

Evaluating the Production Consequences of Design Decisions using MATLAB and Simulink

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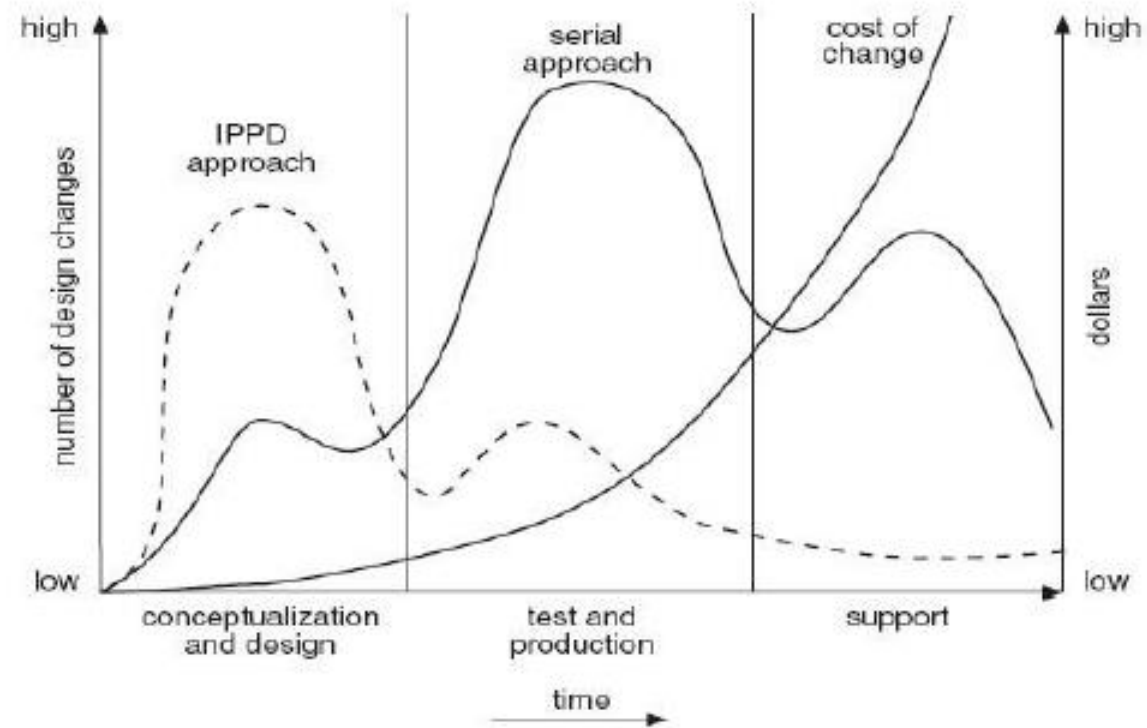
Dr. Tim Sprock (now at NIST)



Dr. George Thiers (now at ModGeno)

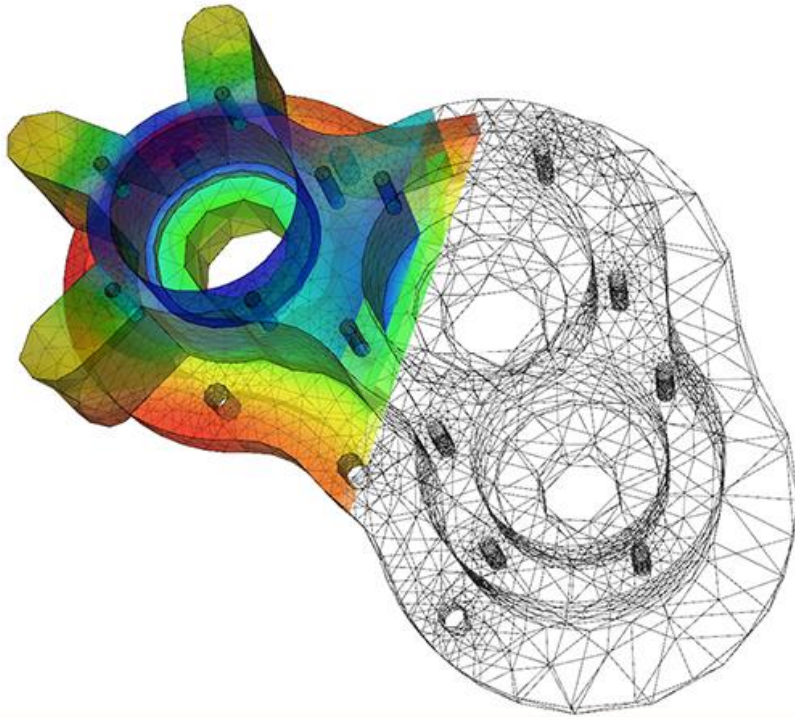


Integrated Product-Process Development



A Fundamental Obstacle to IPPD

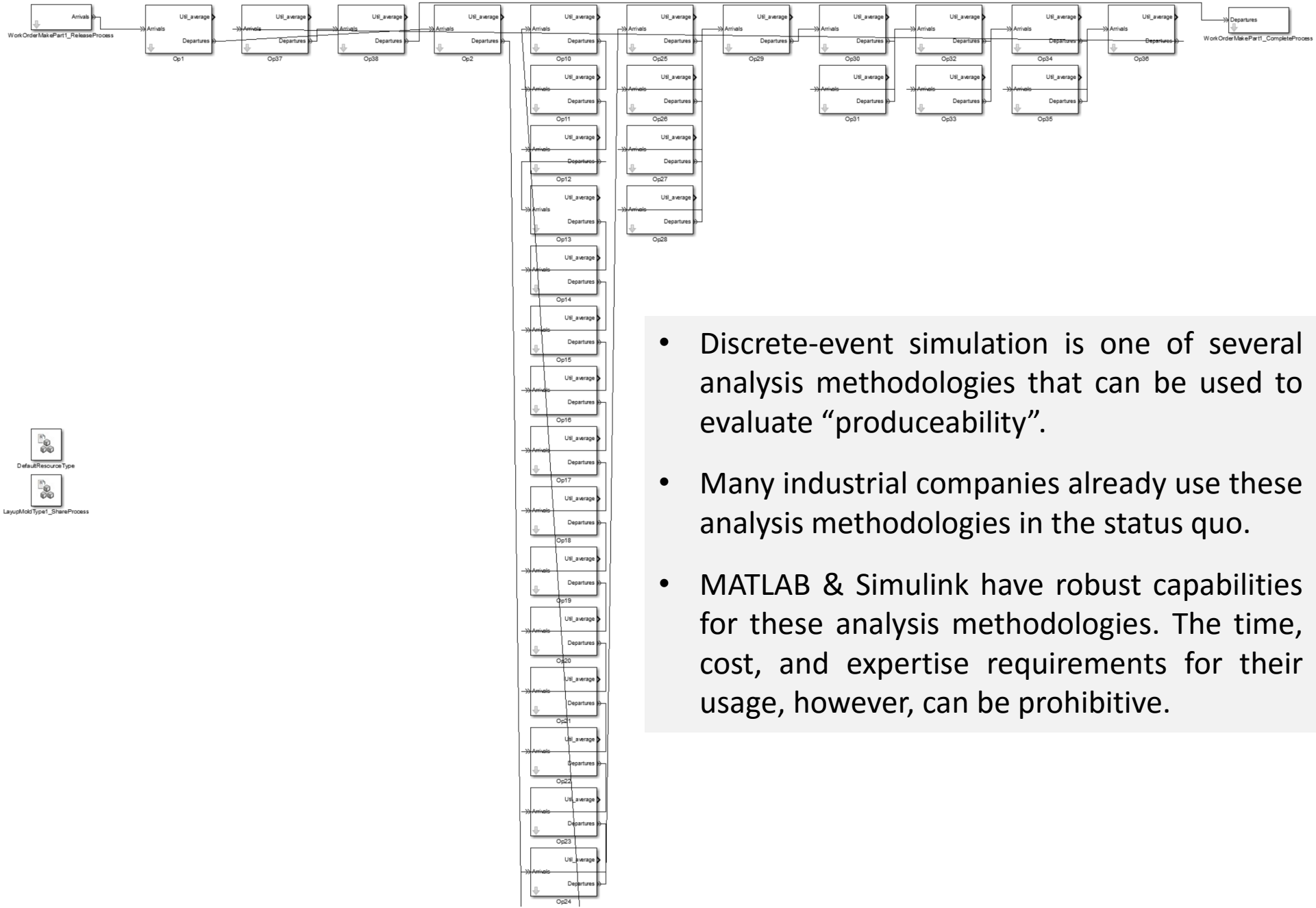
Tool support for the design and operation of industrial engineering systems (manufacturing systems, supply chains, sustainment systems, warehouses, distribution centers, ...) **is far less sophisticated than for products themselves.**



An analogy: When designing a part in a CAD environment, finite-element analysis is push-button accessible – a mesh and the mathematical analysis model can be automatically generated.

