Model-Based Systems Engineering for Aerospace Manufacturing

Leon McGinnis, Georgia Tech

George Thiers, ModGeno

Agenda

1) MBSE, Digital Thread, IIoT, Industrie 4.0

2) Information-Exchange Standards

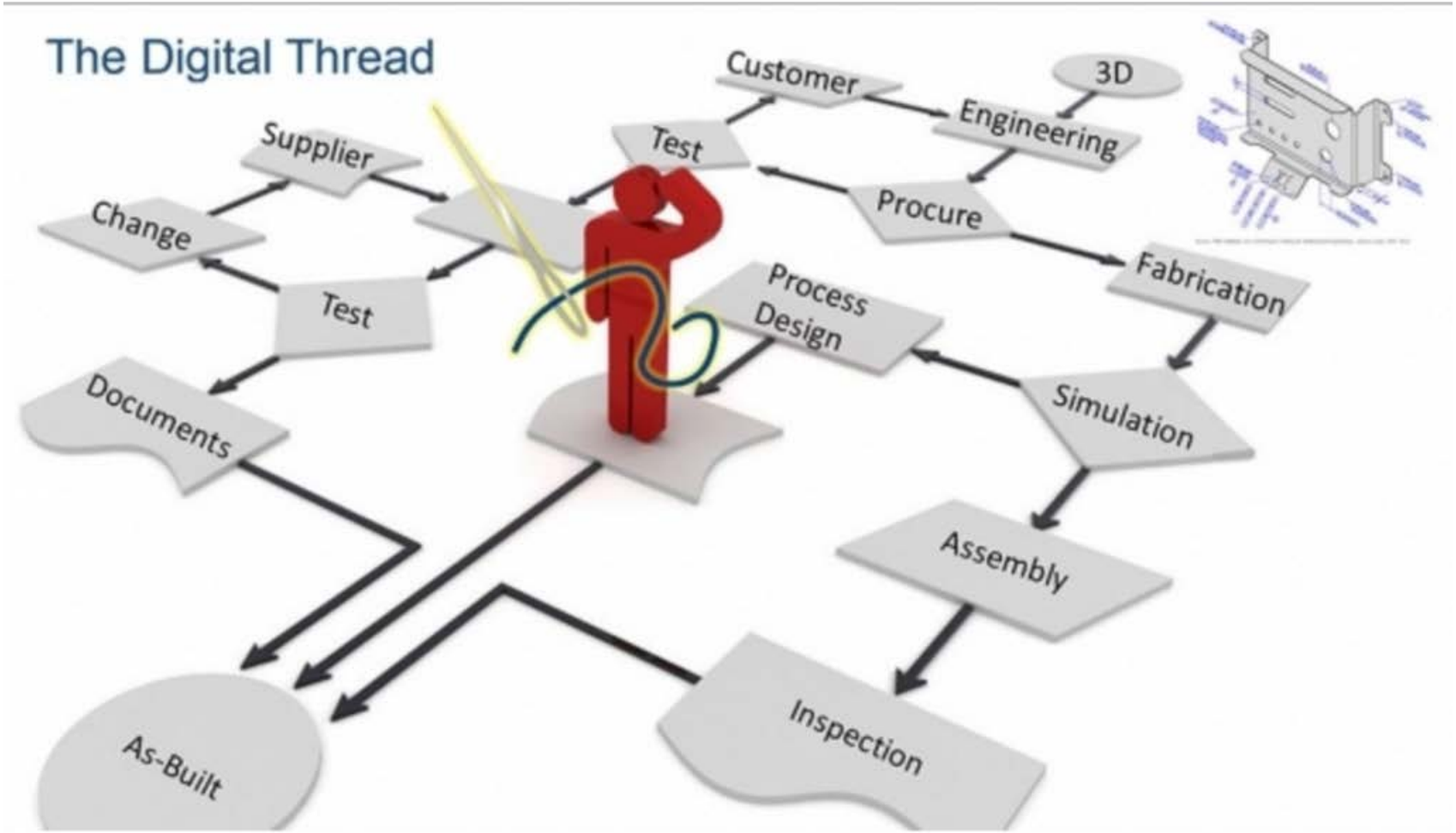
3) Why Exchanging Information Is Not Enough

4) DELS, reference model

5) Current State of Development / Commercialization

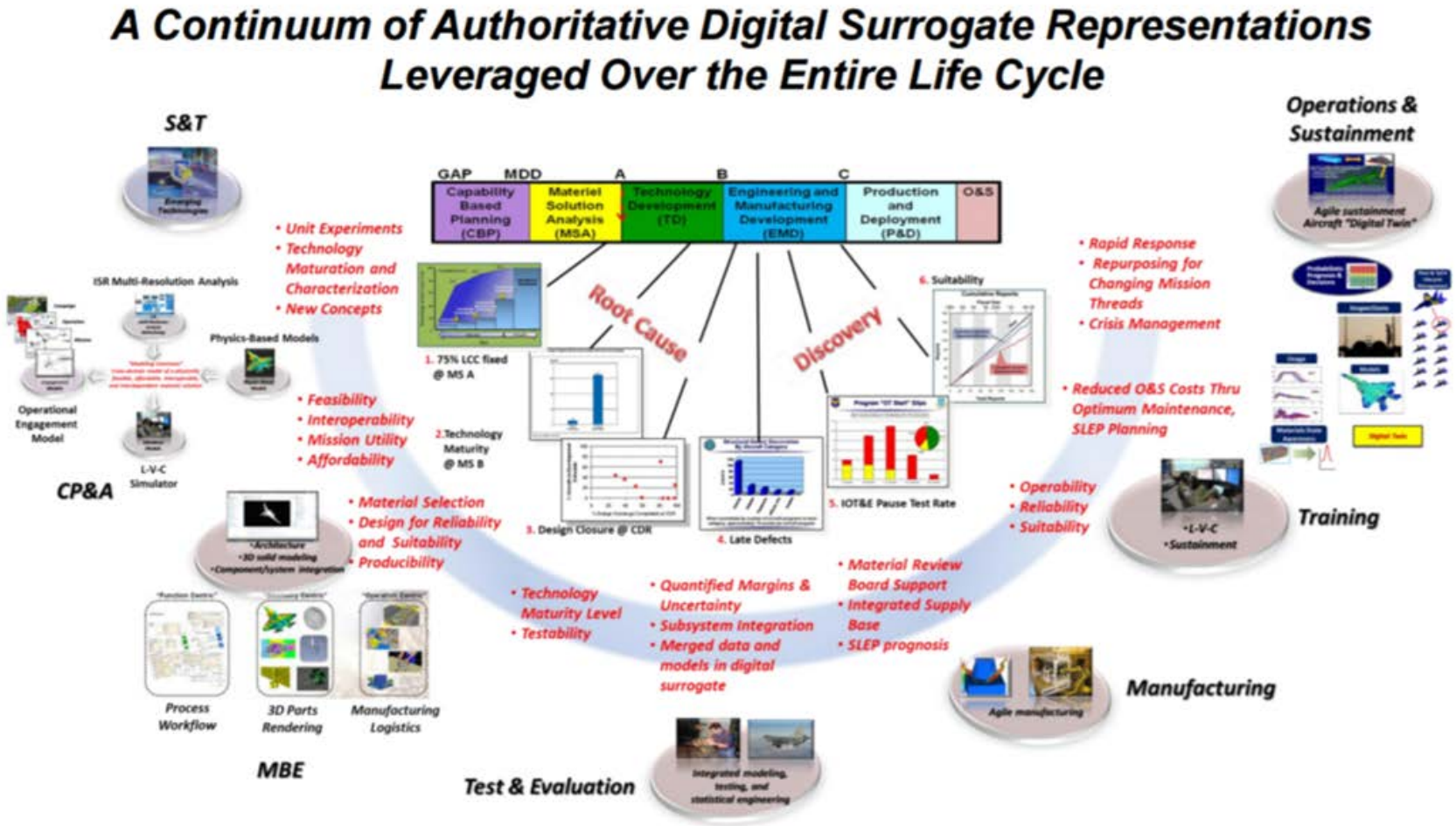
6) INCOSE initiative: Call for Participation

MBSE, Digital Thread, IIoT, Industrie 4.0



http://www.industryweek.com/systems-integration/demystifying-digital-thread-and-digital-twin-concepts?page=2

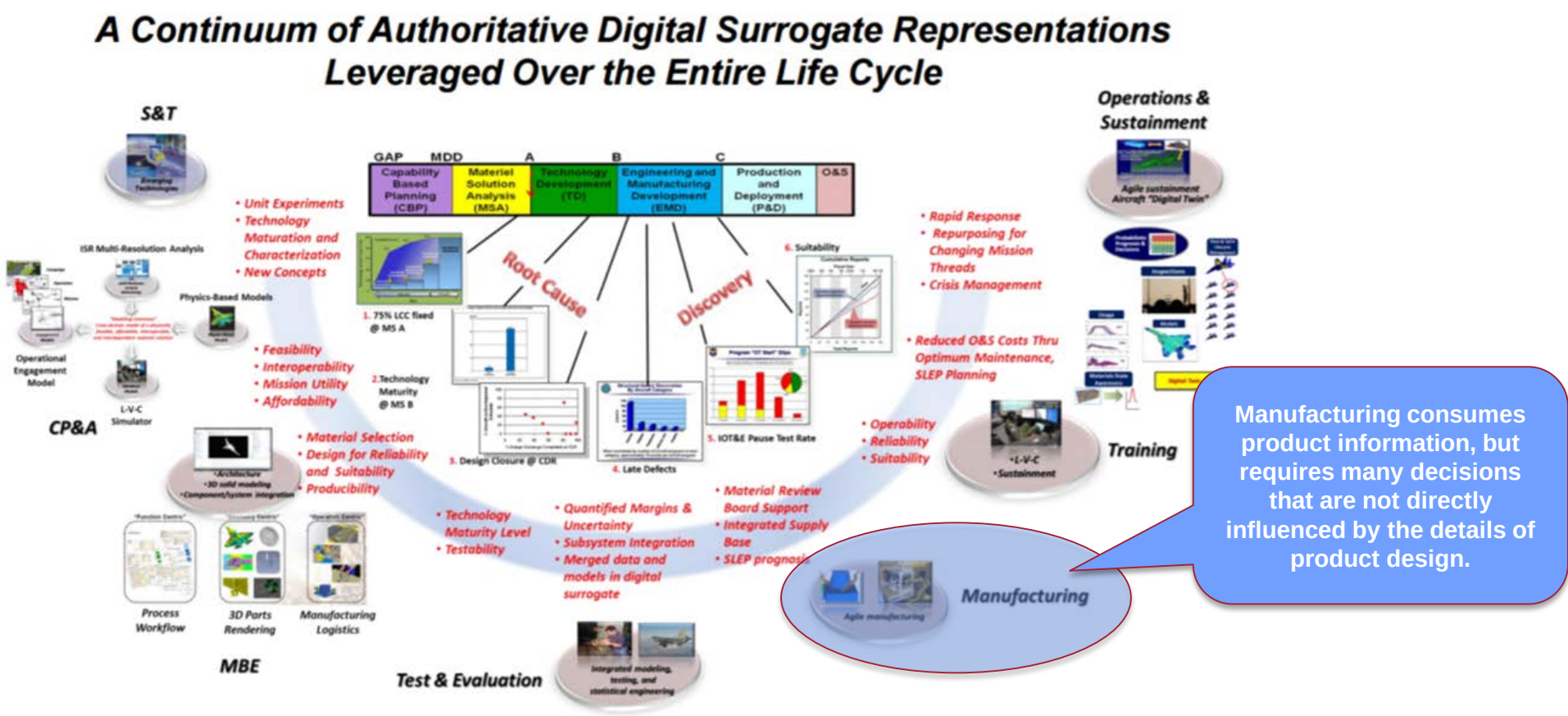
MBSE, Digital Thread, IIoT, Industrie 4.0



Dr. Ed Kraft, Technical Adviser, Arnold Engineering Development Center

https://www.nist.gov/sites/default/files/documents/el/msid/1Kraft_DigitalThread.pdf

MBSE, Digital Thread, IIoT, Industrie 4.0



Production Decision Making

Planning

WHAT PRODUCTION TECHNOLOGIES?
How is production allocated?
Who are the suppliers?
Where are they located?
Contingencies?
Where are our factories?
What about inventories?
What do our factories produce?
How do we transport?

Supply Chain Design

Operations Management

Accept a job?
Which resources to assign?
How to sequence tasks
When to change resources?
Where does job go next?

