2017 annual INCOSE international workshop
Los Angeles, CA, USA
January 28 - 31, 2017

System and Analysis Integration for Production & Logistics Systems

Conrad Bock[a], Leon McGinnis[b], & Timothy Sprock[a]
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Outline

- Digital Thread
- What are the fundamental challenges?
- Why & What are DELS
  - Commonalities First, Specifics Later
- Why is this interesting to the MBSE Initiative
- What do we want?

Digital Thread

- Digital Thread: platform for information to integrate product design, production and logistics systems design, and later stages of product lifecycle (sustainment)

- Design for Manufacturing: product/production design integration

- Production System Design Methodology: Processes, decision-making support, and analysis tools
  - Without a reference model you can't do it right today in a non ad-hoc way. Even with a reference model, you can't do it throughout the product's lifecycle since all of the analysis models have to be built by hand.

The SE "Vee" for both product & process

System Development	System Process Development
Con Ops	Global supply chain concept
Requirements/ Architecture	Technical capabilities and capacities, SC architecture
Detailed Design	Sourcing plan, facility design, planning/control concepts
Implement	Virtualize, test concepts, program roll-out
Integrate, Test, Verify	Global SC simulation, contingency analyses, standards, …
System V&V	Deployment
Operations & Maintenance	Operations

Computational support

CAD, FEA, CFD, PDM/PLM, REQUIREMENTS, SysML, and many more; increasing levels of integration and interoperability

Use models to specify, analyze, integrate, simulate, verify, validate—virtually, across disciplines

Excel, Visio, some CAD, optimization, simulation; not integrated, not interoperable

Use documents to specify and communicate, independent *ad hoc* models to support decision making

…velopment	System Process Development
…Ops	Global supply chain concept
…irements/ A…tecture	Technical capabilities and capacities
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Fundamental Challenges

- (Lack of) Common semantics & syntax for specifying production systems *(reference model)*
  - Difficulty of integration in PDM/PLM systems

- Time and expense of hand-coding analysis models (imagine if every FEA/CFD required a simulation engineer to hand-code the model)
  - Very limited decision support to production system engineers

- (Lack of) An engineering design methodology for production systems
  - Very difficult to capture/re-use learnings from experience—lots of tacit rather than explicit knowledge

What are DELS?

Discrete event logistics systems (DELS) are a class of dynamic systems that are defined by the transformation of 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).

<u>Examples include:</u>

- Supply chains
- Manufacturing systems
- Transportation
- Material handling systems
- Storage systems
- Humanitarian logistics
- Healthcare logistics
- Semiconductor manufacturing
- Reverse and Remanufacturing Logistics
- And many more …

- Fundamentally, these systems are very similar, and often DELS are actually composed of other DELS.
- This similarity (and integration) produces a common set of analysis approaches that are applicable across the many systems in the DELS domain.

Interest to MBSE Community

- Bring a different domain into the INCOSE community
  - In the design of logistics systems, we don’t have good SE tools and practices
- Why can INCOSE have a big impact on this domain?
  - In addition to the SE best practices, MBSE has been transformative!
  - Explicit modeling and design methods
    - Consensus on how we talk about our artifacts and design them
  - Want to learn from MBSE community
- What are the things we need to do to have an impact:
  - Reference models, common design process, conforming and supporting analysis models and tools.
  - Build a community around a shared vision of DELS MBSE

It’s (long past) time to bring the power of (model based) systems engineering to production systems and global supply chains!

What does it take to do that?

Where are we in the journey?

Tuesday @ 8:10am in MBX/Ecosystems

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MBSE for Discrete Event Logistics Systems (DELS)

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www.incose.org/IW2017

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- What are DELS?
- What are the fundamental challenges for DELS?
- Why do we need system models and MBSE?
    - What are the types of analysis models and problems we're interested in for DELS (SAI)?
- Where are we now?
    - What is contained in the DELS reference model?
    - System-Analysis Integration Use Case
- Where do we want to go?

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- Storage systems
- Humanitarian logistics
- Healthcare logistics
- Sustainment Logistics
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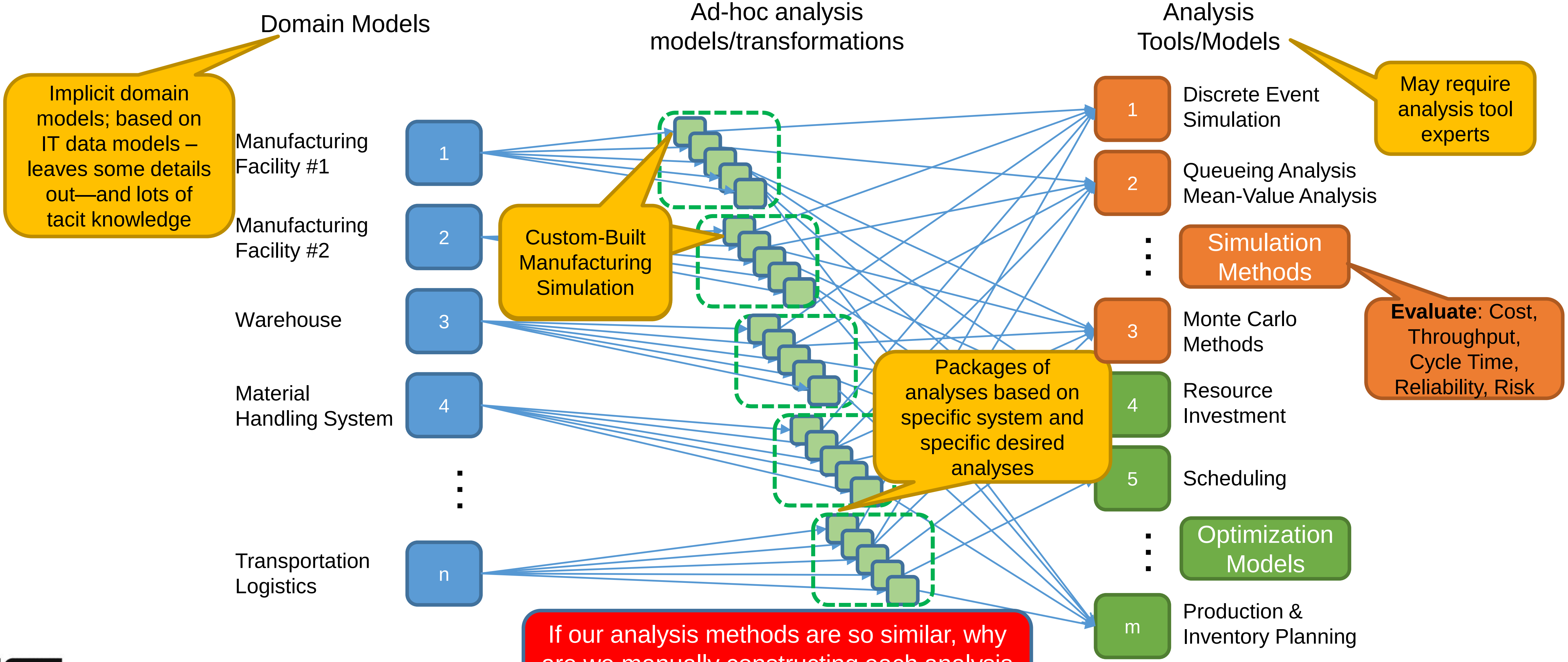
Need for Model-Based Methods

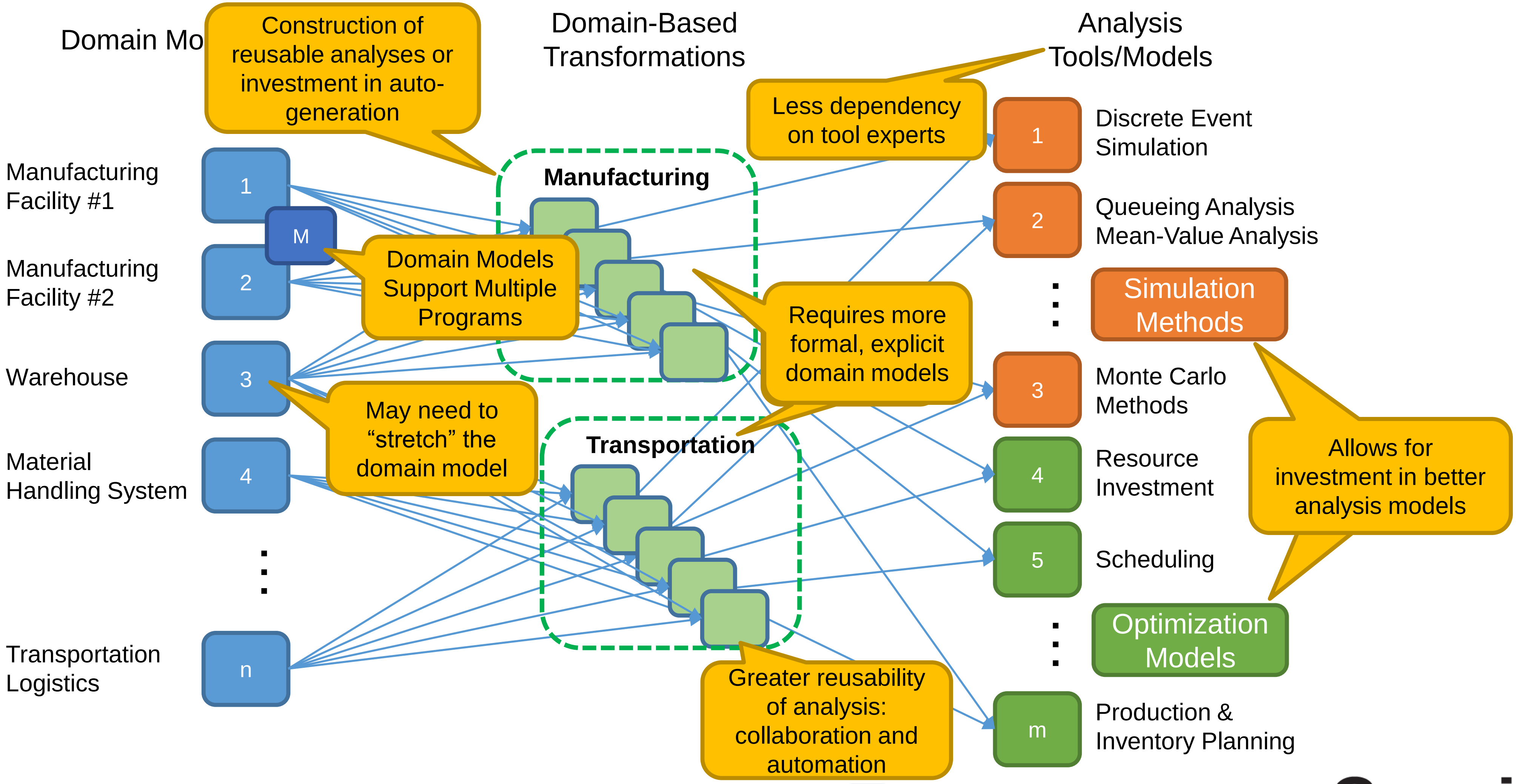
- Current methods and tools are limited for production systems engineering
  - Formal specification & analysis automation
  - Design and teaching
- Documentation & Organization of Knowledge
  - Existing Systems Models (industry)
  - Existing Analysis Models (academia)
- Bridge between system and analysis models
  - Interoperability between different analysis models of the same system
  - Greater reusability of analysis: collaboration and automation
  - Modeling & Simulation Interoperability (MSI); Systems Analysis Integration (SAI)

System Model to Analysis Model Transformation: Status Quo – Manual Ad-Hoc Analysis Generation