For operations research analysis of industrial engineering systems (discrete-event simulation, statistics in support, optimization on top), we effectively create the mesh and write the analysis code by hand, each and every time, even to answer routine and well-understood questions which we have seen before and know how to answer.

A Fundamental Obstacle to IPPD



- Discrete-event simulation is one of several analysis methodologies that can be used to evaluate “produceability”.
- Many industrial companies already use these analysis methodologies in the status quo.
- MATLAB & Simulink have robust capabilities for these analysis methodologies. The time, cost, and expertise requirements for their usage, however, can be prohibitive.

What Would Better Tool Support Enable?

- Predicting the behavior and performance of manufacturing process and facility designs, quickly and at very low cost.
- Receiving fast and frequent feedback about the production consequences of design decisions.
- Extending Value Stream Maps into variability exploration tools, such that standard hours, inventory buffers, and supplier delivery schedules can be chosen for robustness.
- Considering more improvement ideas and alternatives, evaluating more production scenarios and their impacts, and exploring more of a production system's design space.

Results: Manufacturing Demo

File Tools

System Definition:

Manufacturing_v12

AirportEnvironment_v4

ValueStreamMapping

System Instance:

Save System Instance

Question:

How To Answer:

Solver:

Formulate and Solve

Pose A New QuestionAnswers

Results: Manufacturing Demo

- ✚ manufacturing
 - > 📄 Job
 - > 📄 Operation -> Job
 - 📄 WorkOrderType
 - > 📄 WorkOrderReleaseProcess
 - 📄 RawMaterialType
 - > 📄 RawMaterialSupplyProcess
 - 📄 MobileResourceType
 - > 📄 MobileResourceSharingProcess
 - > 📄 Facility
 - > 📄 Cell
 - > 📄 Workstation
 - > 📄 Product

Results: Manufacturing Demo

File Tools

System Definition: Manufacturing_v12

System Instance:

(Create New)
man12_OneJob_Elementary
man12_OneJob_LessFidelity
man12_OneJob_MoreFidelity
man12_OneFacilityOneProduct_Simple
man12_OneFacilityOneProduct_GenericLessFidelity
man12_OneFacilityOneProduct_GenericMoreFidelity
man12_OneFacilityOneProduct
man12_OneFacilityTwoProducts_Simple
man12_OneFacilityTwoProducts_Generic
man12_OneFacilityTwoProducts
man12_TwoFacilitiesOneProduct_Generic

Save System Instance

manufacturing

- Job
 - workOrder : EReference [0..1]
 - componentJob : EReference [0..*]
 - componentOperation : EReference [0..*]
 - successorJobs : EReference [0..*]
- Operation
 - time-mean : EAttribute [0..1]
 - time-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - processParallelCapacity : EAttribute [0..1]
 - processBatchSize : EAttribute [0..1]
 - requiredRawMaterialTypes : EAttribute [0..1]
 - requiredMobileResourceTypes : EAttribute [0..1]
 - resourceTypesAssembledIntoOutput : EAttribute [0..1]
 - resourceTypesDisassembledFromInput : EAttribute [0..1]
- WorkOrderType
- WorkOrderReleaseProcess
 - workOrderType : EReference [0..1]
 - interReleaseTime-mean : EAttribute [0..1]

Question:

How To Answer:

Solver:

Formulate and Solve

Pose A New Question

Answers

Results: Manufacturing Demo

FileTools

System Definition: Manufacturing_v12System Instance: man12_OneFacilityOneProduct_GenericLessFidelitySave System Instance

manufacturing

- Job
 - workOrder : EReference [0..1]
 - componentJob : EReference [0..*]
 - componentOperation : EReference [0..*]
 - successorJobs : EReference [0..*]
- Operation
 - time-mean : EAttribute [0..1]
 - time-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - processParallelCapacity : EAttribute [0..1]
 - processBatchSize : EAttribute [0..1]
 - requiredRawMaterialTypes : EAttribute [0..1]
 - requiredMobileResourceTypes : EAttribute [0..1]
 - resourceTypesAssembledIntoOutput : EAttribute [0..1]
 - resourceTypesDisassembledFromInput : EAttribute [0..1]
- WorkOrderType
- WorkOrderReleaseProcess
 - workOrderType : EReference [0..1]
 - interReleaseTime-mean : EAttribute [0..1]

MobileResourceType	Operation	Product	RawMaterialSupplyProcess
RawMaterialType	WorkOrderReleaseProcess	WorkOrderType	Workstation
Cell	Facility	Job	MobileResourceSharingProcess
InstanceID	workOrder (WorkOrderType)		
Job_MakePart1	WorkOrderMakePart1		
Job1			
Job2			
Job3			
Job4			
Job5			
Job6			
Job7			
Job8			
Job9			
Job10			
Job11			

DESCRIBE: What are (Network size metrics) for a certain (Job)?
DESCRIBE: What are (Network size metrics) for a certain (Cell)?
PREDICT: What is the (expected) (Raw Cycle Time) of a certain (Job)?
PREDICT: What is the (expected) (Throughput) of a certain (Job)?
PREDICT: What is the (expected) (Throughput) of making certain (Product)s in a certain (Facility)?

Question:How To Answer:Solver:Formulate and Solve

Pose A New QuestionAnswers

Results: Manufacturing Demo

FileTools

System Definition: Manufacturing_v12

System Instance: man12_OneFacilityOneProduct_GenericLessFidelity

Save System Instance

manufacturing

- Job
 - workOrder : EReference [0..1]
 - componentJob : EReference [0..*]
 - componentOperation : EReference [0..*]
 - successorJobs : EReference [0..*]
- Operation
 - time-mean : EAttribute [0..1]
 - time-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - processParallelCapacity : EAttribute
 - processBatchSize : EAttribute [0..1]
 - requiredRawMaterialTypes : EAttribute
 - requiredMobileResourceTypes : EAttribute
 - resourceTypesAssembledIntoOutput : EAttribute
 - resourceTypesDisassembledFromInput : EAttribute
- WorkOrderType
- WorkOrderReleaseProcess
 - workOrderType : EReference [0..1]
 - interReleaseTime-mean : EAttribute

RawMaterialTypeWorkOrderReleaseProcessWorkOrderTypeWorkstation

CellFacilityJobMobileResourceSharingProcess

MobileResourceTypeOperationProductRawMaterialSupplyProcess

InstanceID	time-mean (float)	time-stdev (float)	time-units (nvarchar(255))	process
Job1	1	0.1	minutes	1
Job2	1	0.1	minutes	1
Job3	22	0.1	minutes	1
Job4	4	0.1	minutes	5
Job5	1	0.1	minutes	1
Job6	2	0.1	minutes	1
Job7	2	0.1	minutes	1
Job8	2	0.1	minutes	1
Job9	1	0.1	minutes	1
Job10	1	0.1	minutes	1
Job11	1	0.1	minutes	1

Question: PREDICT: What is the (expected) (Throughput) of a certain product?

How To Answer: Discrete Event Simulation

Solver:

Formulate and Solve

Pose A New Question

Answers

Results: Manufacturing Demo

FileTools

System Definition: Manufacturing_v12System Instance: man12_OneFacilityOneProduct_GenericLessFidelitySave System Instance

