Simulation Support for Innovative Product-Process Development

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George Thiers, Georgia Tech

GLOBAL PRODUCT DATA INTEROPERABILITY SUMMIT 2015

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Collaborative Work

- Boeing + Georgia Tech: Strategic University Partnership
- Design-To-Production Transition Project
  - Michael Christian, Engineering Technical Fellow, Principle Investigator, The Boeing Company
  - Prof. Leon McGinnis, GT faculty, project director
  - George Thiers, GT PhD Student, now graduated
  - Tim Sprock, PhD Student
- Pilot project
  - Major aircraft manufacturer, new program development
  - Dr. George Thiers, GT Post-doc
- MBSE Tools, Inc: Commercialization of research ideas
  - Dr. George Thiers, founder

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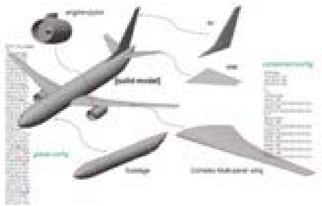
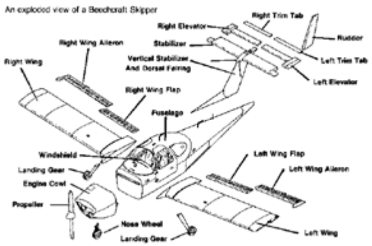
Context & Vision—What Is D2P?



Concept to Detail



D2P

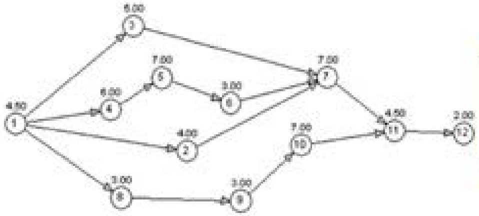
Intent: Make D2P decision-making better, faster, cheaper, more reliable

Goal: Capture D2P knowledge in models to:

1) Provide seamless access to analysis mo[dels]
2) Facilitate integrated ergonomics & safety analysis
3) Facilitate model inconsistency detection

Today

D2P



Concept to Detail

www.nationaldefensemagazine.org

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Agenda for Today

- The Challenge
  - Supporting the “integrated process development” in IPPD for advanced technologies, like composites
  - Focus on understanding the cost/performance trade-offs as product definition and market projections change
- The Concept
  - Capture simulation knowledge and automate simulation modeling process
- The Implementation
  - SysML, Simio, Bridging abstraction
- The Pilot Study
  - Source information
  - Simulation results
- Where to Next?

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Goal of IPPD

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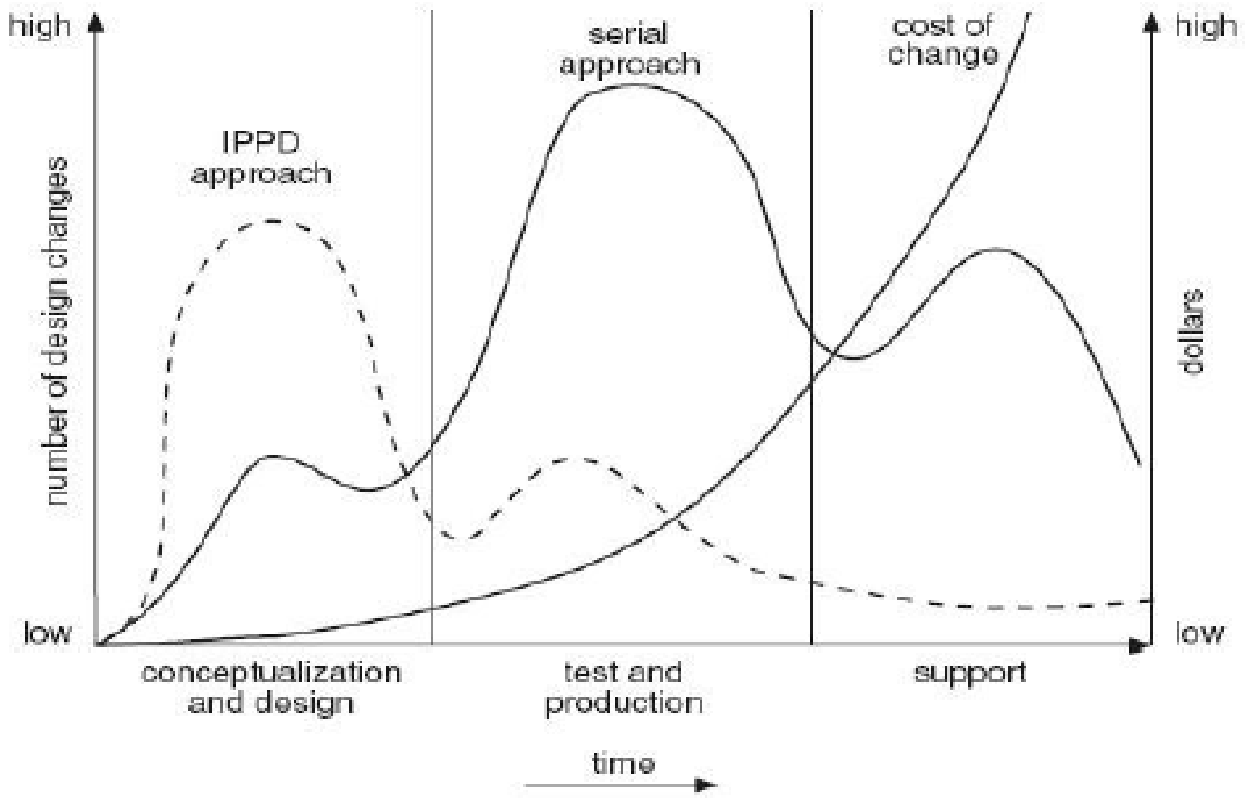