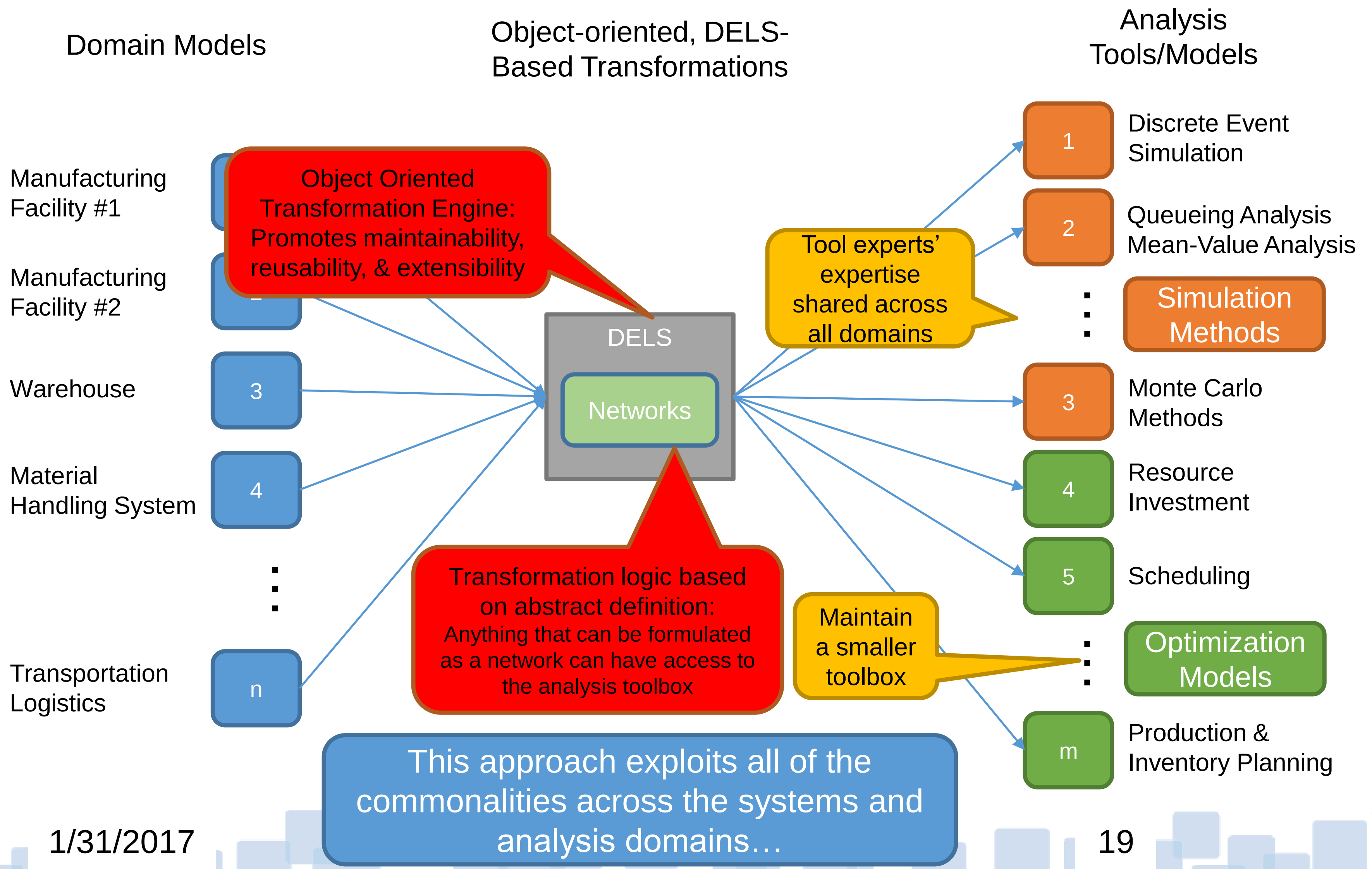


If our analysis methods are so similar, why are we manually constructing each analysis model for each system?

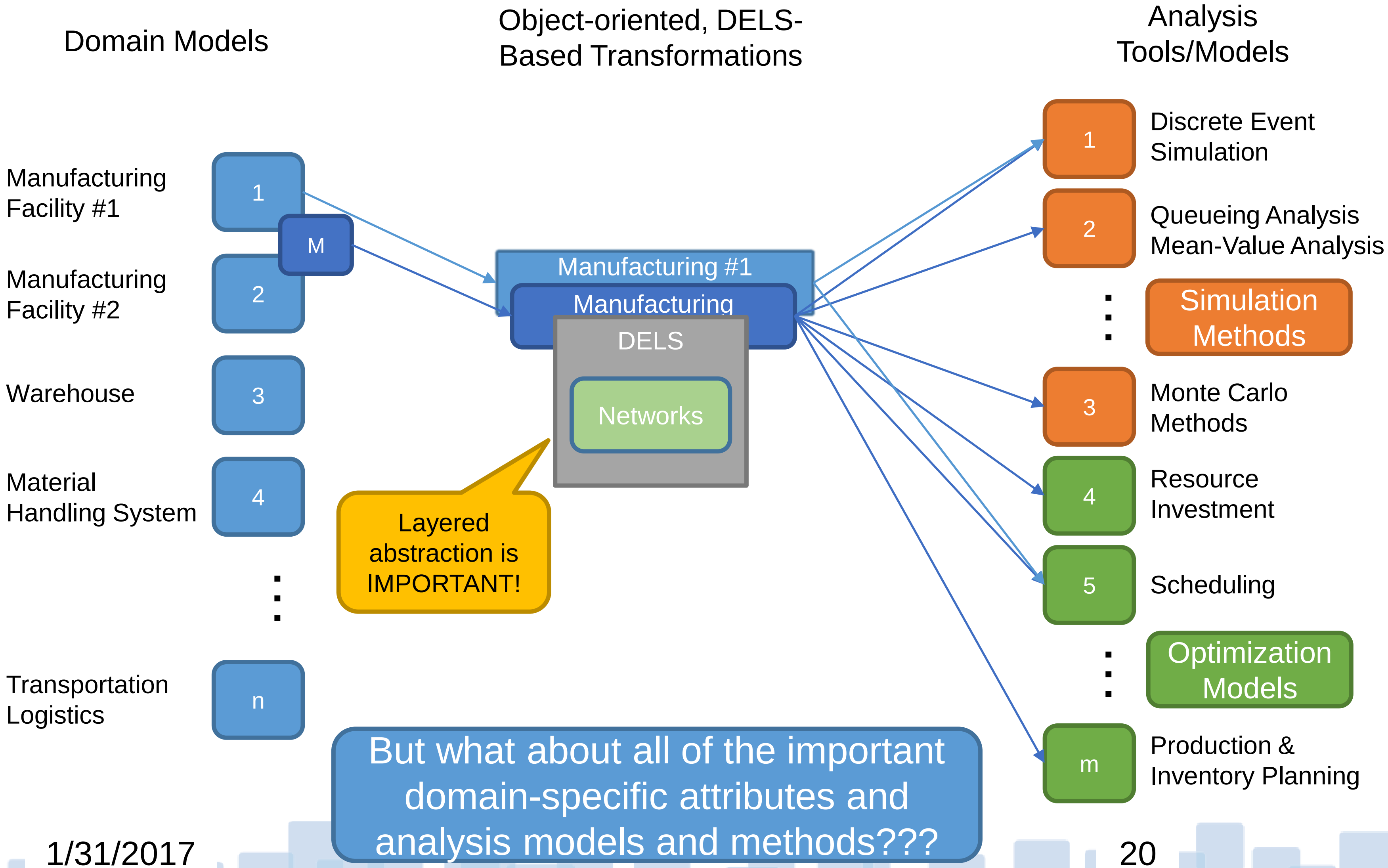
System Model to Analysis Model Transformation: M2M Methods Based on Domain Models



System Model to Analysis Model Transformation: M2M Methods Based on DELS Abstraction



System Model to Analysis Model Transformation: *Extending* M2M Methods Based on DELS Abstraction



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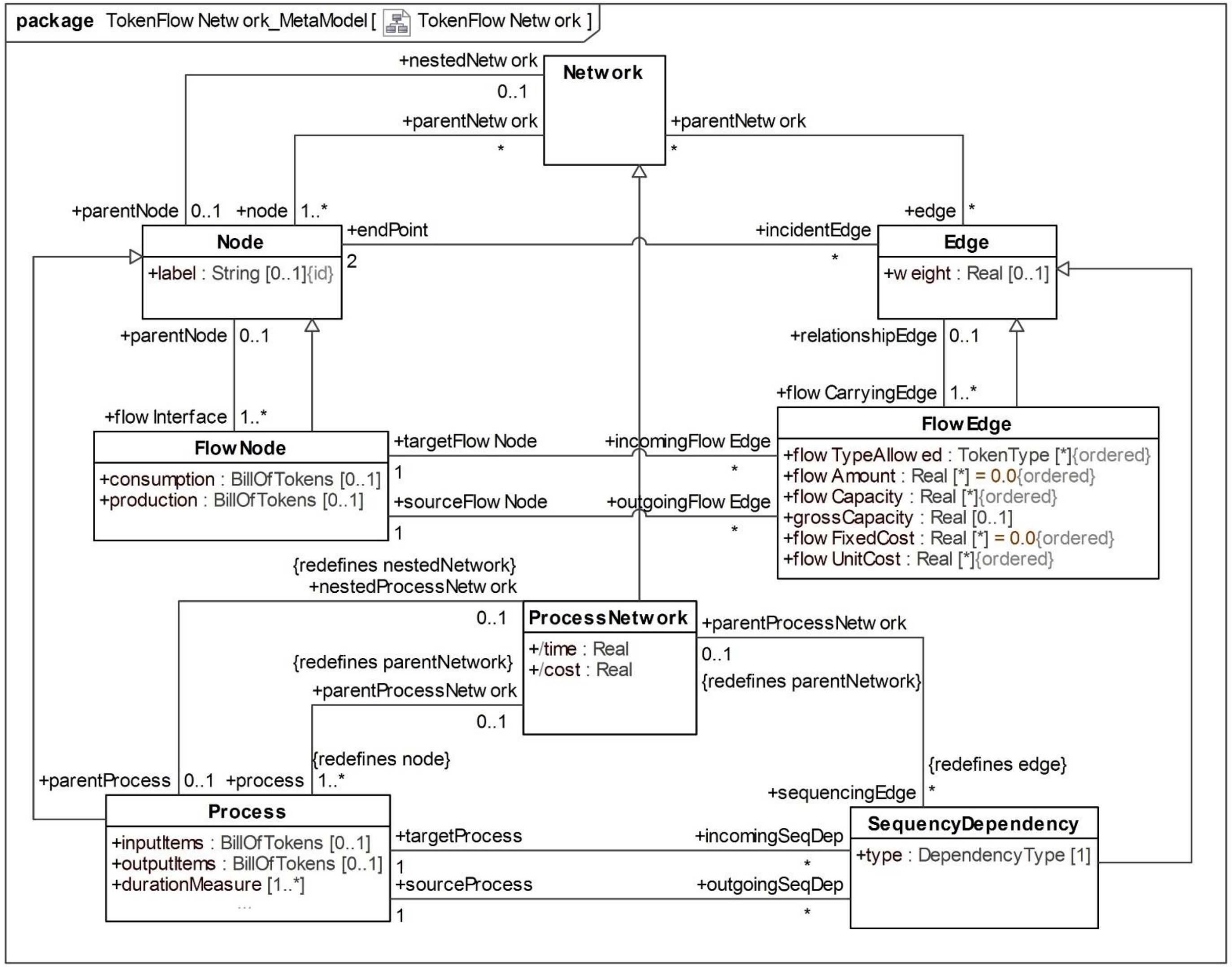
DELS Reference Model

- Network Abstraction (Structural)
  - Abstraction: Networks, Flow Networks, Process Networks
- System Behavior (Plant)
  - Abstraction: Product, Process, Resource, Facility + Task
- Control
  - Admission, Sequencing, Resource Assignment, Routing, & Resource State
- Domain-specific Reference Models
  - Production (Make), Warehousing (Store), Transportation (Move)
  - Supply Chains, Healthcare Logistics, etc.

