A Value Proposition for Applying MBSE to Discrete Manufacturing Systems

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NIST
National Institute of Standards and Technology
U.S. Department of Commerce

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

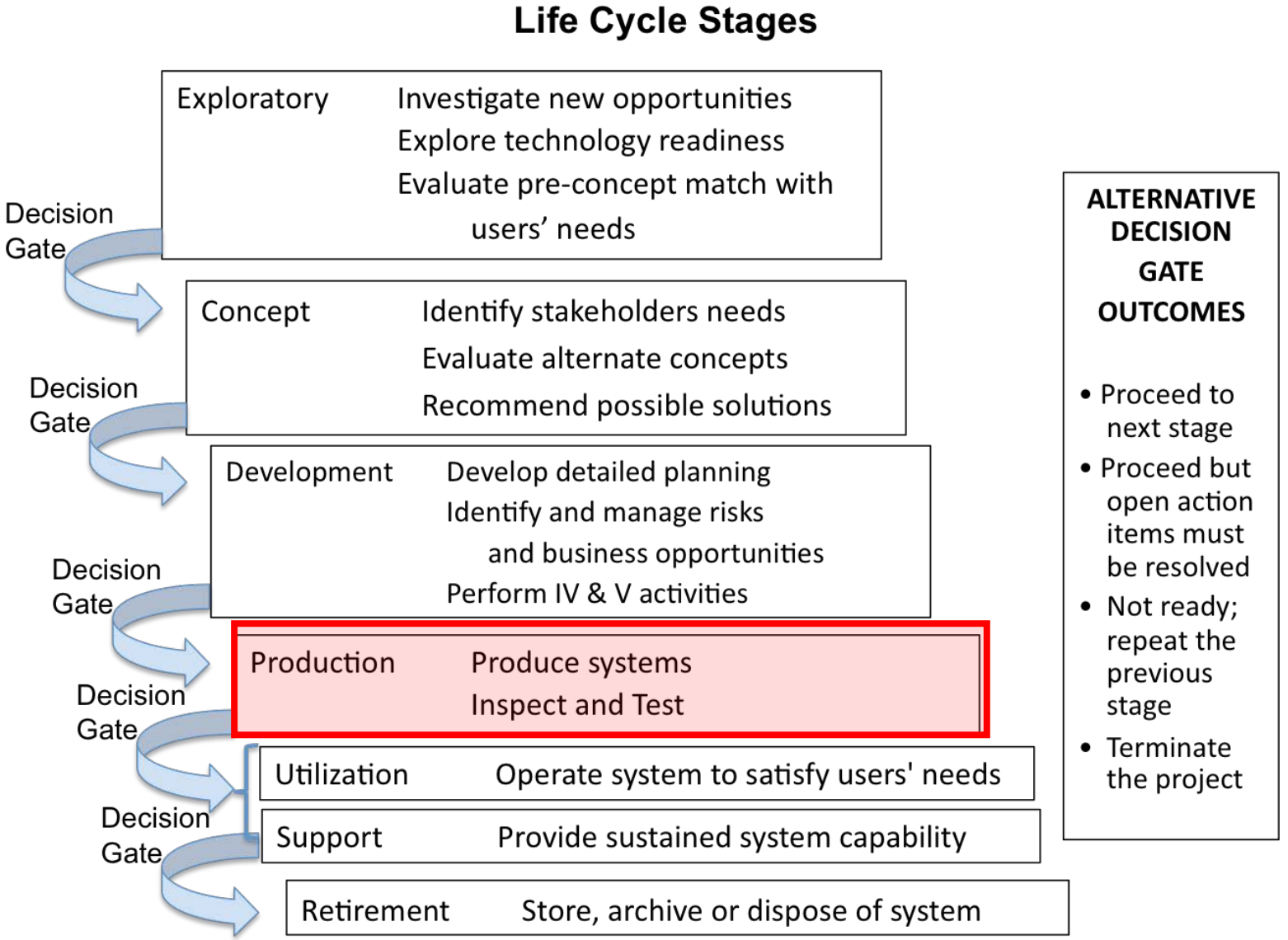
Model-based Industrial and Systems Engineering (MBISE) combines the principles, methods, and tools of model-based systems engineering with those of industrial engineering, et al.

- 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

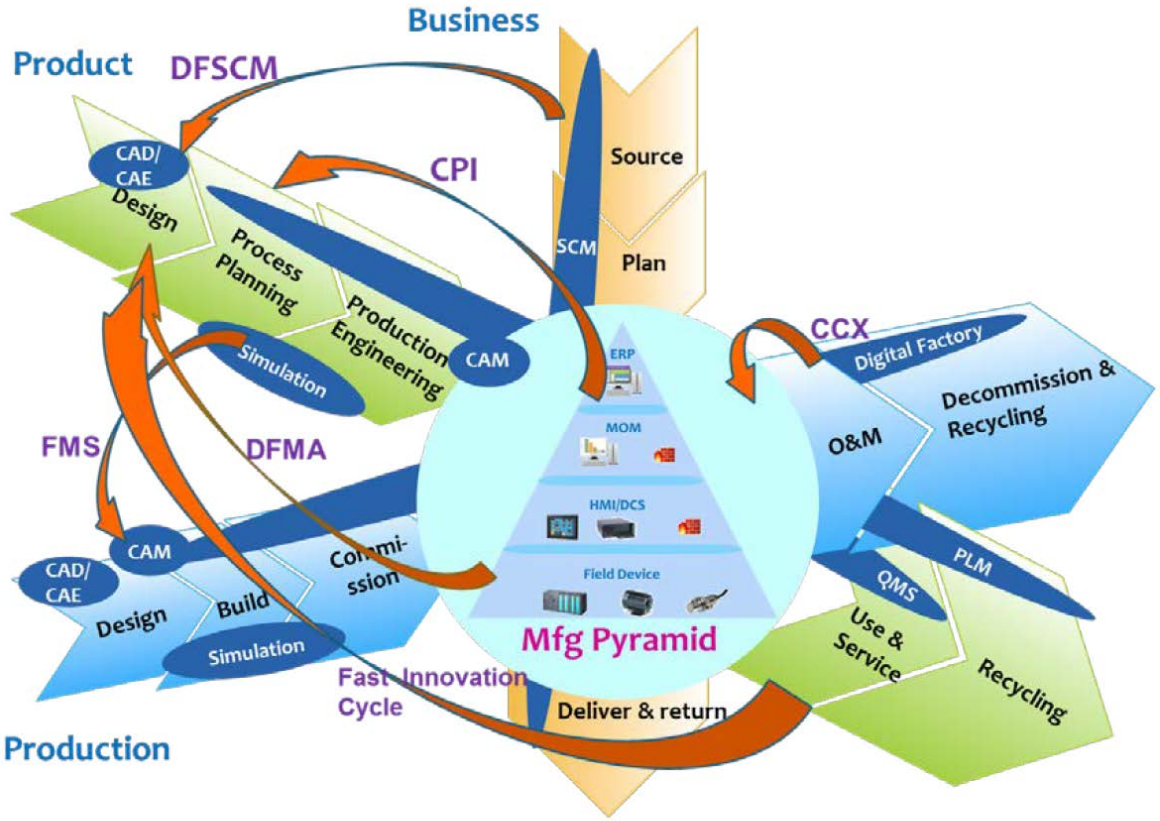
Product and Production System Lifecycles



