GLOBAL PRODUCT DATA INTEROPERABILITY SUMMIT 2019

MBSE for Production Systems

Research Team

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Leon McGinnis

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Leon McGinnis is Professor Emeritus in the Stewart School of Industrial and Systems Engineering at Georgia Tech where he remains active in teaching and research. He is internationally known for his leadership in the material handling research community and his research in the area of discrete event logistics systems. A frequent speaker at international conferences, he has received several awards from professional societies for his innovative research, including the David F. Baker Award from IIE, the Reed-Apple Award from the Material Handling Education Foundation, and the Material Handling Innovation Pioneer award from Material Handling Management Magazine. He is author or editor of eight books, one journal special issue, and more than 110 technical publications. At Georgia Tech, Professor McGinnis has held leadership positions in a number of industry-focused centers and multi-disciplinary programs. His current research explores the adaptation of Model Based Systems Engineering principles and methods to the design and control of discrete event logistics systems (DELS). With support from multiple corporations and the National Institute for Science and Technology, his team is investigating novel approaches for both system design and operational control through material handling. Professor McGinnis is a Fellow of the Institute of Industrial Engineering.

Agenda

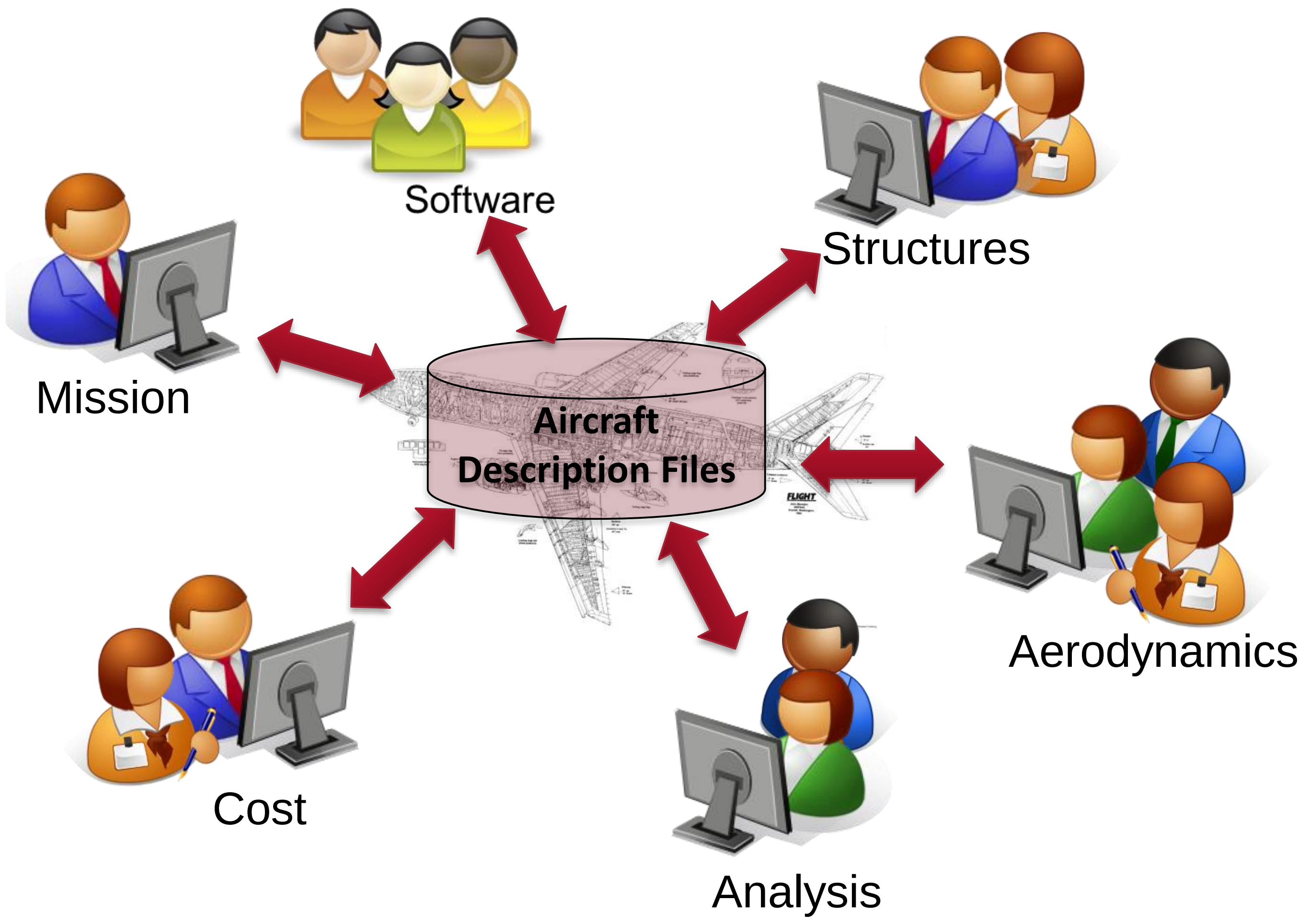
- **Motivation and background**
- **Approach**
- **Product, process and resource models**
- **Decision support integration**
- **Conclusions**

This presentation is based on project work done with Boeing Research and Technology to investigate MBSE application to composite parts manufacturing and assembly. No Boeing proprietary information is contained in the presentation.

Motivation

- **Question: Can we transition systems engineering & design methods and tools from the airplane to the airplane factory?**
  - **Answer: Evidence to date indicates “Yes”**
- **Question: Why would we want to?**
  - **Answer: Reduce time to full rate production and total startup and production cost**

Aircraft Program MBSE



Key: all stakeholders in system design/development work from a “single source of truth”, a federated database, enabling justifiable investment in re-usable decision support tools; ***lots of integrated analysis to support aircraft design decisions***.

Systems Engineering Methodology: RFLP

- **Design the *Requirements***
- **Design the *Functions***
- **Design the *Logical Architecture***
- **Design the detailed *Physical Embodiment***