Network Abstraction

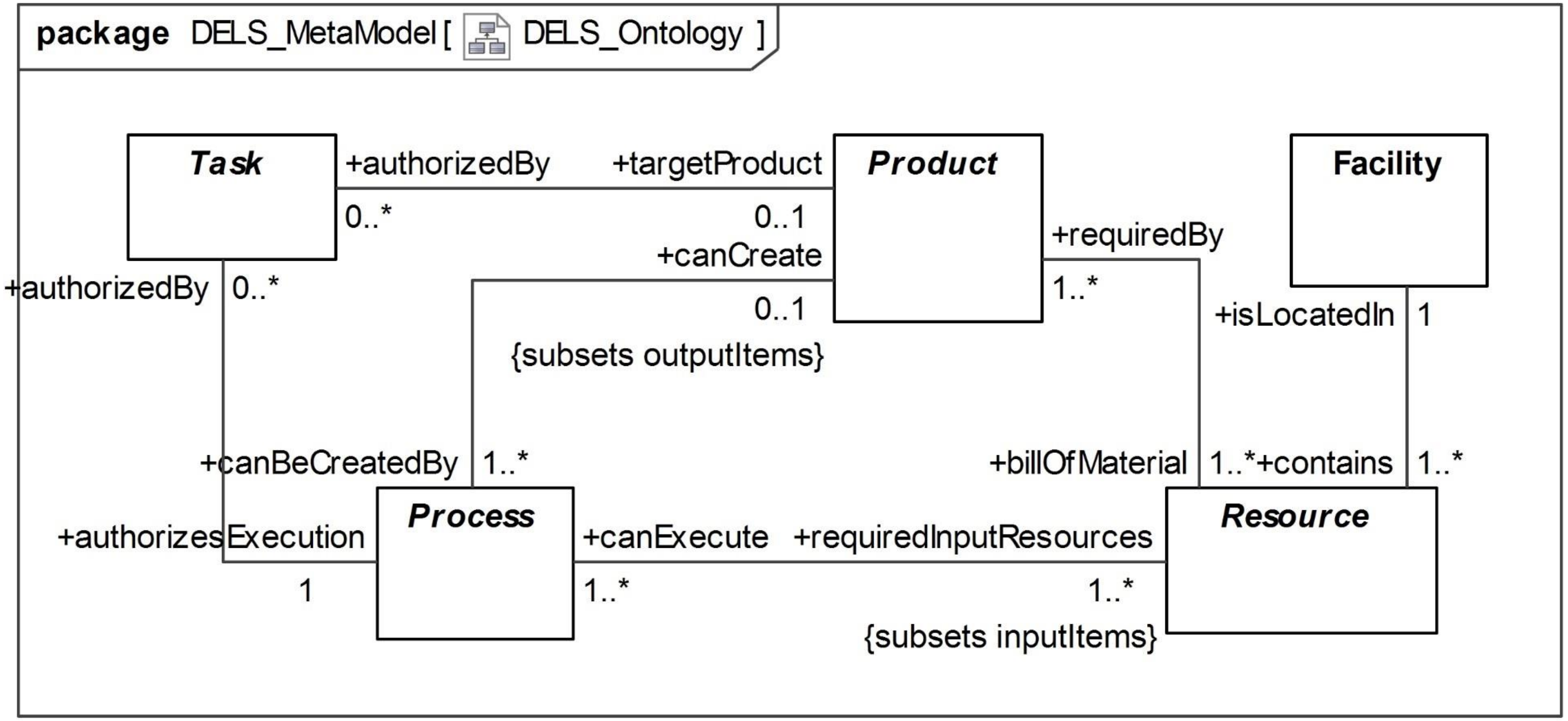
Networks, Flow Networks, and Process & Queueing Networks

- Form the basis of many analysis methods in the industrial engineering and operations research (IEOR) domain.
- Abstract and reusable across many related domains

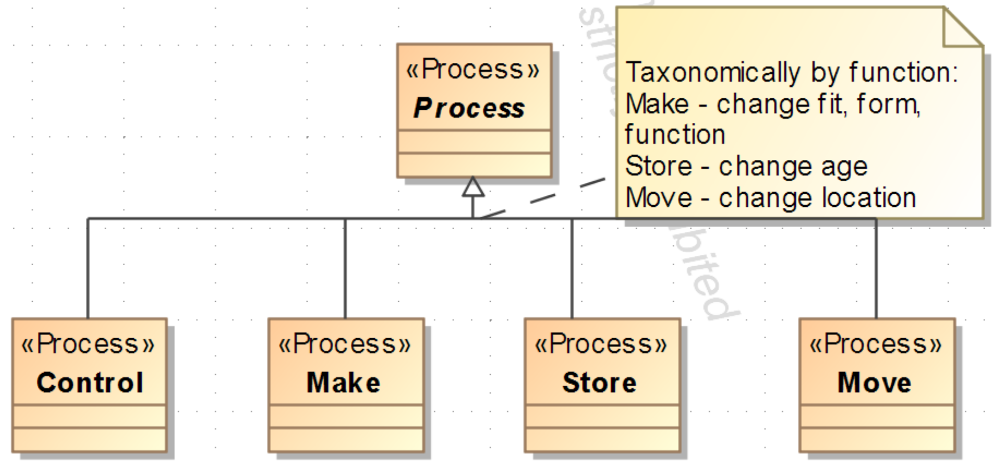


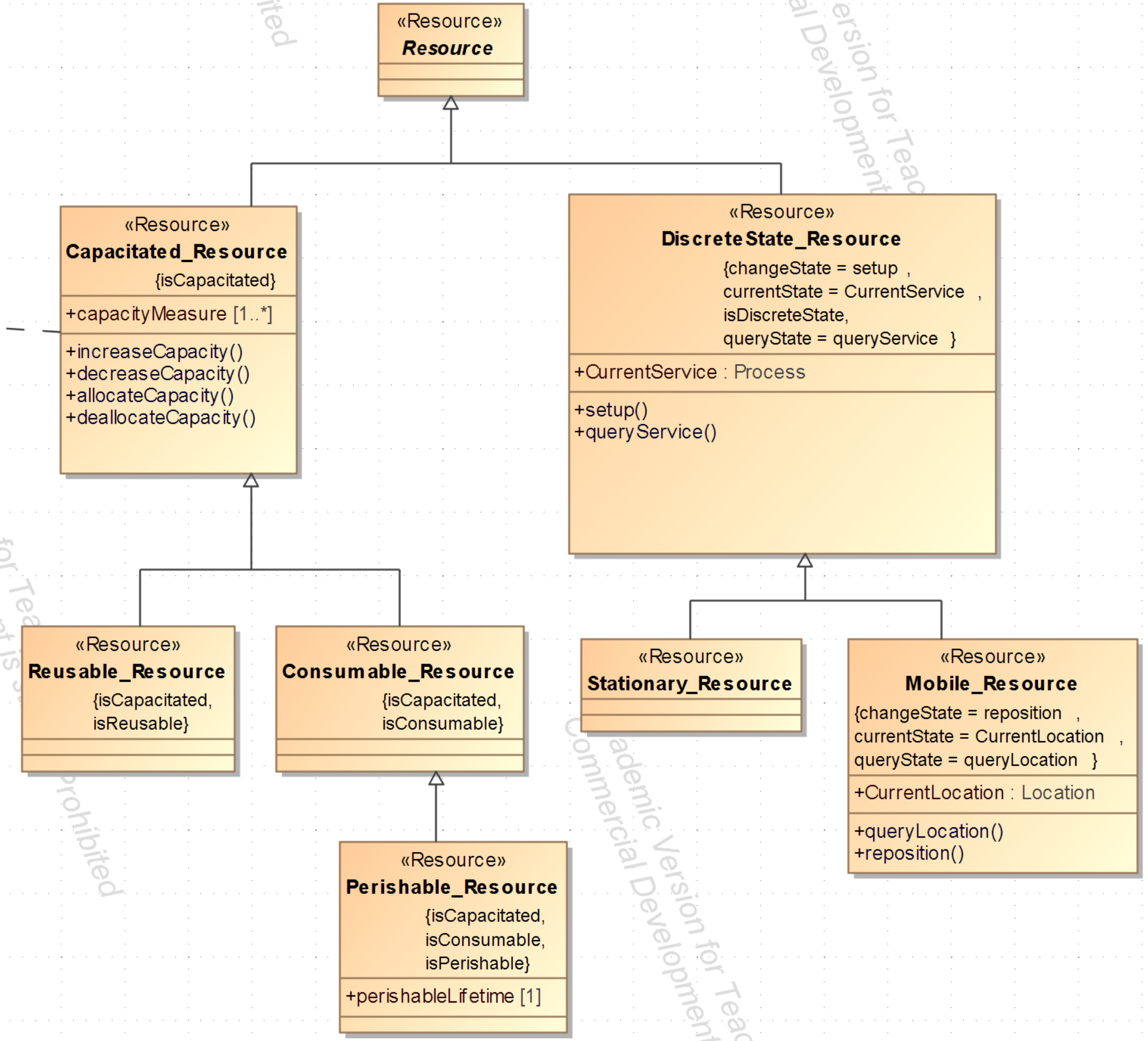
DELS Behavior – Product, Process, Resource, Facility

Fundamental concepts necessary to describe the behaviors of which the DELS is capable.



Taxonomies of DELS Behavior

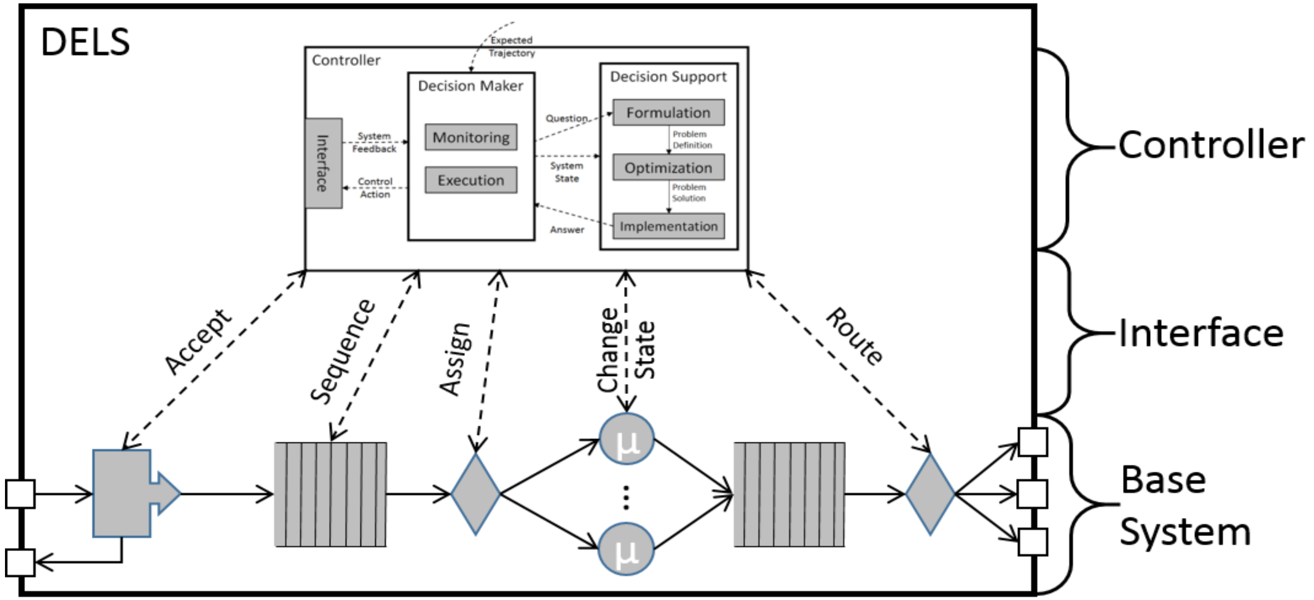




Can be elaborated to support more expressive and fine-grained system models, capturing more particular aspects of classes of systems.

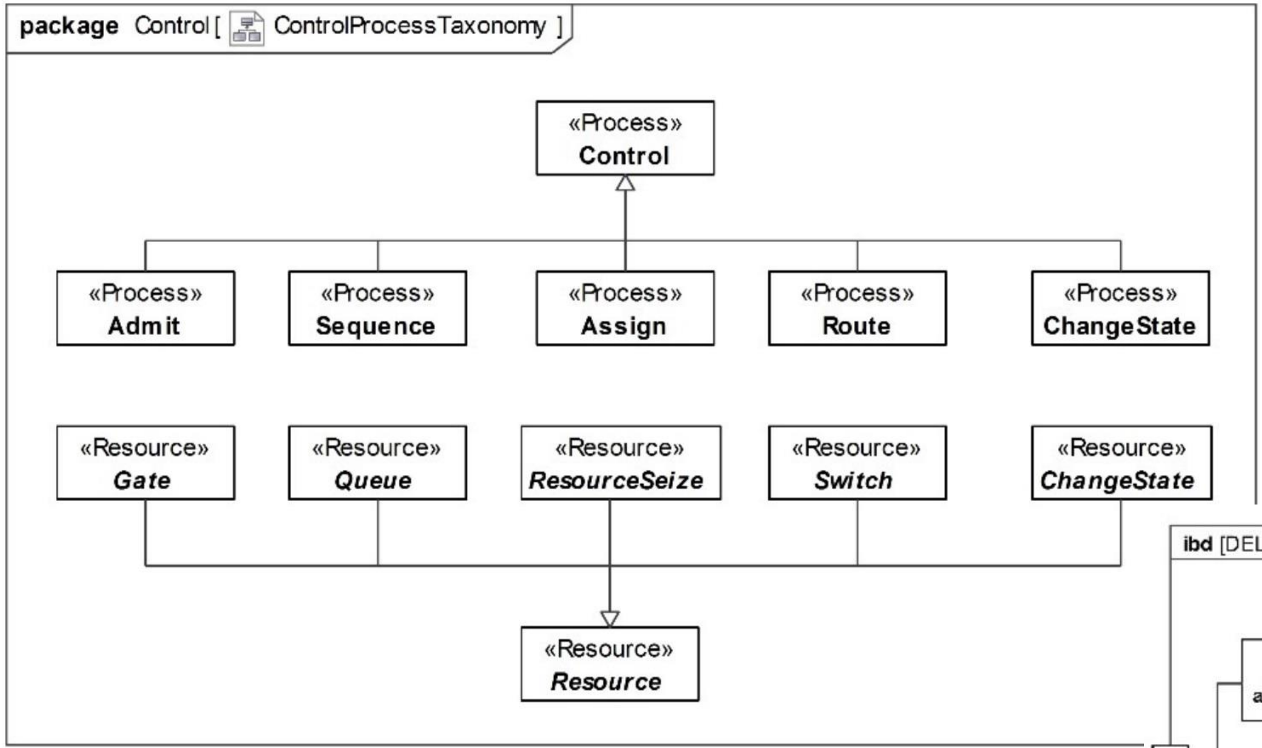
Operational Control

Functional mechanisms that **manipulate flows of tasks** and **resources** through a system in real-time, or near real-time.