Production System Design

Behavior

G00 - Positioning at rapid speed; Mill and Lathe
G01 - Linear interpolation (machining a straight line); Mill and Lathe
G02 - Circular interpolati
G03 - Circular interpolati
G04 - Mill and Lathe, Dw
G09 - Mill and Lathe, Exa
G10 - Setting offsets in th

M00 - Program stop; Mill and Lathe
M01 - Optional program stop; Lathe and Mill
M02 - Program end; Lathe and Mill
M03 - Spindle on clockwise; Lathe and Mill
M04 - Spindle on counterclockwise; Lathe and Mill
M05 - Spindle off; Lathe and Mill
M06 - Toolchange; Mill

Part and assembly design

MBSE, Digital Thread, IIoT, Industrie 4.0

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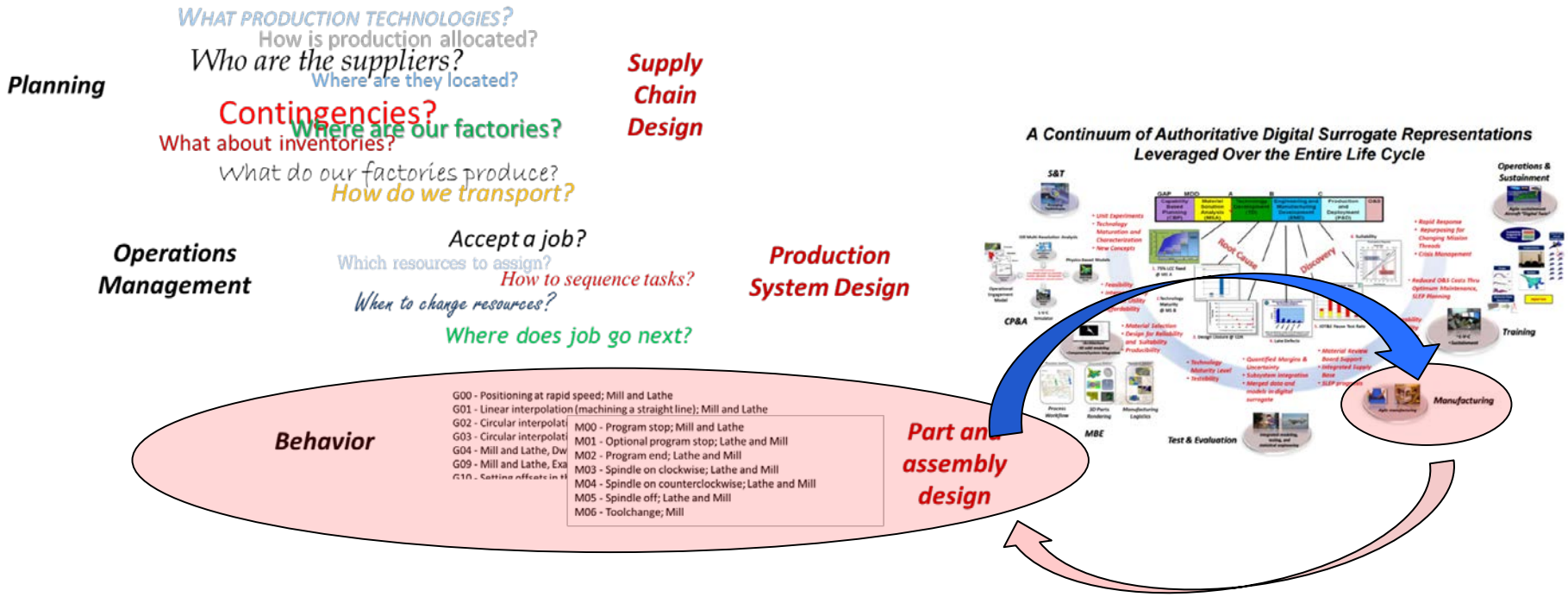

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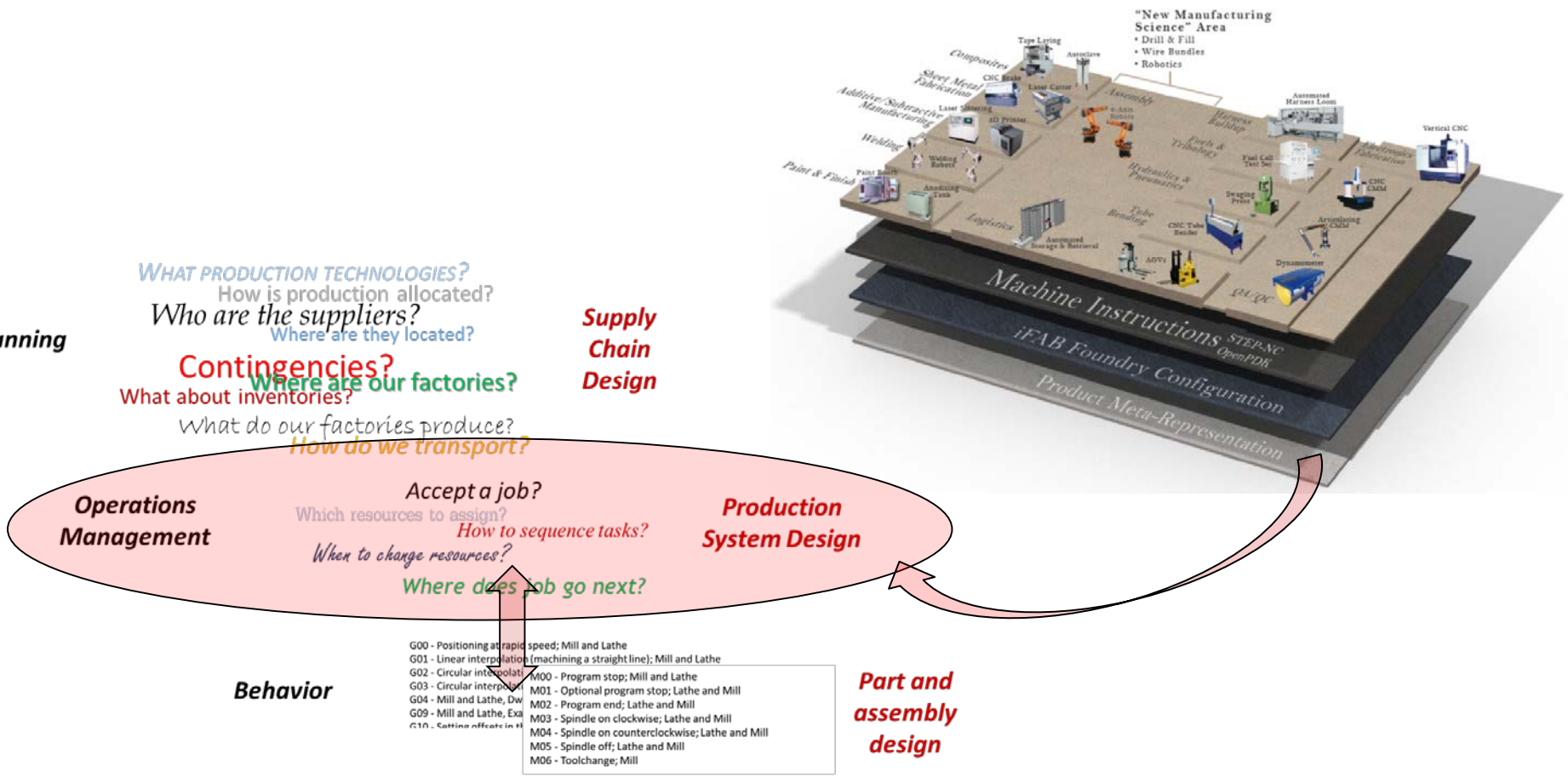

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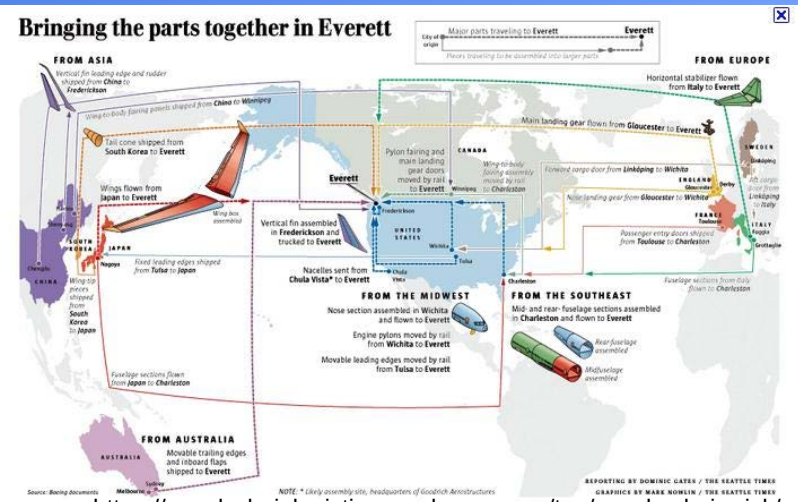

https://supplychainlogistics.wordpress.com/tag/supply-chain-risk/

Planning

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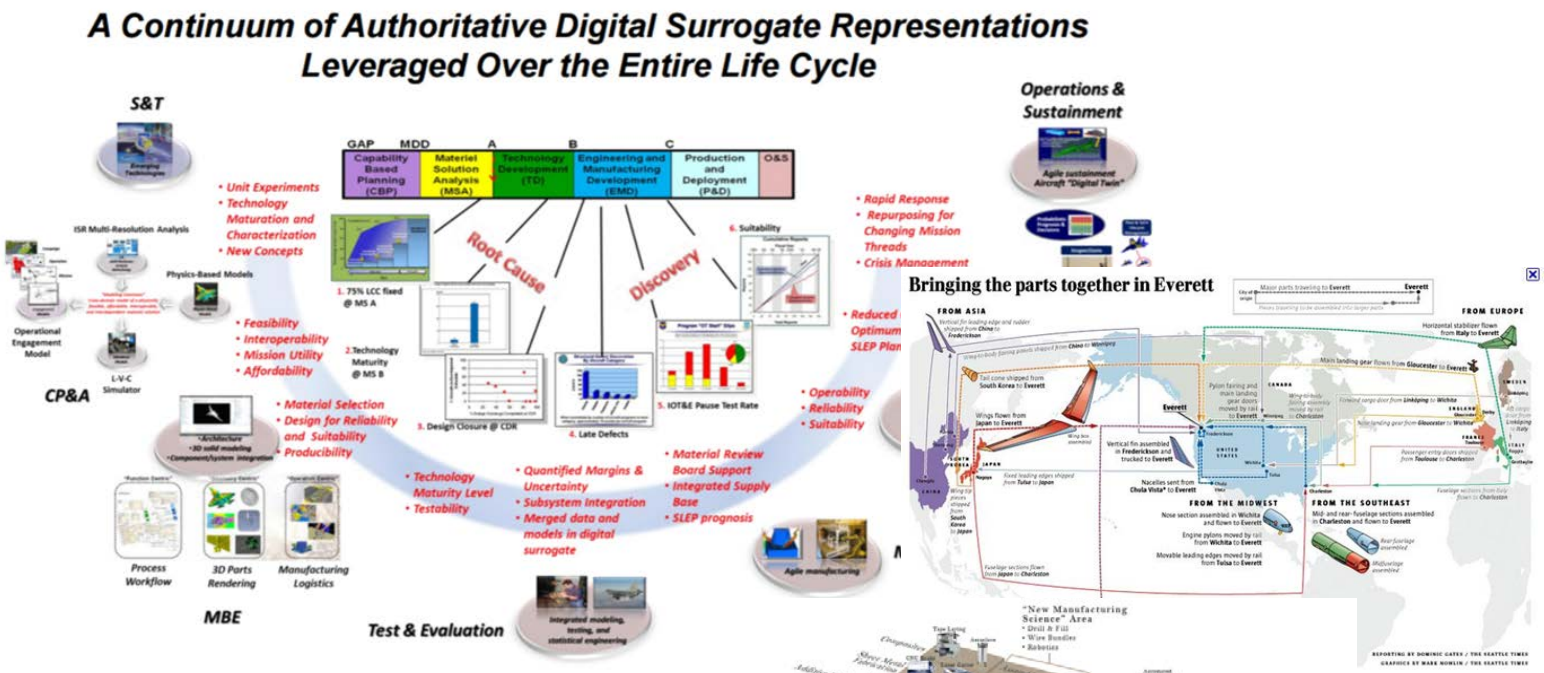

Lifecycle decision making needs good, reliable estimates of time to market, delivered cost, product quality, and supply chain reliability. And these systems need to be developed in parallel with the product.

How can they be integrated into the digital thread?

Information-Exchange Standards

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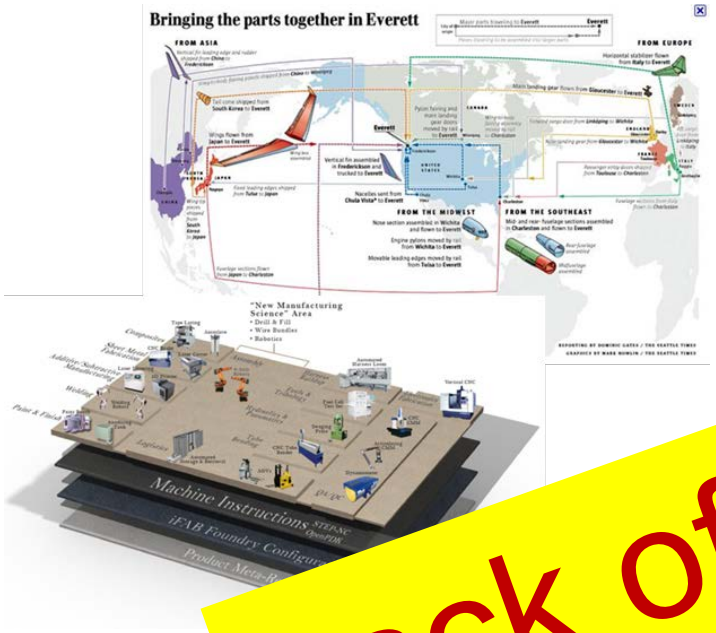


Lack of Integration!