INCOSE *Systems Engineering Handbook* (INCOSE 2012) – https://www.sebokwiki.org/wiki/System_Life_Cycle_Process_Models:_Vee

Product and Production System Lifecycles

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



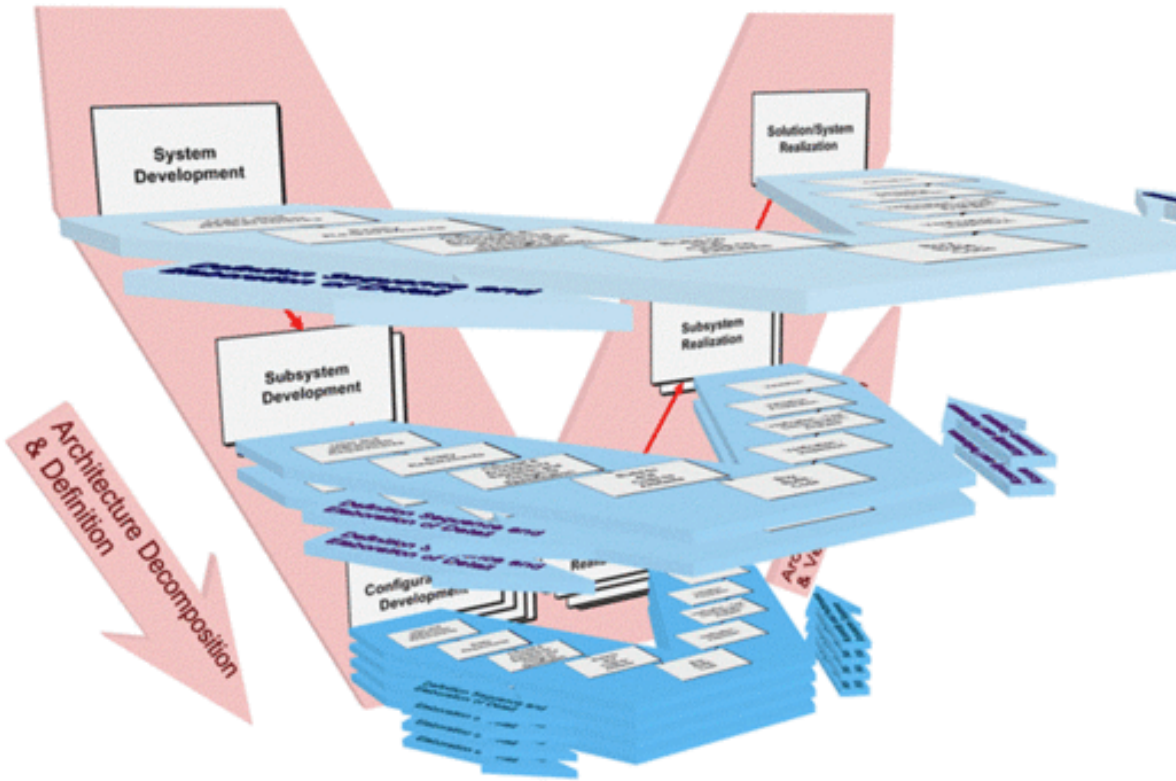


Figure 1. Smart Manufacturing Ecosystem

Left: Lu, Yan, Katherine C. Morris, and Simon Frechette. "Current standards landscape for smart manufacturing systems." *National Institute of Standards and Technology, NISTIR* 8107 (2016): 39.
Right: Mooz, Hal, and Kevin Forsberg. "The Dual Vee–Illuminating the Management of Complexity." *INCOSE International Symposium*. Vol. 16. No. 1. 2006.

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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?

