization
  - Queuing Analysis
  - Discrete-event simulation (SimEvents)

- Two test cases
  - Supply chain to flow network optimization to discrete event simulation (multi-fidelity)
  - DELS to queuing network to discrete event simulation
  - (PLANNED) Discrete Manufacturing Example

- Related Projects:
  - Model-based simulation optimization interoperability
  - Repeatable/reusable methods of building discrete event simulation models

https://github.com/usnistgov/dels-analysis-integration
Email timothy.sprock@nist.gov for access
Disclaimer: Far less mature w/ limited documentation
System-Analysis Integration Methods: Extending M2M Methods Based on DELS Abstraction

Domain Models:
1. Manufacturing Facility #1
2. Manufacturing Facility #2
3. Warehouse
4. Material Handling System
5. Transportation Logistics

Object-oriented, DELS-Based Transformations:
- Manufacturing #1
- DELS Networks

Analysis Tools/Models:
1. Discrete Event Simulation
2. Queueing Analysis
3. Mean-Value Analysis
4. Resource Investment
5. Scheduling
6. Optimization Models
7. Production & Inventory Planning

Layered abstraction is IMPORTANT!
On-going Work

- Focus on smart manufacturing
  - Integrate manufacturing library (m-SysML) from DARPA iFab project
  - Develop case study – possibly leading to a model-based virtual testbed
- Continue to refine the operational control model library
- Mature the system-analysis integration reference implementation
  - Add case studies to support manufacturing and operational control
  - Identify other discrete event simulation platforms for integration
    - Work towards PIM of discrete event simulation for manufacturing operations
Objective: Increase the availability of reference models, awareness of these models and methods, and successful use of MBSE in the production, logistics, and industrial engineering communities.

Specific challenges in providing a foundation to production and logistics [systems] engineering are the lack of:

- Standard reference models
- Well-structured engineering design methodologies
- Integrated analysis models and tools available to support design and operational decision-making.


Telecon every Friday at 11am Eastern
Roadmap - Identify a Case Study

• “... advancing the practice and adoption of formal system modeling and model-based systems engineering methodologies in production and logistics systems development and operations.”

• “Do you have any examples to get me started?”

• Identify small case study to model
  • Include all SysML diagrams and syntax
  • Domain-specific concepts:
    • Product, Process, Resource, & Facility
    • How do you control your system?
    • What do you want to know about the system?
    • System Architecture
Overview: ‘How-to’ guide on applying constructing system models using the DELS framework and model libraries

Document (Preview):
https://v2.overleaf.com/read/rsjqhzmxtxq

More Details:

SysML Models (Coming Soon):
https://github.com/usnistgov/DiscreteEventLogisticsSystems
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Thank you!

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