Digital Fac

industrie 4.0

IIoT

CPS

Brilliant Factory

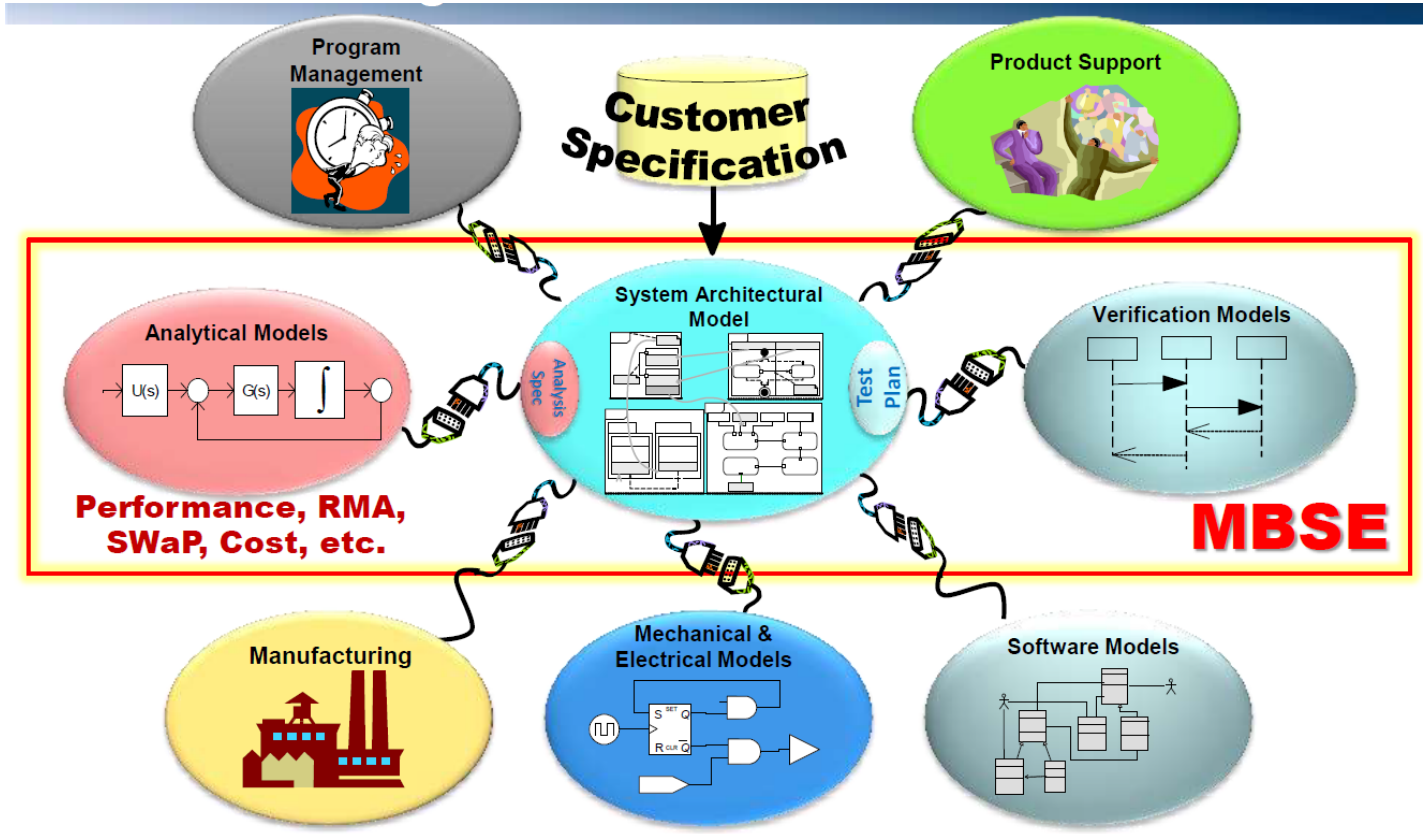
Why Exchanging Information Is Not Enough

- **New materials—composites**
- **New business models—strategic partners vs vendors**
- **Faster time to market**
- **Changing product requirements—P2P vs hub & spoke**
- **Changing production technologies—additive, smart, …**

- **“Copy the past and tweak” is no longer a feasible production system or supply chain design/development strategy**

- **=> We need to be able to specify and analyze the complete supply chain at levels of fidelity comparable to the specification and analysis of the product**

Why Exchanging Information Is Not Enough



http://www.incose.org/docs/default-source/delaware-valley/mbse-overview-incose-30-july-2015.pdf?sfvrsn=0

Discrete Event Logistics Systems, reference model

- **Research and development program of the Keck Virtual Factory Lab at Georgia Tech**
  - **Industry partners over the last 10 years include: Boeing, FedEx, GE, Lockheed, McKesson, Rockwell Collins, UTRC**
  - **Sponsorship from NIST**
- **Commercialization through ModGeno**
  - **NIST SBIR award**

Discrete Event Logistics Systems, reference model

Need to address:

- **(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**

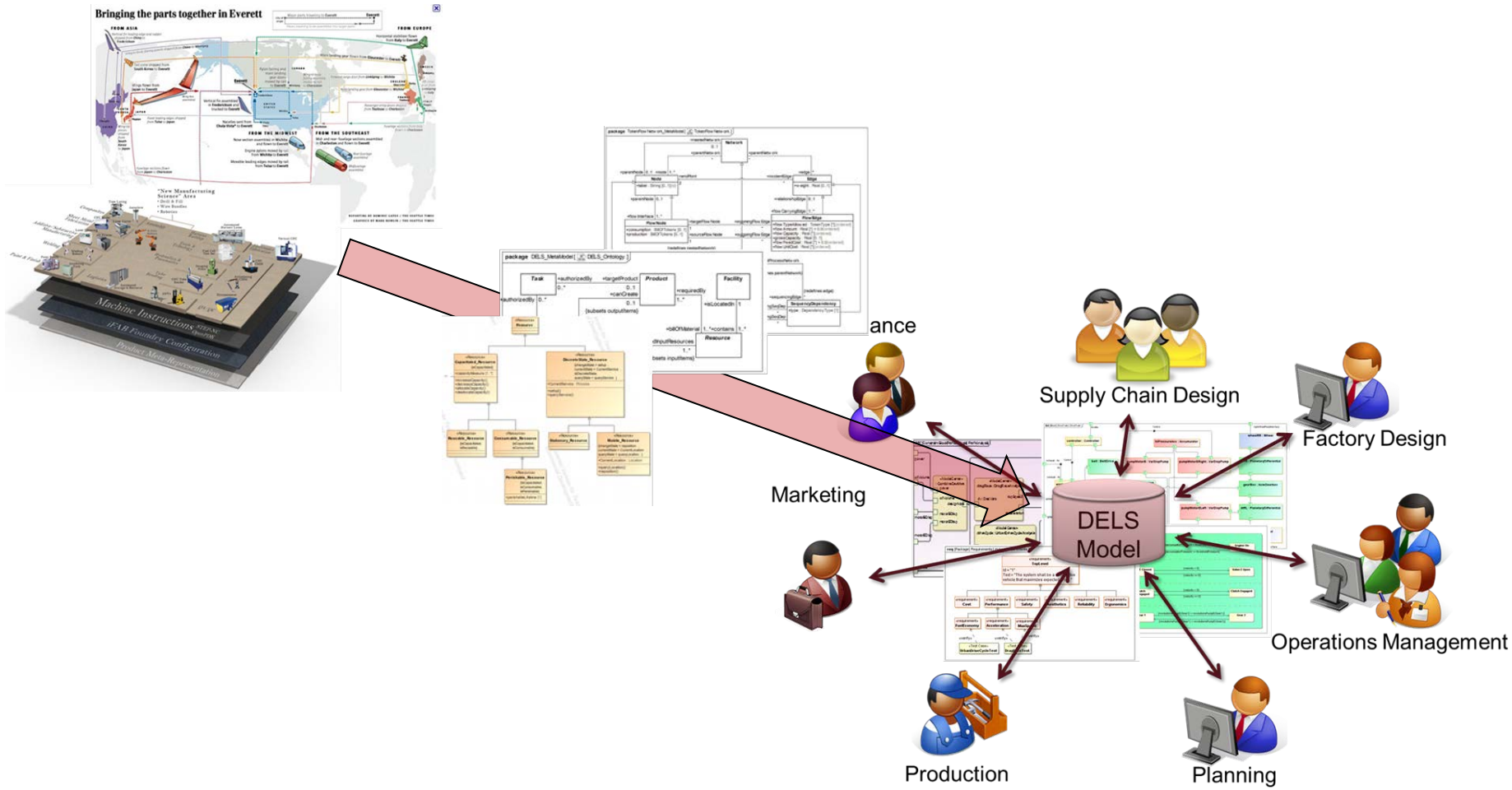
First, Identify the Domain

- Manufacturing systems are systems:
  - through which materials (**product**, tasks) flow
  - and are transformed by **processes** (make, move, store, measure)
  - executed using **resources** (people, equipment, inventory)
  - organized in some way (**facility** or network)

- Product/Process/Resource/Facility

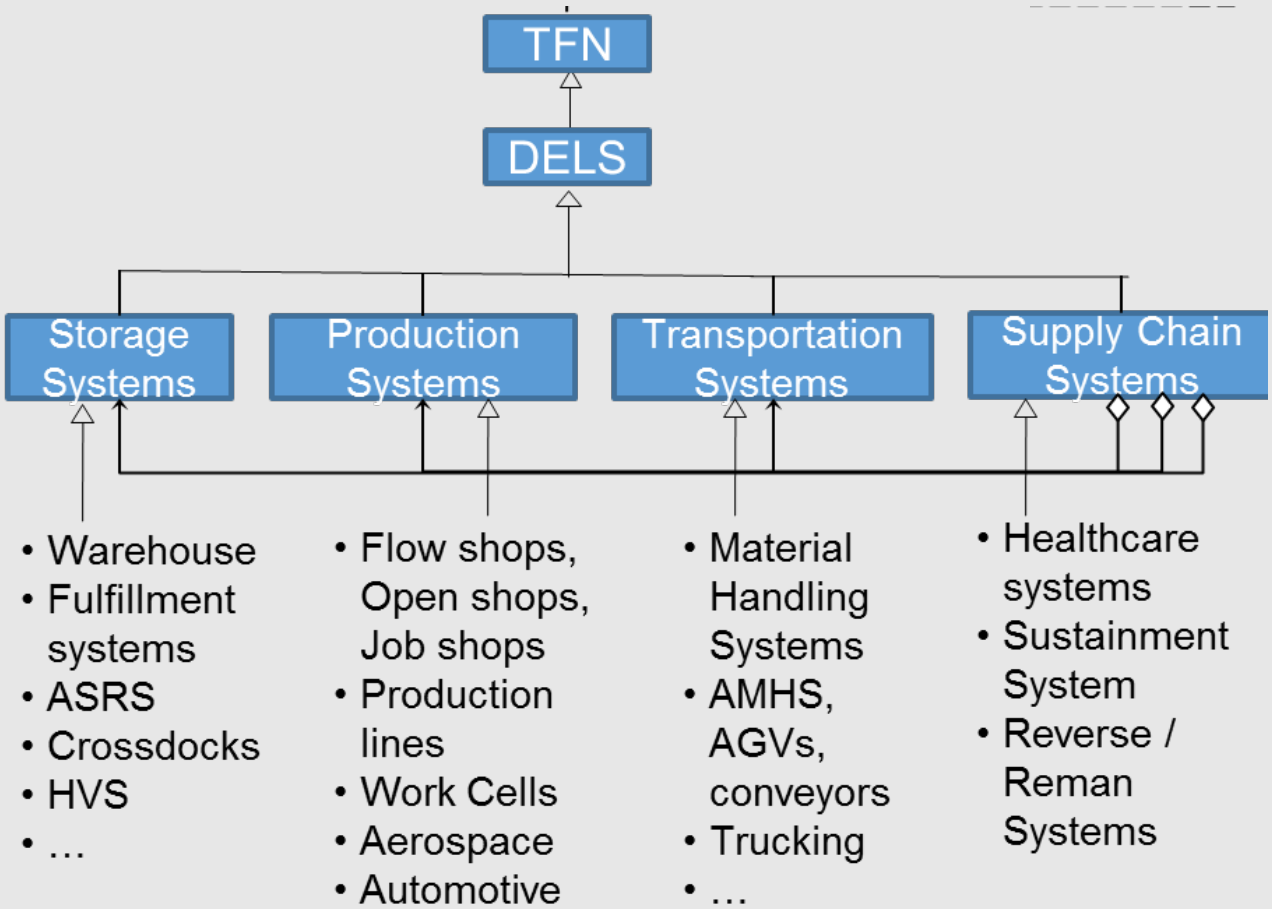
Discrete Event Logistics Systems, or DELS

Discrete Event Logistics Systems, reference model



Discrete Event Logistics Systems, reference model

A DELS model is actually a layered series of models:



Abstract
(more general semantics)

Principle: Define knowledge and transformations at the most abstract level possible, such that everything defined at lower abstract levels becomes reusable at every higher concrete level.

Concrete
(more specific semantics)

Discrete Event Logistics Systems, 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.**

DELS Modeling Framework

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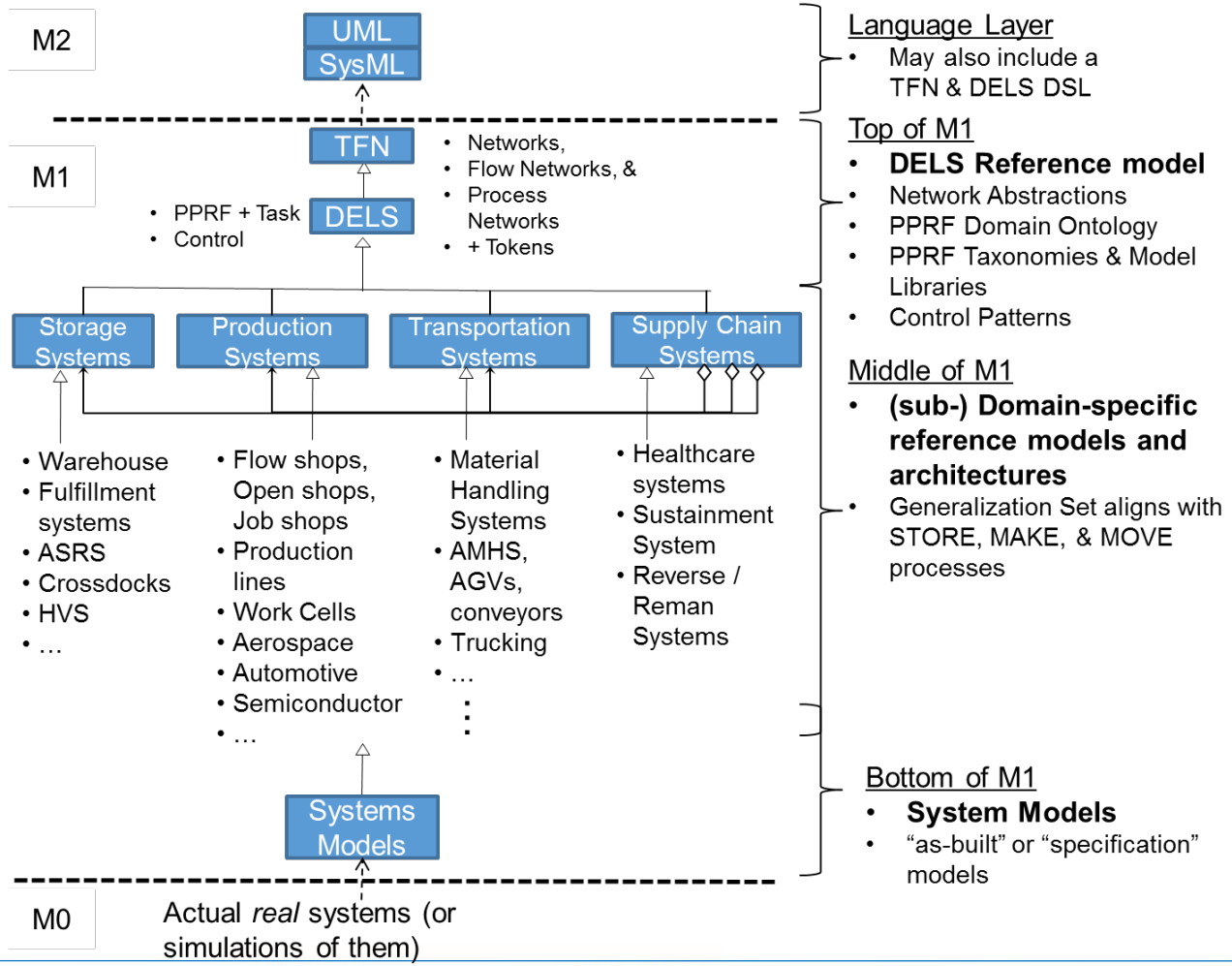
Framework both for elaborating the reference model and for using it to model existing systems or to support future system design