Contemporary Production System Design

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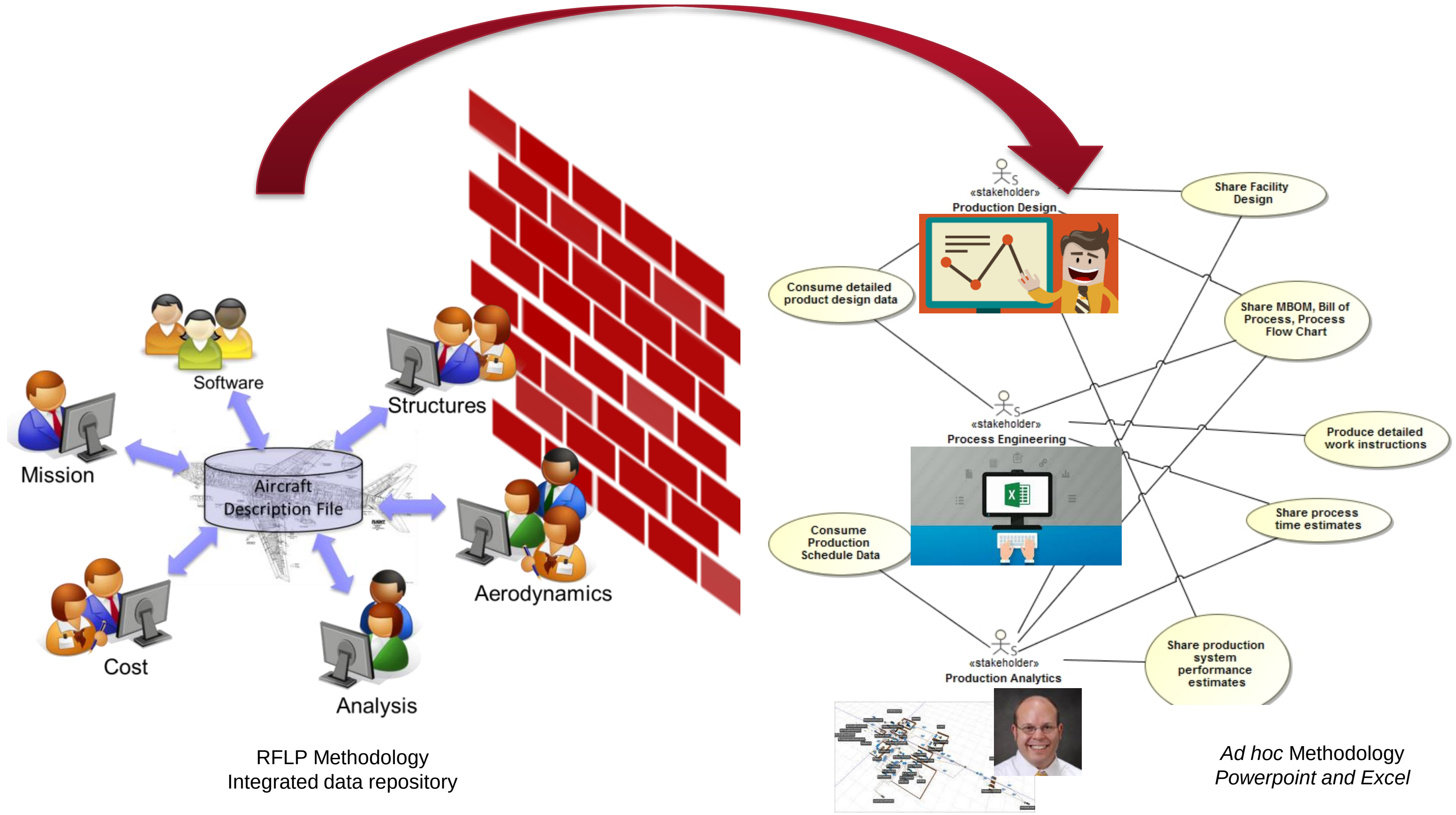

RFLP Methodology
Integrated data repository

Ad hoc Methodology
Powerpoint and Excel

In ***production systems*** development the level of information integration and decision support lags far behind ***product systems***.

Early stage modeling tools are powerpoint, excel, and hand-built simulations.

Even as product definition matures, production system analysis models are still hand-built.

Start with Conceptual Semantics

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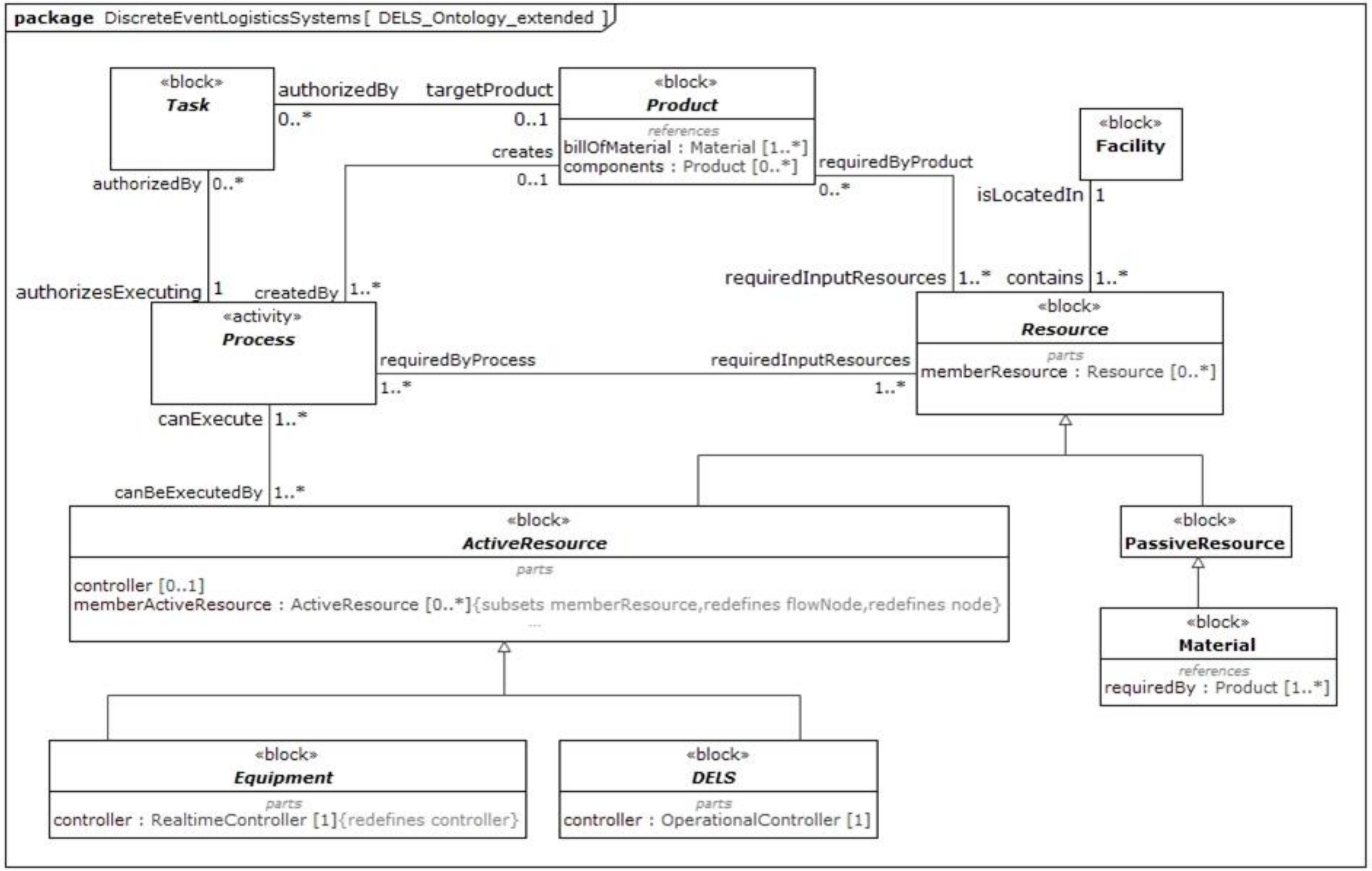

Factory is a “discrete event logistics system” (*DELS*)—a network of resources through which products flow and are transformed by processes executed by resources and authorized by controllers. Products require processes and resources have process capabilities.

Fundamental concepts:

- **Process as behavior of resource**
- **Task as authorization of resource behavior**
- **Product flowing through network of resources**
- **Plant-control separation**

Framework for integrated production system modeling!