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Reality of IPPD

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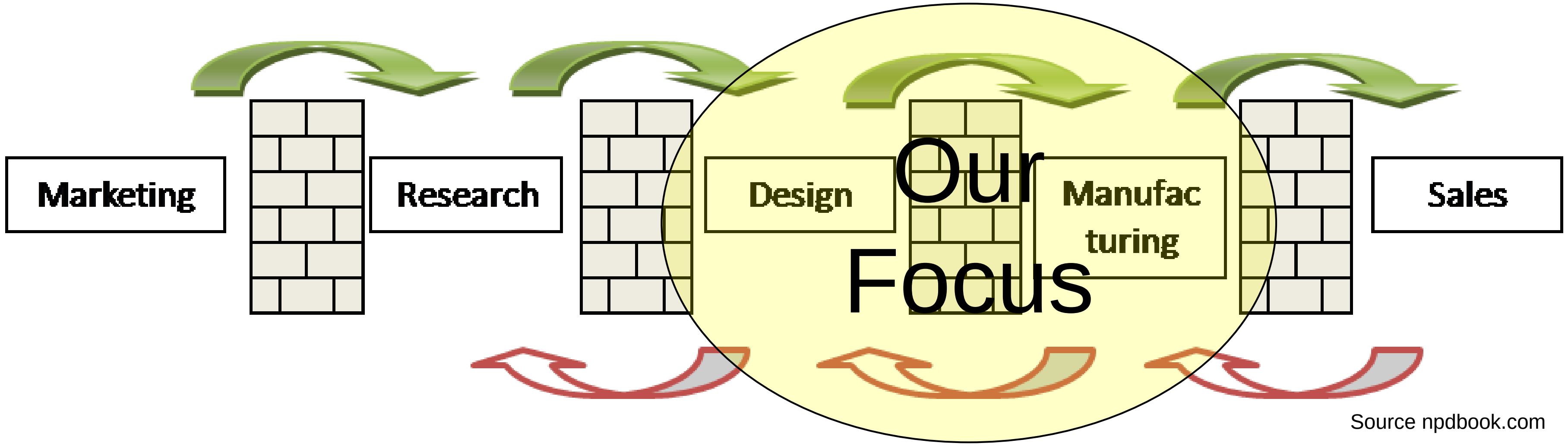

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“Integrated” => Sequential, with feedback

Goal is frequent, fast feedback…3F

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Our Specific Challenge

- Predicting the (rate/cost) behavior of a (new!) complex process design
- Time and expense of (hand-building) discrete event simulation models => *not fast, not frequent feedback*
- But, we know how to build the models, it's just managing the details of each specific design that takes time (and therefore $)

- *Can we give simulation capability to the process designer, much as FEA is available to the part designer, i.e., "on demand, instantaneous"?*