DELS Network Abstraction

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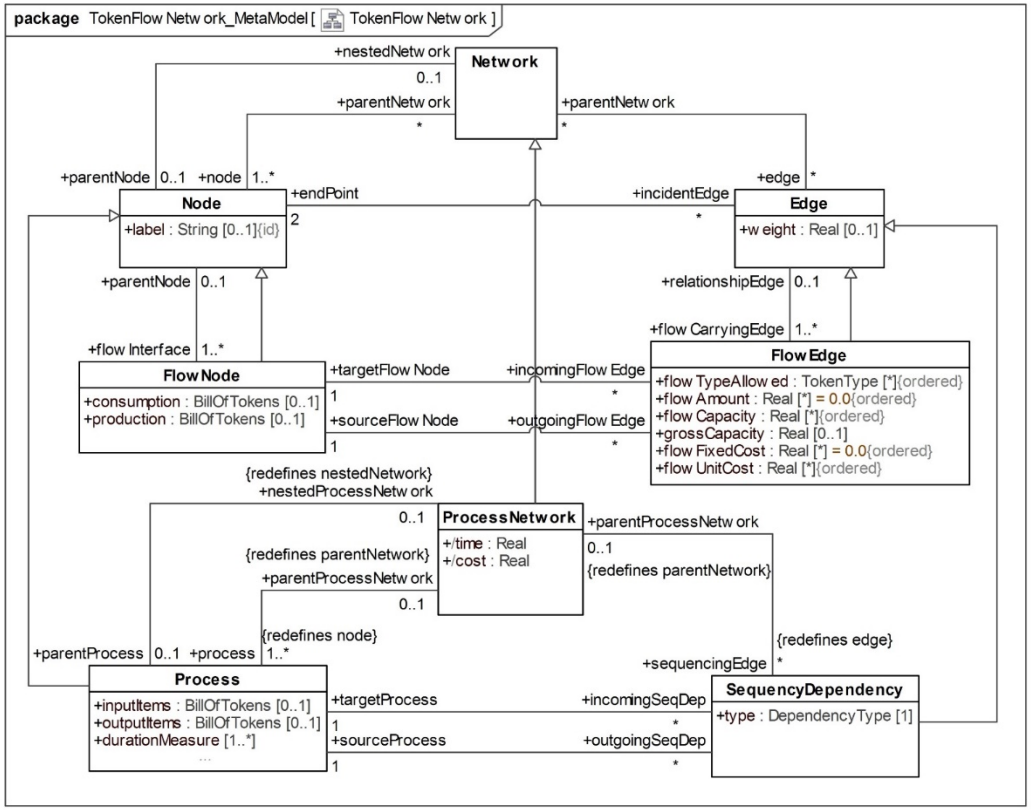
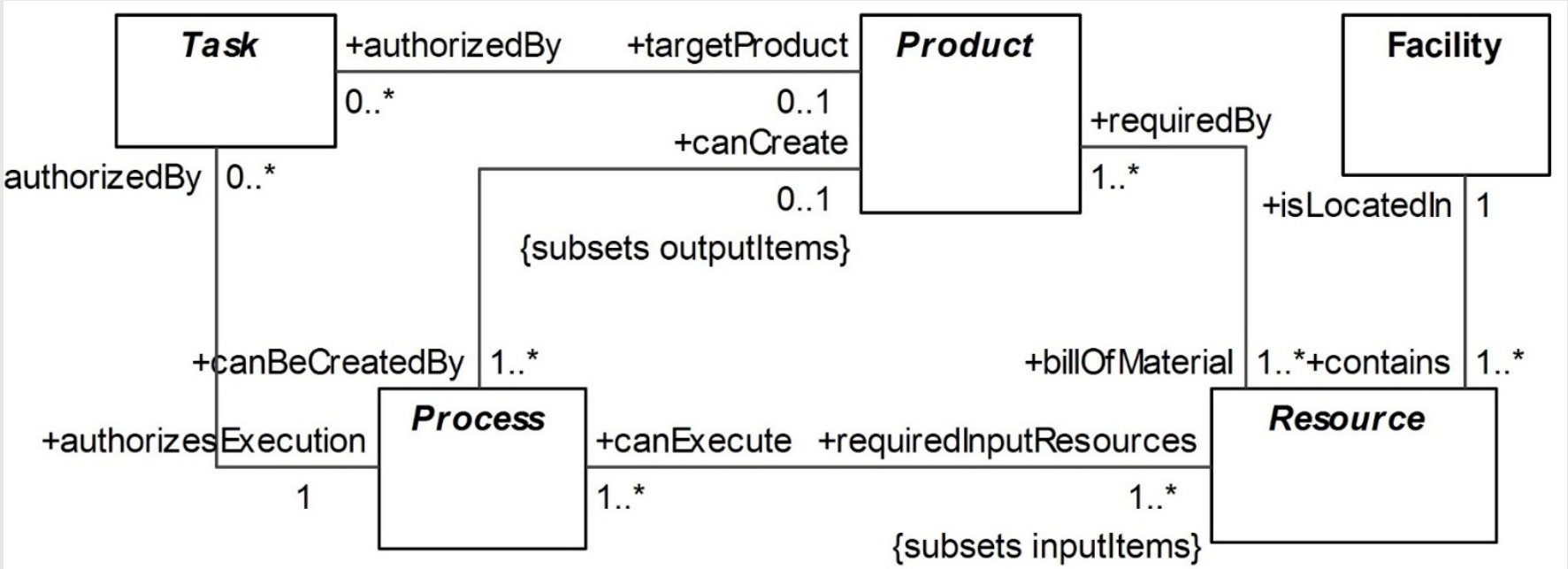
Most abstract system representation, which enables and supports model-to-model transformation for large classes of systems



Discrete Event Logistics Systems, reference model

Layer 2, ***Discrete Event Logistics System*** (abstract): Core semantics include *Product*, *Process*, *Resource*, and *Facility*.



What else? An important pattern is *plant / control separation*, common in product models but not so much in production system models.

Discrete Event Logistics Systems, reference model

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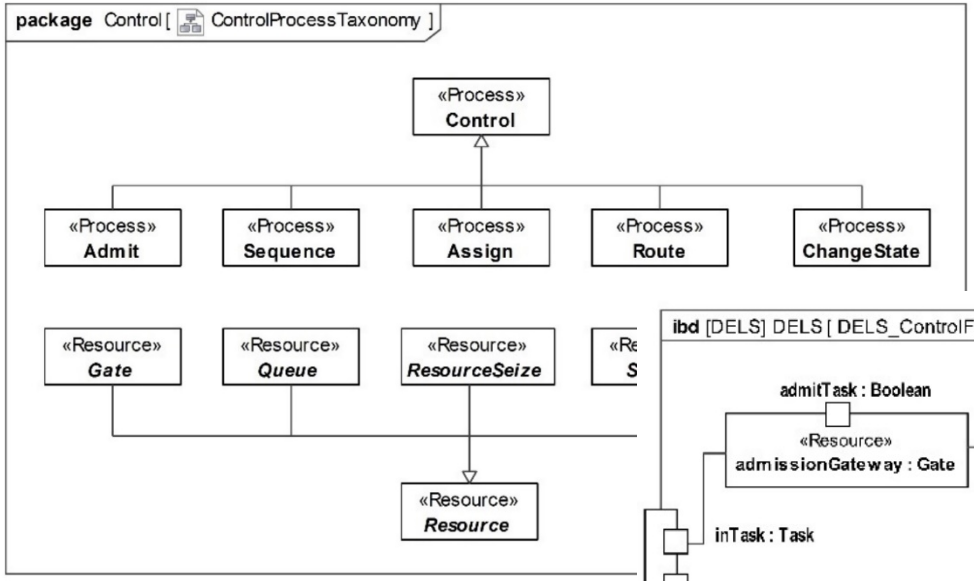
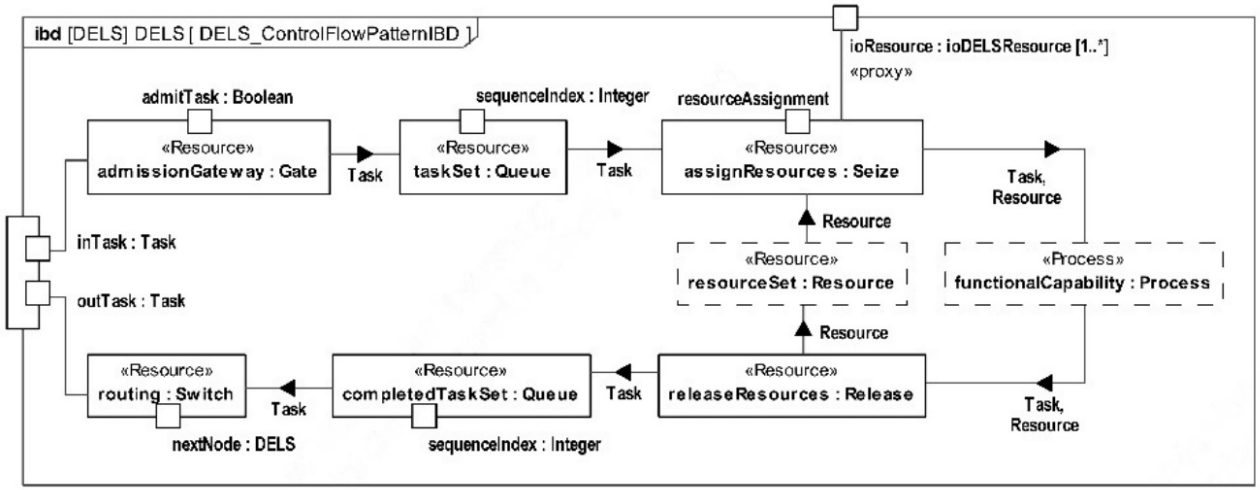


Maps the **decision variables** in the controller's decision problem to a particular **actuator function** and **execution mechanism** in the plant



Plant/Control model integration

DELS Behavior Taxonomies

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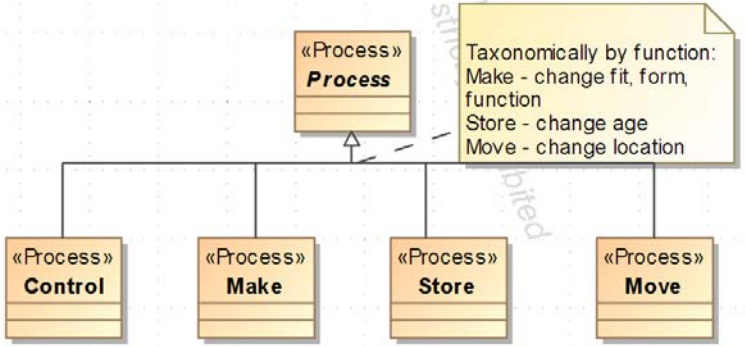
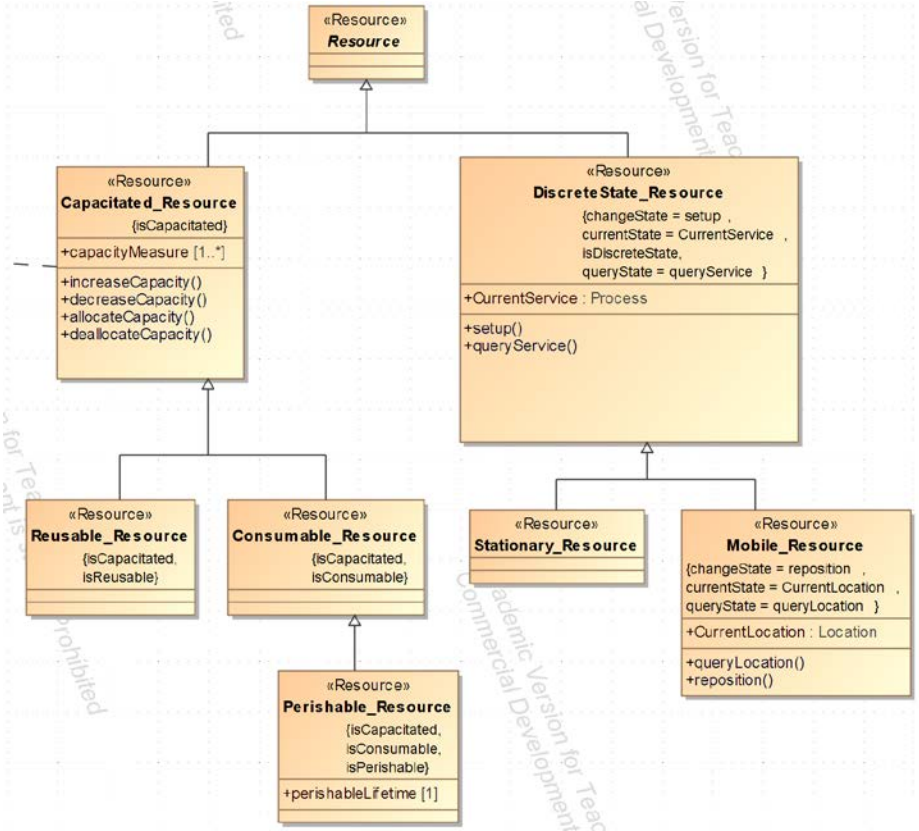




Most abstract resource models that capture most resource behavior patterns

Discrete Event Logistics Systems, reference model

Level 4

Business Planning & Logistics
Plant Production Scheduling, Business Management, etc

4 - Establishing the basic plant schedule - production, material use, delivery, and shipping. Determining inventory levels.