Stakeholders: Production system engineers

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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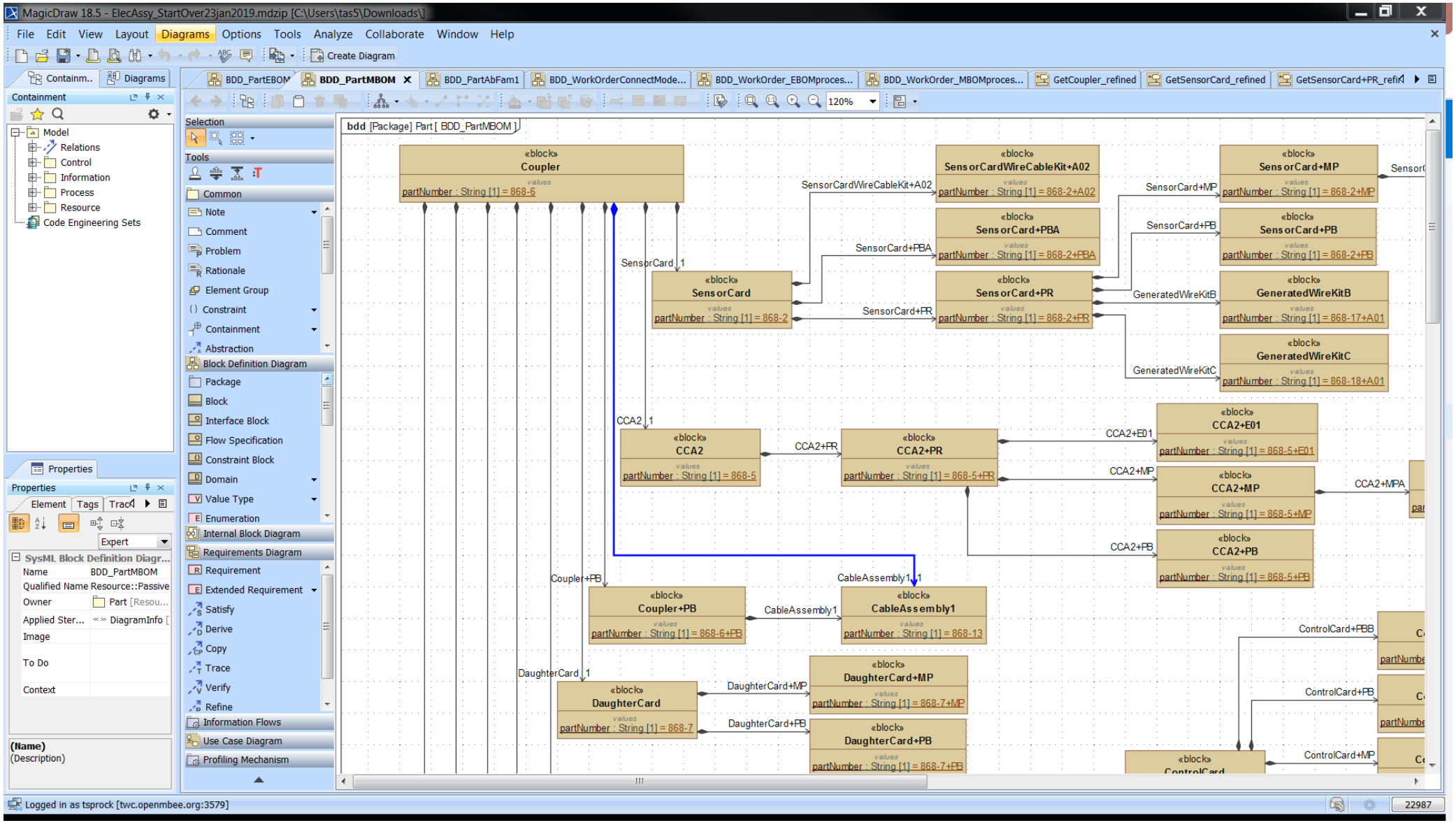
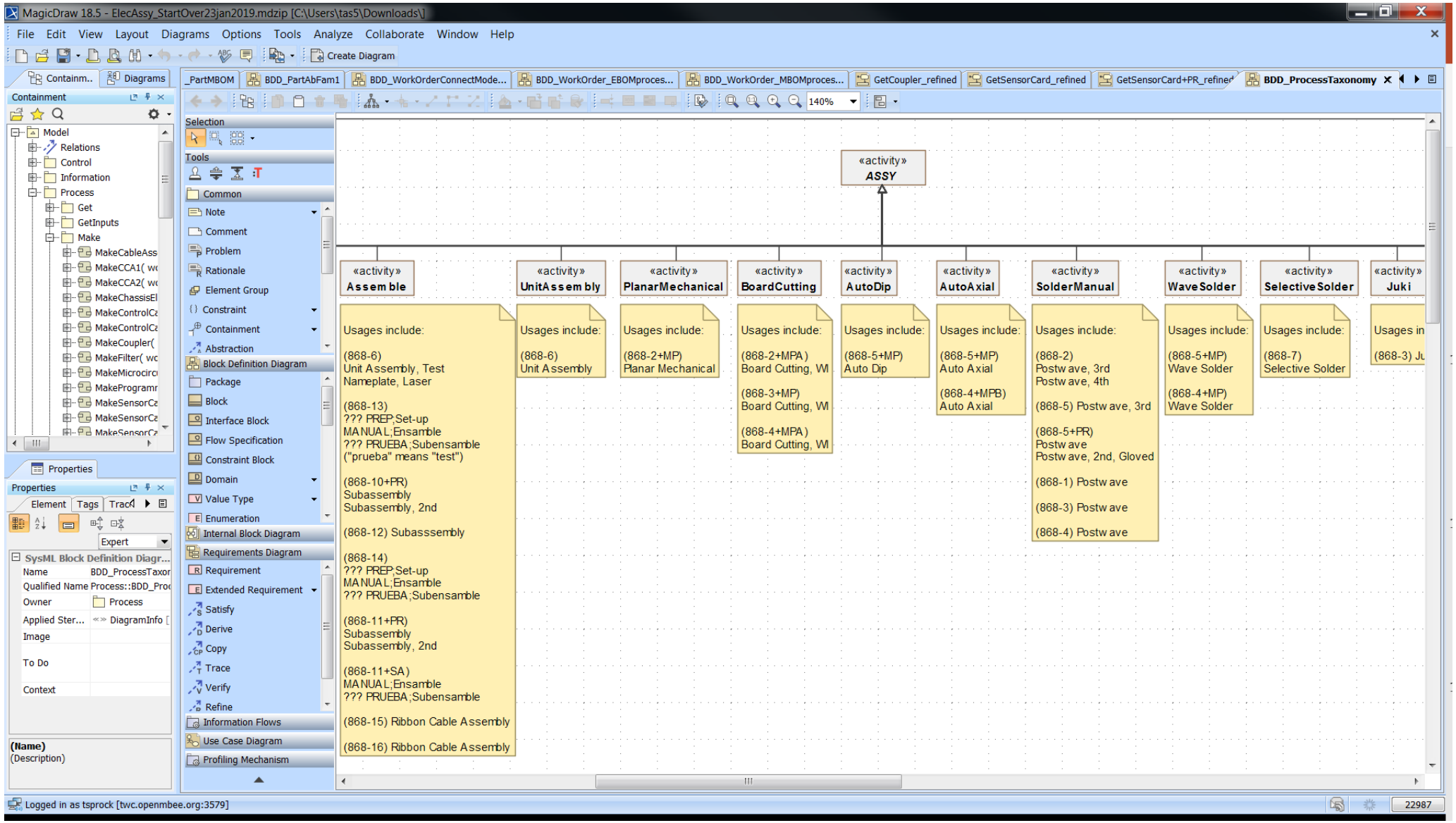
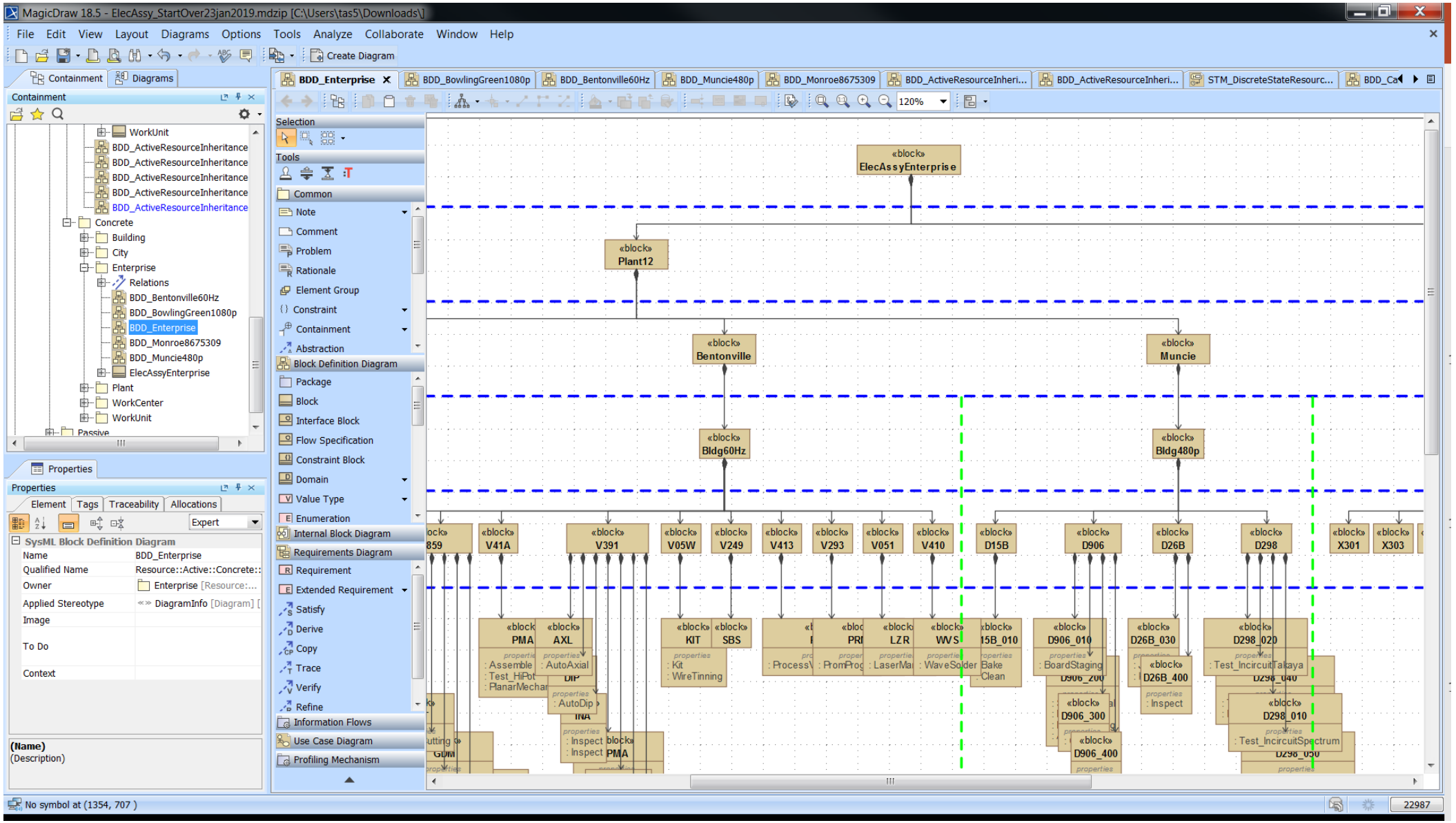
What does MBISE look like? **Product Definition**