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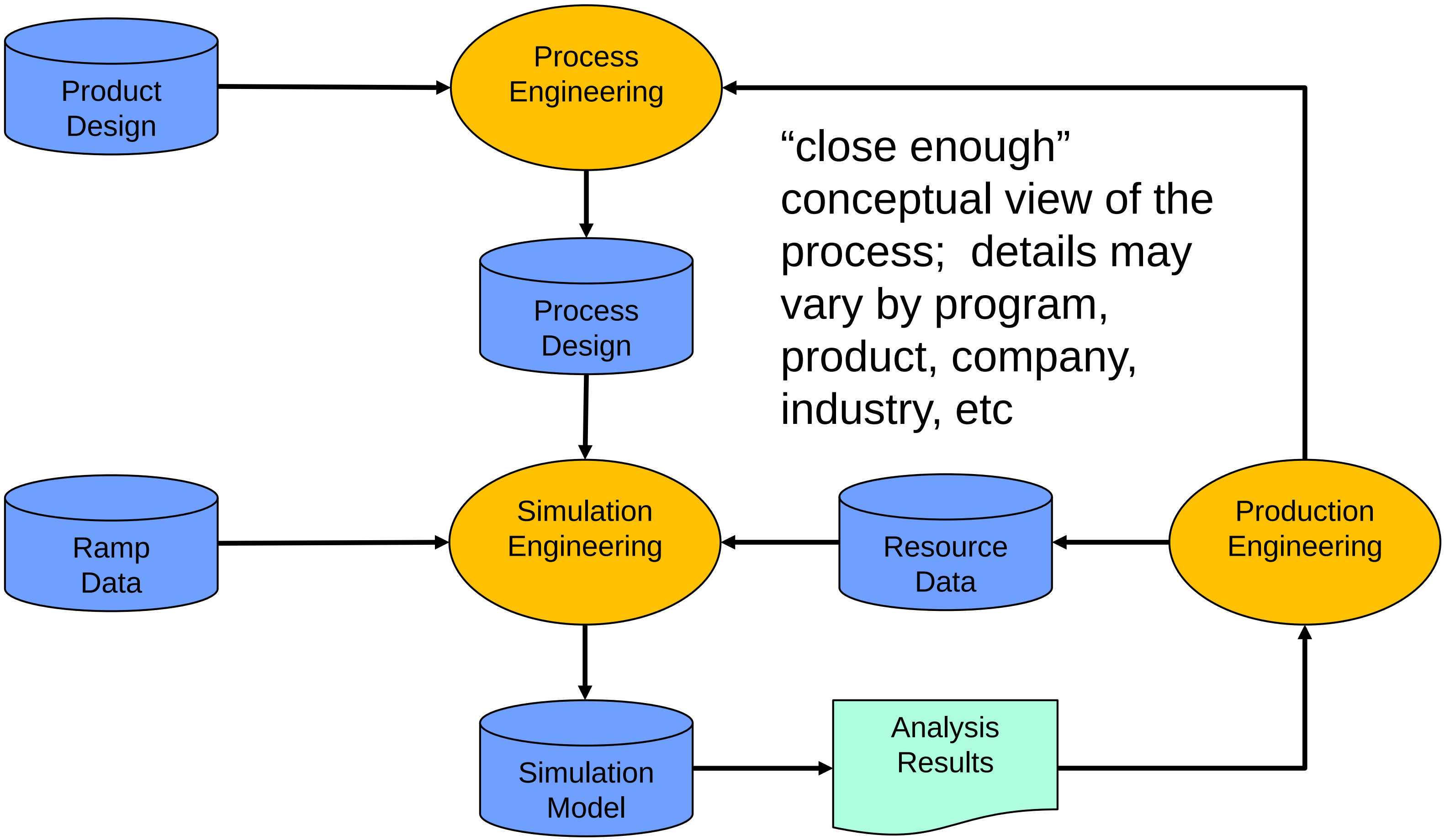
As-Is Process Simulation Process



"close enough" conceptual view of the process; details may vary by program, product, company, industry, etc