manufacturing

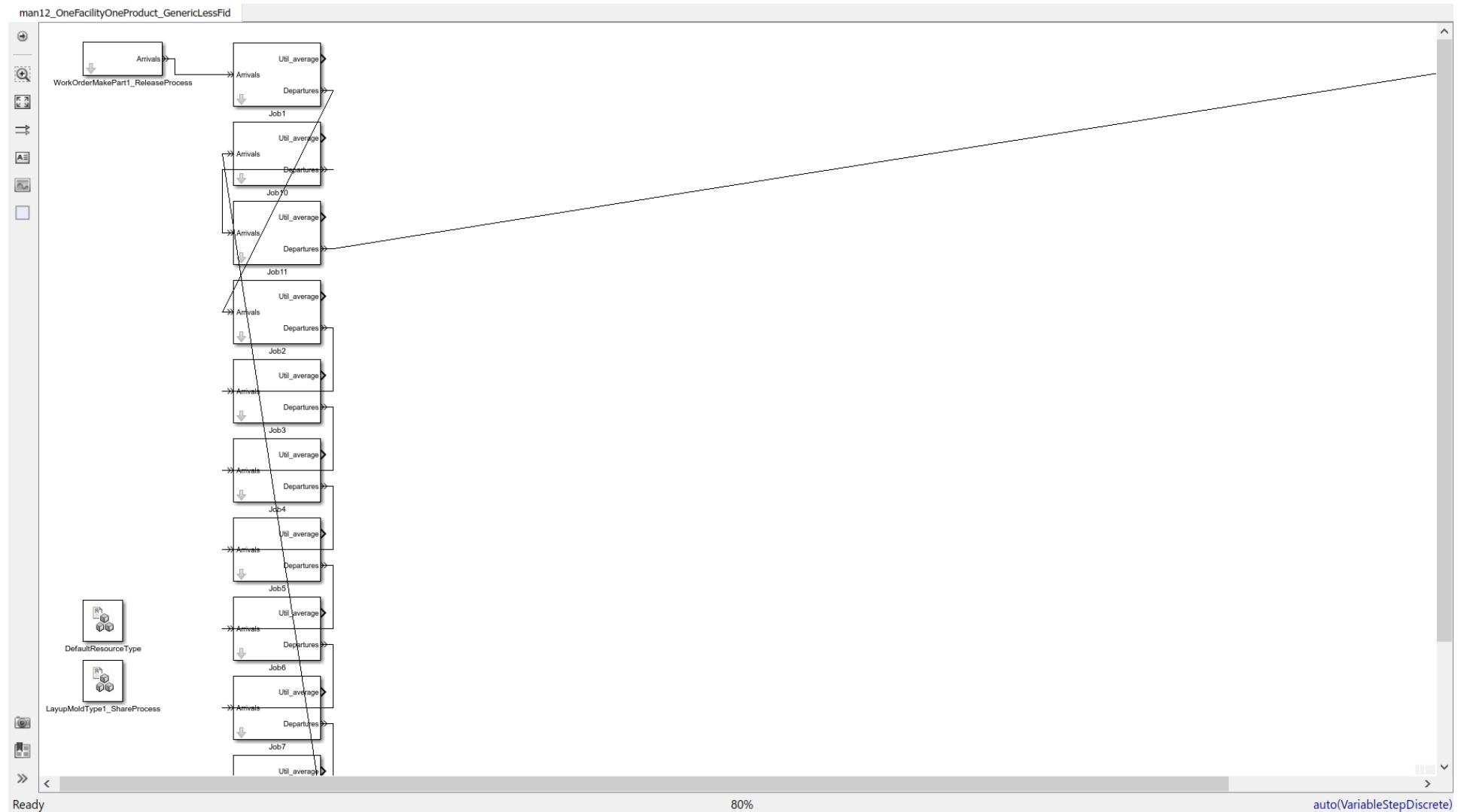
- Job
 - workOrder : EReference [0..1]
 - componentJob : EReference [0..*]
 - componentOperation : EReference [0..*]
 - successorJobs : EReference [0..*]
- Operation
 - time-mean : EAttribute [0..1]
 - time-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - processParallelCapacity : EAttribute [0..1]
 - processBatchSize : EAttribute [0..1]
 - requiredRawMaterialTypes : EAttribute [0..1]
 - requiredMobileResourceTypes : EAttribute [0..1]
 - resourceTypesAssembledIntoOutput : EAttribute [0..1]
 - resourceTypesDisassembledFromInput : EAttribute [0..1]
- WorkOrderType
 - workOrderReleaseProcess : EReference [0..1]
 - interReleaseTime-mean : EAttribute [0..1]

RawMaterialType	WorkOrderReleaseProcess	WorkOrderType	Workstation	
Cell	Facility	Job	MobileResourceSharingProcess	
MobileResourceType	Operation	Product	RawMaterialSupplyProcess	
InstanceID	time-mean (float)	time-stdev (float)	time-units (nvarchar(255))	product
Job1	1	0.1	minutes	1
Job2	1	0.1	minutes	1
Job3	22	0.1	minutes	1
Job4	4	0.1	minutes	5
Job5	1	0.1	minutes	1
Job6	2	0.1	minutes	1
Job7	2	0.1	minutes	1
Job8	2	0.1	minutes	1
Job9	1	0.1	minutes	1
Job10	1	0.1	minutes	1
Job11	1	0.1	minutes	1

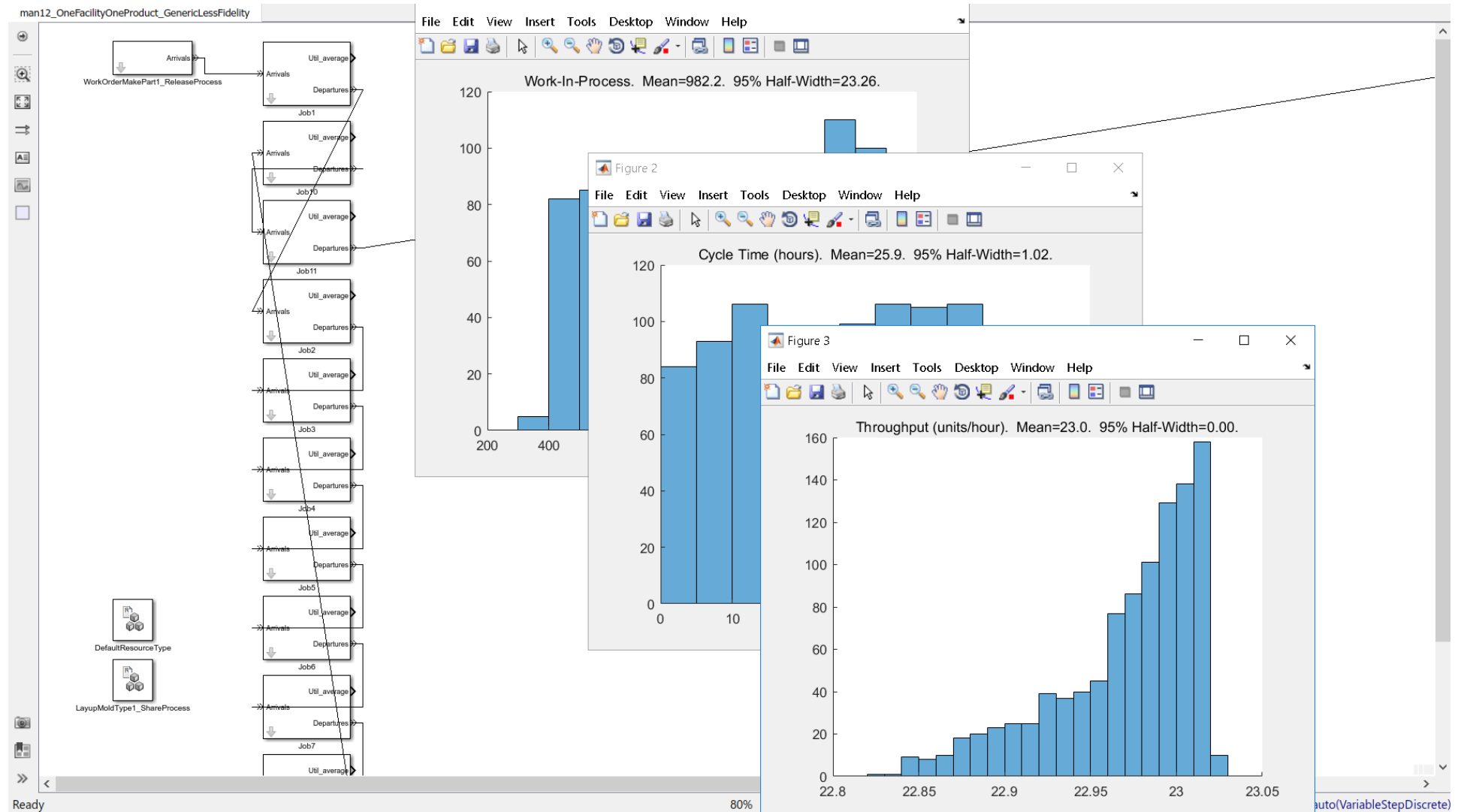
Question: PREDICT: What is the (expected) (Throughput) of a cell (Job A)How To Answer: Discrete Event SimulationSolver: MATLABFormulate and Solve