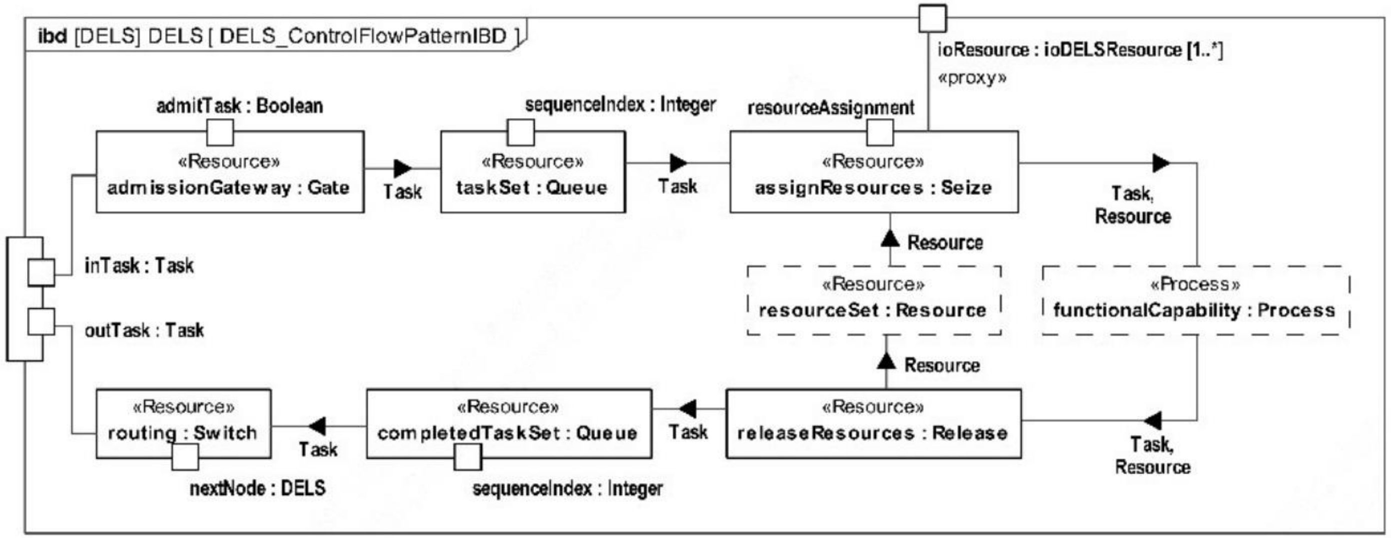
- Which tasks get serviced? (Admission/Induction)
- When {sequence, time} does a task get serviced? (Sequencing/Scheduling)
- Which resource services a task? (Assignment/Scheduling)
- Where does a task go after service? (Routing)
- What is the state of a resource? (task/services can it service/provide)

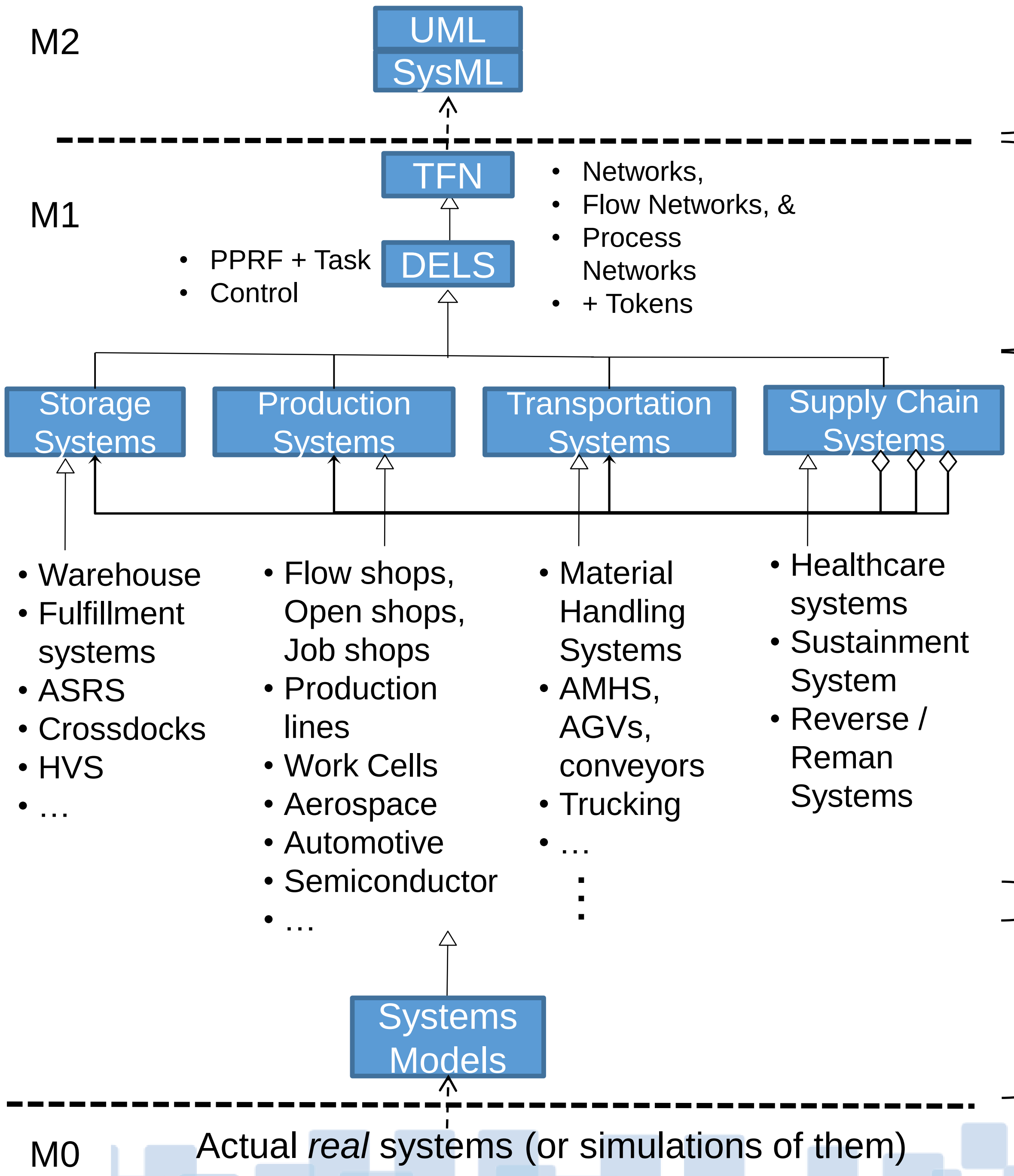
Operational Control



Extends the PPRF definition to special classes of control processes and resources

Maps the **decision variables** in the controller's decision problem to a particular **actuator function** and **execution mechanism** in the plant





Language Layer

- May also include a TFN & DELS DSL

Top of M1

- **DELS Reference model**
- Network Abstractions
- PPRF Domain Ontology
- PPRF Taxonomies & Model Libraries
- Control Patterns

Middle of M1

- **(sub-) Domain-specific reference models and architectures**
- Generalization Set aligns with STORE, MAKE, & MOVE processes

Bottom of M1

- **System Models**
- “as-built” or “specification” models

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

Georgia Tech

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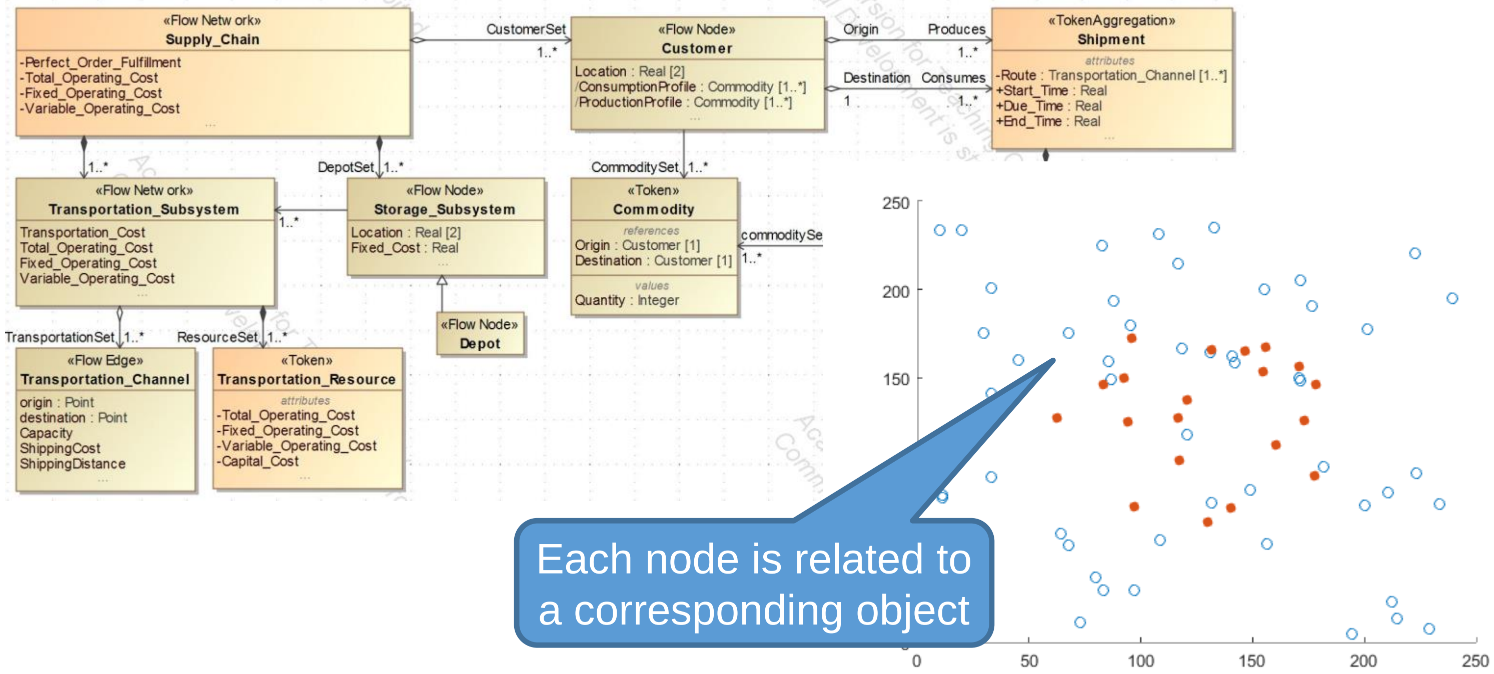
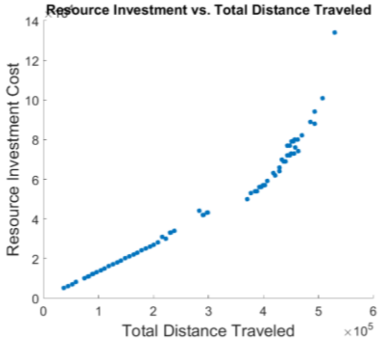
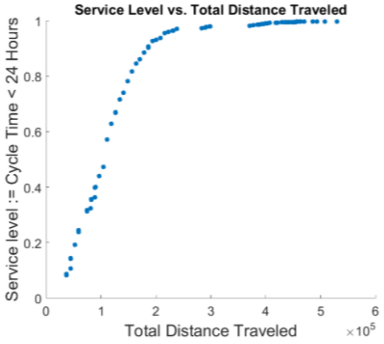
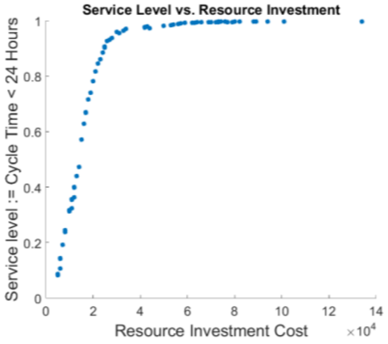
System-Analysis Integration – Use Case