Time Frame
Months, weeks, days, shifts

Level 3

Manufacturing Operations Management
Dispatching Production, Detailed Production Scheduling, Reliability Assurance, ...

3 - Work flow / recipe control to produce the desired end products. Maintaining records and optimizing the production process.

Time Frame
Shifts, hours, minutes, seconds

Level 2

Manufacturing Control
Basic Control, Supervisory Control, Process Sensing, Process Manipulation,...

2 - Monitoring, supervisory control and automated control of the production process

Level 1

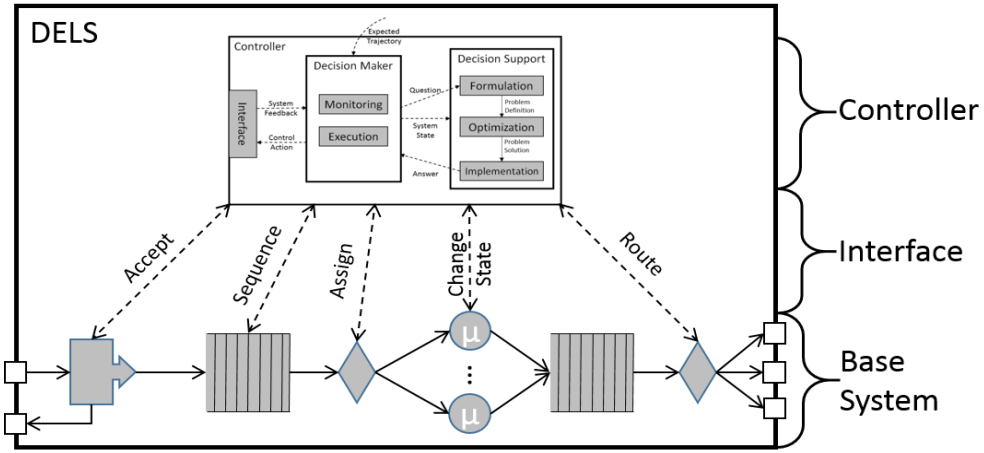
1 - Sensing the production process, manipulating the production process

Level 0

0 - The physical production process

Discrete Event Logistics Systems, reference model

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

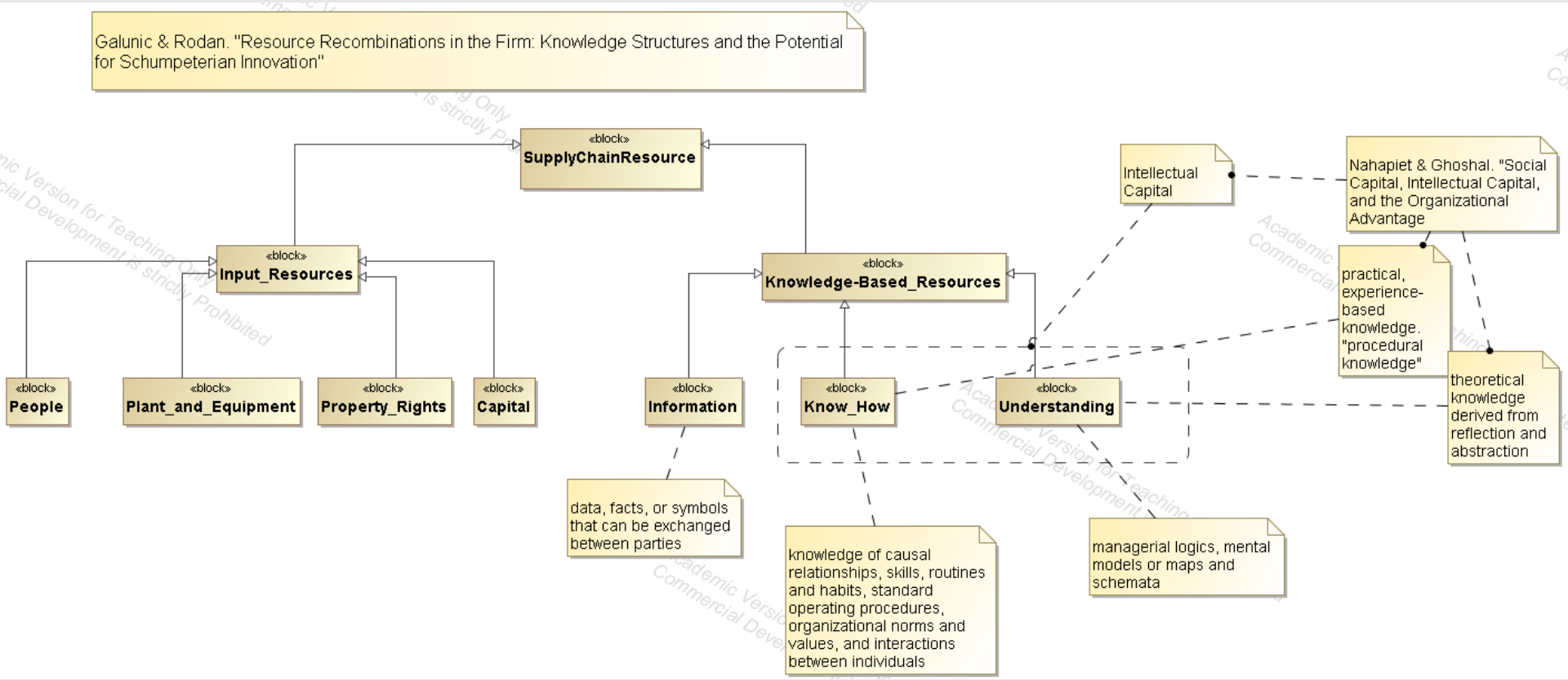


Control formulation that captures what really happens in DELS control, <u>and</u> provides an organizing framework for <u>all</u> published "scheduling" theory.

- **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)**

Discrete Event Logistics Systems, reference model

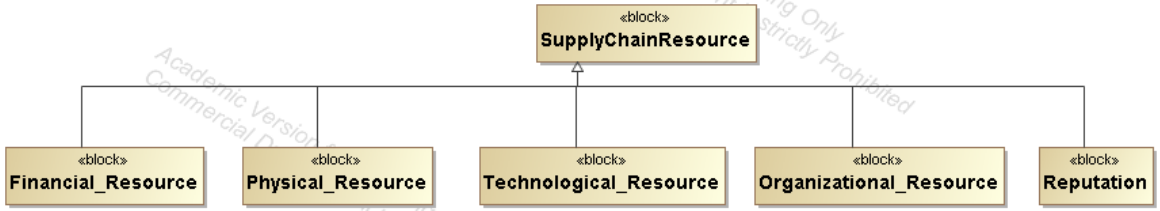
Layer 3, ***Supply Chain*** (more concrete)

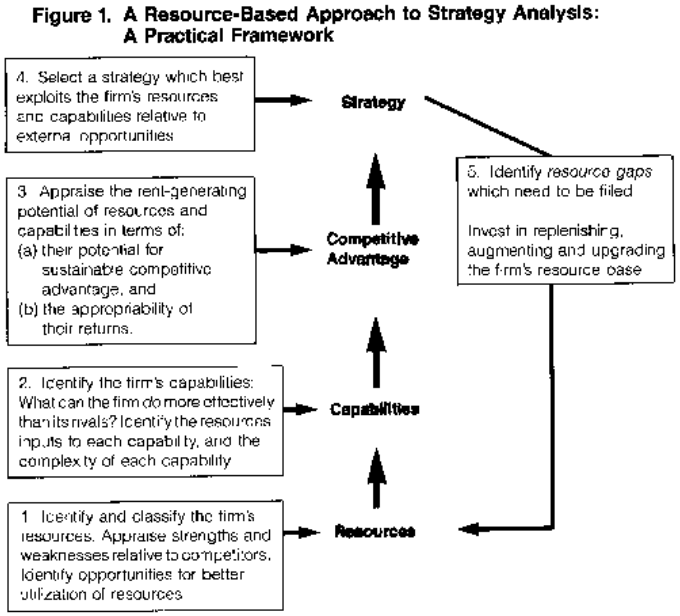


Discrete Event Logistics Systems, reference model

Layer 3, ***Supply Chain*** (more concrete)

Grant, Robert M. "The resource-based theory of competitive advantage: implications for strategy formulation." *California management review* 33.3 (1991): 114-135.





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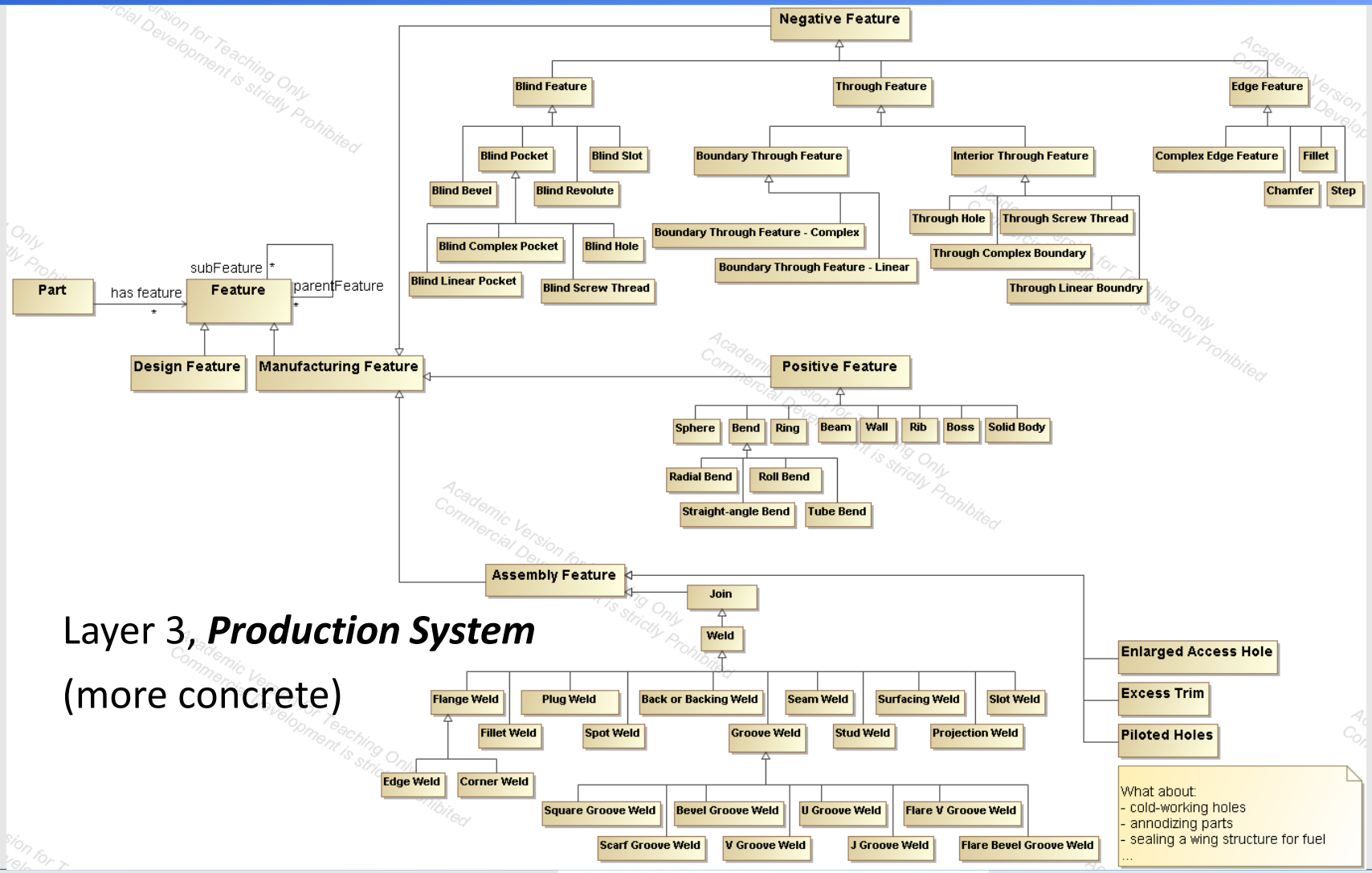
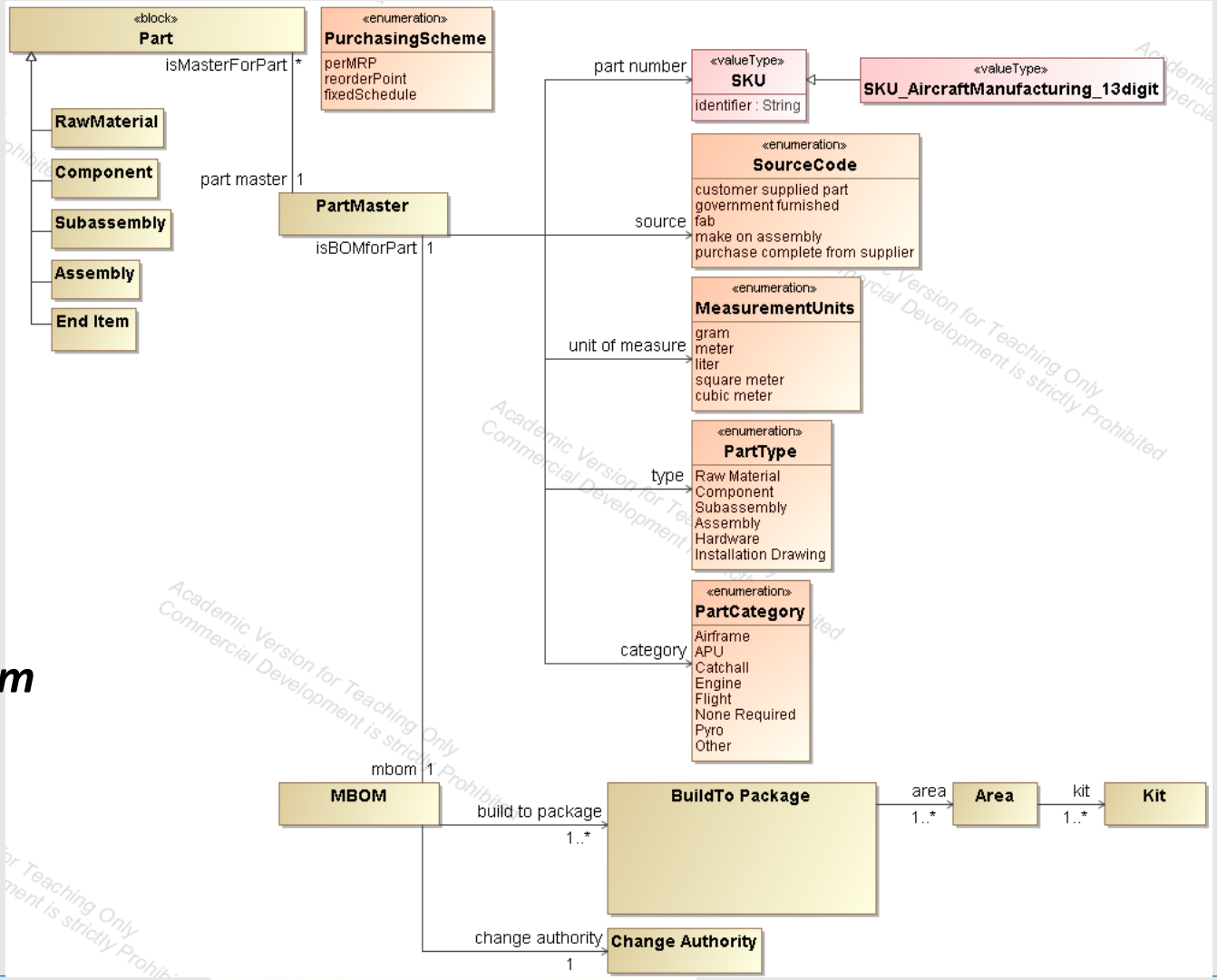