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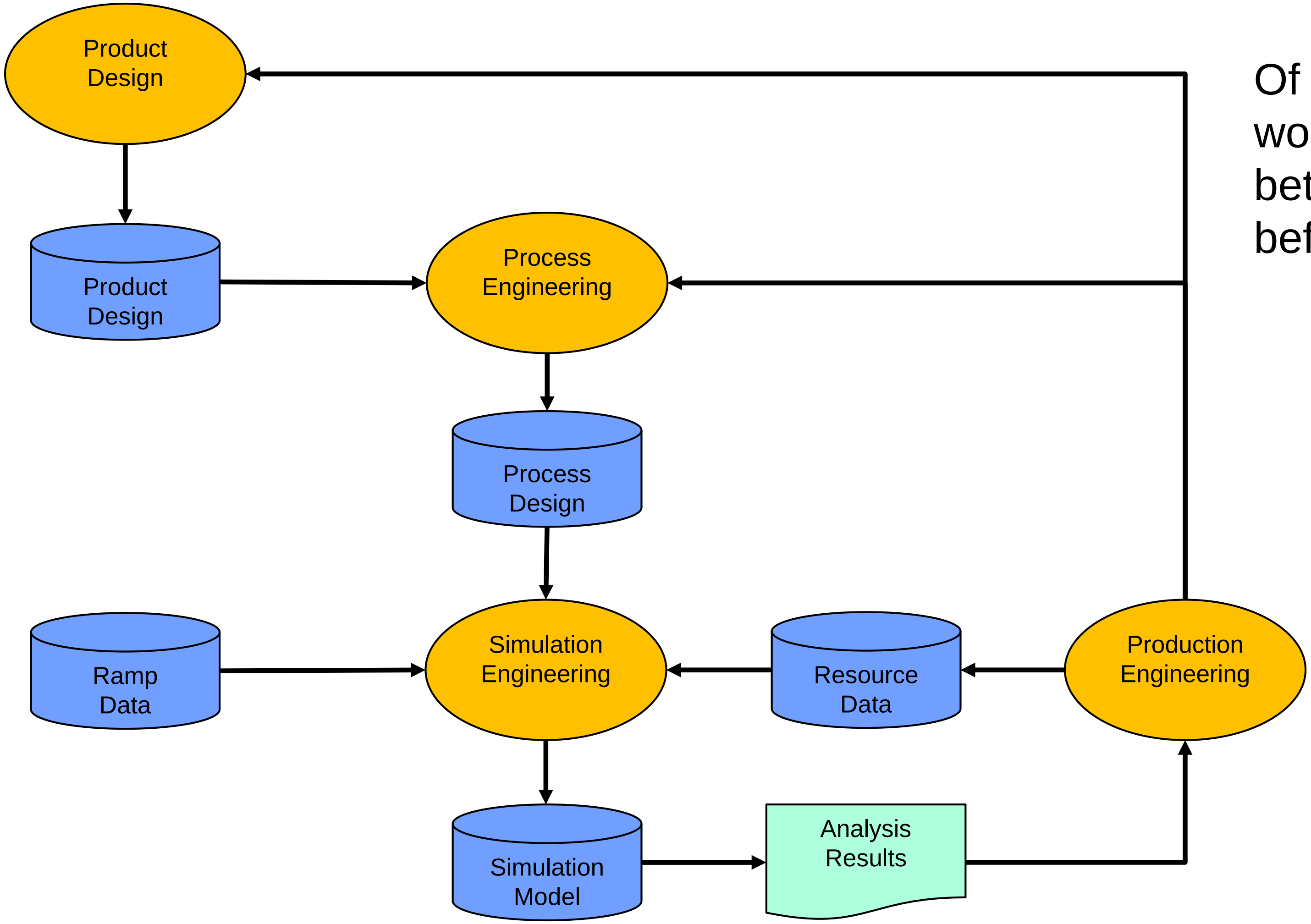
As-Is Process Simulation Process



Of course, this would be even better, but let's walk before we run…

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So, What Is The Problem?

I've got a PhD in materials, but I can't communicate with my simulation engineer.

- Simulation Engineers speak a different language than Process and Production Engineers!
- **Lots of time and effort goes into "translating" from one domain to another.**

Useful analogy: Suppose the part designer had to explain the part to an "FEA Simulation Engineer" in order to get a stress or thermal analysis done; how often would FEA be used? Automating the meshing, the generation of the analysis, and the presentation of analytic results has transformed part design.

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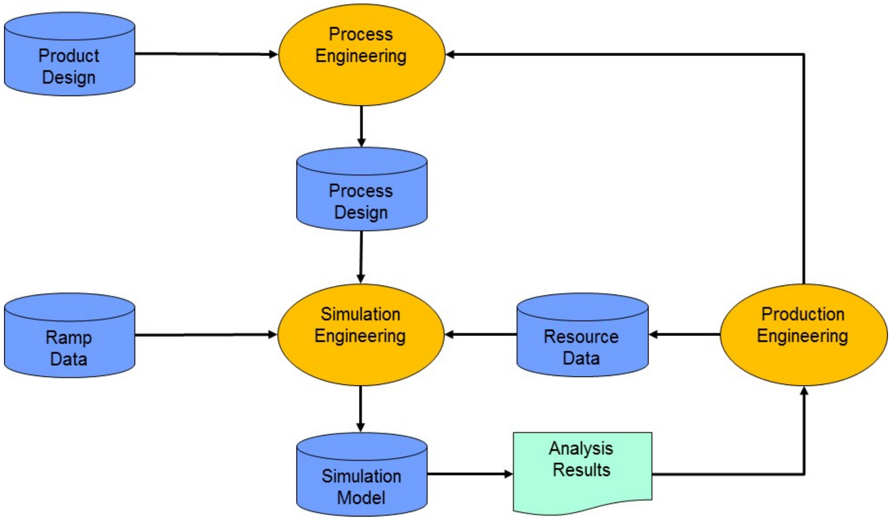
So, What Is The Problem?