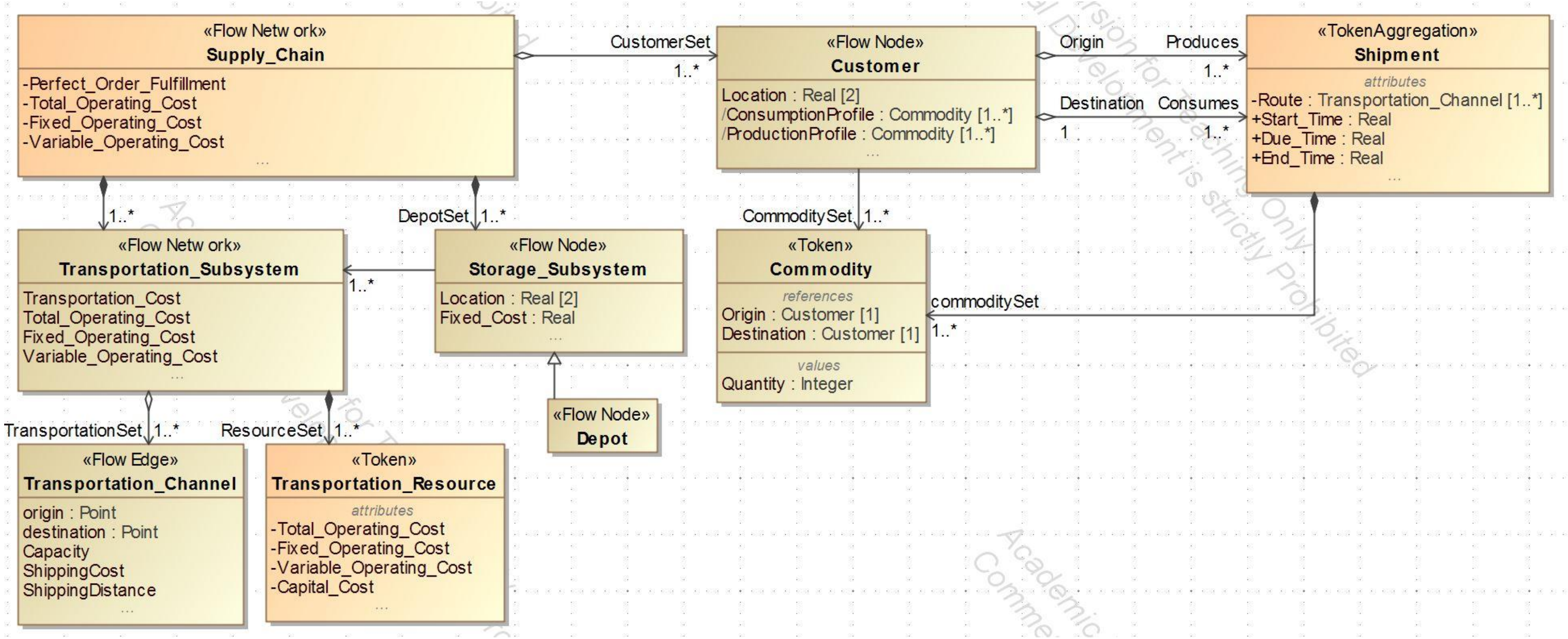
Strategy:

- Start with a system model or a reference model
- Generate an analysis model from the system model
- Use analysis model to support design decision making
- OR connect to an optimization model and search for candidate designs

Reference Models

Domain-specific reference model provides a pattern for constructing conforming system instance models and analysis models.

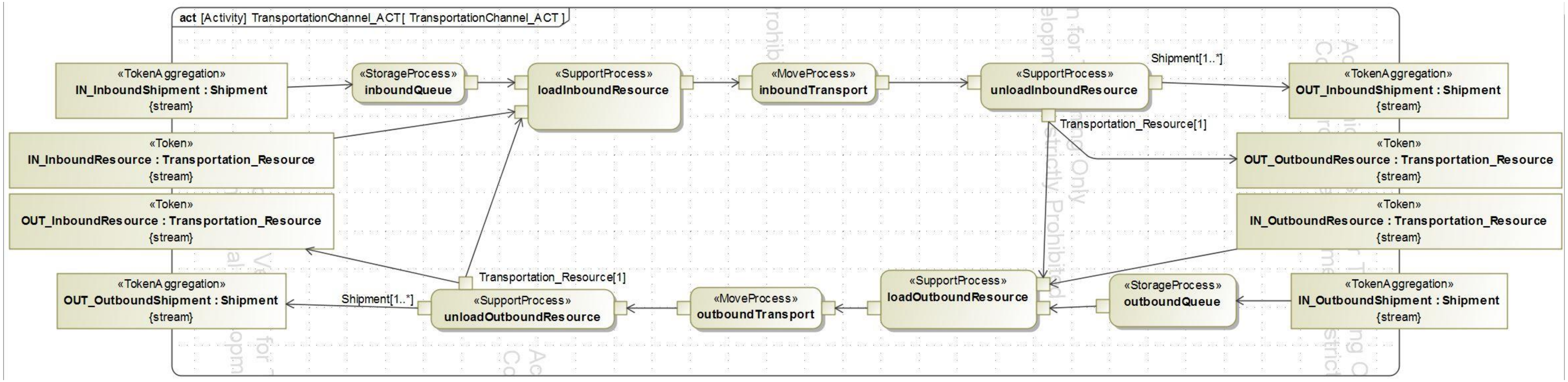
- The system of interest is a distribution supply chain.



Transportation Channel Behavior

A formal specification of the behavior of the transportation channel provides a template for constructing the corresponding (simulation) analysis component.

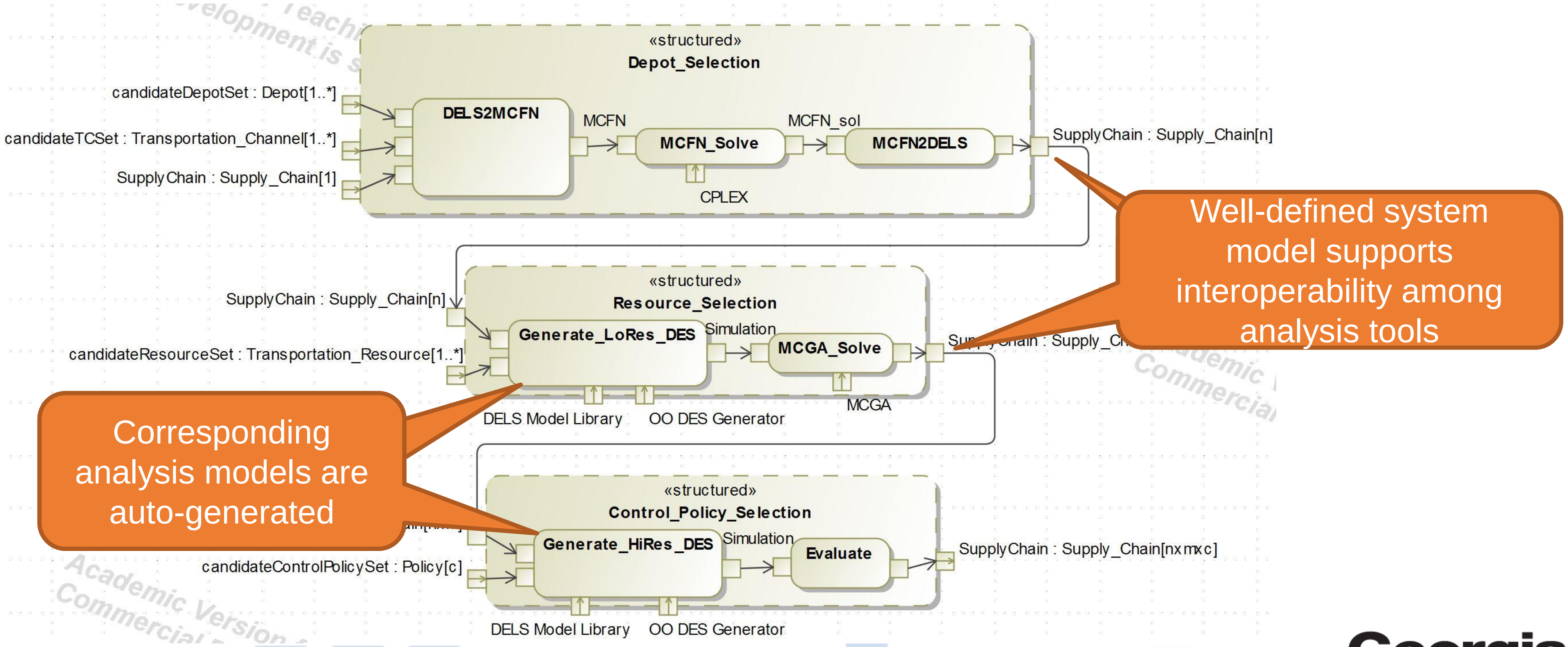
- Component-based generative methods for simulation models
- V&V of model library components, compose models from components



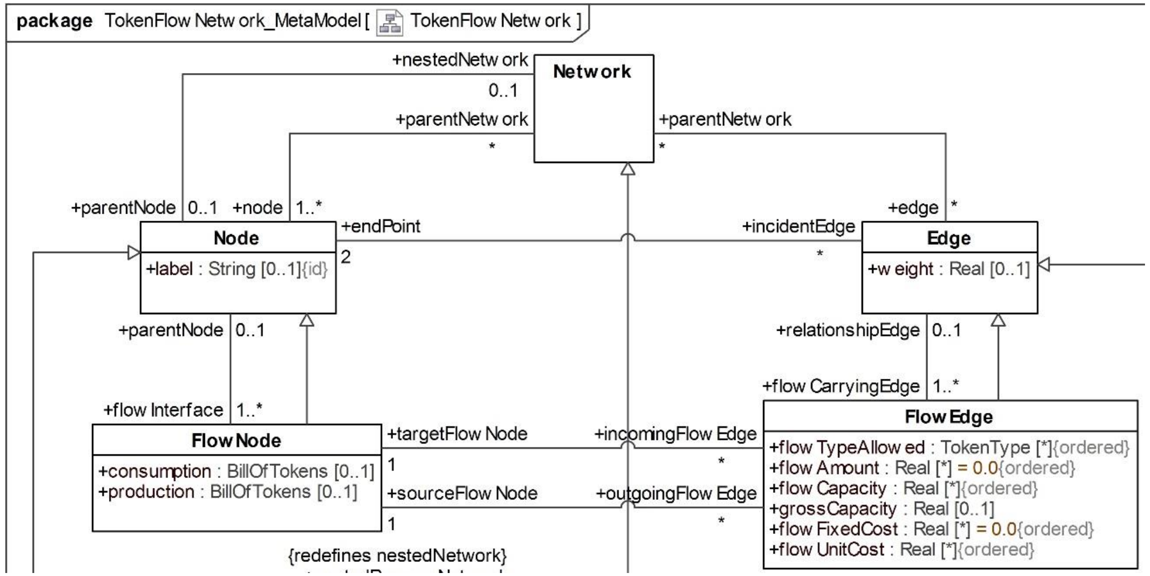
Analysis Methodology Overview

Hierarchical design methodology uses tailored simulation optimization methods at each level to optimize the structure, behavior, and control of the DELS

- Generate a large number of candidate solutions with corresponding simulation models specified at varying levels of aggregate, approximation, and resolution

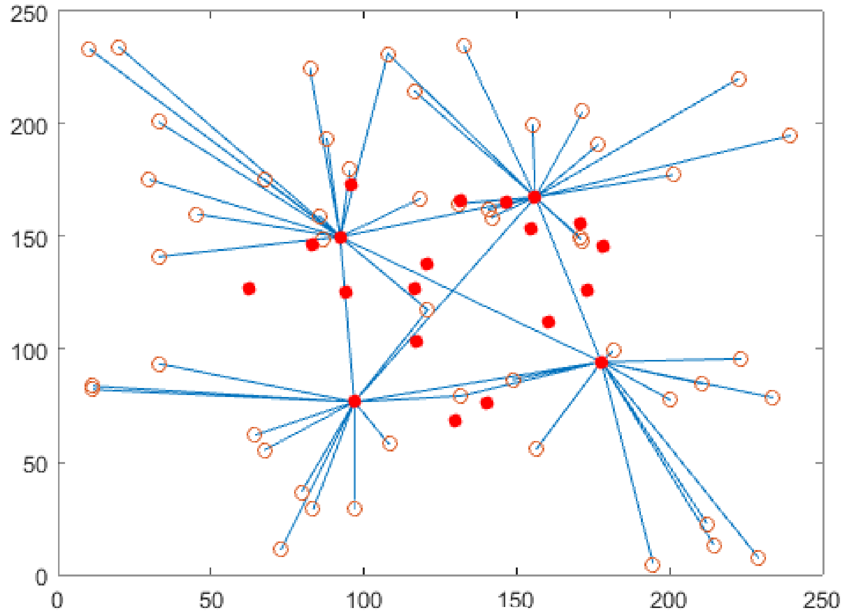


Optimize Network Structure – Where to put the depots?