Pose A New QuestionAnswers

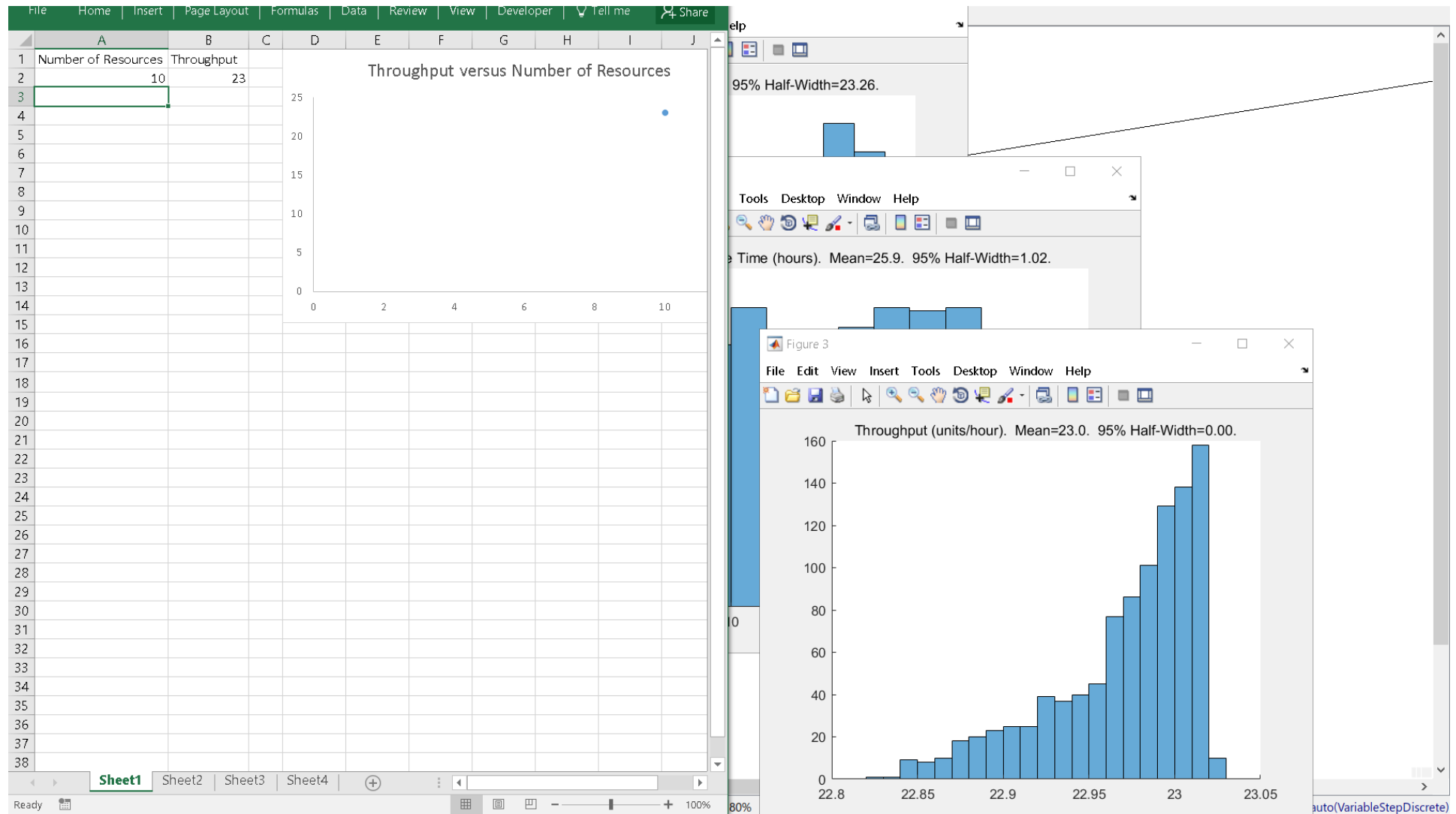
Results: Manufacturing Demo



Results: Manufacturing Demo



Results: Manufacturing Demo



Results: Manufacturing Demo

FileTools

System Definition: Manufacturing_v12

System Instance: man12_OneFacilityOneProduct_GenericLessFidelity

Save System Instance

manufacturing

- Job
 - workOrder : EReference [0..1]
 - componentJob : EReference [0..*]
 - componentOperation : EReference [0..1]
 - successorJobs : EReference [0..*]
- Operation
 - time-mean : EAttribute [0..1]
 - time-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - processParallelCapacity : EAttribute [0..1]
 - processBatchSize : EAttribute [0..1]
 - requiredRawMaterialTypes : EAttribute [0..1]
 - requiredMobileResourceTypes : EAttribute [0..1]
 - resourceTypesAssembledIntoOut : EAttribute [0..1]
 - resourceTypesDisassembledFrom : EAttribute [0..1]
- WorkOrderType
- WorkOrderReleaseProcess
 - workOrderType : EReference [0..1]
 - interReleaseTime-mean : EAttribute [0..1]

MobileResourceType	Operation	Product	RawMaterialSupplyProcess
RawMaterialType	WorkOrderReleaseProcess	WorkOrderType	Workstation
Cell	Facility	Job	MobileResourceSharingProcess
InstanceID	mobileResourceType (MobileResourceType)		initialNumberAvailable (int)
Pool_LayupMoldType1	LayupMoldType1		11

Question: PREDICT: What is the (expected) (Throughput) of a certain How?

Answer: Discrete Event Simulation

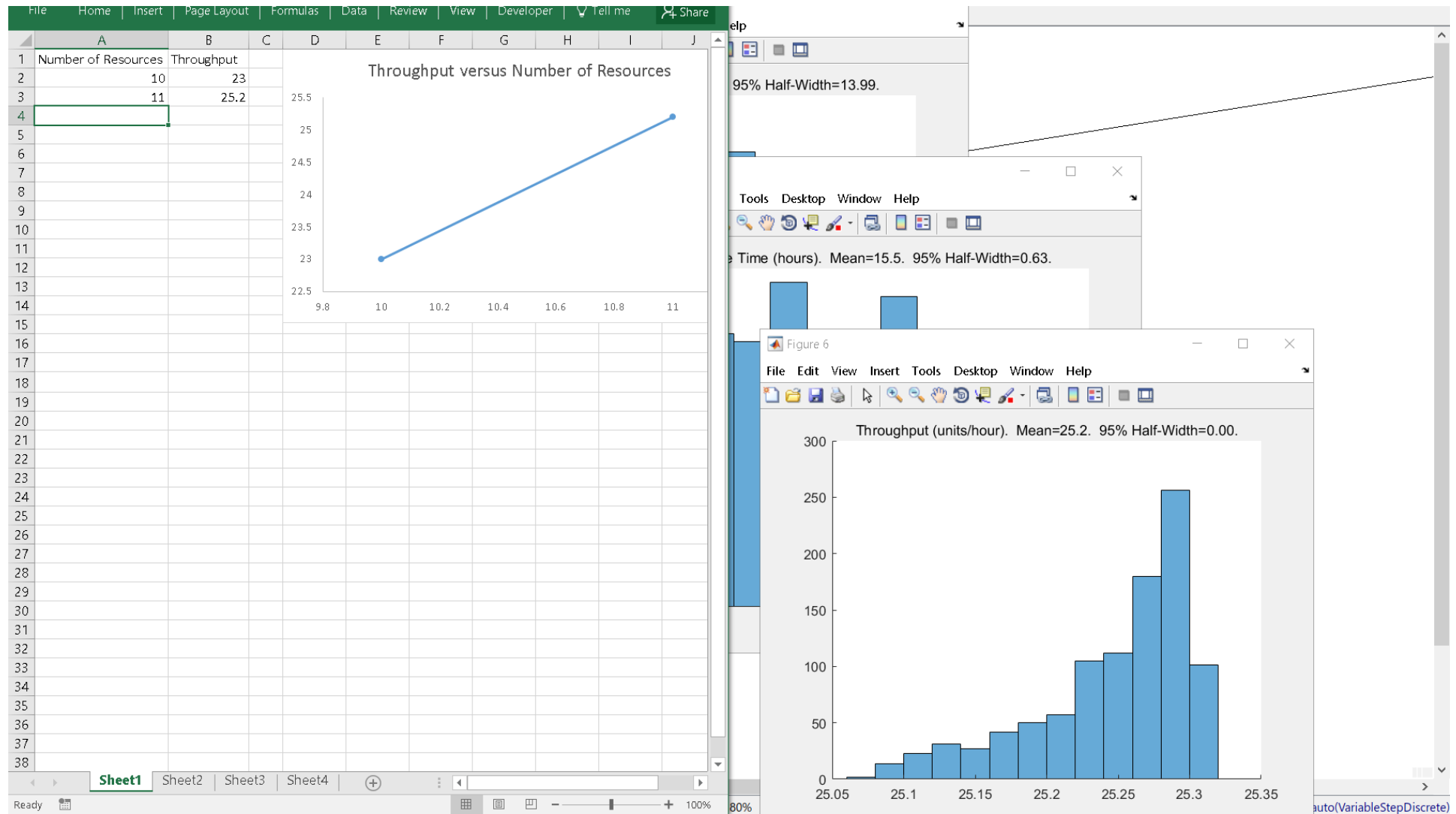
Solver: MATLAB

Formulate and Solve

Pose A New Question

Answers

Results: Manufacturing Demo



Results: Manufacturing Demo

FileTools

System Definition: Manufacturing_v12

System Instance: man12_OneFacilityOneProduct_GenericLessFidelity

Save System Instance

manufacturing

- Job
 - workOrder : EReference [0..1]
 - componentJob : EReference [0..*]
 - componentOperation : EReference [0..*]
 - successorJobs : EReference [0..*]
- Operation
 - time-mean : EAttribute [0..1]
 - time-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - processParallelCapacity : EAttribute [0..1]
 - processBatchSize : EAttribute [0..1]
 - requiredRawMaterialTypes : EAttribute [0..1]
 - requiredMobileResourceTypes : EAttribute [0..1]
 - resourceTypesAssembledIntoOut : EAttribute [0..1]
 - resourceTypesDisassembledFrom : EAttribute [0..1]
- WorkOrderType
- WorkOrderReleaseProcess
 - workOrderType : EReference [0..1]
 - interReleaseTime-mean : EAttribute [0..1]

MobileResourceType	Operation	Product	RawMaterialSupplyProcess
RawMaterialType	WorkOrderReleaseProcess	WorkOrderType	Workstation
Cell	Facility	Job	MobileResourceSharingProcess
InstanceID	mobileResourceType (MobileResourceType)		initialNumberAvailable (int)
Pool_LayupMoldType1	LayupMoldType1		12

Question: PREDICT: What is the (expected) (Throughput) of a certain How?