- Today, we can only afford to close the loop between Production and Process Engineering infrequently
- We would like to be able to close the loop with Design *and with Marketing*
- *We need to be able to do the Simulation Engineering "on the fly", very inexpensively*

- **WE NEED AUTOMATION!**

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Conceptual Approach

- Organizing themes
- Reference model
- Specific *kinds* of questions
- Simulation components
- Bridging abstraction
- Model-to-model transformation

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1. Organizing Themes

- Product (D): what is produced, part specs, MBOMs, etc
- Process (P): how it's produced
- Resource (R): what is used in a process
- Facility: organization of resources and processes
- Production level (L): the rate of production

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2. Reference Model

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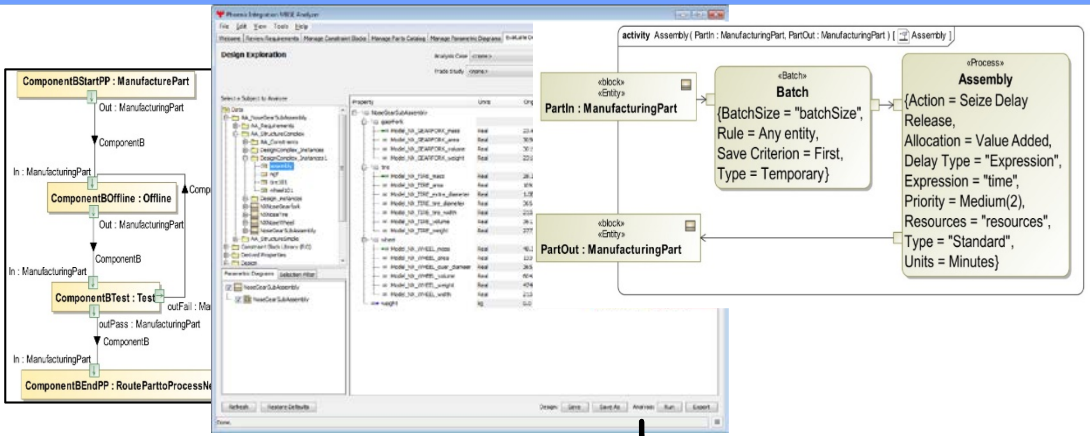

Object oriented
Graphical
Formal semantics and syntax
“Universal”

Abstraction Process

Process Engineering Domain
Expert Knowledge

Production Engineering Domain
Expert Knowledge

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3. Specific kinds of questions

- What capacity of R is needed, with design D, process P, and production level L?
- How much WIP will be needed to support L, with R, D, and P?
- What will be cycle time with L, R, D, and P?
- What will be the utilization of R?
- What will be the bottleneck process?
- ….

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By knowing the *kinds* of questions

- We know what *kinds* of facts are needed in order to answer the questions
- We can develop configurable, parameterized “simulation components” that ***can be assembled*** to answer the questions
- Given instance data for D, P, R, and L, we can automate the assembly of simulation components to answer a specific question

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4. Simulation Components

Reference Model

+

- What capacity of R is needed, with design D, process P, and production level L?
- How much WIP will be needed to support L, with R, D, and P?
- What will be cycle time with L, R, D, and P?
- What will be the utilization of R?
- What will be the bottleneck process?
- ….