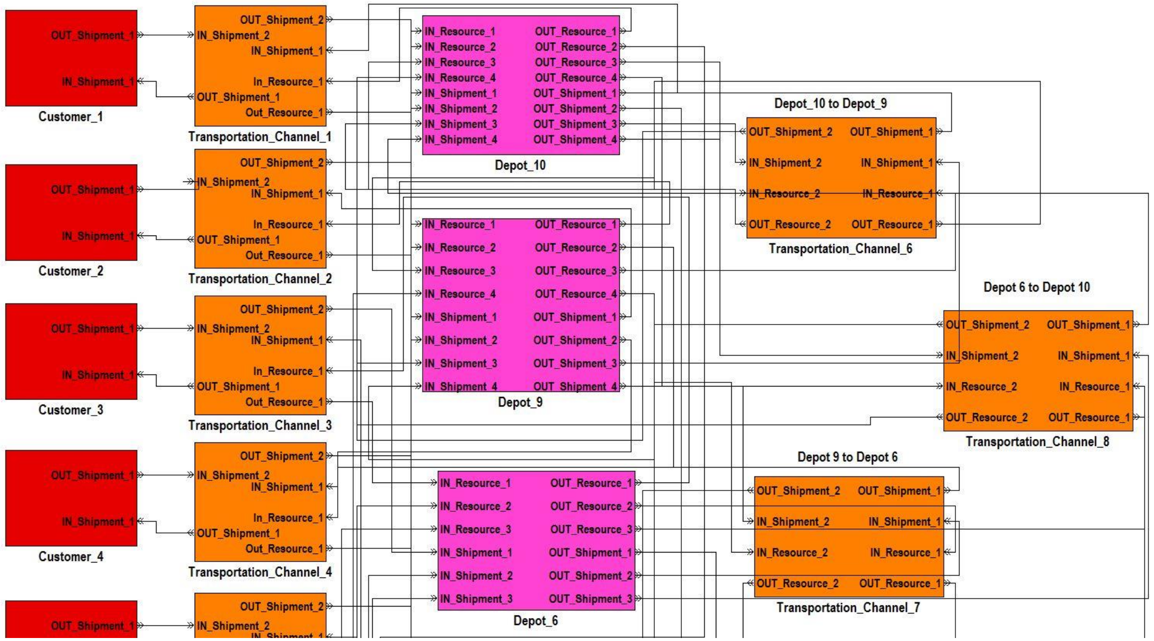
Goal: Reduce the computational requirements of optimizing the distribution network structure.

Strategy: Formulate and solve a corresponding multi-commodity flow network and facility location problem.



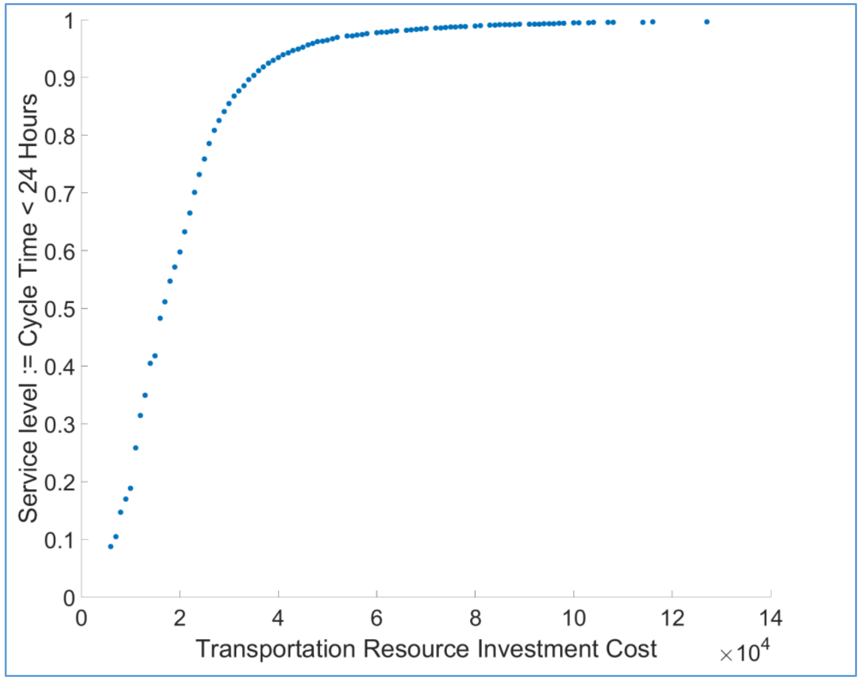
- Abstract the Supply Chain model to a Flow Network model that forms the backbone of the analysis model
  - Aggregate and approximate the flows and costs
- Solve MCFN using a COTS solver (CPLEX)

Resource Selection – How many trucks?



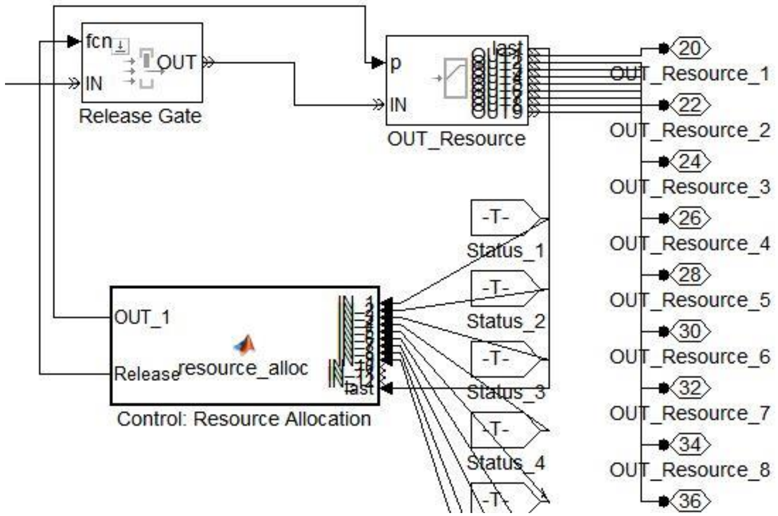
Goal: Capture and evaluate the behavioral aspects of the system using discrete event simulation.

Strategy: Generate a DES that simulates a probabilistic flow of commodities through the system.



- For each candidate supply chain network structure, generate a portfolio of solutions to the fleet sizing problem
- Trade-off cycle time/service level and resource investment cost

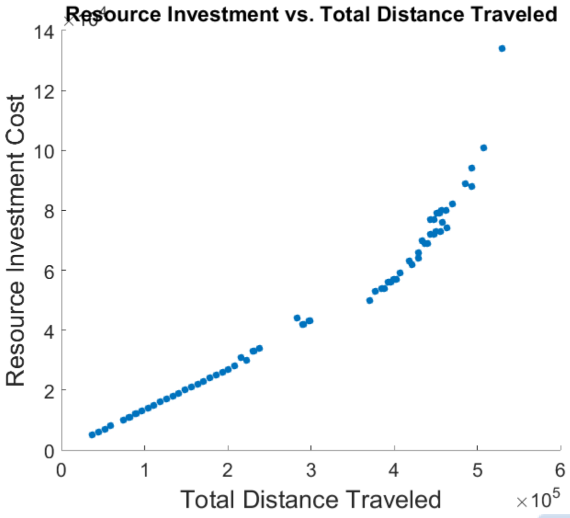
Configure Control Policies – Which Truck? When?

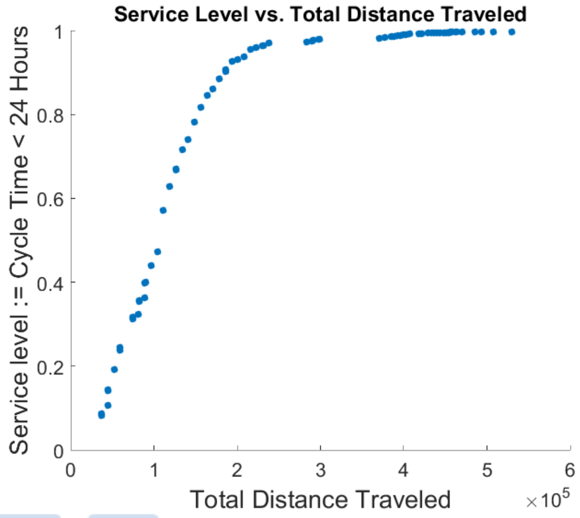


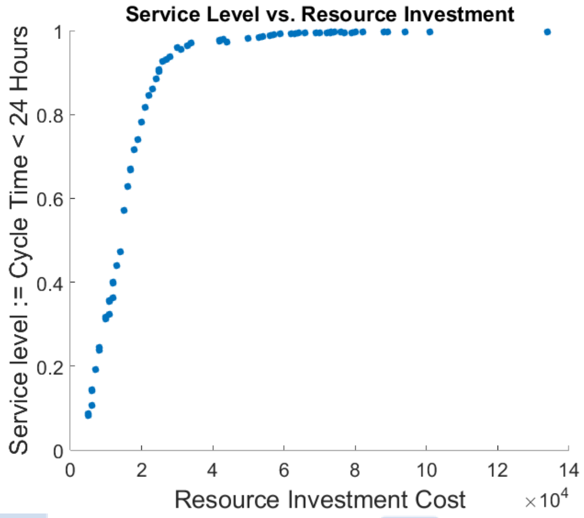
Goal: Select and design a detailed specification of the control policies for assigning trucks to pickup/dropoff tasks at customers.

Strategy: Generate a high-fidelity simulation that is detailed enough to fine-tune resource and control behavior.

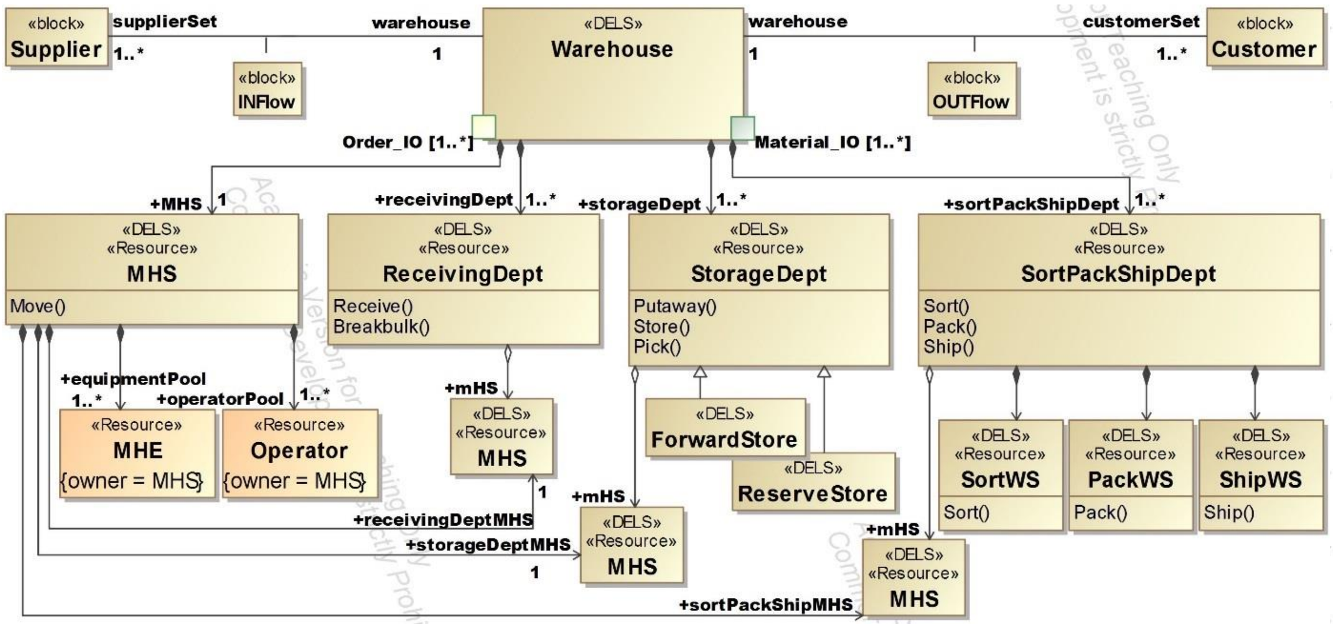
Trade-off Service Level, Capital Costs, and Travel Distance