Answer: Discrete Event Simulation

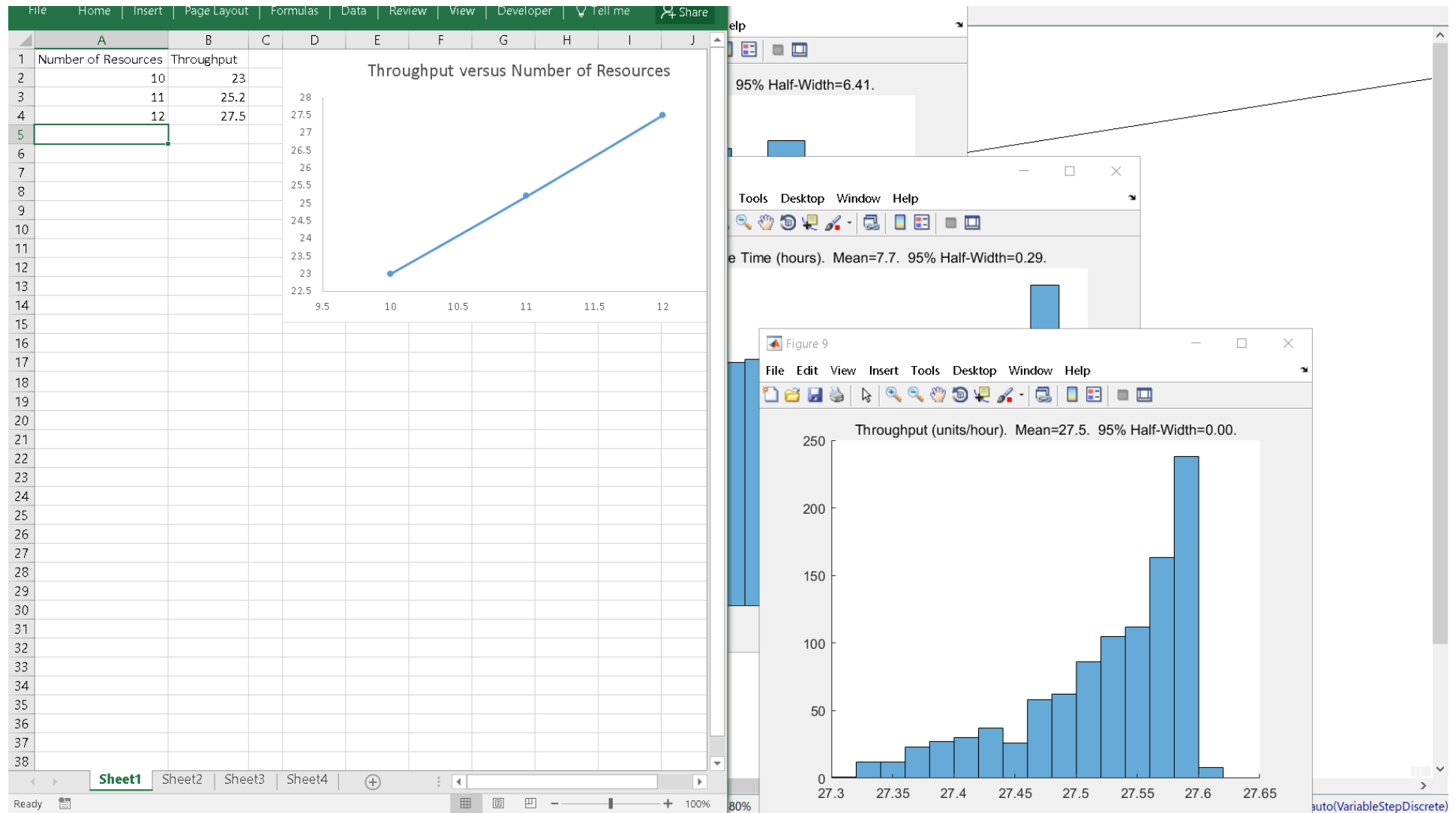
Solver: MATLAB

Formulate and Solve

Pose A New Question

Answers

Results: Manufacturing Demo



Results: Manufacturing Demo

FileTools

System Definition: Manufacturing_v12System Instance: man12_OneFacilityOneProduct_GenericLessFidelitySave System Instance

manufacturing

- Job
 - workOrder : EReference [0..1]
 - componentJob : EReference [0..*]
 - componentOperation : EReference [0..*]
 - successorJobs : EReference [0..*]
- Operation
 - time-mean : EAttribute [0..1]
 - time-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - processParallelCapacity : EAttribute [0..1]
 - processBatchSize : EAttribute [0..1]
 - requiredRawMaterialTypes : EAttribute [0..1]
 - requiredMobileResourceTypes : EAttribute [0..1]
 - resourceTypesAssembledIntoOutput : EAttribute [0..1]
 - resourceTypesDisassembledFromInput : EAttribute [0..1]
- WorkOrderType
- WorkOrderReleaseProcess
 - workOrderType : EReference [0..1]
 - interReleaseTime-mean : EAttribute [0..1]

MobileResourceType	Operation	Product	RawMaterialSupplyProcess
RawMaterialType	WorkOrderReleaseProcess	WorkOrderType	Workstation
Cell	Facility	Job	MobileResourceSharingProcess
InstanceID	mobileResourceType (MobileResourceType)	initialNumberAvailable (int)	
Pool_LayupMoldType1	LayupMoldType1	12	

Operation_requiredMobileResourceTypes (GenericTypeTable)		
Operation_requiredRawMaterialTypes (GenericTypeTable)		
Operation_resourceTypesAssembledIntoOutput (GenericTypeTable)		
Operation_resourceTypesDisassembledFromInput (GenericTypeTable)		
Product_processPlanRouting (GenericTypeTable)		
Workstation_workstationProcessBatch (GenericTypeTable)		
Cell_ownedWorkstations_Workstation (RefTable)		
Facility_mobileResourceSharingProcess_MobileResourceSharingProcess (RefTable)		
Facility_ownedCells_Cell (RefTable)		
Facility_rawMaterialSupplyProcess_RawMaterialSupplyProcess (RefTable)		
Facility_workOrderReleaseProcess_WorkOrderReleaseProcess (RefTable)		
Job_componentJob_Job (RefTable)		
Job_componentOperation_Operation (RefTable)		
Job_successorJobs_Job (RefTable)		
(Job) InstanceID	successorJobs (Job)	
Job1	Job2	
Job2	Job3	
Job3	Job4	
Job4	Job5	
Job5	Job6	
Job6	Job7	
Job7	Job8	
Job8	Job9	
Job9	Job10	
Job10	Job11	

Question:How To Answer:Solver:Formulate and Solve

Demonstration of Efficacy

To demonstrate an improvement in the accessibility and affordability of discrete-event simulation analysis for production systems, in one hour of work, I evaluated 100 different alternatives for a production system and answered several questions about each:

- Change resource numbers
 - Change order release schedule
 - Change material resupply variability
 - Change process plan fidelity/ level of abstraction
 - Change workstation batching rules
 - Change a process plan's routing through a facility
 - Change the facility executing a process plan
 - Change other process plans executing concurrently in a facility
-
- Parametric Changes
- Structural Changes

Results: Manufacturing Demo

File Tools

System Definition: Manufacturing_v12 System Instance: Save System Instance

manufacturing

- Job
 - workOrder : EReference [0..1]
 - componentJob : EReference [0..*]
 - componentOperation : EReference [0..*]
 - successorJobs : EReference [0..*]
- Operation
 - time-mean : EAttribute [0..1]
 - time-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - processParallelCapacity : EAttribute [0..1]
 - processBatchSize : EAttribute [0..1]
 - requiredRawMaterialTypes : EAttribute [0..1]
 - requiredMobileResourceTypes : EAttribute [0..1]
 - resourceTypesAssembledIntoOutput : EAttribute [0..1]
 - resourceTypesDisassembledFromInput : EAttribute [0..1]
- WorkOrderType
- WorkOrderReleaseProcess
 - workOrderType : EReference [0..1]
 - interReleaseTime-mean : EAttribute [0..1]

(Create New)

man12_OneJob_Elementary

man12_OneJob_LessFidelity

man12_OneJob_MoreFidelity

man12_OneFacilityOneProduct_Simple

man12_OneFacilityOneProduct_GenericLessFidelity

man12_OneFacilityOneProduct_GenericMoreFidelity

man12_OneFacilityOneProduct

man12_OneFacilityTwoProducts_Simple

man12_OneFacilityTwoProducts_Generic

man12_OneFacilityTwoProducts

man12_TwoFacilitiesOneProduct_Generic

Question:

How To Answer:

Solver:

Formulate and Solve

Pose A New Question Answers

Results: Manufacturing Demo

FileTools

System Definition: Manufacturing_v12System Instance: man12_OneFacilityOneProduct_GenericLessFidelitySave System Instance

manufacturing

- Job
 - workOrder : EReference [0..1]
 - componentJob : EReference [0..*]
 - componentOperation : EReference [0..*]
 - successorJobs : EReference [0..*]
- Operation
 - time-mean : EAttribute [0..1]
 - time-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - processParallelCapacity : EAttribute [0..1]
 - processBatchSize : EAttribute [0..1]
 - requiredRawMaterialTypes : EAttribute [0..1]
 - requiredMobileResourceTypes : EAttribute [0..1]
 - resourceTypesAssembledIntoOut : EAttribute [0..1]
 - resourceTypesDisassembledFrom : EAttribute [0..1]
- WorkOrderType
 - workOrderReleaseProcess : EReference [0..1]
 - interReleaseTime-mean : EAttribute [0..1]

RawMaterialType	WorkOrderReleaseProcess	WorkOrderType	Workstation
Cell	Facility	Job	MobileResourceSharingProcess
MobileResourceType	Operation	Product	RawMaterialSupplyProcess
InstanceID	time-mean (float)	time-stdev (float)	time-units (nvarchar(255)) processBatchSize (int)
Job1	1	0.1	minutes 1
Job2	1	0.1	minutes 1
Job3	22	0.1	minutes 1
Job4	4	0.1	minutes 5
Job5	1	0.1	minutes 1
Job6	2	0.1	minutes 1
Job7	2	0.1	minutes 1
Job8	2	0.1	minutes 1
Job9	1	0.1	minutes 1
Job10	1	0.1	minutes 1
Job11	1	0.1	minutes 1

Question:How To Answer:Solver:Formulate and Solve

Pose A New QuestionAnswers

Results: Manufacturing Demo

FileTools

System Definition: Manufacturing_v12

System Instance: man12_OneFacilityOneProduct_GenericMoreFidelity

Save System Instance

manufacturing

- Job
 - workOrder : EReference [0..1]
 - componentJob : EReference [0..*]
 - componentOperation : EReference [0..*]
 - successorJobs : EReference [0..*]
- Operation
 - time-mean : EAttribute [0..1]
 - time-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - processParallelCapacity : EAttribute [0..1]
 - processBatchSize : EAttribute [0..1]
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 - requiredMobileResourceTypes : EAttribute [0..1]
 - resourceTypesAssembledIntoOut : EAttribute [0..1]
 - resourceTypesDisassembledFrom : EAttribute [0..1]
- WorkOrderType
 - workOrderReleaseProcess : EReference [0..1]
 - interReleaseTime-mean : EAttribute [0..1]

RawMaterialType	WorkOrderReleaseProcess	WorkOrderType	Workstation
Cell	Facility	Job	MobileResourceSharingProcess
MobileResourceType	Operation	Product	RawMaterialSupplyProcess
InstanceID	time-mean (float)	time-stdev (float)	time-units (nvarchar(255)) processBatchSize
Op1	1	0.01	minutes 1
Op2	1	0.01	minutes 1
Op3	1	0.01	minutes 1
Op4	1	0.01	minutes 1
Op5	1	0.01	minutes 1
Op6	1	0.01	minutes 1
Op7	1	0.01	minutes 1
Op8	1	0.01	minutes 1
Op9	1	0.01	minutes 1
Op10	1	0.01	minutes 1
Op11	1	0.01	minutes 1
Op12	1	0.01	minutes 1
Op13	1	0.01	minutes 1
Op14	1	0.01	minutes 1
Op15	1	0.01	minutes 1
Op16	1	0.01	minutes 1
Op17	1	0.01	minutes 1
Op18	1	0.01	minutes 1
Op19	1	0.01	minutes 1
Op20	1	0.01	minutes 1
Op21	1	0.01	minutes 1
Op22	1	0.01	minutes 1
Op23	1	0.01	minutes 1
Op24	1	0.01	minutes 1

Job_componentOperation_Operation (RefTable)

(Job) InstanceID	componentOperation (Operation)
Job1	Op1
Job2	Op2
Job3	Op3
Job3	Op4
Job3	Op5
Job3	Op6
Job3	Op7
Job3	Op8
Job3	Op9
Job3	Op10
Job3	Op11
Job3	Op12
Job3	Op13

Question:

How To Answer:

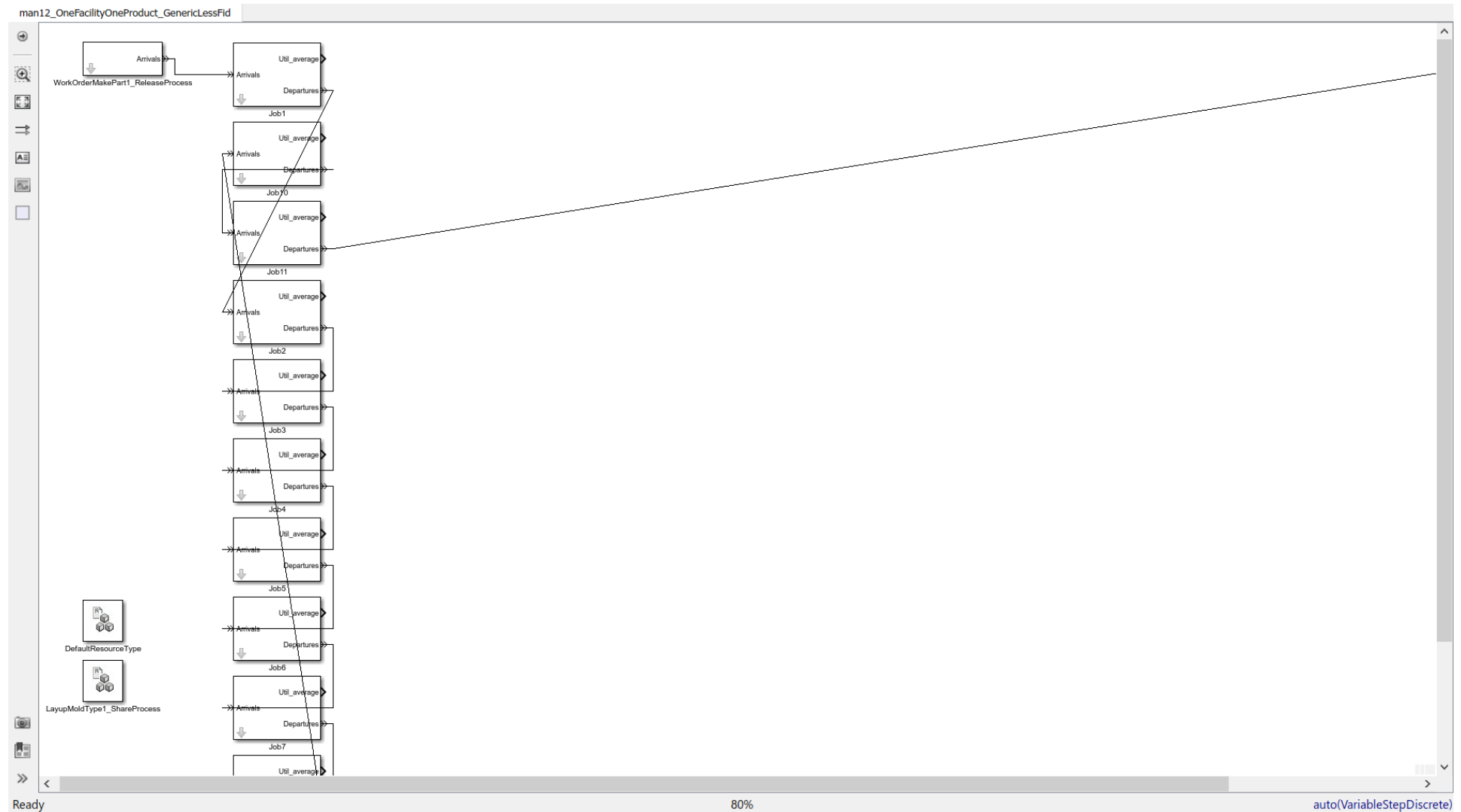
Solver:

Formulate and Solve

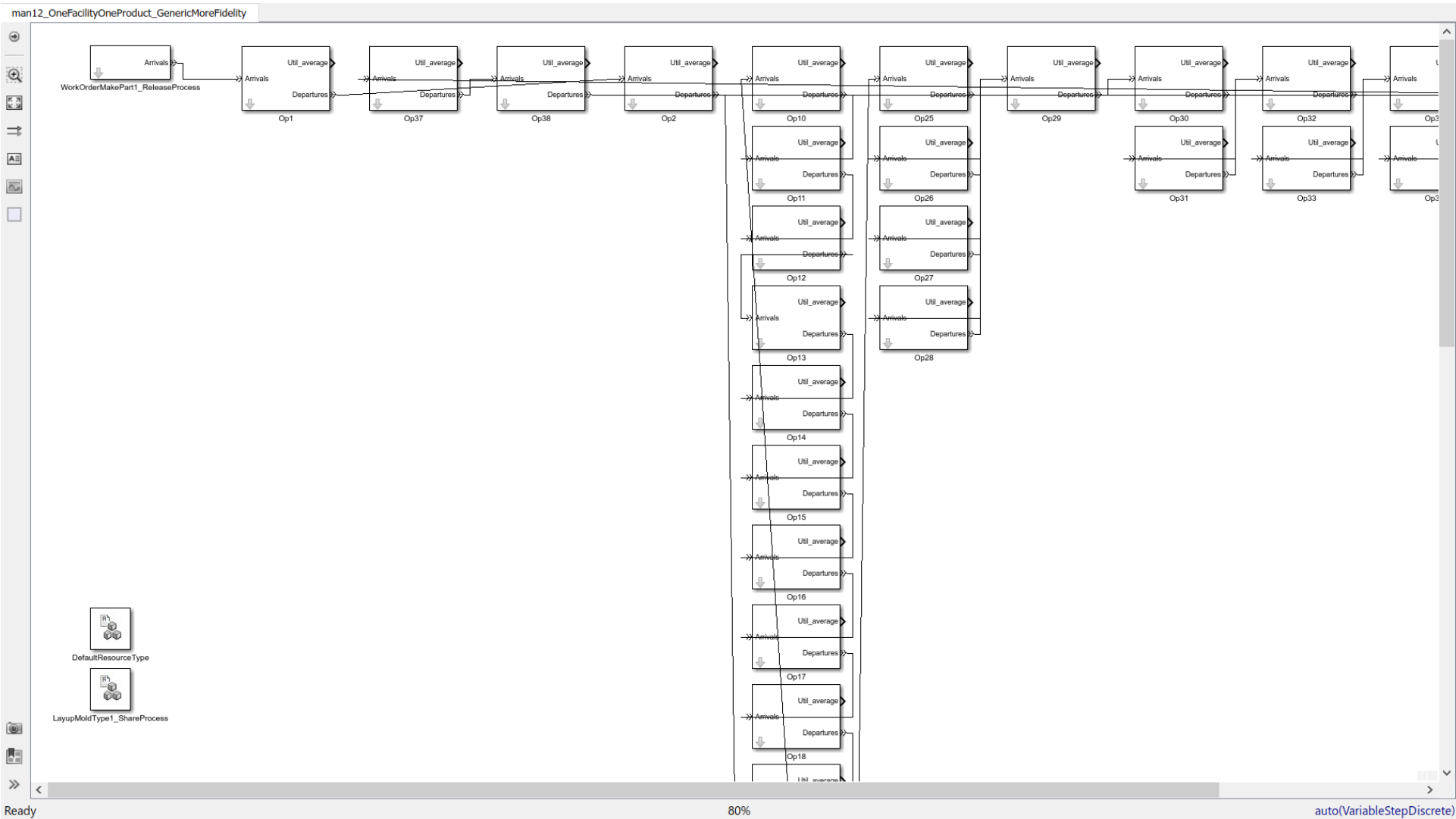
Pose A New Question

Answers

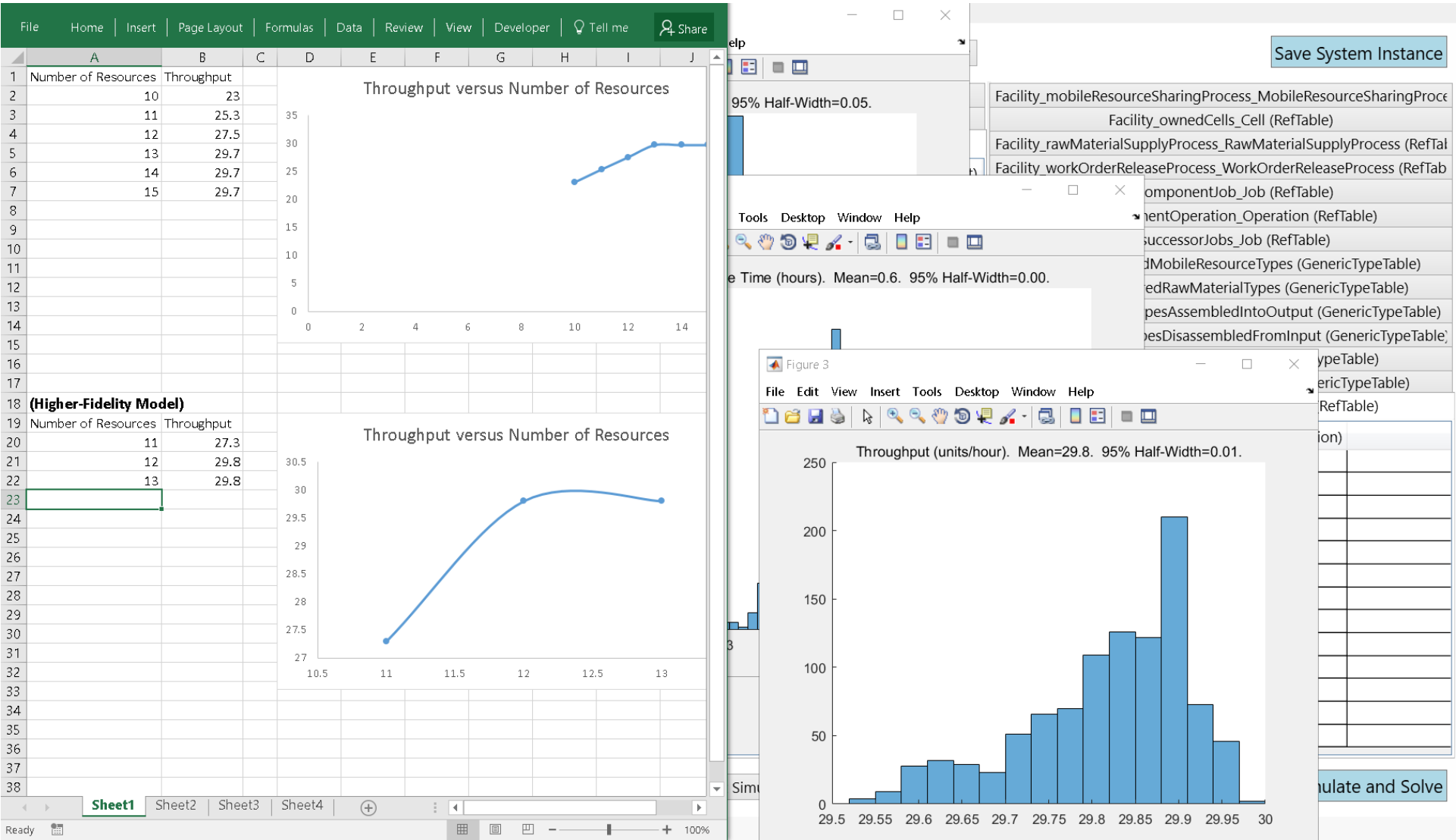
Results: Manufacturing Demo



Results: Manufacturing Demo



Results: Manufacturing Demo



Results: Air Cargo Sort Hub Demo

File Tools

System Definition:

Manufacturing_v12

AirportEnvironment_v4

ValueStreamMapping

System Instance:

Save System Instance

Question:

How To Answer:

Solver:

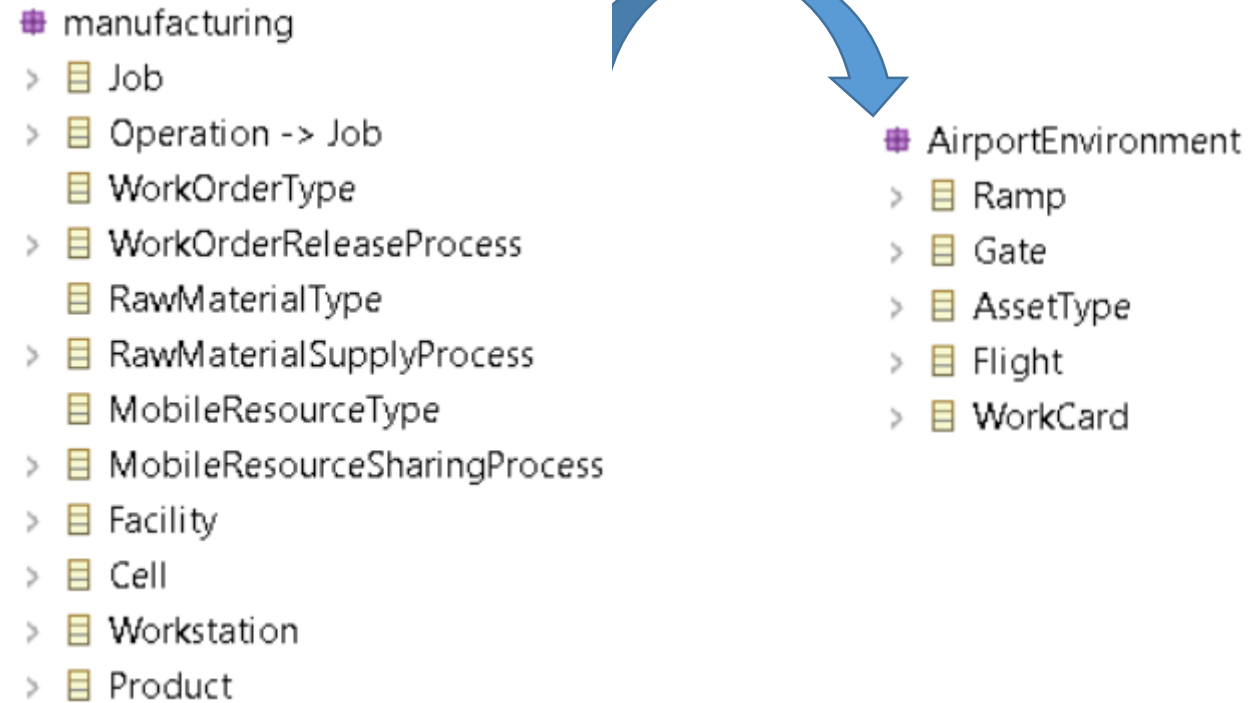
Formulate and Solve

Pose A New QuestionAnswers

Results: Air Cargo Sort Hub Demo

- ✦ AirportEnvironment
 - > 📄 Ramp
 - > 📄 Gate
 - > 📄 AssetType
 - > 📄 Flight
 - > 📄 WorkCard