=

Simulation Component Library

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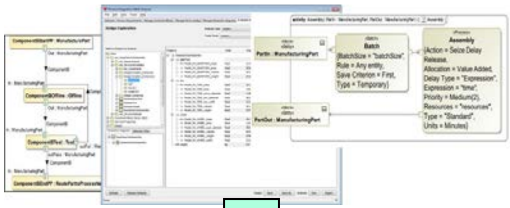
5. Bridging Abstraction

Reference Model



Mapping

Bridging Abstraction

Mapping

Simulation Component Library

Token Flow Network

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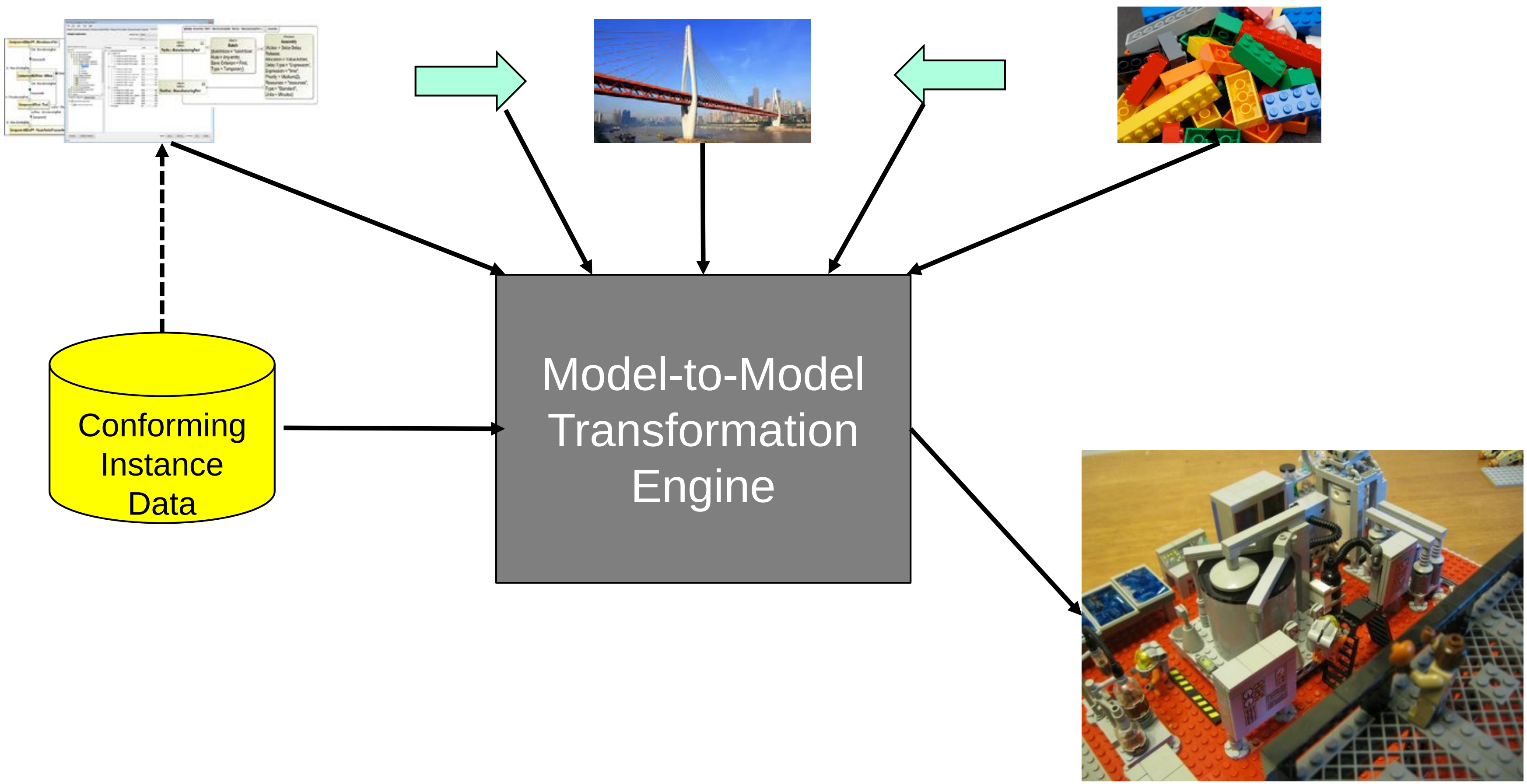
6. Model-to-Model Transformation



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Implementation

- Reference Model: SysML/UML, Ecore
- Bridging Abstraction: SysML/UML
- Simulation: Simio, Tecnomatix Plant Simulation, SimEvents
- Mappings: Underlying representation is XML
- M2M transform: C#
- Data: Excel/Access (tabular view) or Visio (diagram view)

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Pilot Study: Composite Part Manufacturing