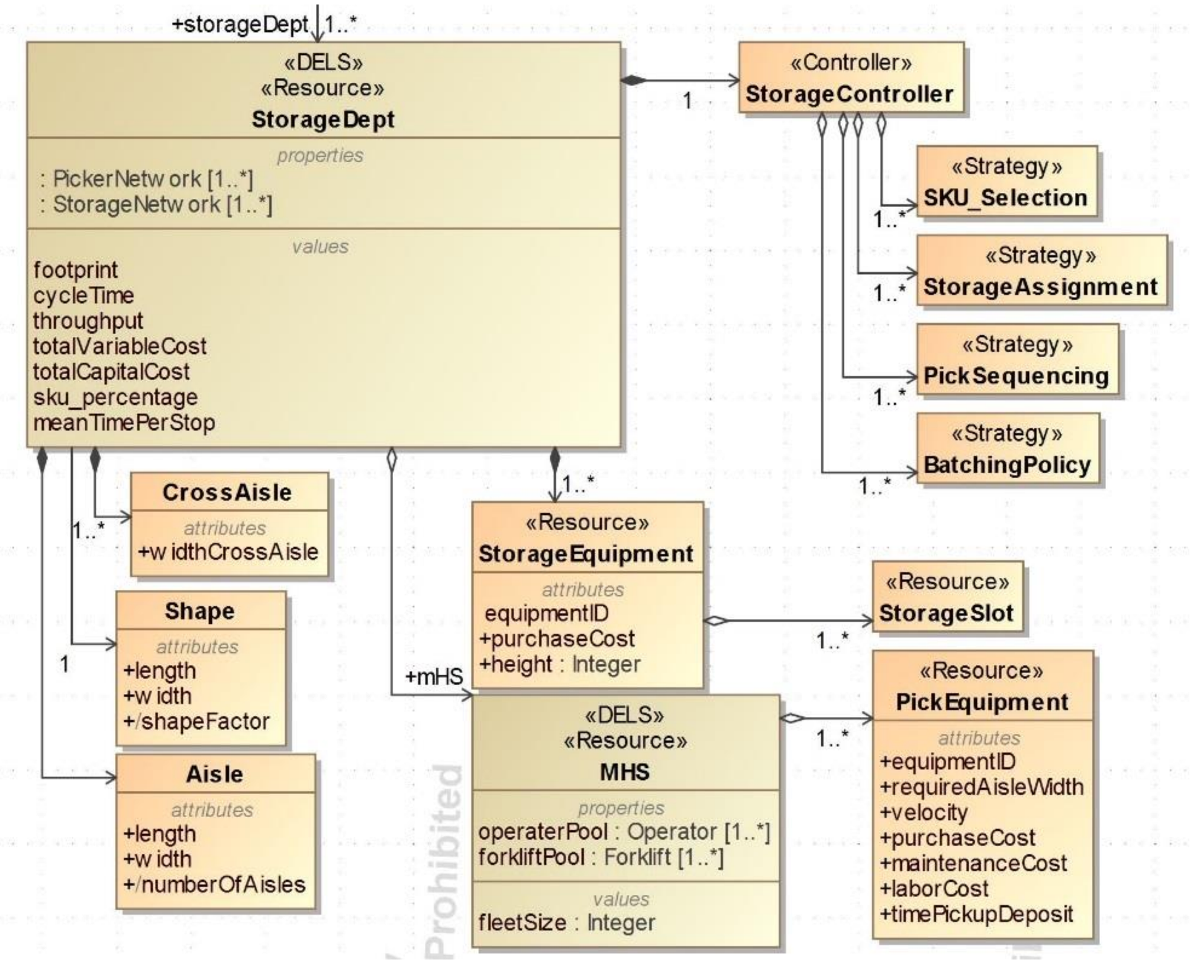


Warehouses

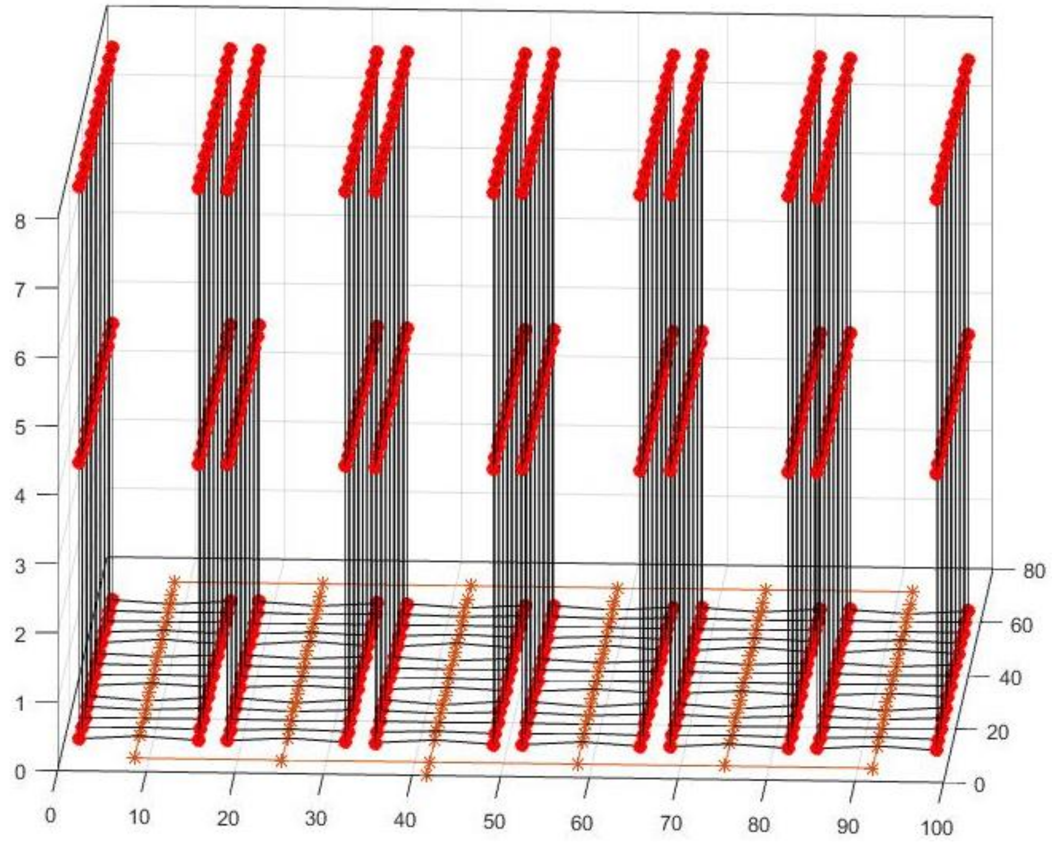


Same Strategy:

- Start with a system model,
- Generate simulation models and analysis models (decision support),
- Generate candidate designs.

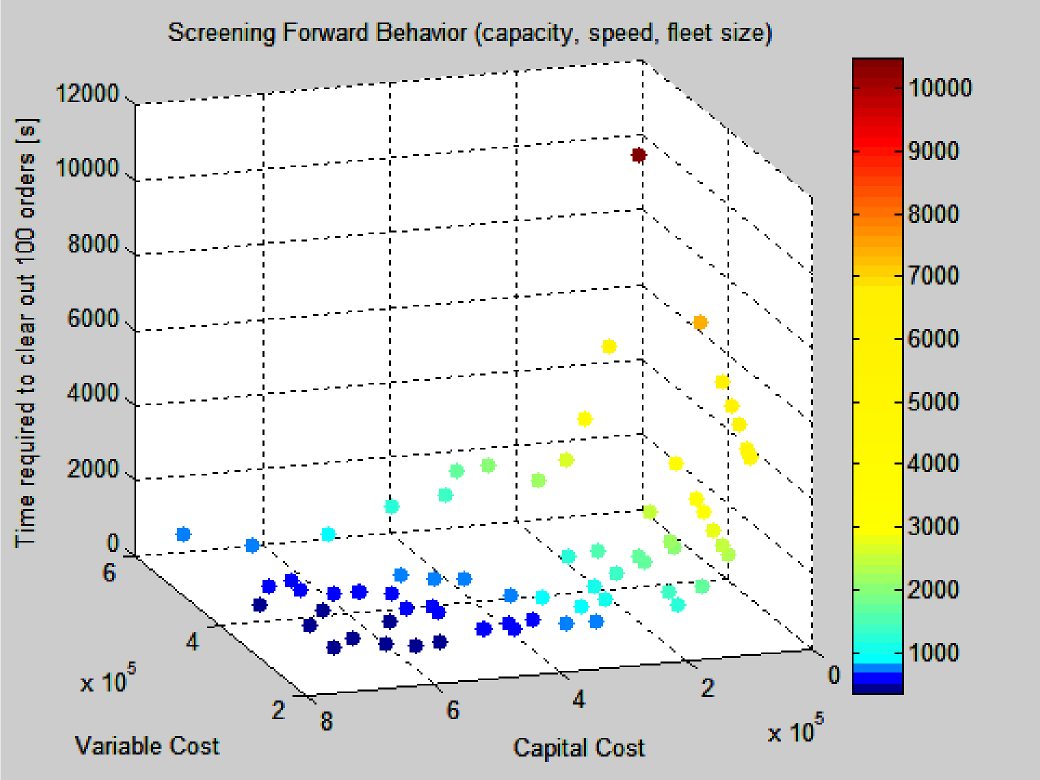


Analysis Model Generation



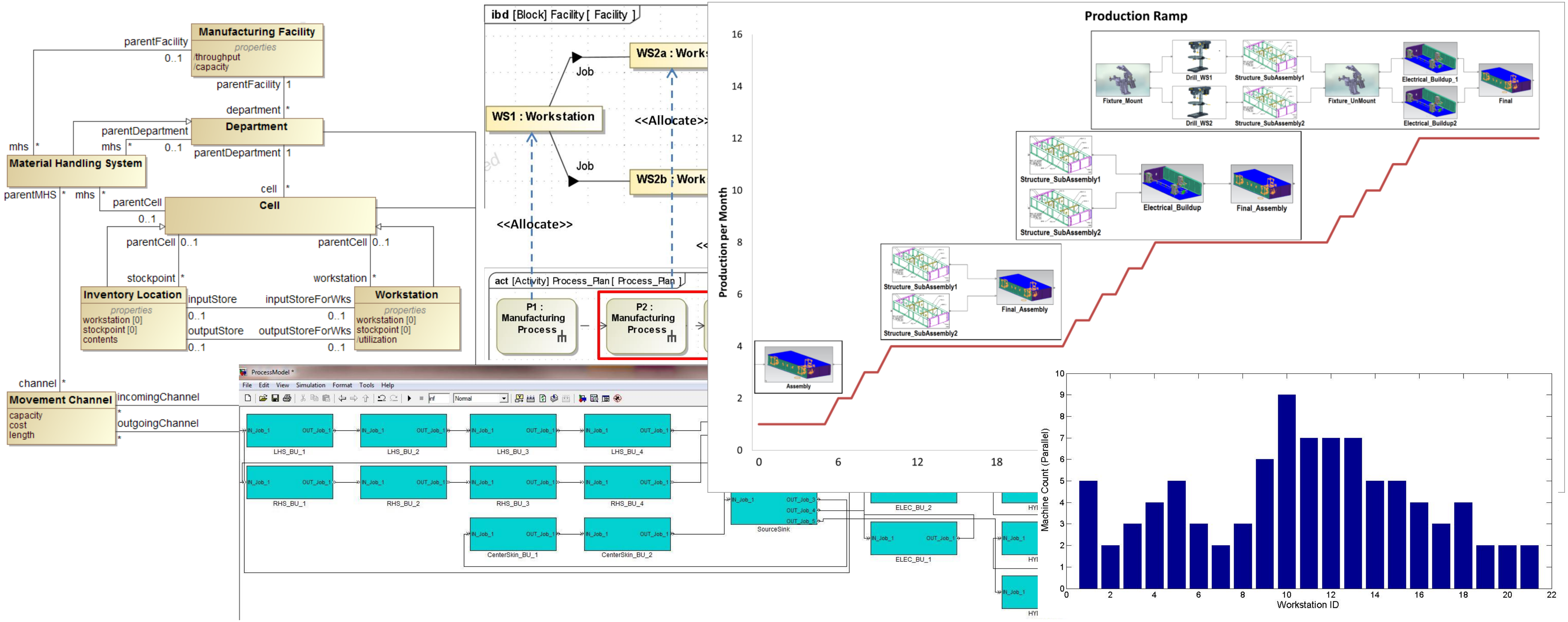
Metrics to support decision making:

- time required to clear out 100 orders (proxy for throughput),
- average time per tour (proxy for cycle time),
- capital cost,
- variable cost



For each layout, simulation model evaluates the performance of the storage and retrieval behavior and control

Manufacturing Facilities



Why do it this way?

- Mediate simulation and optimization tools with an explicit system model
  - A formal system model enables a greater degree of (semantic) interoperability
  - Generate many simulation models from the system model at varying degrees of fidelity, aggregation, and approximation
- Interoperability based on a formal domain model allows tailoring of analysis methods to take advantage of domain-specific strategies.
  - Optimization heuristics
  - Advances in simulation and computing technology
  - Integrate with information systems for real-time data, providing decision-support, and executing operational control

Where do we want to go?