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 …

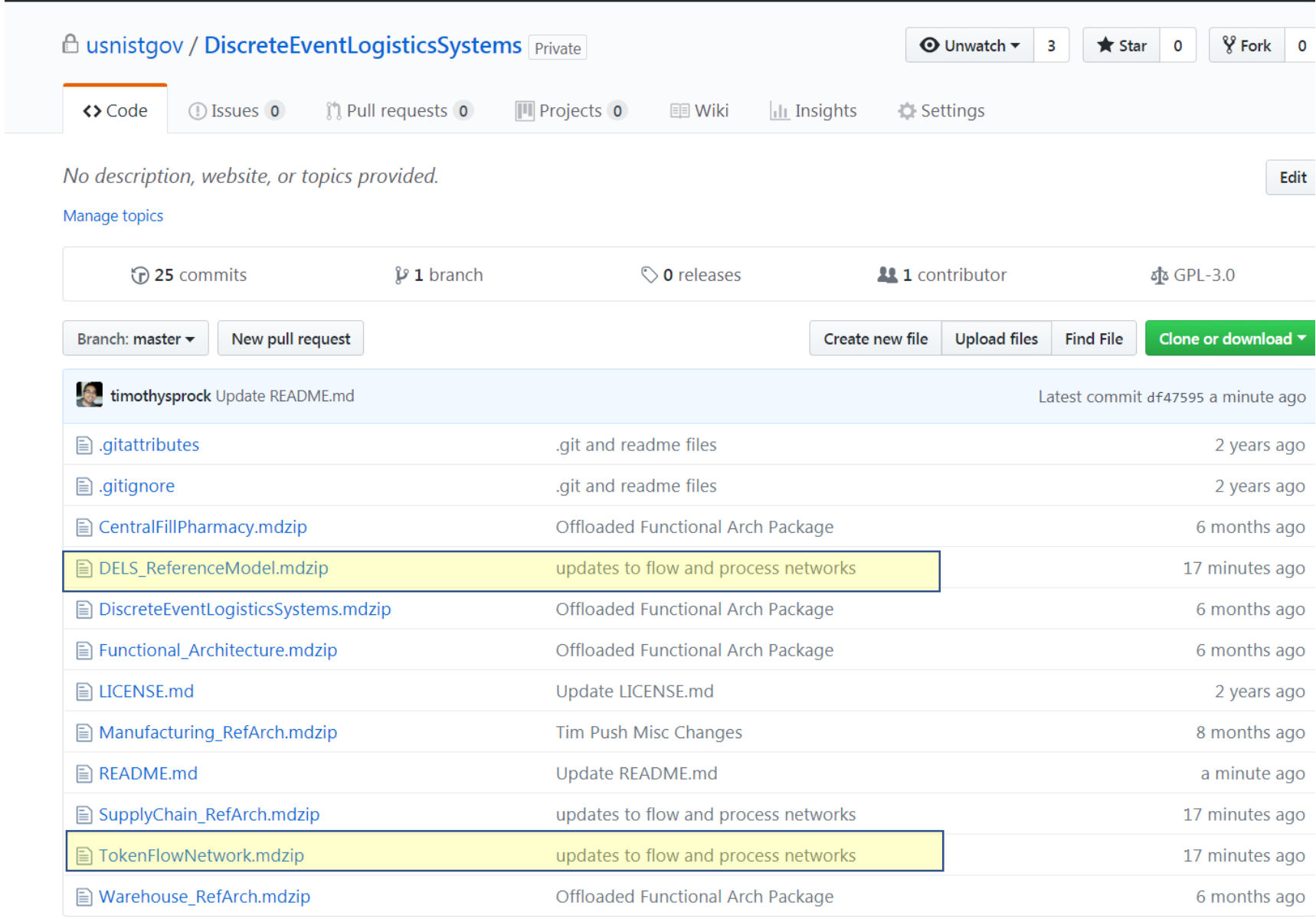
Overview: DELS-related Products

- 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/rsjqhqzmxtxq
  - 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