Our Approach

- **Take composite parts manufacturing as the “use case”**
- **Develop DELS-based production system model using SysML**
- **Demonstrate potential for analysis integration**
- **Write a “playbook” explaining how to develop the model**
- **Extract the abstractions (the upper levels of a taxonomy) for product, process and resource**

Product Modeling

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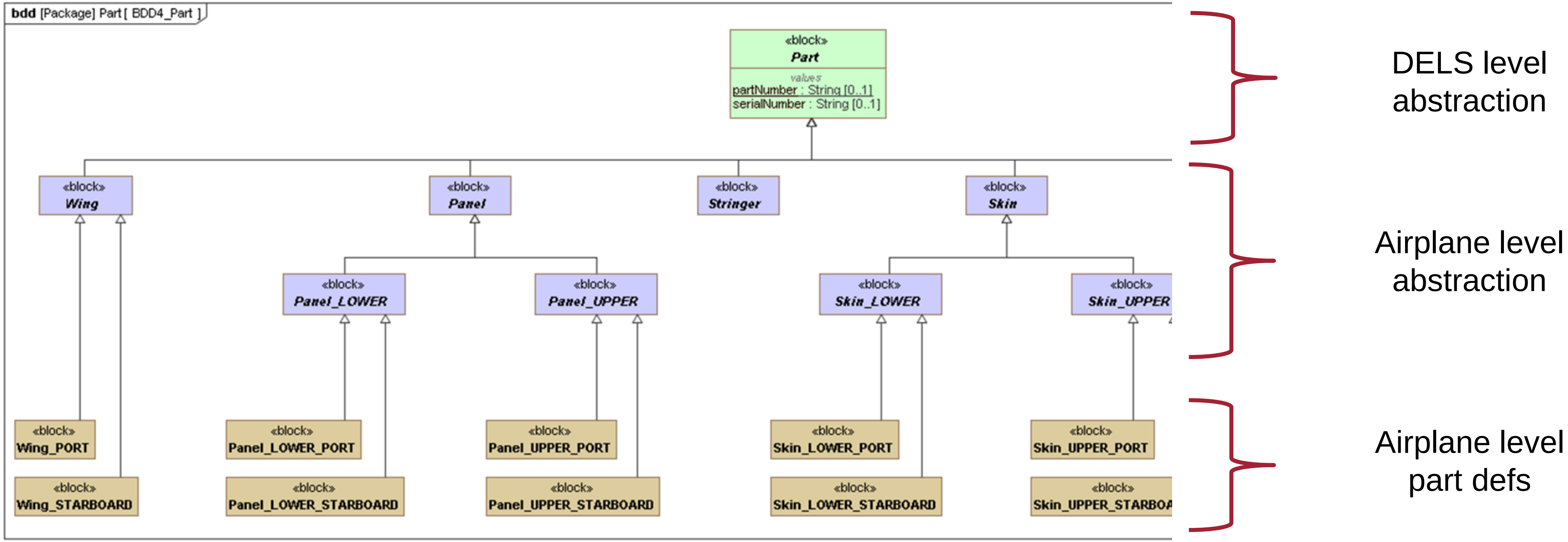
Building reusable product taxonomy/abstractions



Process Modeling

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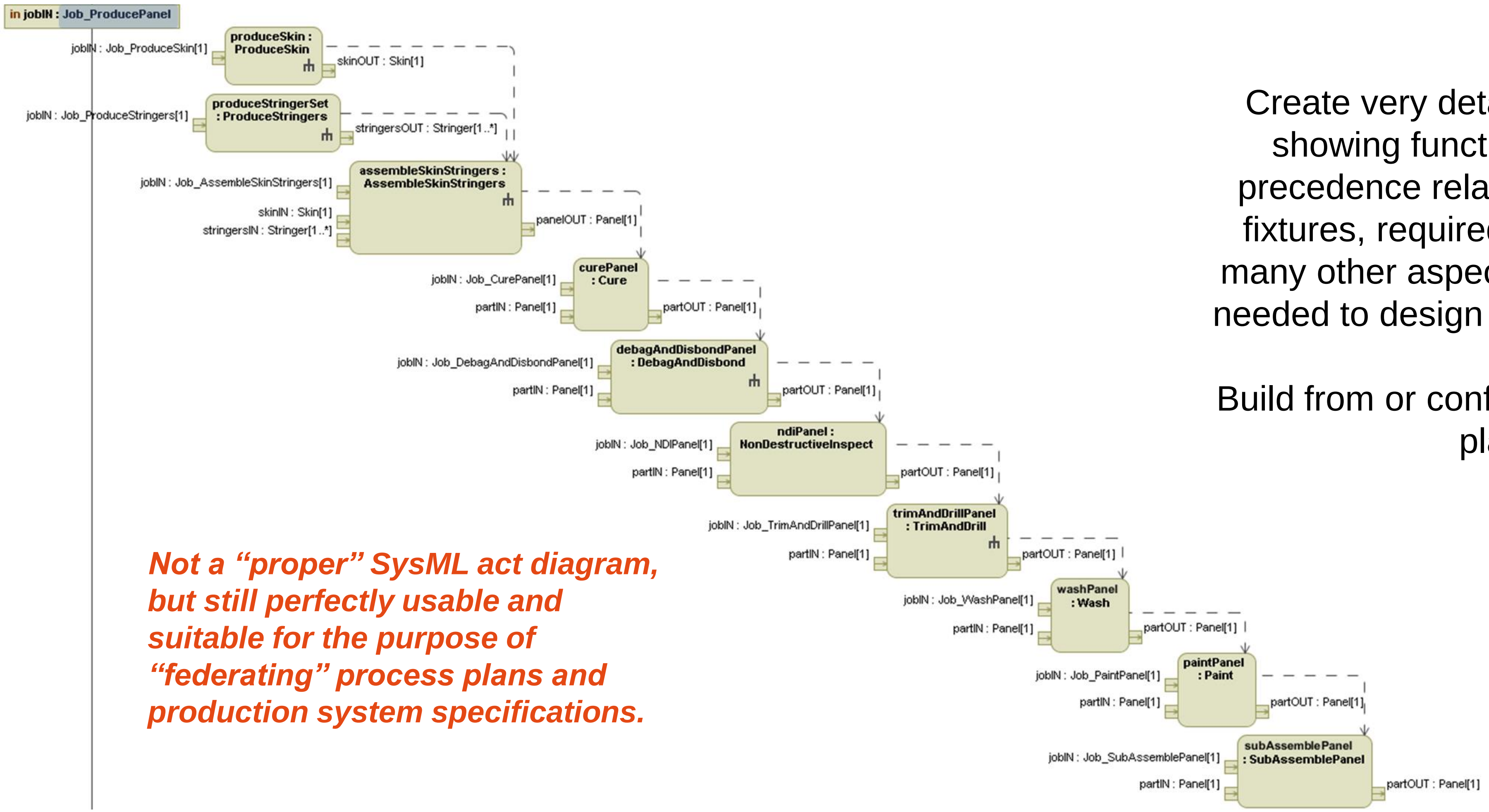

Create very detailed process models, showing functional processes and precedence relationships. Can include fixtures, required part orientation, and many other aspects of process definition needed to design the production process.

Build from or conform to existing process plan data.

Not a "proper" SysML act diagram, but still perfectly usable and suitable for the purpose of "federating" process plans and production system specifications.