Layer 3, ***Production System***

(more concrete)

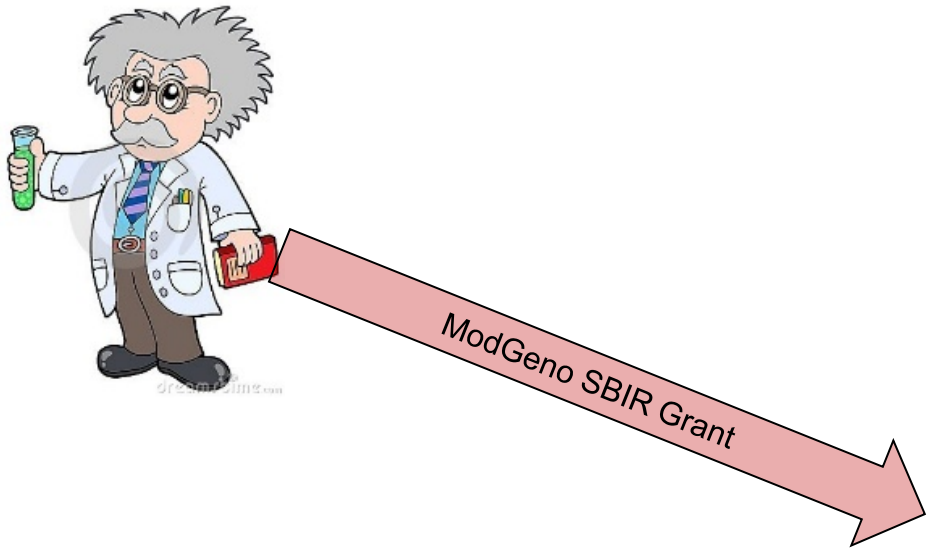
Discrete Event Logistics Systems, reference model



Layer 3, ***Production System***

(more concrete)

Commercialization



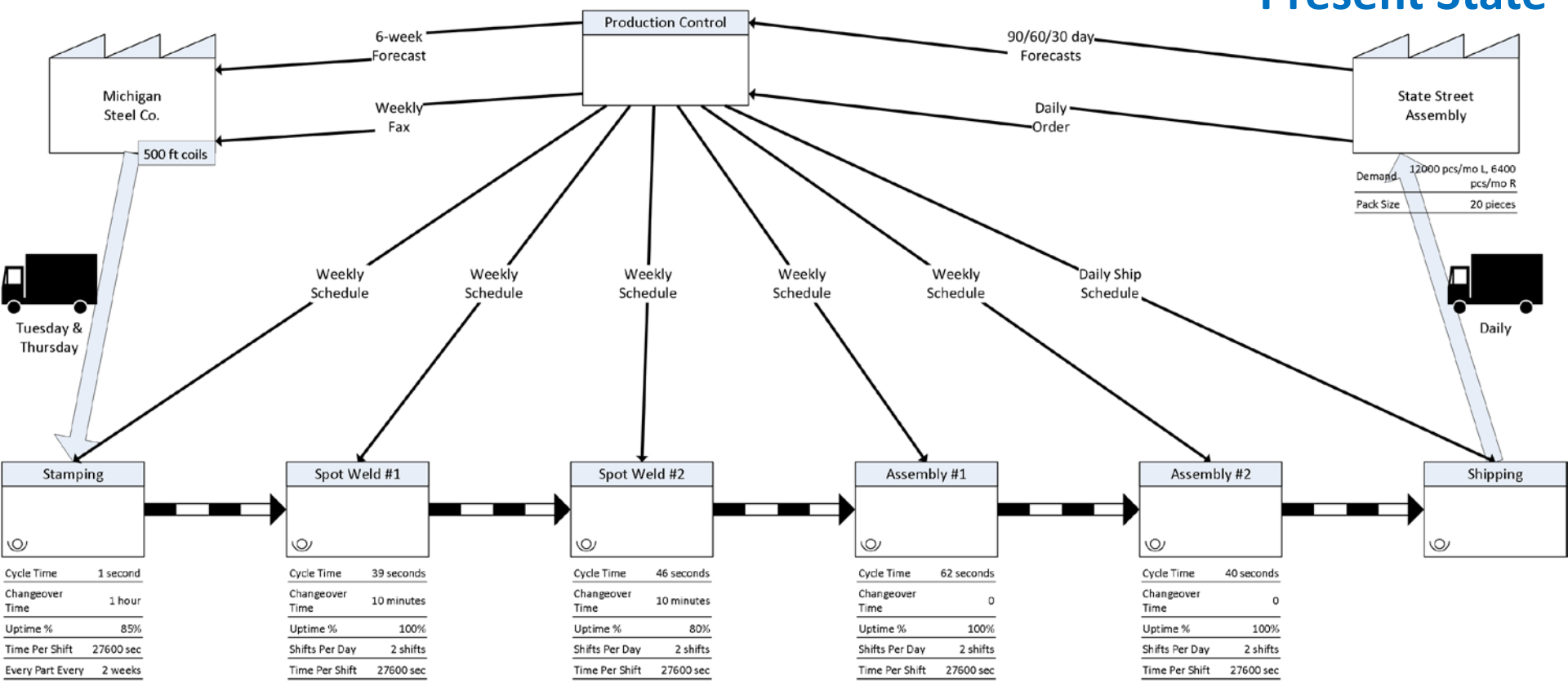
ModGeno is currently conducting an SBIR Phase 1 feasibility study, sponsored by NIST. We're starting with Value Stream Maps, a low-resolution model that many manufacturers already have, making them an ideal place to start.

https://www.nasa.gov/feature/nasa-aeronautics-budget-proposes-return-of-x-planes

Commercialization

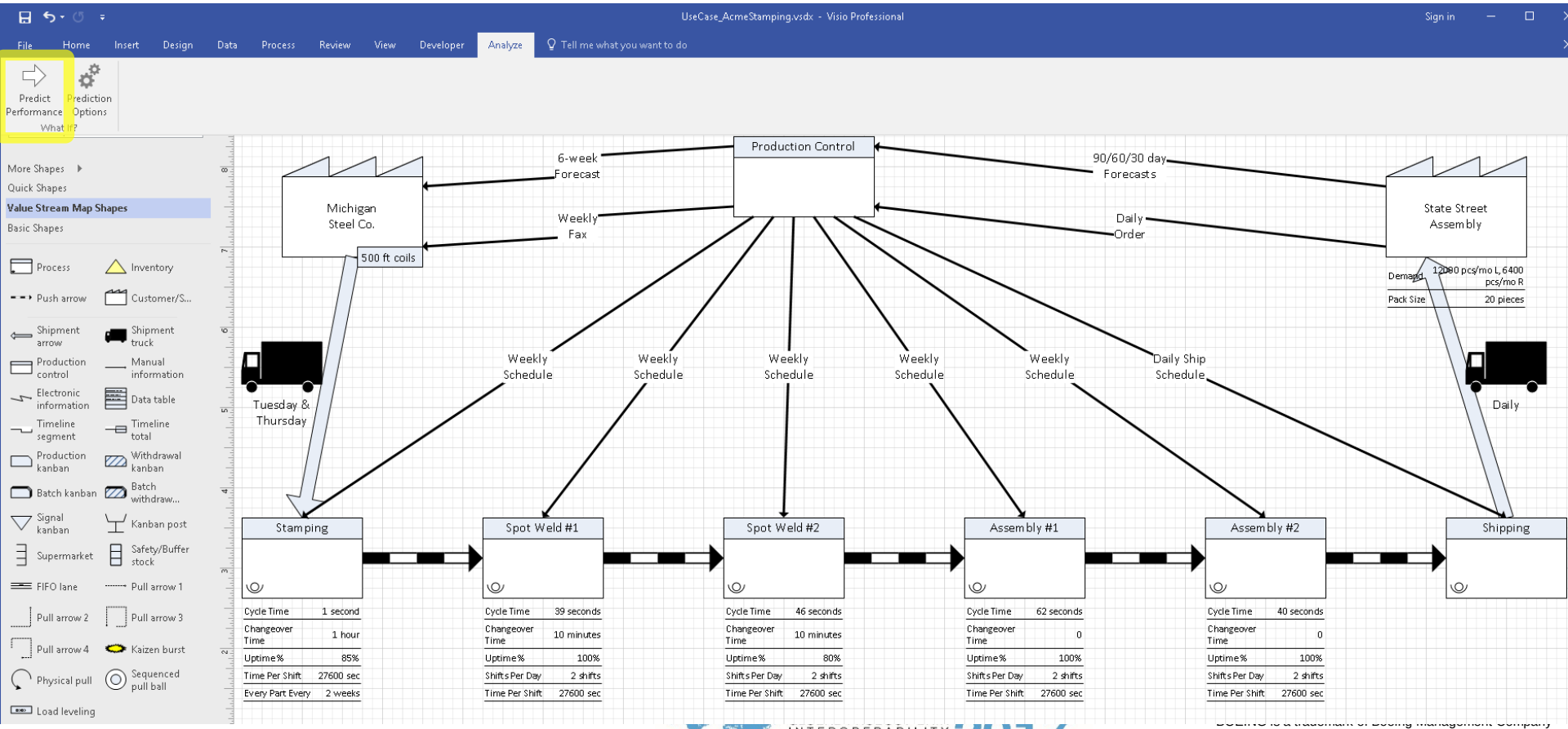
DEMO: Use a Virtual Manufacturing System to drive continuous improvement.
Source (of the model and the process): Shook & Rother, Learning to See, 1998.

Present State



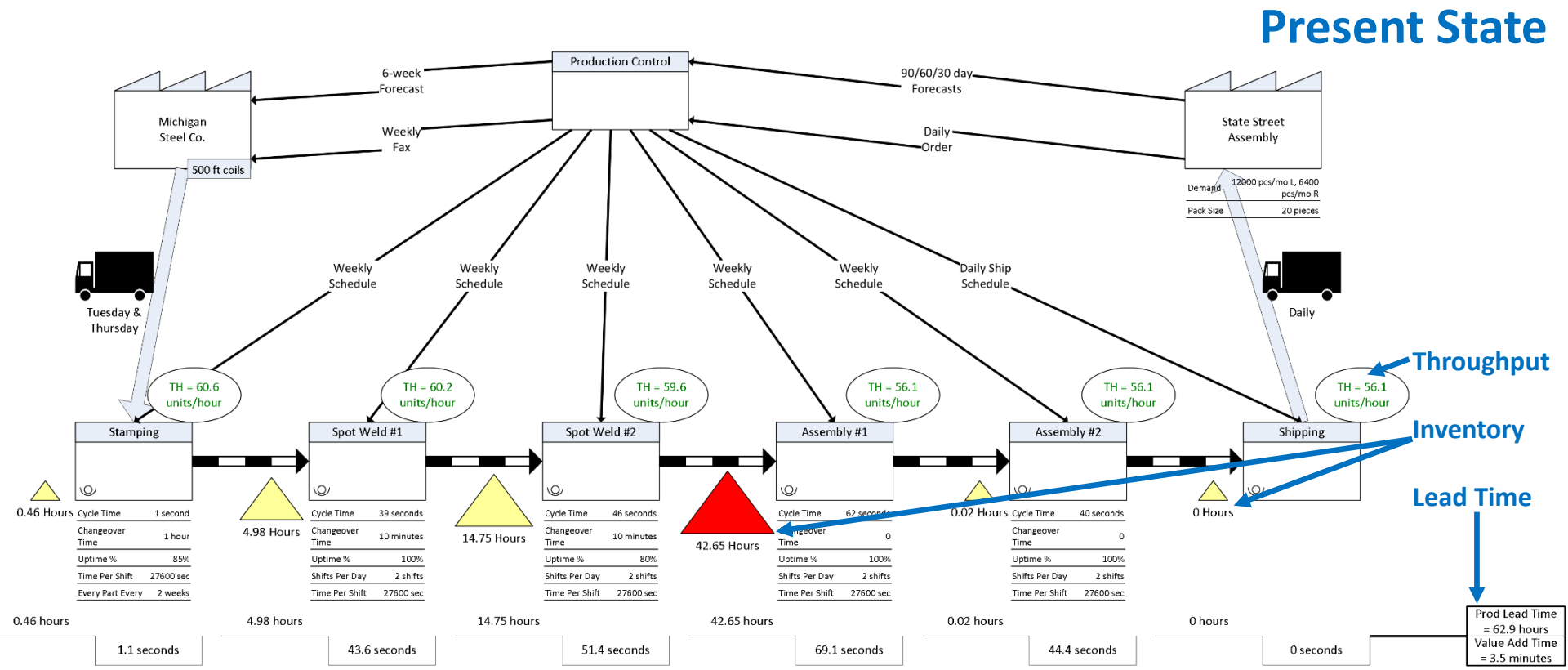
Commercialization

Feasibility Study: Prove the technology as a plugin, inserted into the Visio platform.
(*Why? Because that's where the users are – there are many lean manufacturing engineers who will never use SysML and MagicDraw, but may use Value Stream Maps in a tool like Visio.*)