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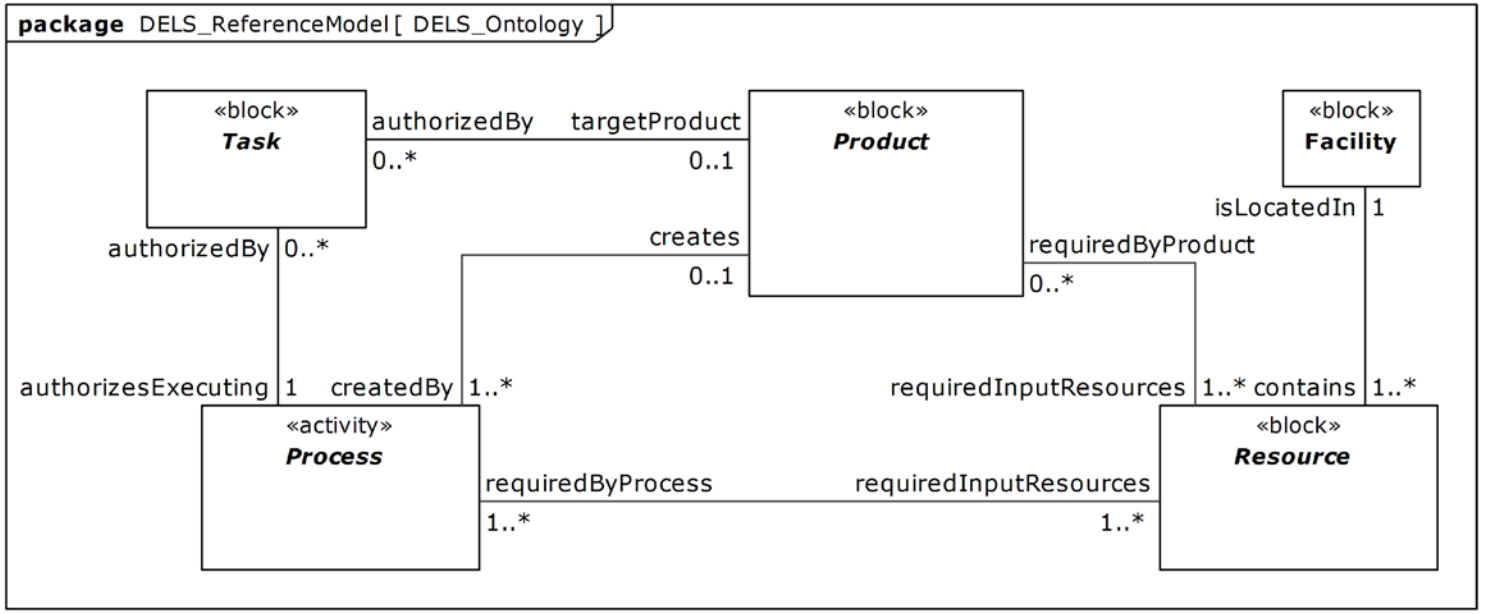
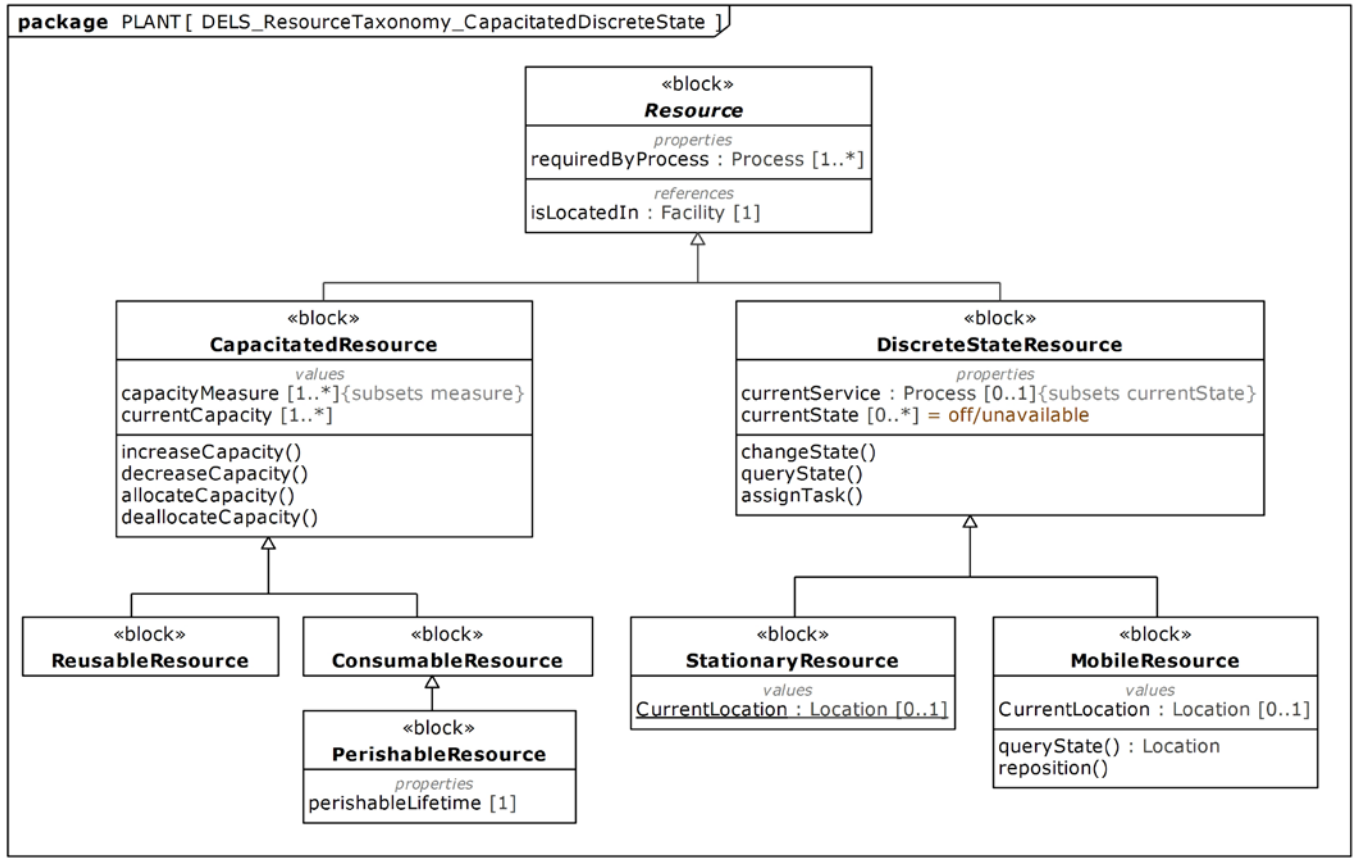
DELS Model Libraries