Process-Product Model Integration

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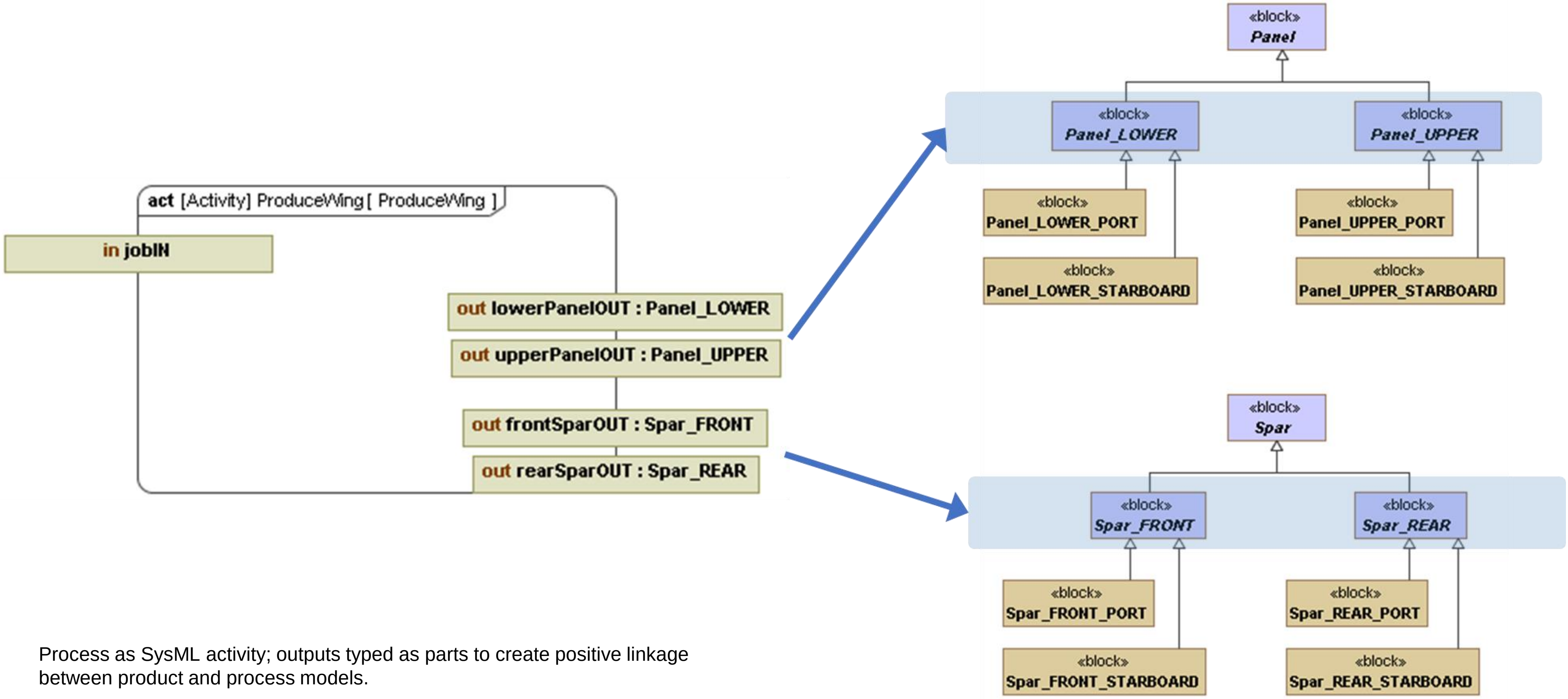

Process as SysML activity; outputs typed as parts to create positive linkage between product and process models.

Resource Modeling

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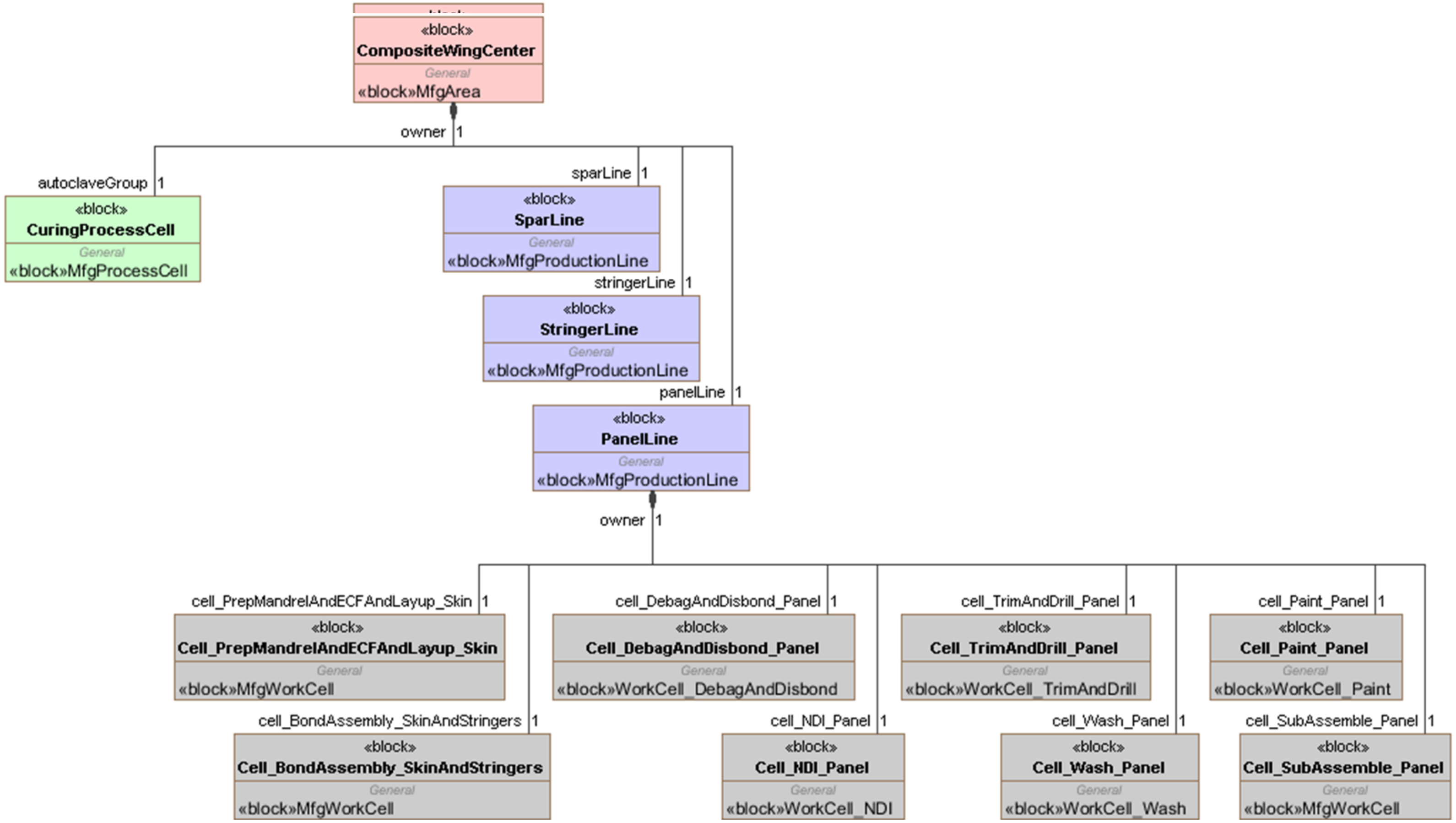

Organization of resources

Cell-level resource definition; can refine further as needed, to identify specific equipment, trades, etc.

Resource-Process Model Integration

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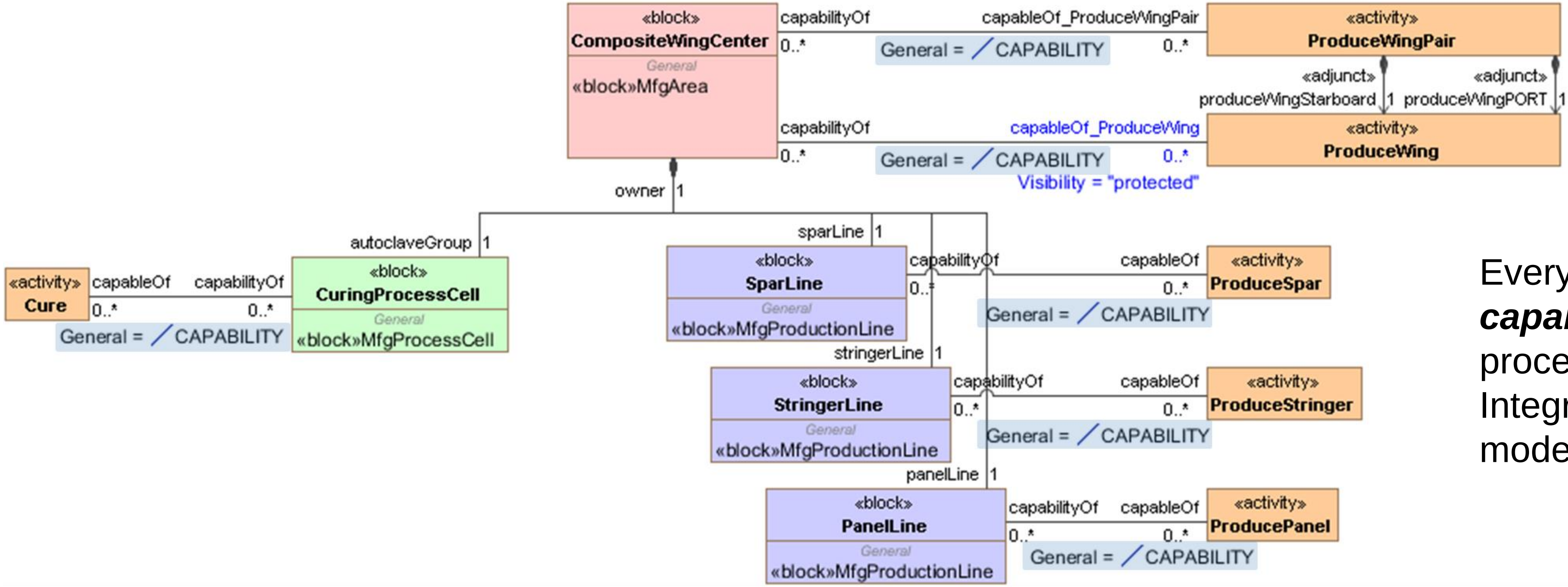
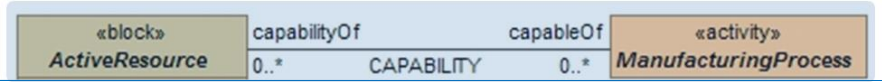