- Serial process: multi-stage layup, autoclave, cleanup
- Parts flow and fixtures flow
- Parts design changes
- Production level changes
- Determine resource costs, WIP, leadtime
- Data from Process Engineering in spreadsheets
- Simio simulations

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Pilot Study Process

- Understand source data
- Develop Simio component library
- Develop generic mappings, M2M transform
- Demonstrate automation using “typical” data

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Input #1: Reference Model


```
manufacturing
  Job
    time-mean : EDouble
    time-stdev : EDouble
    time-units : EString
    componentOperation : Job
    requiredRawMaterialTypes : EMap<RawMaterialType, EInt>
    requiredPartTypes : EMap<PartType, EInt>
    requiredWorkOrderTypes : EMap<WorkOrderType, EInt>
    requiredMobileResourceTypes : EMap<MobileResourceType, EInt>
    resourceTypesAssembledIntoOutput : EMap<MobileResourceType, EInt>
    resourceTypesDisassembledFromInput : EMap<MobileResourceType, EInt>
    successorJobs : Job
  Operation -> Job
    Job
    parentJob : Job
  RawMaterialType
    quantityOnHand : EInt
    interSupplyTime-mean : EDouble
    interSupplyTime-stdev : EDouble
    interSupplyTime-units : EString
    supplyBatchSize : EInt
  PartType
    quantityOnHand : EInt
    interSupplyTime-mean : EDouble
    interSupplyTime-stdev : EDouble
    interSupplyTime-units : EString
    supplyBatchSize : EInt
  WorkOrderType
    interReleaseTime-mean : EDouble
    interReleaseTime-stdev : EDouble
    interReleaseTime-units : EString
  MobileResourceType
    quantityOnHand : EInt
```

- A reference model (a.k.a. *system model* or *domain-specific language*, which is closely related to an *ontology*) defines a schema for describing a system, scenarios within it, and alternatives to it.
- Reference modeling languages include entity-relationship diagrams, the IDEF family, UML, SysML, Ecore, OPM, and more.
- If the modeling language is object-oriented, then a reference model only defines schema. An analogy is that a reference model defines an Excel workbook's sheets and column headers, but not any data.

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Input #2: System Description conforming to Reference Model

- manufacturing
  - Job
    - time-mean : EDouble
    - time-stdev : EDouble
    - time-units : EString
    - componentOperation : Job
    - requiredRawMaterialTypes : EMap<RawMaterialType, EInt>

Job_requiredRawMaterialTypes

(Job) InstanceID	requiredRawMaterialTypes	requiredRawMaterialTypes
Op1	1	LargePlySheet

- MobileResourceType
  - quantityOnHand : EInt

MobileResourceType

InstanceID	quantityOnHand
LayupMoldType1	10
LayupMoldType2	12
ToolType1	8
ToolType2	8
OperatorL11	2
OperatorL12	2
OperatorL13	1
OperatorL14	1

- RawMaterialType
  - quantityOnHand : EInt
  - interSupplyTime-mean : EDouble
  - interSupplyTime-stdev : EDouble
  - interSupplyTime-units : EString
  - supplyBatchSize : EInt

RawMaterialType

InstanceID	quantityOnHand	interSupplyTime-mean	interSupplyTime-stdev	interSupplyTime-units	supplyBatchSize
LargePlySheet	20	1	0.1	hours	12

- The reference model defines a language; now use it to capture concrete descriptions of systems, scenarios, and alternatives.
- Languages for capturing conforming system descriptions include tabular environments (Excel) and diagram environments (Visio).
- A reference model and conforming system description together comprise a complete “system model”.

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Input #3: Ask a Question

- A system model is not enough; analysis is performed to answer a question.
- Any question? No, only questions which analysts know how to answer, and for which they have captured the formulation process for an answering analysis model in a reusable way.
- The question driving this pilot project (stated informally) is "What is the minimum number of resources needed to support a given production rate?"