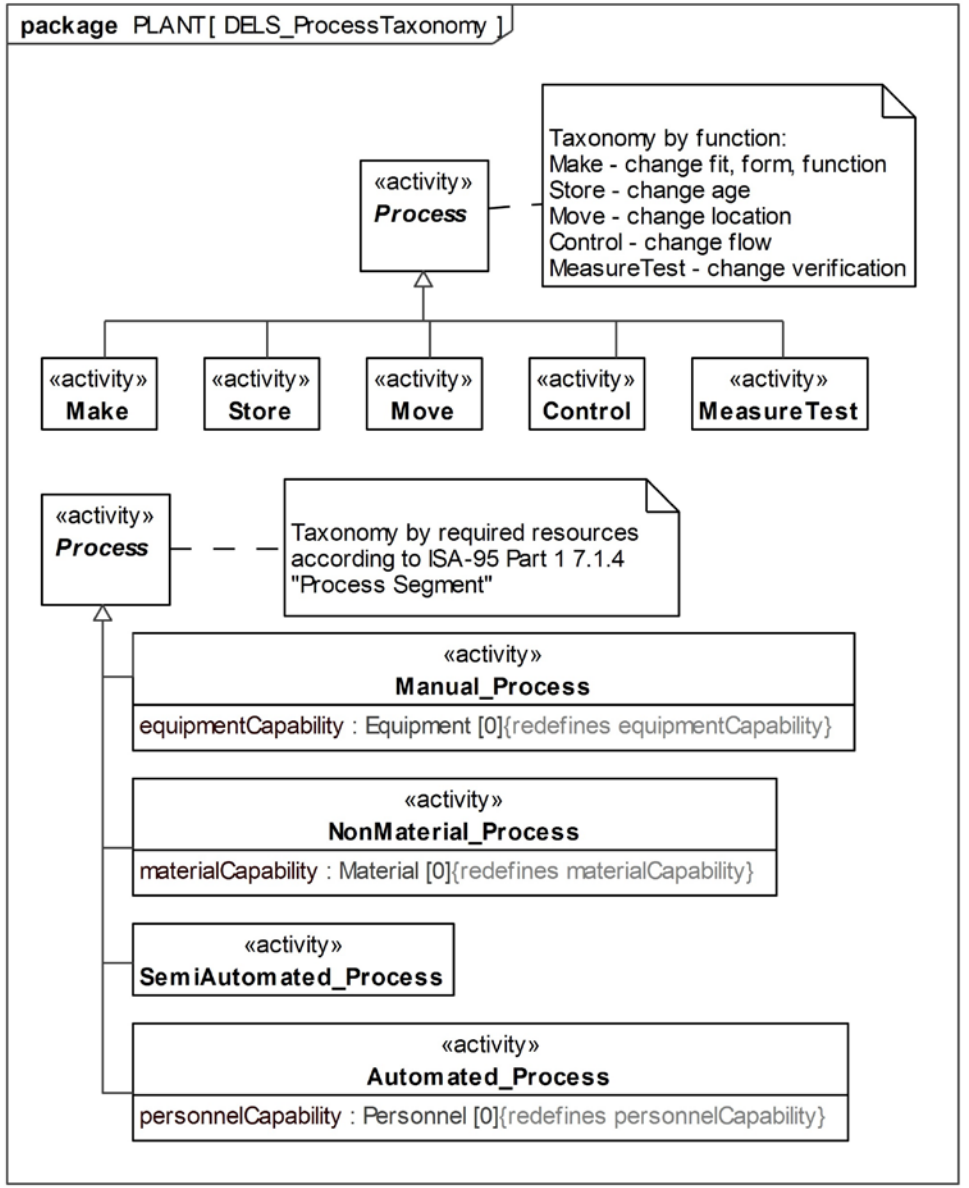


- Each element is elaborated with taxonomies and model libraries
  - Draw upon standards such as ISO MANDATE (ISO 15531), EBC (ISO 16400), MTConnect, ISA-95 (IEC 62264), etc.

Examples – Process & Resource Taxonomy

- "Upper" abstractions help map to key analysis model libraries
- Domain-specific model libraries specialize these into more concrete elements

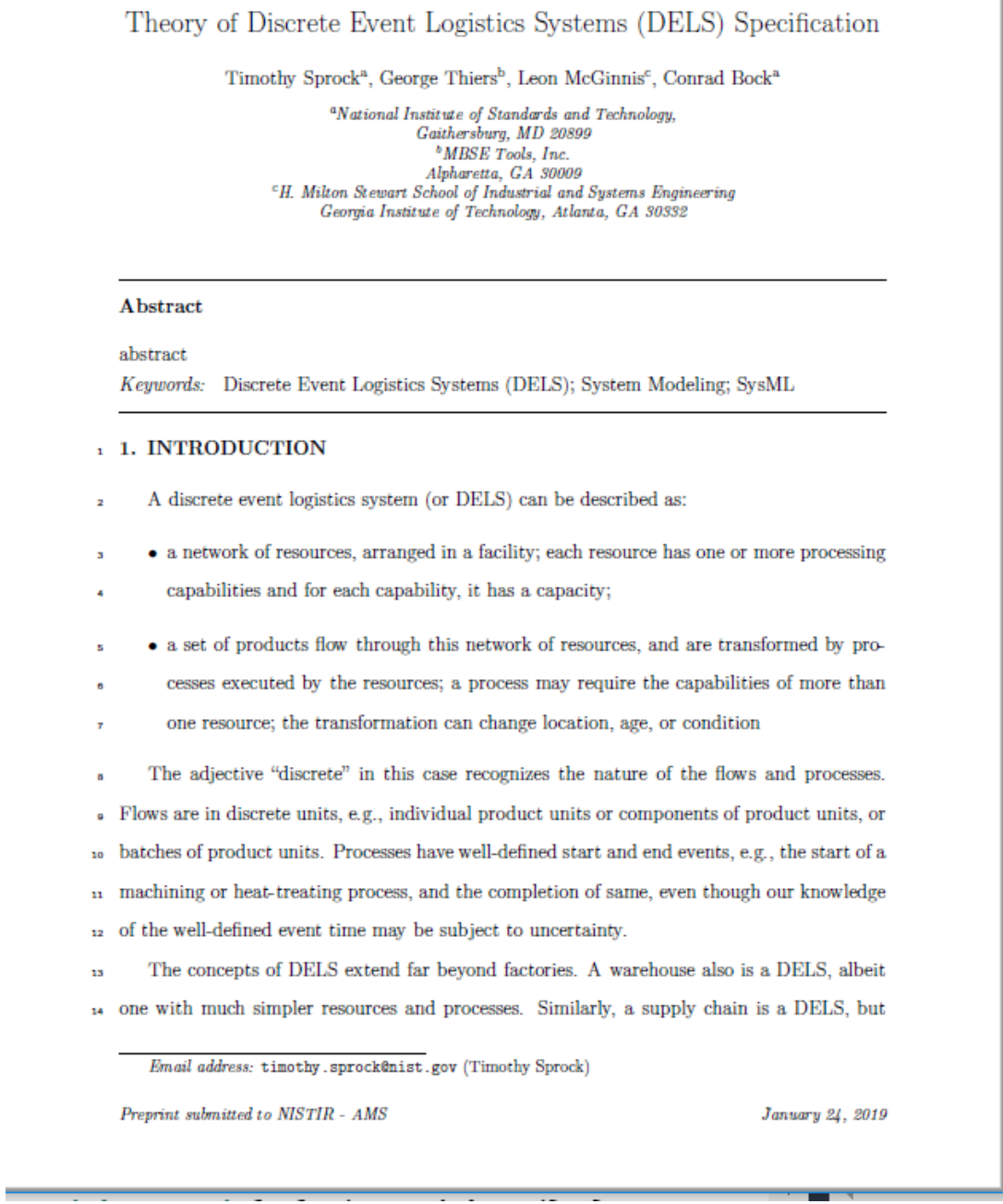




DELS Model Libraries Documentation

Overview: Description of the DELS modeling framework and model libraries. Includes SysML diagrams (views).