Every resource has process ***capabilities*** which correspond to the processes required by the products. Integrating the resource and process models.



Integrating DELS-based MBSE and RFLP design methodology

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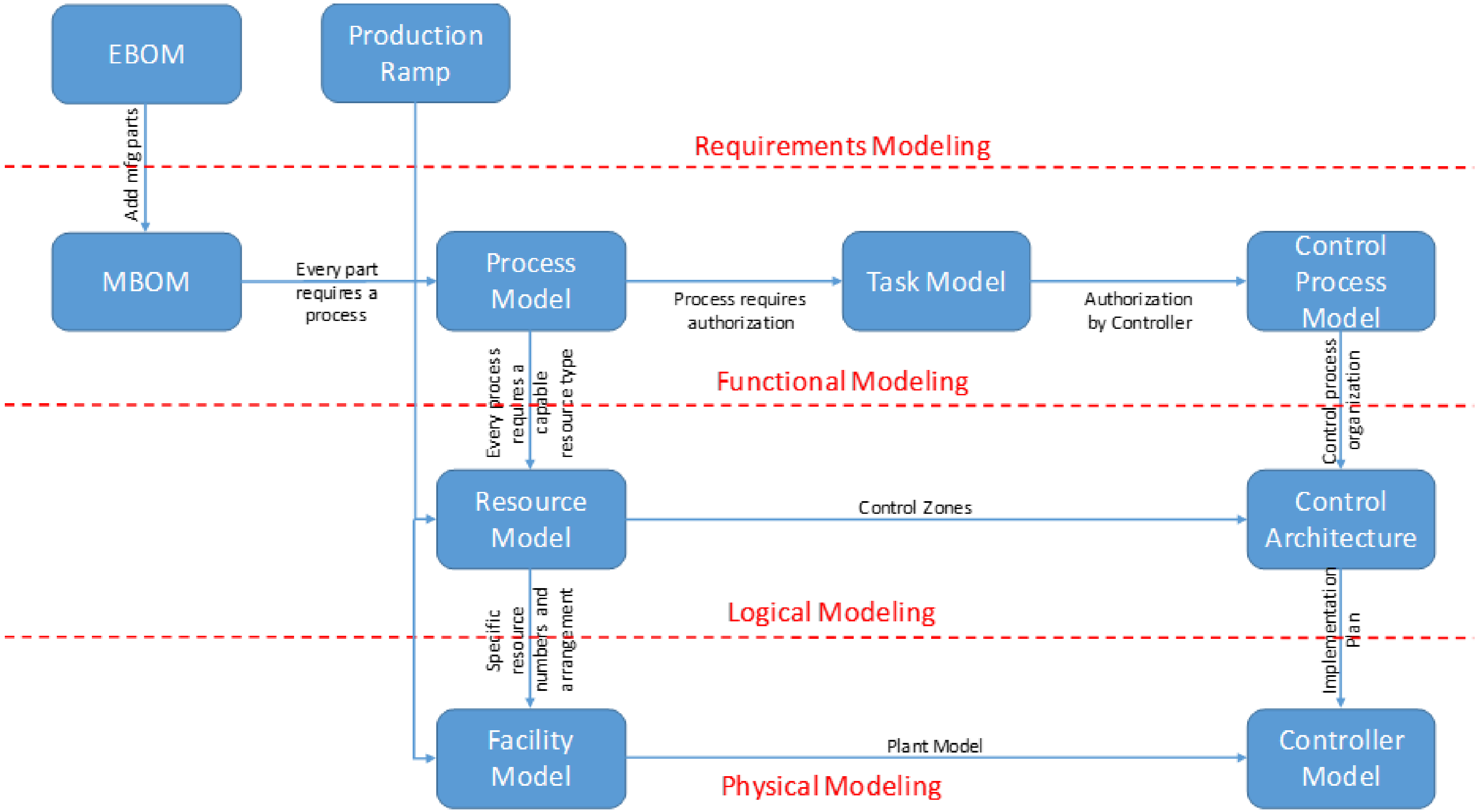

Model Verification and Design Decision Support

- **Model verification: is the model internally consistent and complete?**
- **Model analysis: using the model to make predictions about the system—throughput, cycle time, WIP, staffing, etc.**

Model Verification Support Example

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#	Name	Resources Associated With Process- Capability
1	Cell_BondAssembly_SkinAndStringers	AssembleSkinStringers
2	Workstation_Autoclave	Cure
3	WorkCell_DebagAndDisbond	DebagAndDisbond
4	WorkCell_NDI	NonDestructiveInspect
5	WorkCell_Paint	Paint
6	WorkCell_PrepMandrelAndLayupAndBag	PrepMandrelAndLayupAndBag
7	PanelLine	ProducePanel
8	Cell_PrepMandrelAndECFAndLayup_Skin	ProduceSkin
9	SparLine	ProduceSparSet ProduceSpar
10	StringerLine	ProduceStringer ProduceStringers
11	CompositeWingCenter	ProduceWingPair ProduceWing
12	Cell_SubAssemble_Panel	SubAssemblePanel
13	WorkCell_TrimAndDrill	TrimAndDrill
14	WorkCell_Wash	Wash

MagicDraw SysML tool has extensive model query capabilities. This is an example of a table generated to list every active resource and the identified process capabilities.