- INCOSE MBSE Initiative Challenge Team on DELS Modeling
  - Single community for modeling DELS
    - Investigate crossover with transportation and healthcare WGs
- Connect to and engage with production system and logistics organizations
  - For every company that would like to see the benefits of MBSE in their manufacturing and supply chain organizations

For more information

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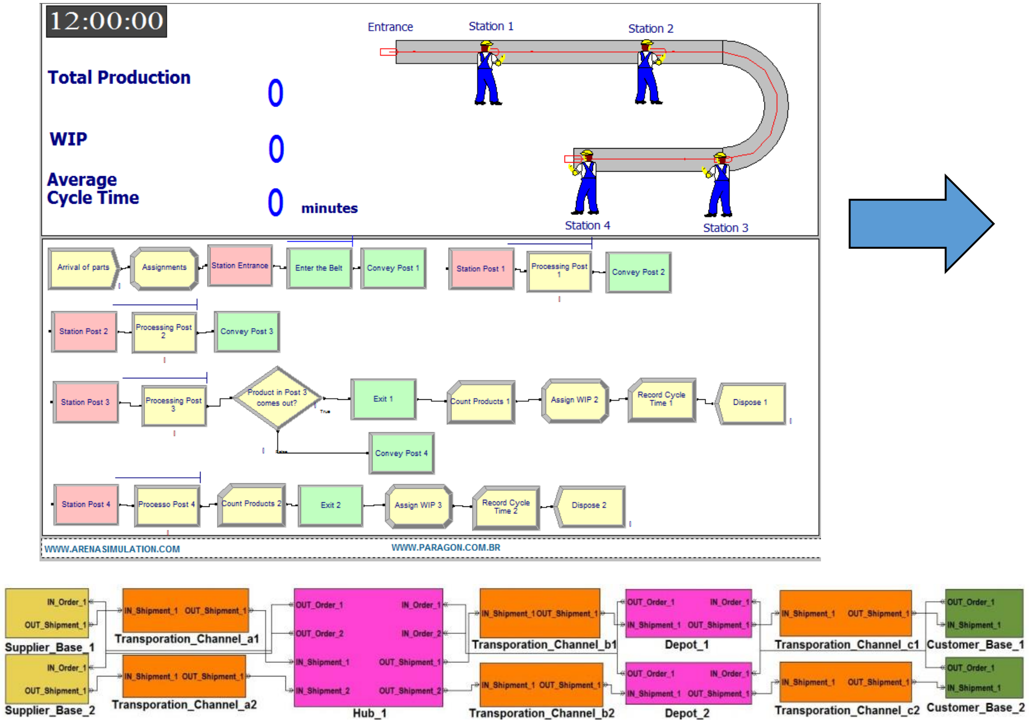
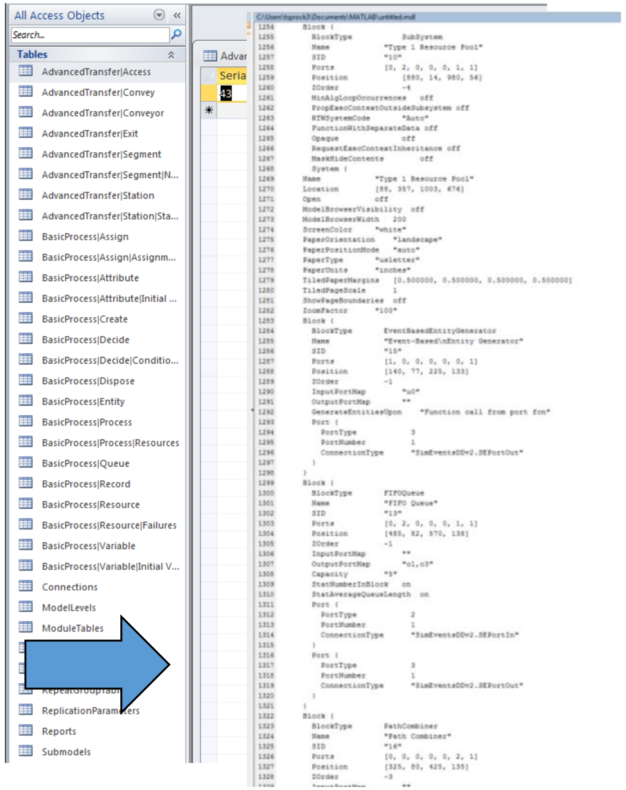
Domain Specific Challenges

Difficulties arise in applying current M2M methodologies for code generation to generating discrete event simulation.

Many popular simulation tools fail to store their models in a well-structured and accessible format, for which there is a published schema.

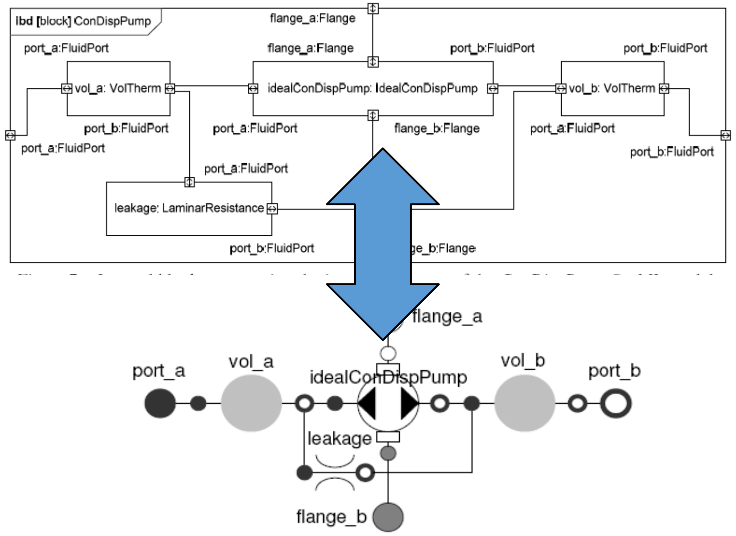




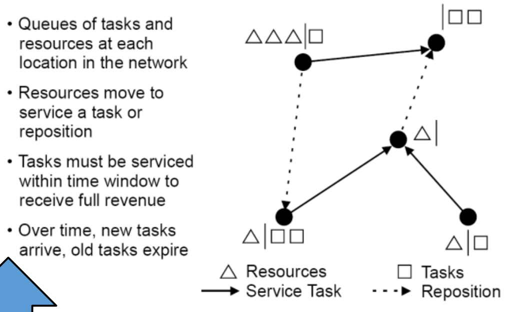
Similar issues with Tecnomatix PlantSim, FlexSim, etc.

Why is Discrete Event Simulation Hard?

OMG's SysML-Modelica Transformation (SyM), Version 1.0



Discrete Optimization has a canonical set-based abstraction (Thiers, 2014)

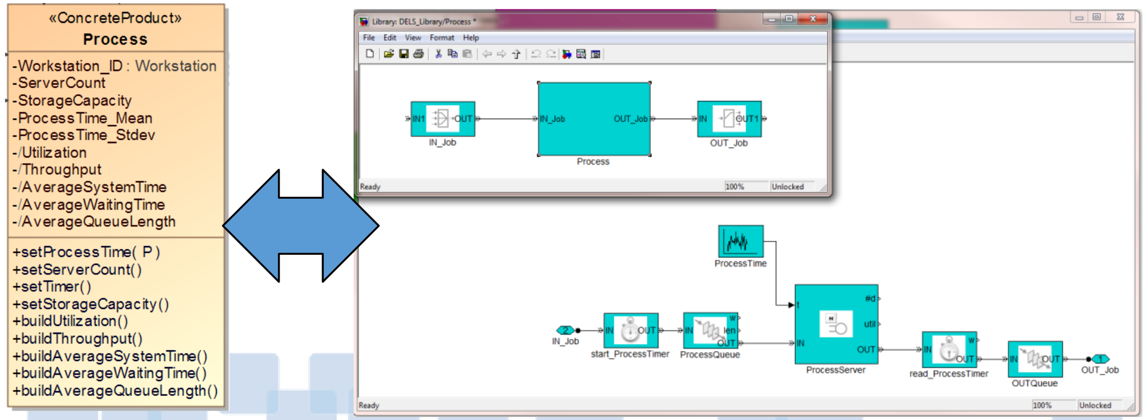


Physical Depiction of Dynamic Resource Allocation Problem

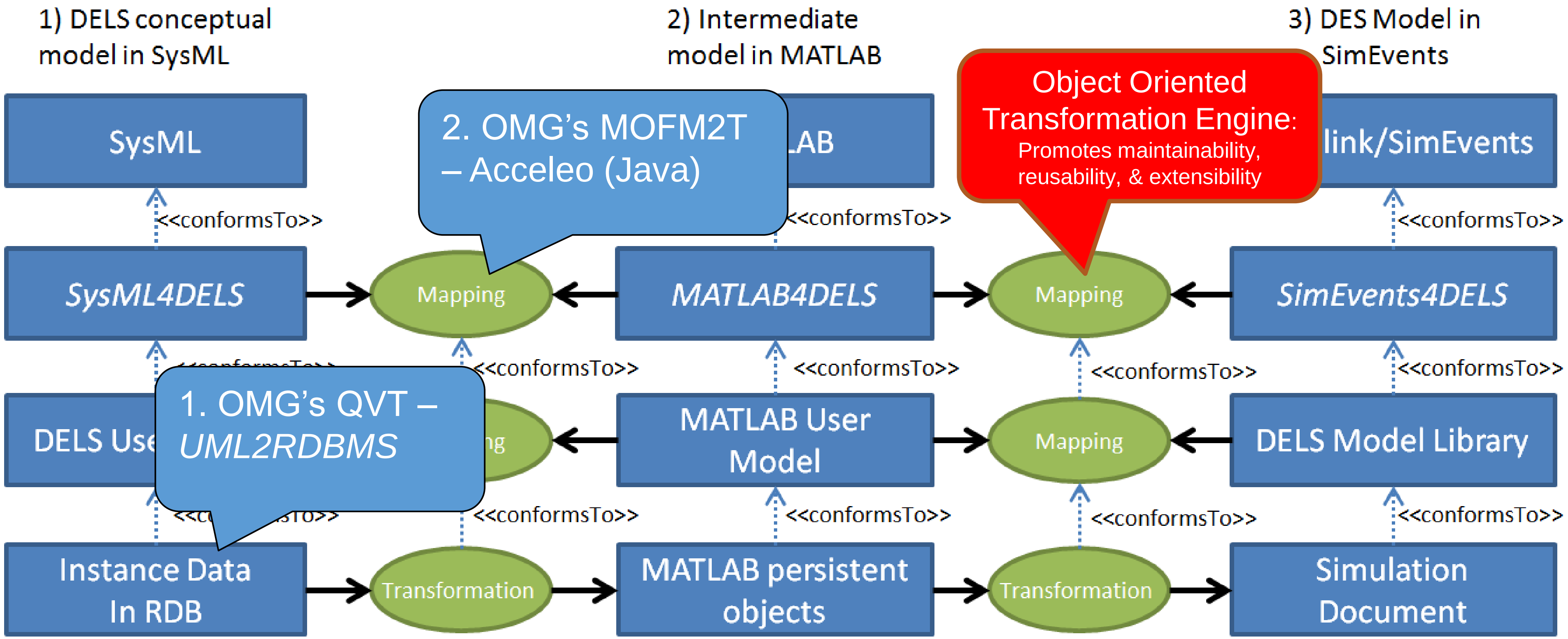
$$\min \quad c^T x$$
$$s.t. \quad Ax = b$$
$$x \geq 0$$

```
set FlowNode;
set FlowEdge within (FlowNode cross FlowNode);
set TokenType;

#Sign convention for netFlow:  Demand is positive, Supply is negative
param netFlow {FlowNode, TokenType};
param flowUnitCost {FlowEdge, TokenType};
param typeCapacity {FlowEdge, TokenType};
param grossCapacity {FlowEdge};

var flowAmount {FlowEdge, TokenType};

minimize netFlowCost:
sum {(i,j) in FlowEdge, c in TokenType}
flowUnitCost[(i,j),c] * flowAmount[(i,j),c];

subject to flowBalance {n in FlowNode, c in TokenType}:
sum {(i,n) in FlowEdge} flowAmount[(i,n),c]
   = netFlow[n,c] + sum{(n,j) in FlowEdge} flowAmount[(n,j),c];

subject to flowBounds {(i,j) in FlowEdge, c in TokenType}:
0 <= flowAmount[(i,j),c] <= typeCapacity[(i,j),c];

subject to edgeGrossCapacity {(i,j) in FlowEdge}:
sum {c in TokenType} flowAmount[(i,j),c] <= grossCapacity[(i,j)];
```

COTS Discrete Event Simulation languages lack a common abstraction and implementation



Transformation Strategy



Result: Seamless Integration of Components Represented in Different Formalisms