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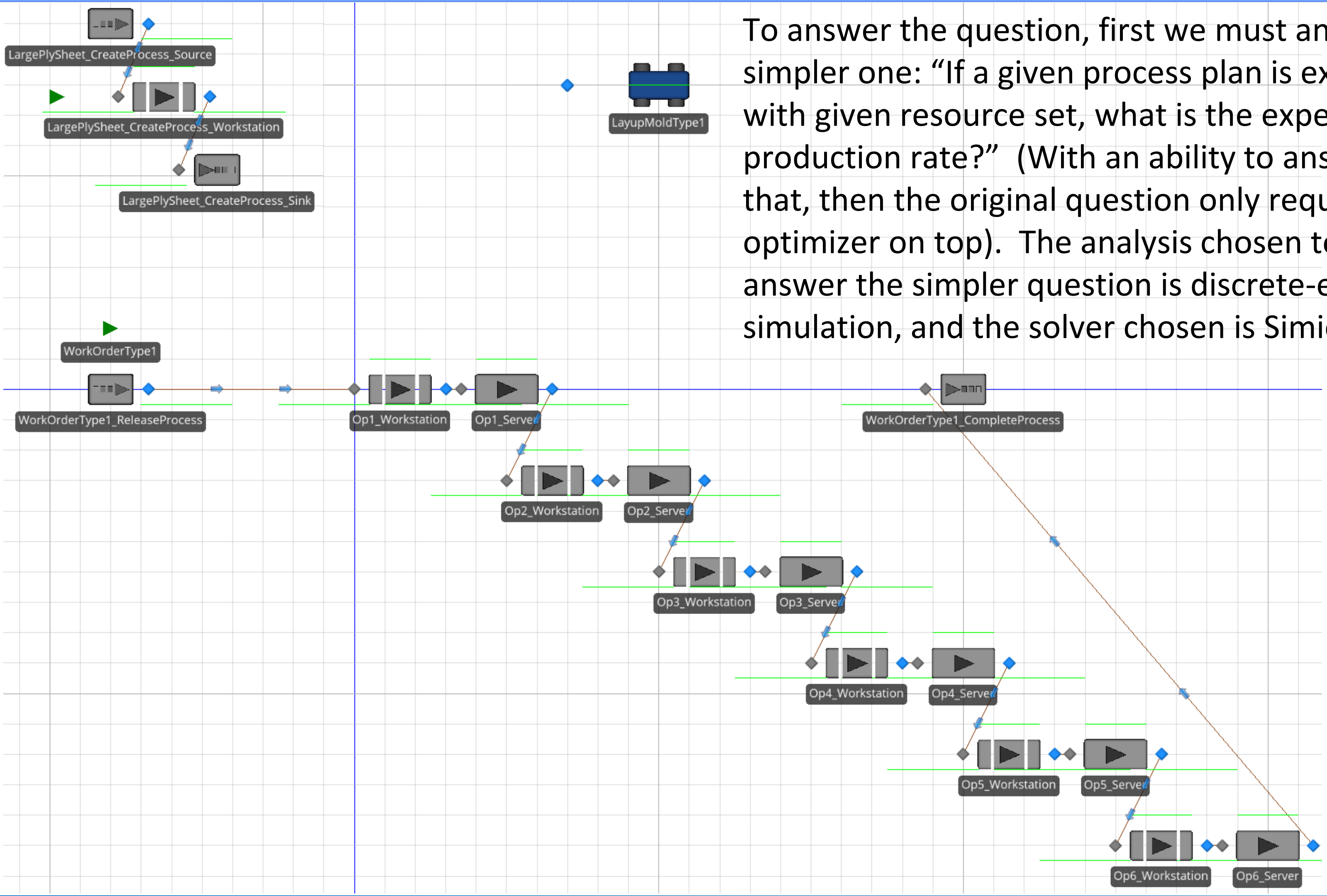
Output #1: An Analysis Model



To answer the question, first we must answer a simpler one: “If a given process plan is executed with given resource set, what is the expected production rate?” (With an ability to answer that, then the original question only requires an optimizer on top). The analysis chosen to answer the simpler question is discrete-event simulation, and the solver chosen is Simio.

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Output #2: An Answer to the Question

A discrete-event simulation model includes both a model and an experiment. Both are auto-formulated, yielding an answer:

	Scenario			Replications		Responses		
	☑	Name	Status	Required	Completed	Throughput	CycleTime	WorkInProcess
▸	☑	Scenario1	Completed	10	10 of 10	11.8167	0.406588	4.8467

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Typical Results

- Handbuilt simulation: *xx person-days, xx days leadtime*
- Auto-generated simulation: "*instantaneous*"
- Development effort to date: *5-6 person weeks*…
- Effort to include additional processes: *minimal*
- Effort to adapt to different simulation language: *it depends*

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Next Steps

- Commercialization of technology
  - As a service: develop specific implementations for large, persistent programs where demand for process simulation is large
  - As a product: generalize reference model, mappings, simulation libraries, and M2M transformation for larger domains (e.g., all of composites manufacturing, composites assembly, all of sheet metal fabrication, traditional aircraft assembly)

- Contacts:
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