Production System Analysis: Use Case Demonstration

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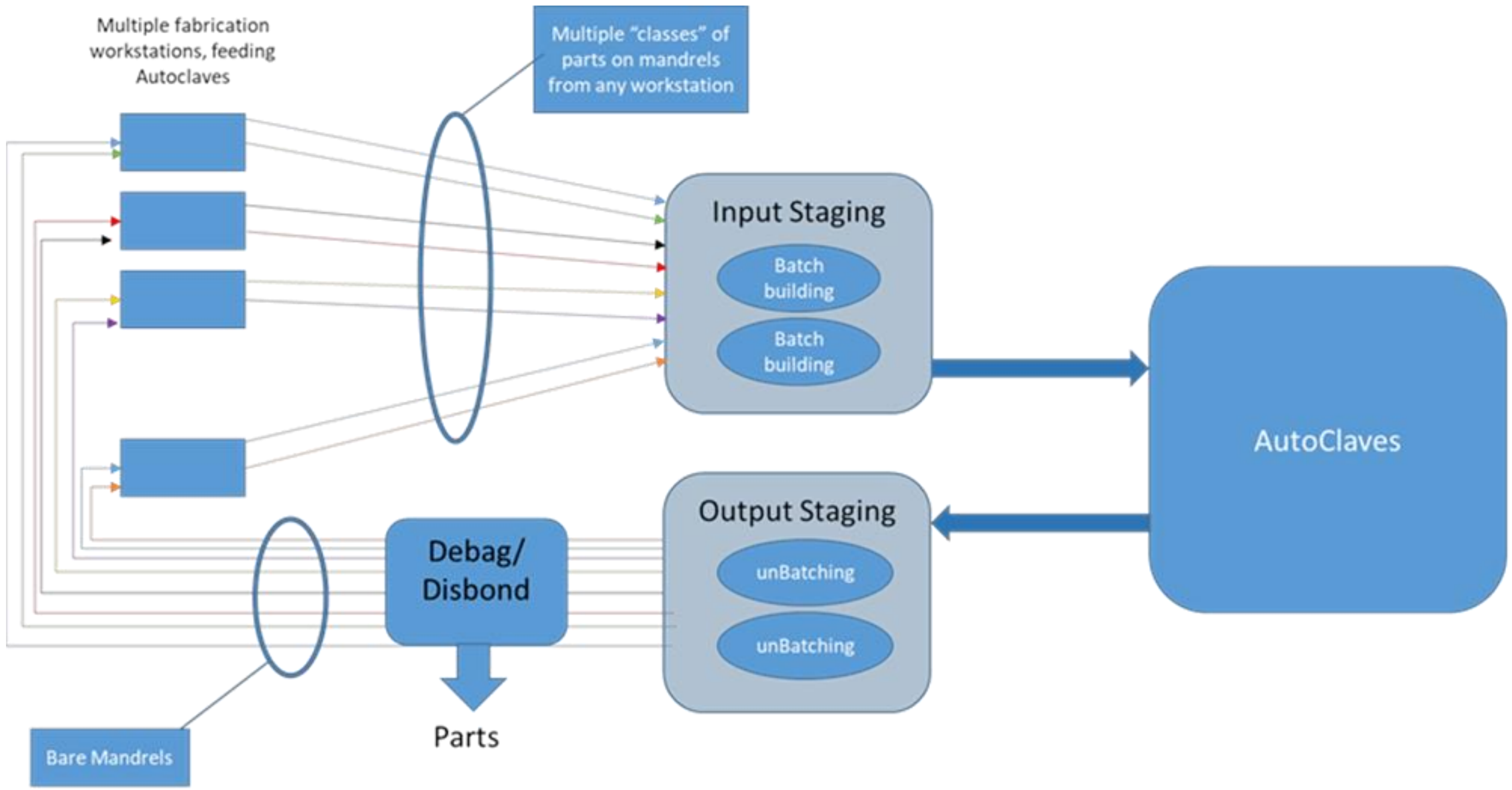

Five part types
Aircraft BoM
Numbers of fab stations
Allowable autoclave loading
Processing times (batching, load/unlad, cure, debag

Demonstrating analysis integration

How many mandrels are needed? A range of analyses, from “quick and dirty” to detailed simulation, can be integrated with the system model, based on an explicit model of the mandrel lifecycle.

- Model the system of interest in SysML, as part of the wing factory model
- Develop the analysis
- Show how it could be integrated with the SysML model

IBD representation of mandrel lifecycle

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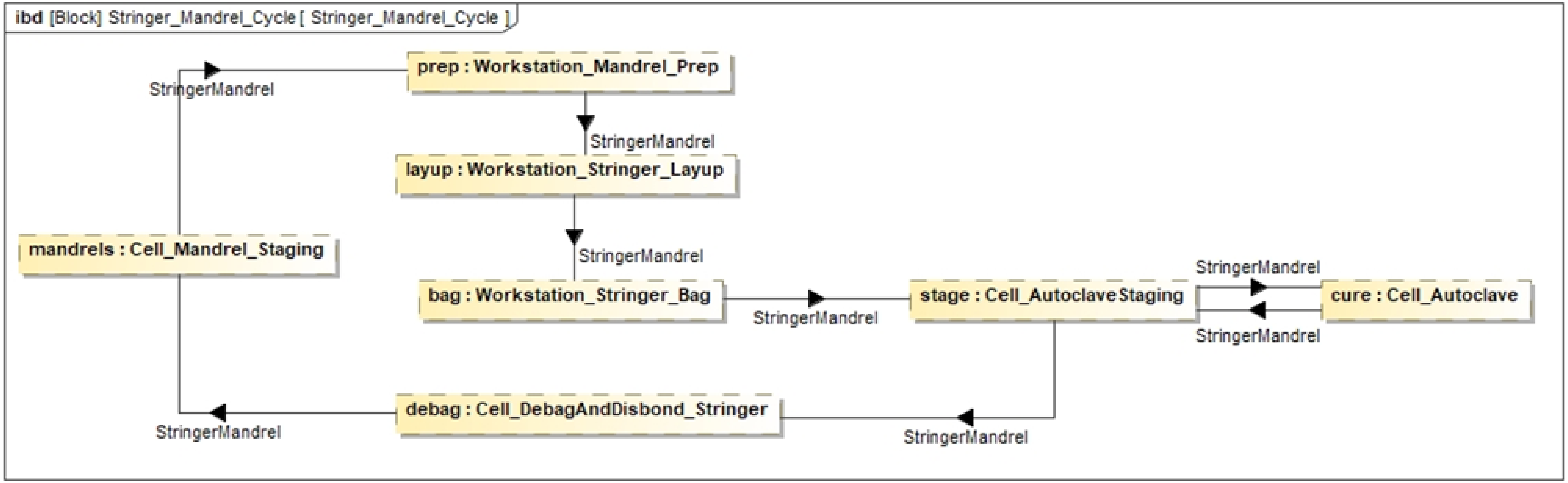

Act representation of mandrel lifecycle

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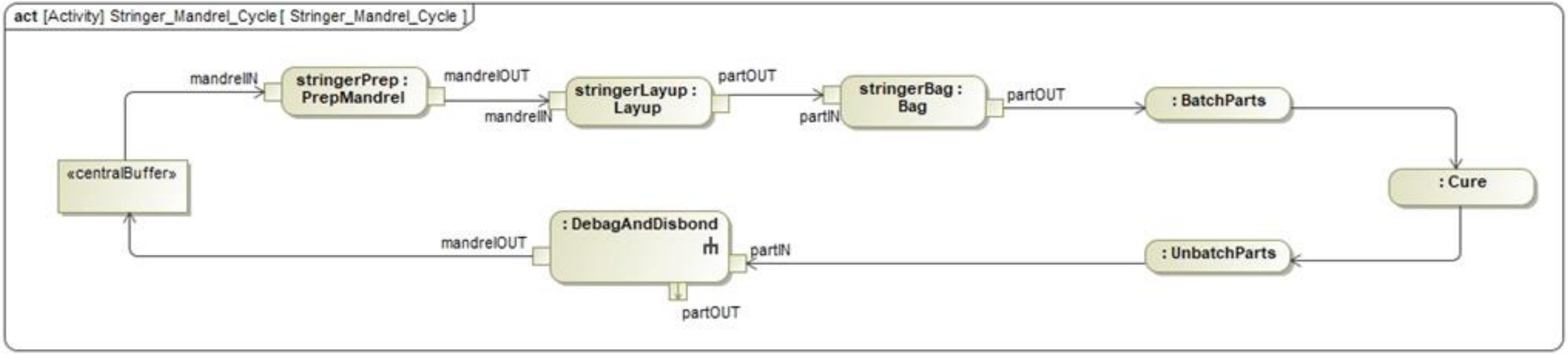

Quick and dirty (deterministic) autoclave capacity analysis

- Batching analysis: which batches of parts are feasible
- Simple deterministic capacity analysis

Part Type	BOM Qty/ Aircraft	Aircraft/ Month	Batch Process Time (hrs)	Batch Size	Total Process Time
Wing panel -WP	4	12	10	1	480
Large fuselage section -FS	4	12	10	1	480
Small fuselage section -FS	4	12	10	2	240
Large spar -LS	4	12	10	4	120
Small spar -SS	6	12	10	6	120

- Adding in load/unload and allowing for 90% utilization implies 3 autoclaves.