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



Theory of Discrete Event Logistics Systems (DELS) Specification

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Abstract

abstract

Keywords: Discrete Event Logistics Systems (DELS); System Modeling; SysML

1. INTRODUCTION

A discrete event logistics system (or DELS) can be described as:

- a network of resources, arranged in a facility; each resource has one or more processing capabilities and for each capability, it has a capacity;
- a set of products flow through this network of resources, and are transformed by processes executed by the resources; a process may require the capabilities of more than one resource; the transformation can change location, age, or condition

The adjective "discrete" in this case recognizes the nature of the flows and processes. Flows are in discrete units, e.g., individual product units or components of product units, or batches of product units. Processes have well-defined start and end events, e.g., the start of a machining or heat-treating process, and the completion of same, even though our knowledge of the well-defined event time may be subject to uncertainty.

The concepts of DELS extend far beyond factories. A warehouse also is a DELS, albeit one with much simpler resources and processes. Similarly, a supply chain is a DELS, but

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Theory of Discrete Event Logistics Systems (DELS) Specification

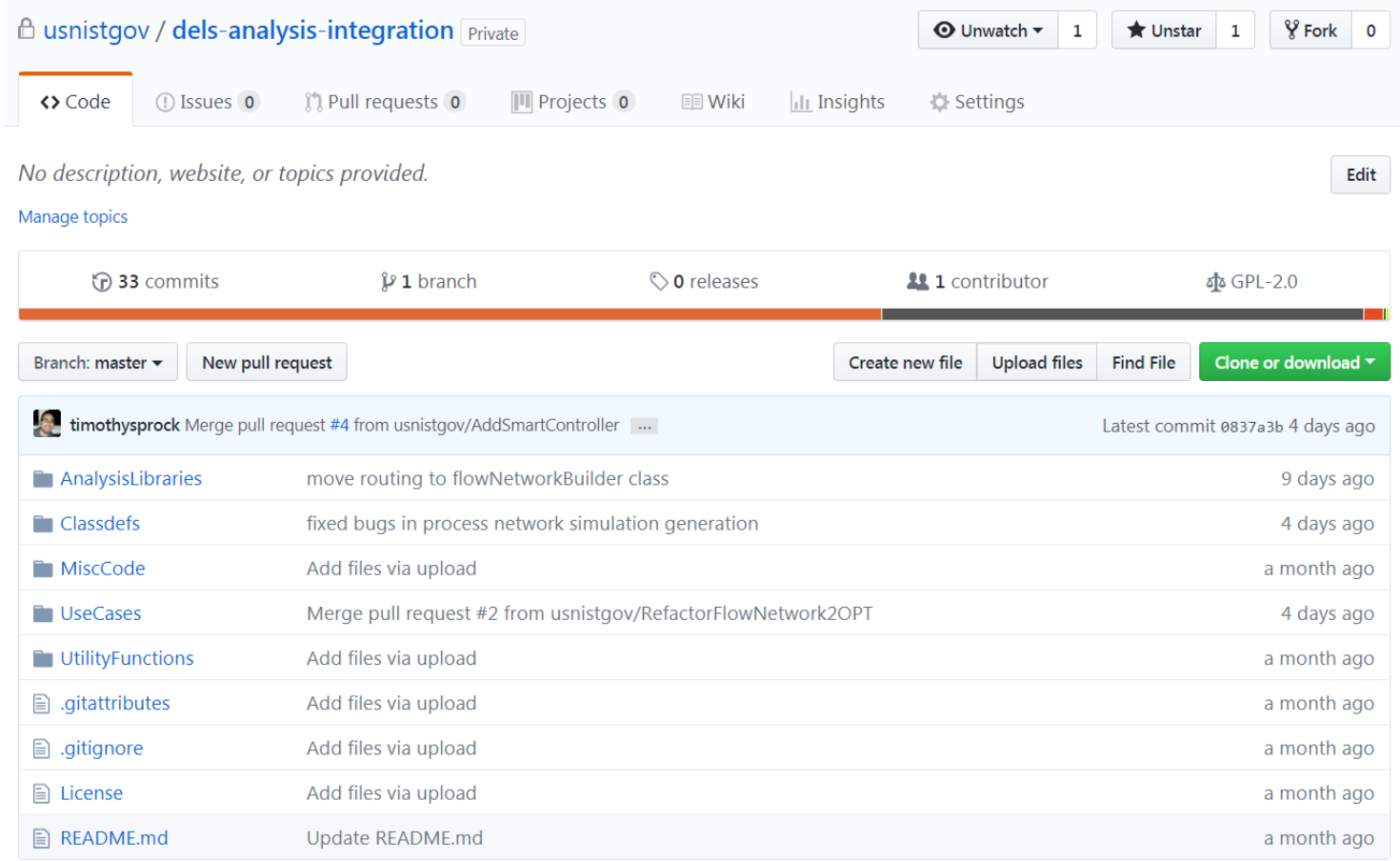
1. Introduction
2. Modeling Framework
3. Network Abstractions
   - 3.1 Basic Networks
   - 3.2 Flow Networks
   - 3.3 Process Networks
4. Discrete Event Logistics Systems
   - 4.1 Resource
   - 4.2 Process
   - 4.3 Product
   - 4.4 Facility
   - 4.5 Task
   - 4.6 Interfaces
5. DELS Operational Control
   - 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