Commercialization

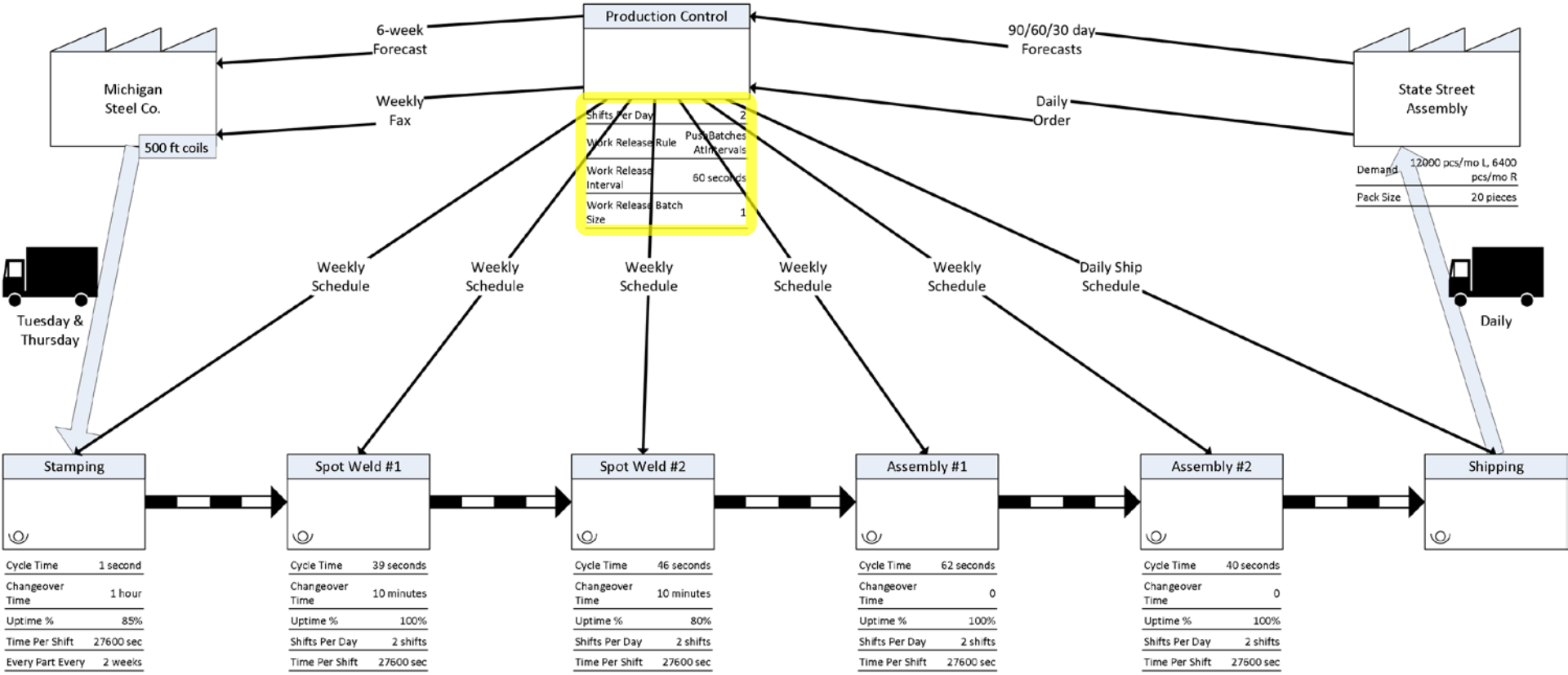
50,000-foot results view: Metrics guiding the continuous improvement process will be *Throughput*, *Inventory*, and *Production Lead Time*.



Step 1: Change Work Release

Before: Release a day's worth of work every morning (920 jobs all-at-once)

Now: Release work according to Takt time (1 job every 60 seconds)



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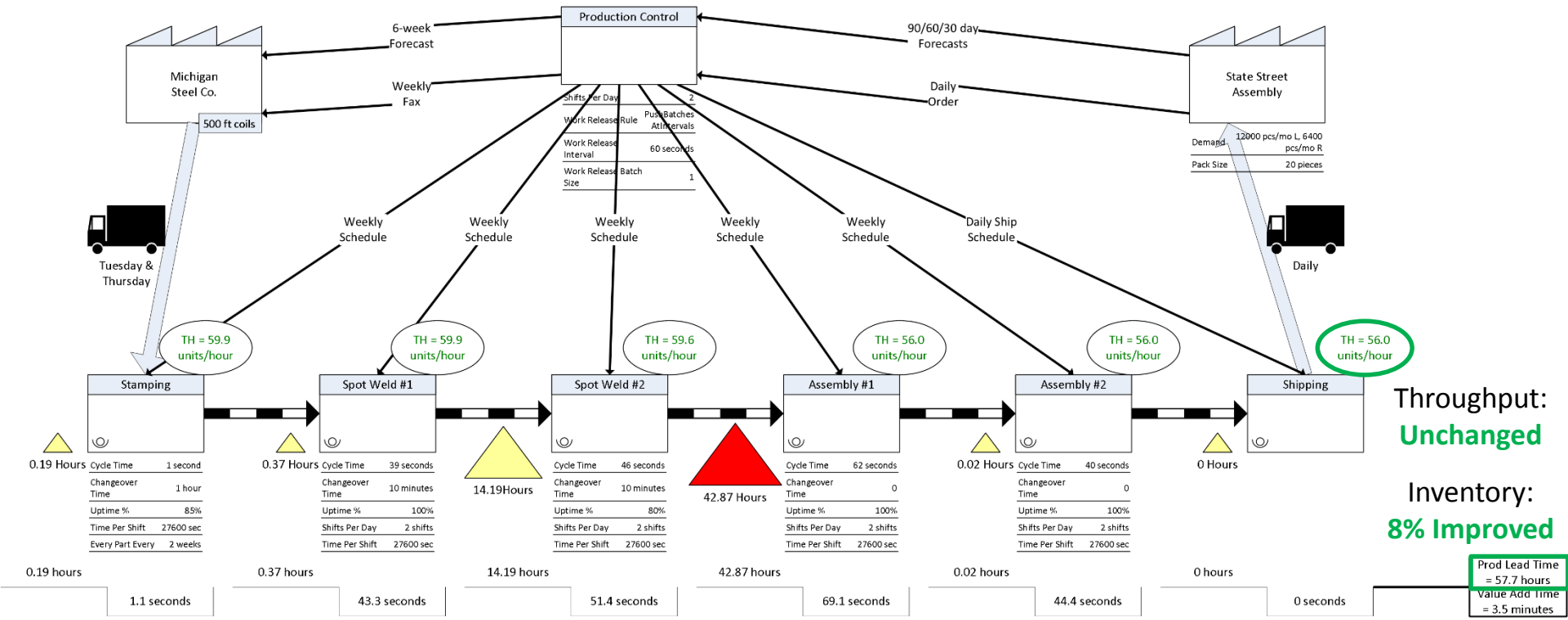


Throughput:
Unchanged

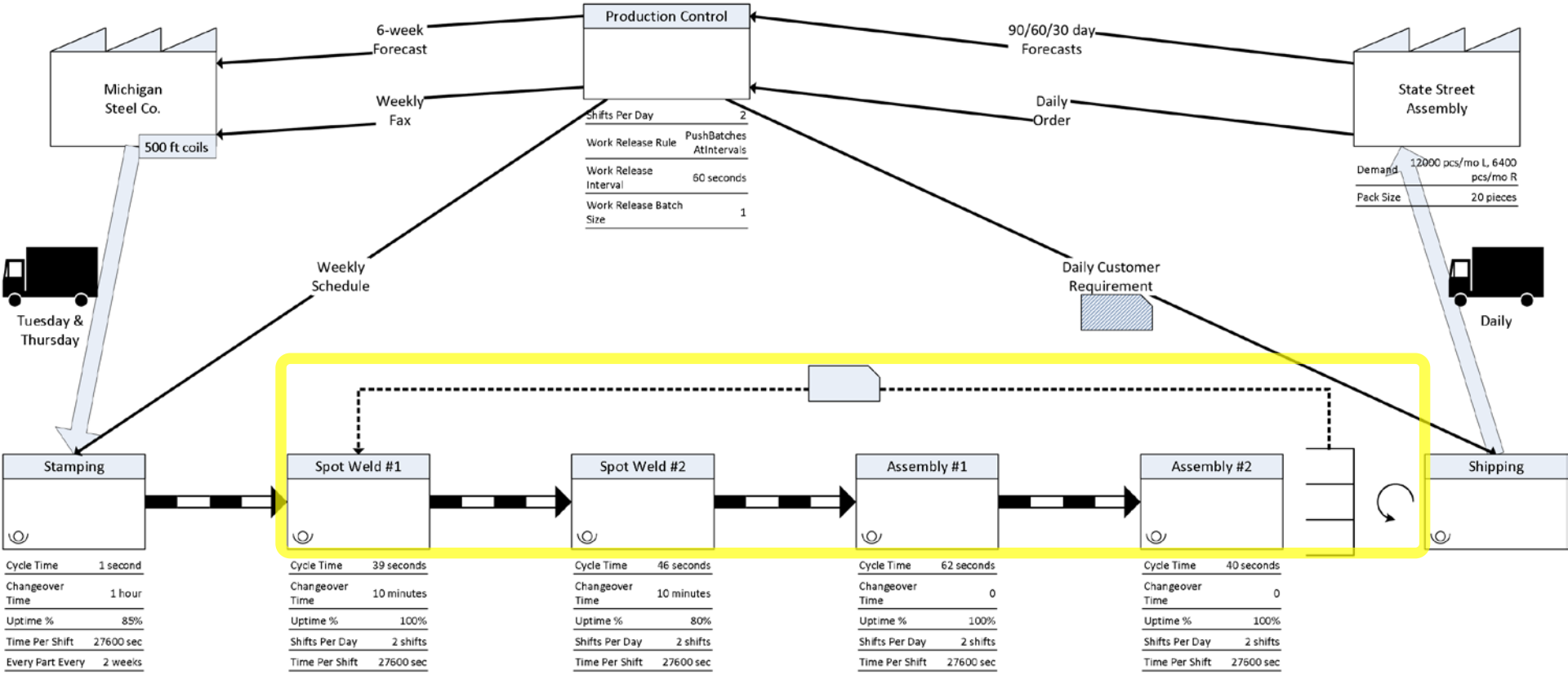
Inventory:
8% Improved

Commercialization

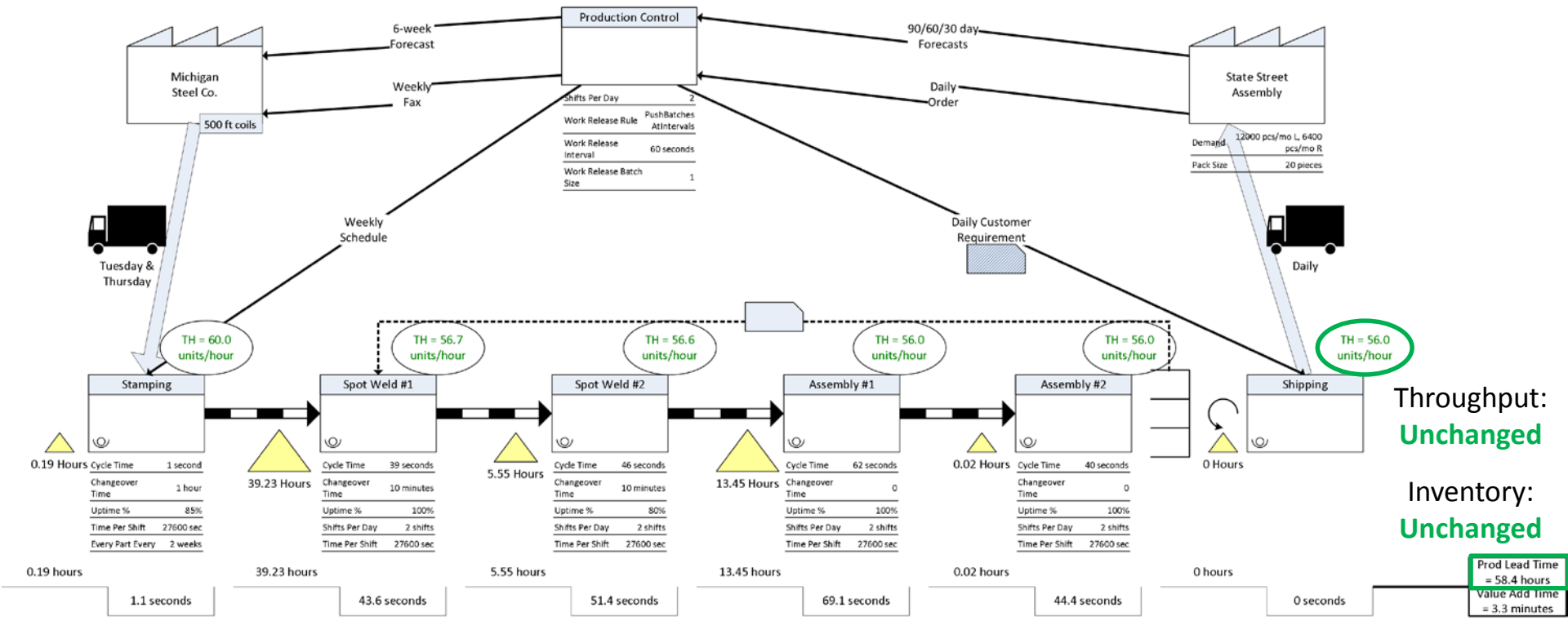
Step 2: Produce to a finished-goods supermarket (= limit the inventory at Shipping)