How many mandrels are needed?

The flow pattern for mandrels is obvious

The cycle time for a single mandrel may include waiting time at each workstation

Two analysis methods:

- Queuing network analysis: a number of simplifying assumptions; allows specification of the amount of variability in the processing times at the stations; relatively fast computation
- Discrete event simulation: can achieve high level of modeling fidelity; can be difficult to build; not so fast computationally

Closed Queuing Network Model

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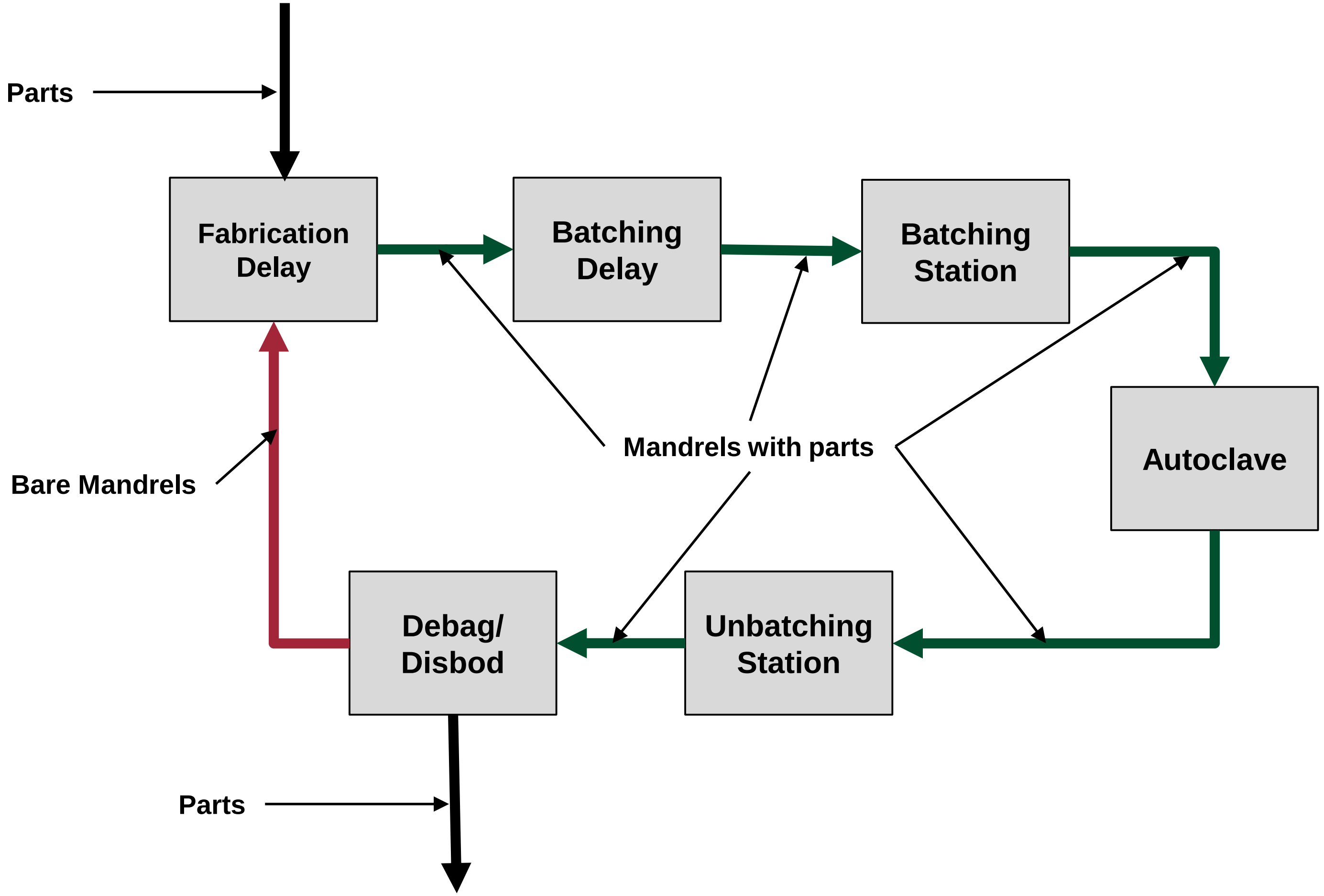

Specify mean and coeffient of variation for processing time at each workstation
Some shenanigans with autoclave processing
Results in a pretty optimistic estimate of mandrel requirements

Closed Queuing Network Analysis Results

	Part Type	WP	SS	LS	SF	LF
Req'd TH		0.067	0.100	0.067	0.067	0.067
Iteration 1	Mandrels	1	6	4	2	1
	TH	0.043	0.114	0.074	0.057	0.043
Iteration 2	Mandrels	2	6	4	3	2
	TH	0.059	0.100	0.064	0.070	0.059
Iteration 3	Mandrels	3	6	5	3	3
	TH	0.070	0.090	0.071	0.059	0.070
Iteration 4	Mandrels	3	7	5	4	3
	TH	0.063	0.097	0.066	0.073	0.063
Iteration 5	Mandrels	4	8	6	4	4
	TH	0.068	0.098	0.070	0.061	0.068
Iteration 6	Mandrels	4	9	6	5	4
	TH	0.063	0.103	0.066	0.071	0.063
Iteration 7	Mandrels	5	9	7	5	5
	TH	0.069	0.095	0.070	0.063	0.069
Iteration 8	Mandrels	5	10	7	6	5
	TH	0.064	0.099	0.067	0.071	0.064

Query the SysML model and automate the construction of the queuing network analysis model. Integrate the analysis either directly or via tools like ModelCenter™

Queuing network analysis tends to be optimistic with regard to mandrel requirement, because it makes some significant simplifying assumptions.

Not quite able to meet throughput requirement.