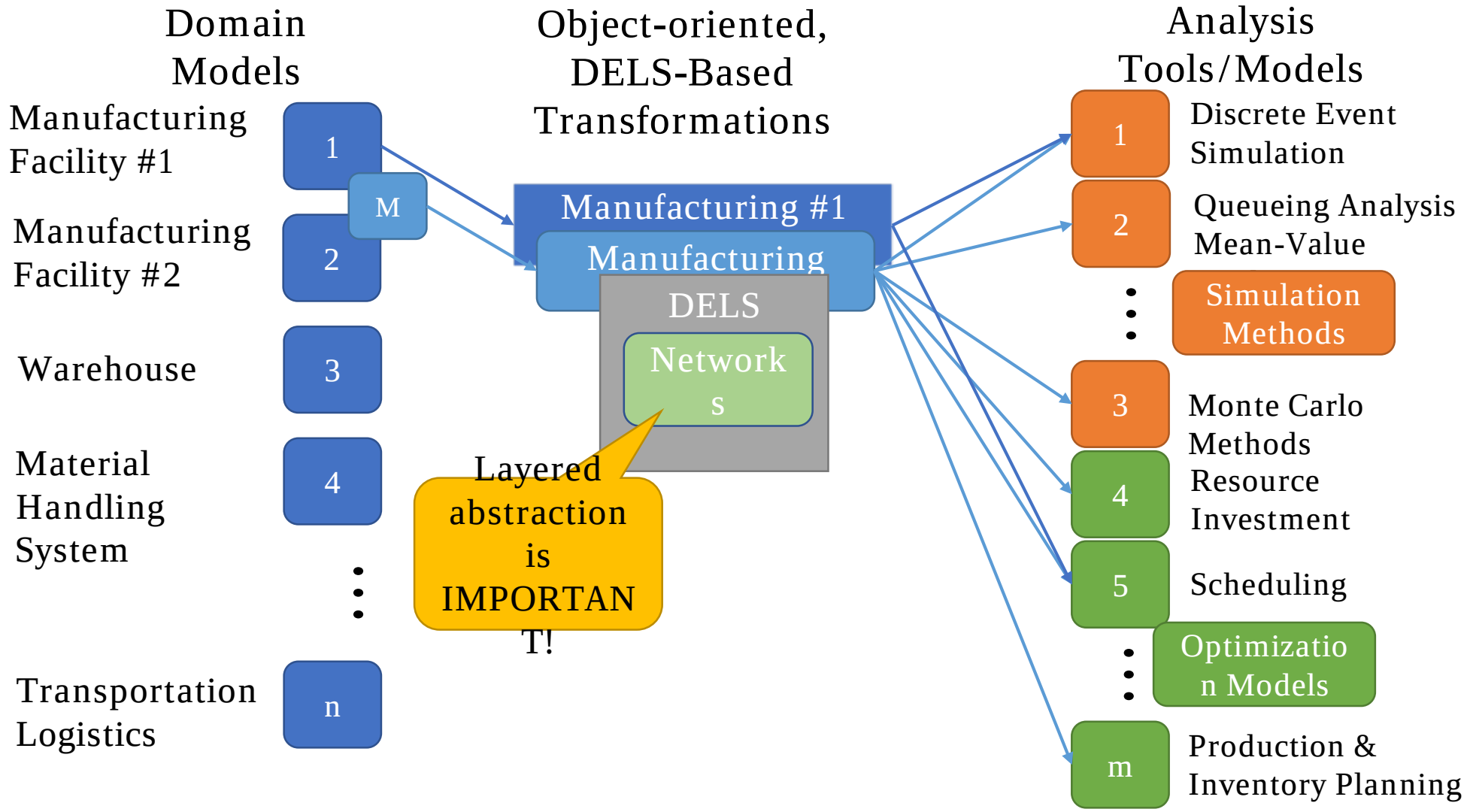


https://github.com/usnistgov/dels-analysis-integration

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



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

INCOSE MBSE Production and Logistics Systems Modeling Challenge Team

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.

http://www.omgwiki.org/MBSE/doku.php?id=mbse:prodlog

Telecon every Friday at 11am Eastern

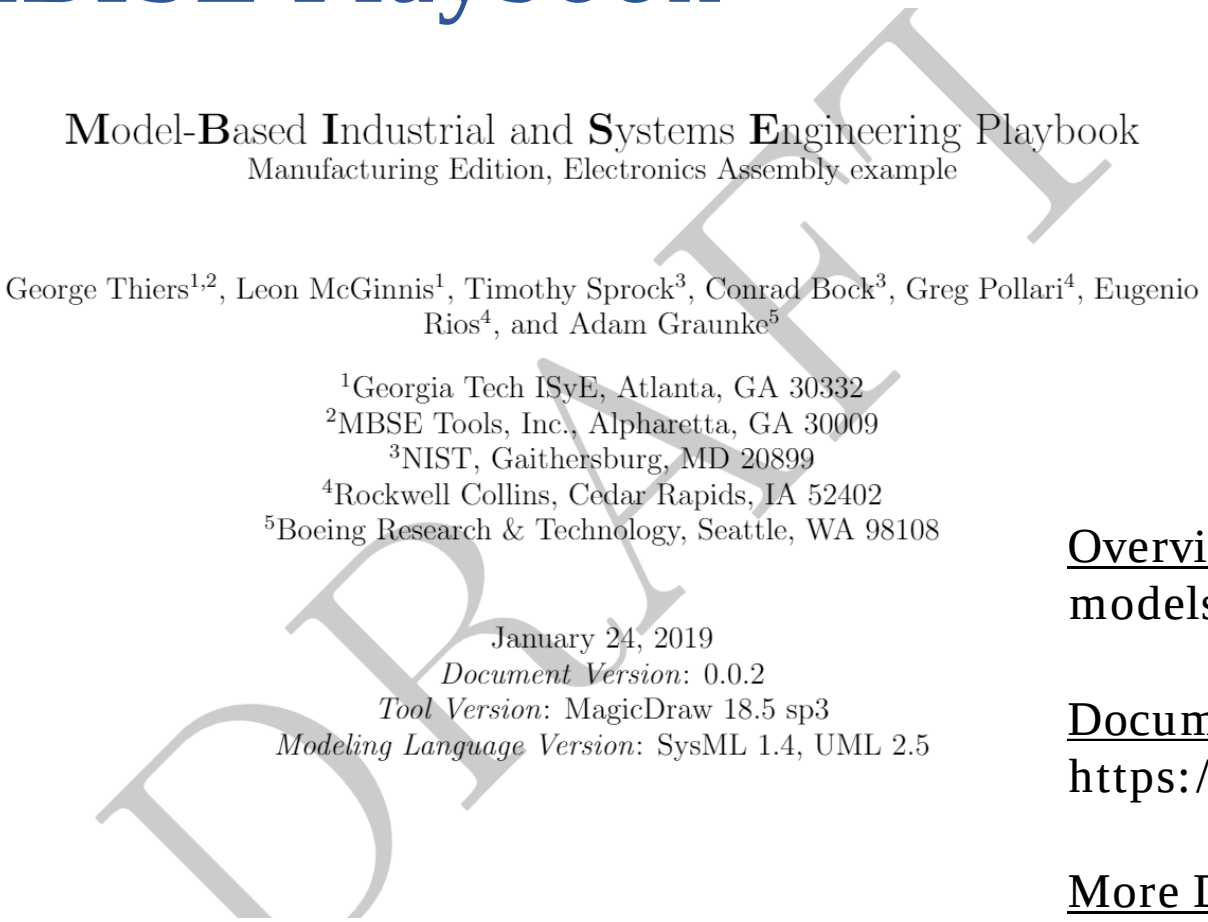
Roadmap - Identify a Case Study

- "… 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

MBISE Playbook



Overview: 'How-to' guide on applying constructing system models using the DELS framework and model libraries

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

More Details:
http://www.omgwiki.org/MBSE/doku.php?id=mbse:prodlog
http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:prodlog:productionlogisticsmodeling_iw2019_v6.pdf

SysML Models (Coming Soon):
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