Before: All push, with unlimited inventory at Shipping

Now: Starting introducing pull, using Kanbans



Commercialization



Throughput: **Unchanged**

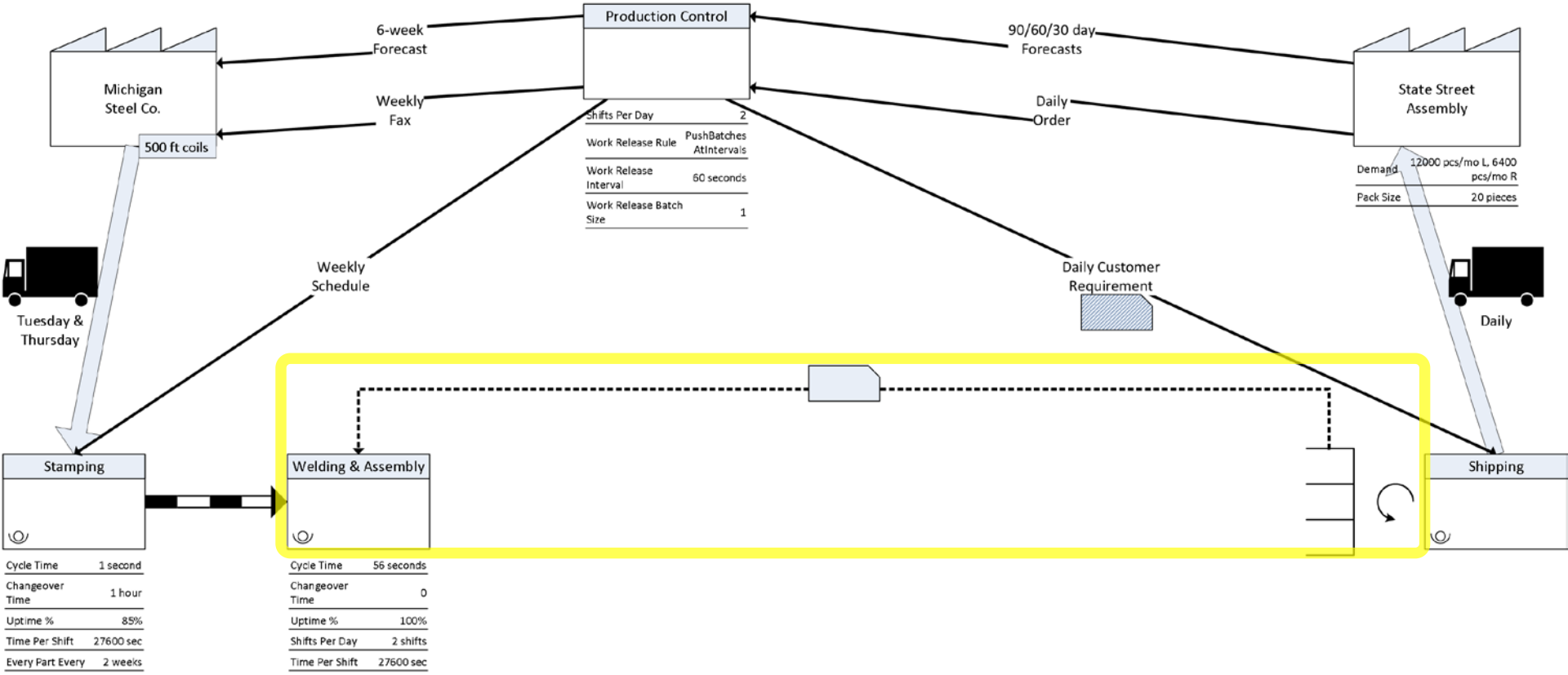
Inventory: **Unchanged**

Commercialization

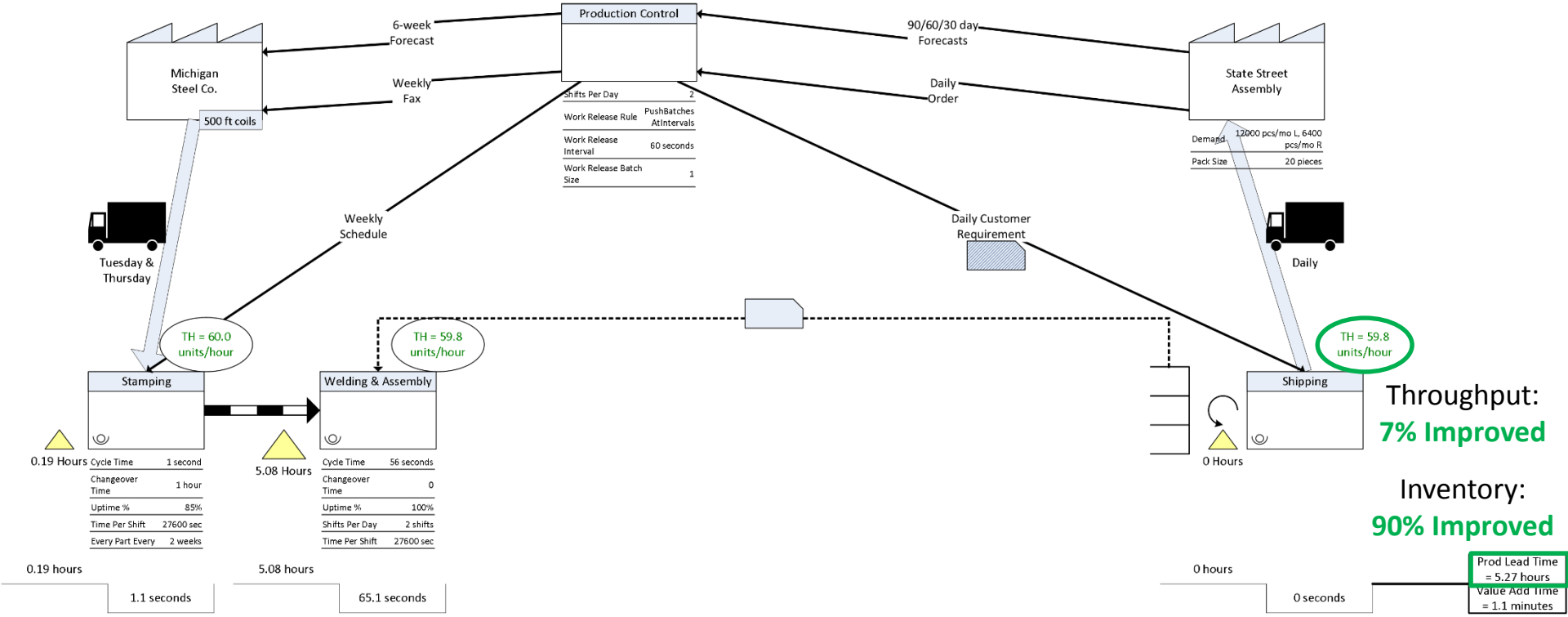
Step 3: Introduce continuous flow

Before: Inventory accumulates between each Welding and Assembly process

Now: Consolidate four processes into one cell, and make process improvements to reduce C/T



Commercialization



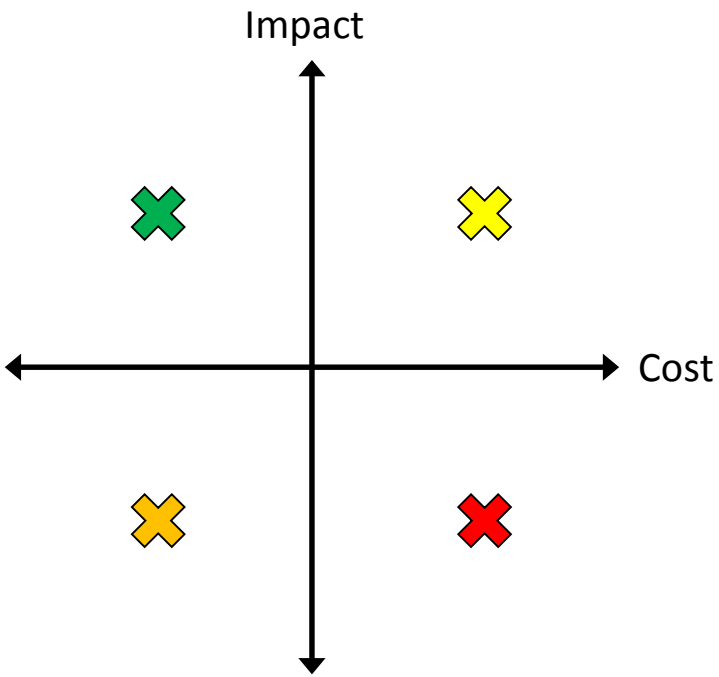
Throughput:
7% Improved

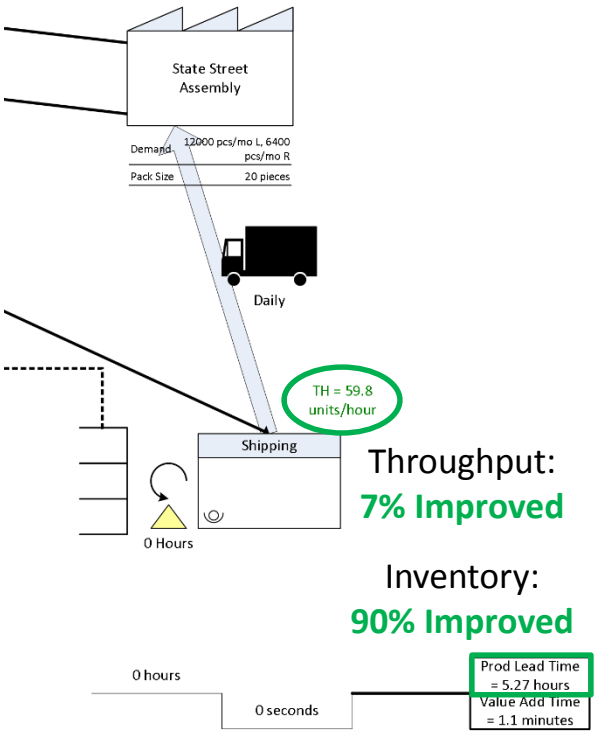
Inventory:
90% Improved

Commercialization

Q: What is the Value?

"Trust Me" versus **"Show Me"**





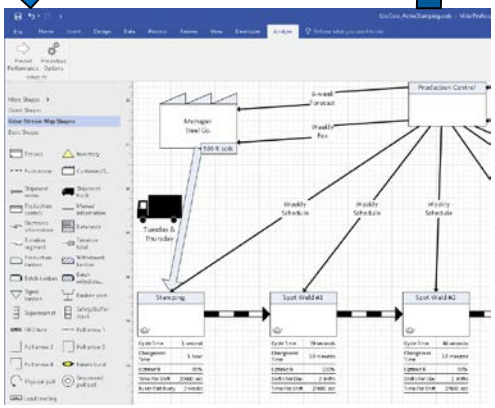
Throughput:
7% Improved

Inventory:
90% Improved

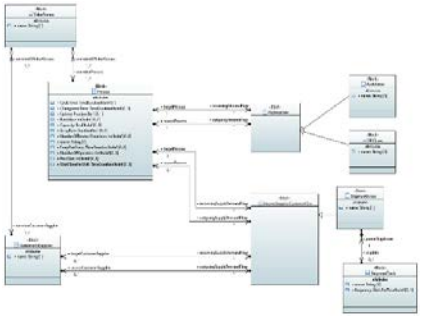
A: The value includes enabling communication, trust, estimating benefits to tradeoff against costs, and continuous improvement.

Commercialization

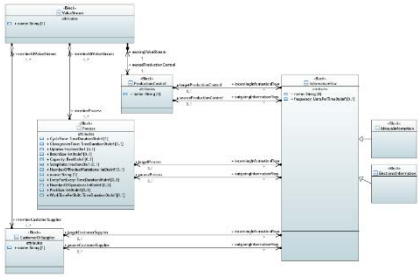
Q: Where is SysML?



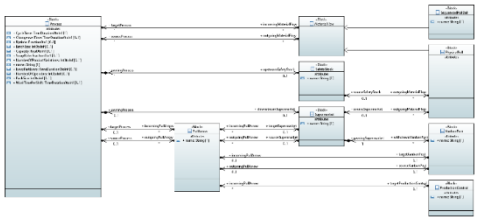
Material Layer, PUSH



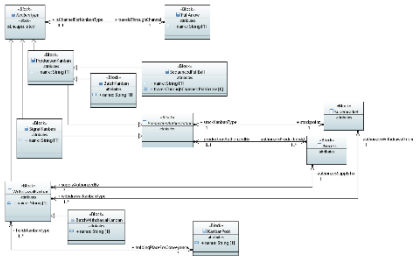
Information Layer



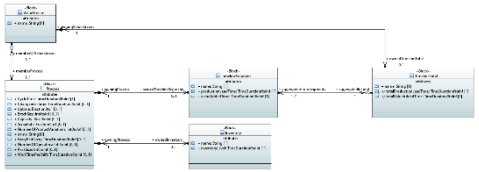
Material Layer, PULL



Kanbans



Performance Layer



A: SysML is present, but in the background. SysML is the vehicle for creating an actionable engineering discipline.

Opportunities to Engage

- **INCOSE MBSE Initiative WG 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**
- **Keck Virtual Factory Lab**
  - **Concept development, analysis model development, M2M transformation**
- **ModGeno**
  - **Product development, program support**

For more information

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leon.mcginnis@isye.gatech.edu
timothy.sprock@nist.gov
conrad.bock@nist.gov
george.thiers@modgeno.com