Simio Simulation Model

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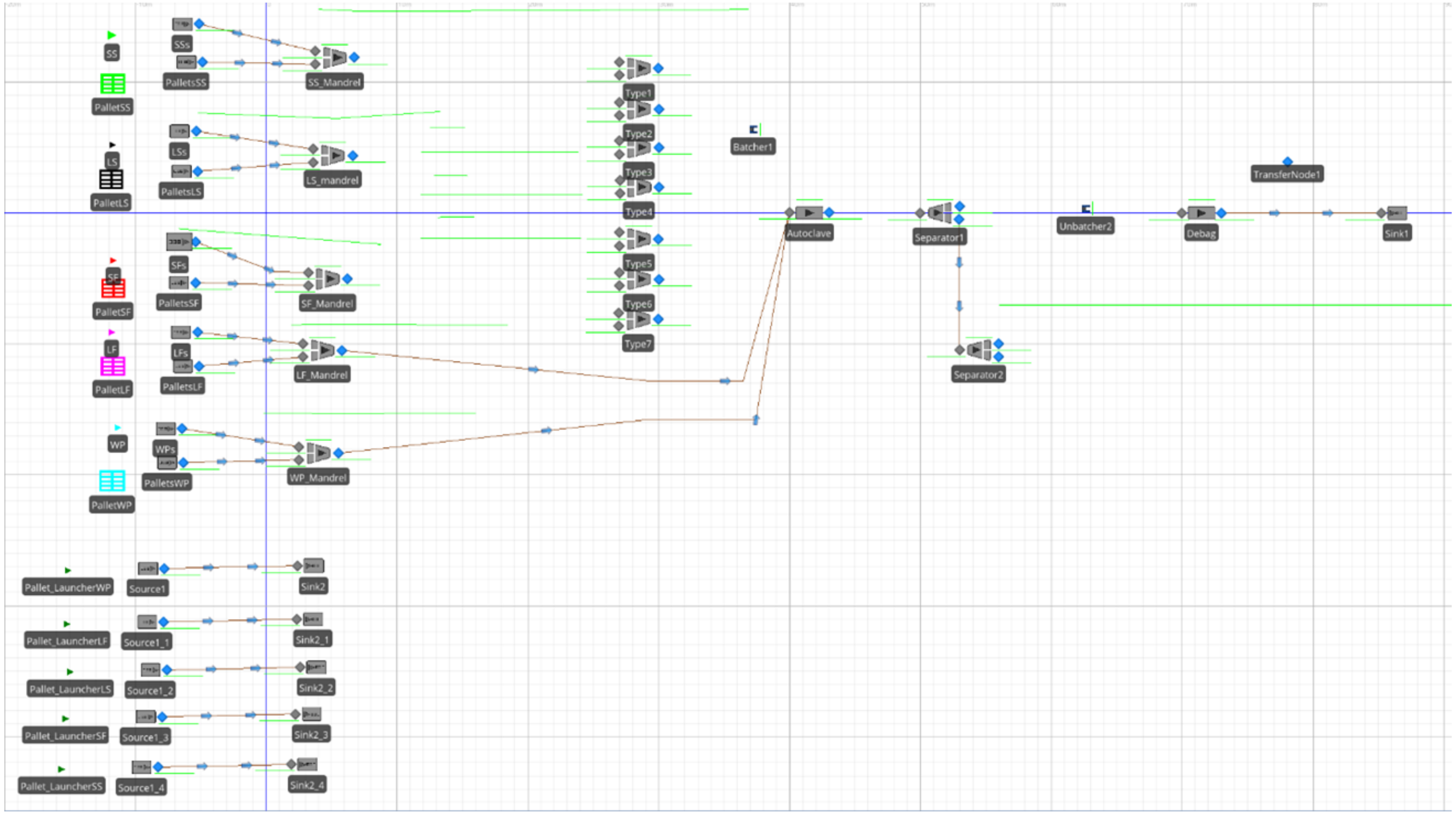

Clever mechanism to model batching and unbatching at autoclave.

Simulation Results

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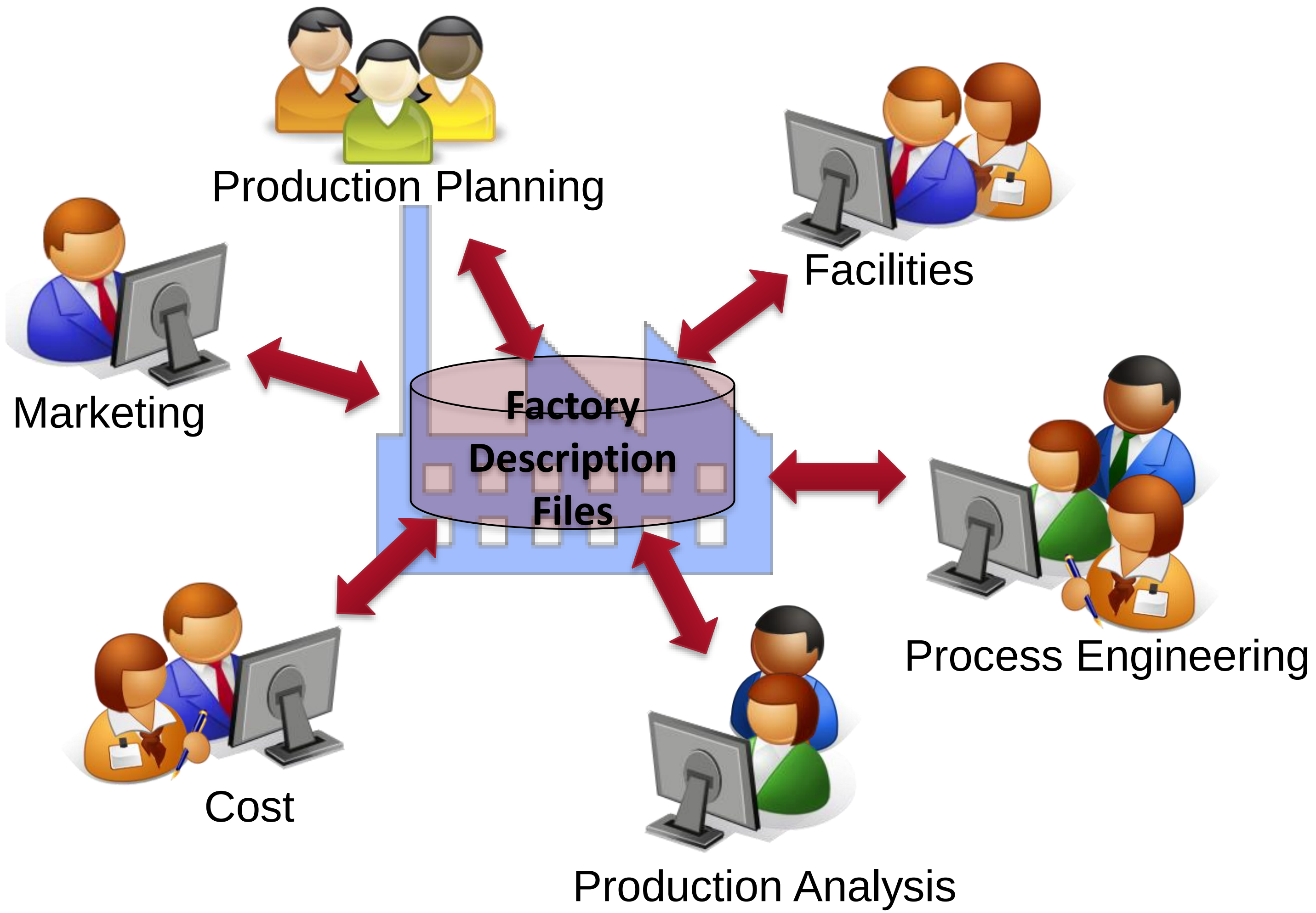
	Part Type	WP	SS	LS	SF	LF
Req'd TH		40	60	40	40	40
Iteration 1	Mandrels	1	6	4	2	1
	TH	15	50	30	18	11
Iteration 2	Mandrels	2	7	5	3	2
	TH	29	50	36	24	22
Iteration 3	Mandrels	3	8	6	4	3
	TH	42	62	43	28	33
Iteration 4	Mandrels	3	8	6	5	4
	TH	43	64	42	37	43
Iteration 5	Mandrels	3	8	6	6	4
	TH	43	64	43	40	42

Query the SysML model and automate the construction of the simulation analysis model. Integrate the analysis either directly or via tools like ModelCenter™

Each one of these analysis methods could be integrated with the SysML modeling tool, and made available to the model without requiring a lot of analysis modeling expertise.

The future of production systems development



Conclusion

- **There is great promise for combining the DELS reference model, the RFLP systems design approach, and the SysML modeling tool, bringing benefits of MBSE to production system design.**
- **There is still work to do to make this an “off the shelf” toolset.**


THANK
YOU
THANK

For more information

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- Contact me for copies of reports on:
  - Theory of DELS (coming soon at NIST)
  - MBSE for Production Systems Analysis (composite wing production case)
  - MBSE for Central Fill Pharmacy (NIST report focused on smart operations management)
  - INCOSE Challenge Team project report (circuit card assembly production case)