Model-Based Systems Engineering for Aerospace Manufacturing

Leon McGinnis, Georgia Tech
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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

A Continuum of Authoritative Digital Surrogate Representations Leveraged Over the Entire Life Cycle

Dr. Ed Kraft, Technical Adviser, Arnold Engineering Development Center
Manufacturing consumes product information, but requires many decisions that are not directly influenced by the details of product design.
Production Decision Making

**Planning**

**WHAT PRODUCTION TECHNOLOGIES?**
- How is production allocated?

**Who are the suppliers?**
- Where are they located?

**Contingencies?**
- 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 interpolation
- G03 - Circular interpolation
- G04 - Mill and Lathe, Dw
- G05 - Mill and Lathe, Exa
- G06 - Cutting off in H
- 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 - Tool change; Mill

**Part and assembly design**
MBSE, Digital Thread, IIoT, Industrie 4.0

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

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

Supply
Chain
Design

Part and assembly design

A Continuum of Authoritative Digital Surrogate Representations Leveraged Over the Entire Life Cycle

Behavior
G00 - Positioning at rapid speed, Mill and Lathe
G01 - Linear interpolation (cuts straight lines), Mill and Lathe
G02 - Circular interpolation
G03 - Circular interpolation, M03 - Optional program stop, Lathe and Mill
G04 - Mill and Lathe, G05 - Spindle on clockwise, Lathe and Mill
G05 - Spindle off, Lathe and Mill
G06 - Tool change, Mill

System Design

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MBSE, Digital Thread, IIoT, Industrie 4.0

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MBSE, Digital Thread, IIoT, Industrie 4.0

Planning

- What production technologies are used?
- How is production allocated?
- Where are our factories?
- What about inventories?
- What do our factories produce?
- How do we transport?

Supply Chain Design

- Contingencies?
- Who are the suppliers?
- Where are they located?
- Accept a job?
- Which resources to assign?
- How to sequence tasks?
- Where does job go next?

Operations Management

- Accepted parts go tox?
- Processed by a machine?
- Watch for a part?
- Watch for a part?

Behavior

- Part and assembly design
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?
Lack of Integration!
• 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

• 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
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)
  - 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.
Discrete Event Logistics Systems, reference model

- **Network Abstraction (Structural)**
  - Abstraction: Networks, Flow Networks, Process Networks

- **System Behavior (Plant)**

- **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

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

Most abstract system representation, which enables and supports model-to-model transformation for large classes of systems.
Discrete Event Logistics Systems, reference model


What else? An important pattern is *plant / control separation*, common in product models but not so much in production system models.
Maps the decision variables in the controller's decision problem to a particular actuator function and execution mechanism in the plant.
Most abstract resource models that capture most resource behavior patterns
Discrete Event Logistics Systems, reference model

Level 0
0 - The physical production process

Level 1
1 - Sensing the production process, manipulating the production process

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

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

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

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

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

Time Frame
Months, weeks, days, shifts
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)

Control formulation that captures what really happens in DELS control, and provides an organizing framework for all published “scheduling” theory.
Layer 3, *Supply Chain* (more concrete)

Gulenic & Rodan, "Resource Recombinations in the Firm: Knowledge Structures and the Potential for Schumpeterian Innovation"
Layer 3, **Supply Chain** (more concrete)

Layer 3, **Production System**

(more concrete)
Layer 3, *Production System*

(more concrete)
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.
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.
Commercialization

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)
Commercialization

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Throughput: Unchanged
Inventory: 8% Improved

Production Control

Michigan Steel Co.
500 ft coils

Stamping
Cycle Time: 1 second
Changeover Time: 10 minutes
Uptime %: 83%
Shifts Per Day: 2 shifts
Time Per Shift: 27600 sec

Spot Weld #1
Cycle Time: 10 seconds
Changeover Time: 1 minute
Uptime %: 100%
Shifts Per Day: 2 shifts
Time Per Shift: 27600 sec

Spot Weld #2
Cycle Time: 40 seconds
Changeover Time: 1 minute
Uptime %: 100%
Shifts Per Day: 2 shifts
Time Per Shift: 27600 sec

Assembly #1
Cycle Time: 12 seconds
Changeover Time: 0
Uptime %: 100%
Shifts Per Day: 2 shifts
Time Per Shift: 27600 sec

Assembly #2
Cycle Time: 40 seconds
Changeover Time: 0
Uptime %: 100%
Shifts Per Day: 2 shifts
Time Per Shift: 27600 sec

Shipping
Cycle Time: 0 seconds
Changeover Time: 0
Uptime %: 100%
Shifts Per Day: 2 shifts
Time Per Shift: 27600 sec

Weekly Schedule

Weekly Forecast

90/60/30 day Forecast

Daily Order

Daily Ship Schedule

Monday & Thursday

Stamco

Spot Weld #1

Spot Weld #2

Assembly #1

Assembly #2

Shipping

Throughput: Unchanged
Inventory: 8% Improved

Prod Lead Time = 57.7 hours
Value Add Time = 3.5 minutes

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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

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Throughput: Unchanged
Inventory: Unchanged
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
Q: What is the Value?

"Trust Me" versus "Show Me"

A: The value includes enabling communication, trust, estimating benefits to tradeoff against costs, and continuous improvement.
Q: Where is SysML?

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

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- 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