Complete Domain Switch, Same Analysis Generators



Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4

System Instance:

(Create New)
airport4_IND
airport4_MEM

Save System Instance

AirportEnvironment

- Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- AssetType
 - numberAvailable : EAttribute [0..1]
- Flight
 - scheduledArrivalTime-mean : EAttril
 - scheduledArrivalTime-stdev : EAttrik
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribu
 - requiredRefuelTime-stdev : EAttribu
 - requiredRefuelAssets : EAttribute [0
 - containerUnloadTime-mean : EAttril

Question:

How To Answer:

Solver:

Formulate and Solve

Pose A New Question

Answers

Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_IND

Save System Instance

AirportEnvironment

- Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- AssetType
 - numberAvailable : EAttribute [0..1]
- Flight
 - scheduledArrivalTime-mean : EAttril
 - scheduledArrivalTime-stdev : EAttrik
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribu
 - requiredRefuelTime-stdev : EAttribu
 - requiredRefuelAssets : EAttribute [0
 - containerUnloadTime-mean : EAttril

AssetTypeFlightGateRampWorkCard

InstanceID	
IND	

Question:

How To Answer:

Solver:

Formulate and Solve

Pose A New Question

Answers

Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_INDSave System Instance

AirportEnvironment

Ramp

gate : EReference [0..*]

flight : EReference [0..*]

asset : EReference [0..*]

Gate

locX : EAttribute [0..1]

locY : EAttribute [0..1]

AssetType

numberAvailable : EAttribute [0..1]

Flight

scheduledArrivalTime-mean : EAttril

scheduledArrivalTime-stdev : EAttrik

time-units : EAttribute [0..1]

scheduledDepartTime : EAttribute [0..1]

gateAssignment : EReference [0..1]

requiredRefuelTime-mean : EAttribu

requiredRefuelTime-stdev : EAttribu

requiredRefuelAssets : EAttribute [0..1]

containerUnloadTime-mean : EAttril

AssetTypeFlightGateRampWorkCard

InstanceID	locX (float)	locY (float)
Gate1	0	0
Gate2	10	0
Gate3	20	0
Gate4	30	0
Gate5	40	0
Gate6	60	0
Gate7	70	0
Gate8	80	0
Gate9	90	0
Gate10	100	0
Gate11	110	0
Gate12	130	0
Gate13	140	0
Gate14	150	0
Gate15	160	0
Gate16	170	0
Gate17	190	0
Gate18	200	0
Gate19	210	0
Gate20	0	20
Gate21	9	20
Gate22	18	20
Gate23	27	20
Gate24	36	20
Gate25	45	20
Gate26	54	20
Gate27	66	20

Question: How To Answer: Solver: Formulate and Solve

Pose A New QuestionAnswers

Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_IND

Save System Instance

AirportEnvironment

- Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- AssetType
 - numberAvailable : EAttribute [0..1]
- Flight
 - scheduledArrivalTime-mean : EAttribute [0..1]
 - scheduledArrivalTime-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0..1]
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribute [0..1]
 - requiredRefuelTime-stdev : EAttribute [0..1]
 - requiredRefuelAssets : EAttribute [0..1]
 - containerUnloadTime-mean : EAttribute [0..1]

AssetTypeFlightGateRampWorkCard

InstanceID	scheduledArrivalTime-mean (float)	scheduledArrivalTime-stdev (float)
Flight1	60	15
Flight2	70	15
Flight3	80	15
Flight4	90	15
Flight5	100	15
Flight6	110	15
Flight7	120	15
Flight8	130	15
Flight9	140	15
Flight10	150	15
Flight11	60	30
Flight12	70	30
Flight13	80	30
Flight14	90	30
Flight15	100	30
Flight16	110	30
Flight17	120	30
Flight18	130	30
Flight19	140	30
Flight20	150	30

Question:

How To Answer:

Solver:

Formulate and Solve

Pose A New Question

Answers

Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_IND

Save System Instance

AirportEnvironment

- Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- AssetType
 - numberAvailable : EAttribute [0..1]
- Flight
 - scheduledArrivalTime-mean : EAttril
 - scheduledArrivalTime-stdev : EAttrik
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0..1]
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribu
 - requiredRefuelTime-stdev : EAttribu
 - requiredRefuelAssets : EAttribute [0..1]
 - containerUnloadTime-mean : EAttril

AssetTypeFlightGateRampWorkCard

InstanceID	timeRequired-mean (float)	timeRequired-stdev (float)	tin
PlannedWorkItem1	10	1	mi
PlannedWorkItem2	20	2	mi
PlannedWorkItem3	30	3	mi
UnplannedWorkItem1	40	4	mi
UnplannedWorkItem2	80	8	mi

Question:

How To Answer:

Solver:

Formulate and Solve

Pose A New Question

Answers

Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_IND

Save System Instance

AirportEnvironment

- Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- AssetType
 - numberAvailable : EAttribute [0..1]
- Flight
 - scheduledArrivalTime-mean : EAttril
 - scheduledArrivalTime-stdev : EAttrik
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribu
 - requiredRefuelTime-stdev : EAttribu
 - requiredRefuelAssets : EAttribute [0
 - containerUnloadTime-mean : EAttril

AssetTypeFlightGateRampWorkCard

InstanceID	numberAvailable (int)
FuelTransferVehicle	50
HighLoader	80
MechanicLevel10	15
MechanicLevel11	10
MechanicLevel12	6

Question:

How To Answer:

Solver:

Formulate and Solve

Pose A New QuestionAnswers

Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_IND

Save System Instance

AirportEnvironment

- Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- AssetType
 - numberAvailable : EAttribute [0..1]
- Flight
 - scheduledArrivalTime-mean : EAttril
 - scheduledArrivalTime-stdev : EAttrik
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0..1]
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribu
 - requiredRefuelTime-stdev : EAttribu
 - requiredRefuelAssets : EAttribute [0..1]
 - containerUnloadTime-mean : EAttril

AssetTypeFlightGateRampWorkCard

InstanceID	numberAvailable (int)	
FuelTransferVehicle	50	
HighLoader	80	
MechanicLevel10	15	
MechanicLevel11	10	
MechanicLevel12	2	

Question:

How To Answer:

Solver:

Formulate and Solve

PREDICT: What is the (expected) (Cycle Time Missed Deadline Fraction) for a collection of (Flight) at a certain (Ramp)?

Pose A New QuestionAnswers

Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_IND

Save System Instance

AirportEnvironment

- Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- AssetType
 - numberAvailable : EAttribute [0..1]
- Flight
 - scheduledArrivalTime-mean : EAttril
 - scheduledArrivalTime-stdev : EAttrik
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0..1]
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribu
 - requiredRefuelTime-stdev : EAttribu
 - requiredRefuelAssets : EAttribute [0..1]
 - containerUnloadTime-mean : EAttril

AssetTypeFlightGateRampWorkCard

InstanceID	numberAvailable (int)	
FuelTransferVehicle	50	
HighLoader	80	
MechanicLevel10	15	
MechanicLevel11	10	
MechanicLevel12	2	

Question: PREDICT: What is the (expected) (Cycle Time Missed Deadline) How To Answer: a certain (Ramp)? Solver:

Formulate and Solve

Pose A New QuestionAnswers

Discrete Event Simulation

Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_IND

Save System Instance

AirportEnvironment

- Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- AssetType
 - numberAvailable : EAttribute [0..1]
- Flight
 - scheduledArrivalTime-mean : EAttril
 - scheduledArrivalTime-stdev : EAttrik
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0..1]
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribu
 - requiredRefuelTime-stdev : EAttribu
 - requiredRefuelAssets : EAttribute [0..1]
 - containerUnloadTime-mean : EAttril

AssetTypeFlightGateRampWorkCard

InstanceID	
IND	

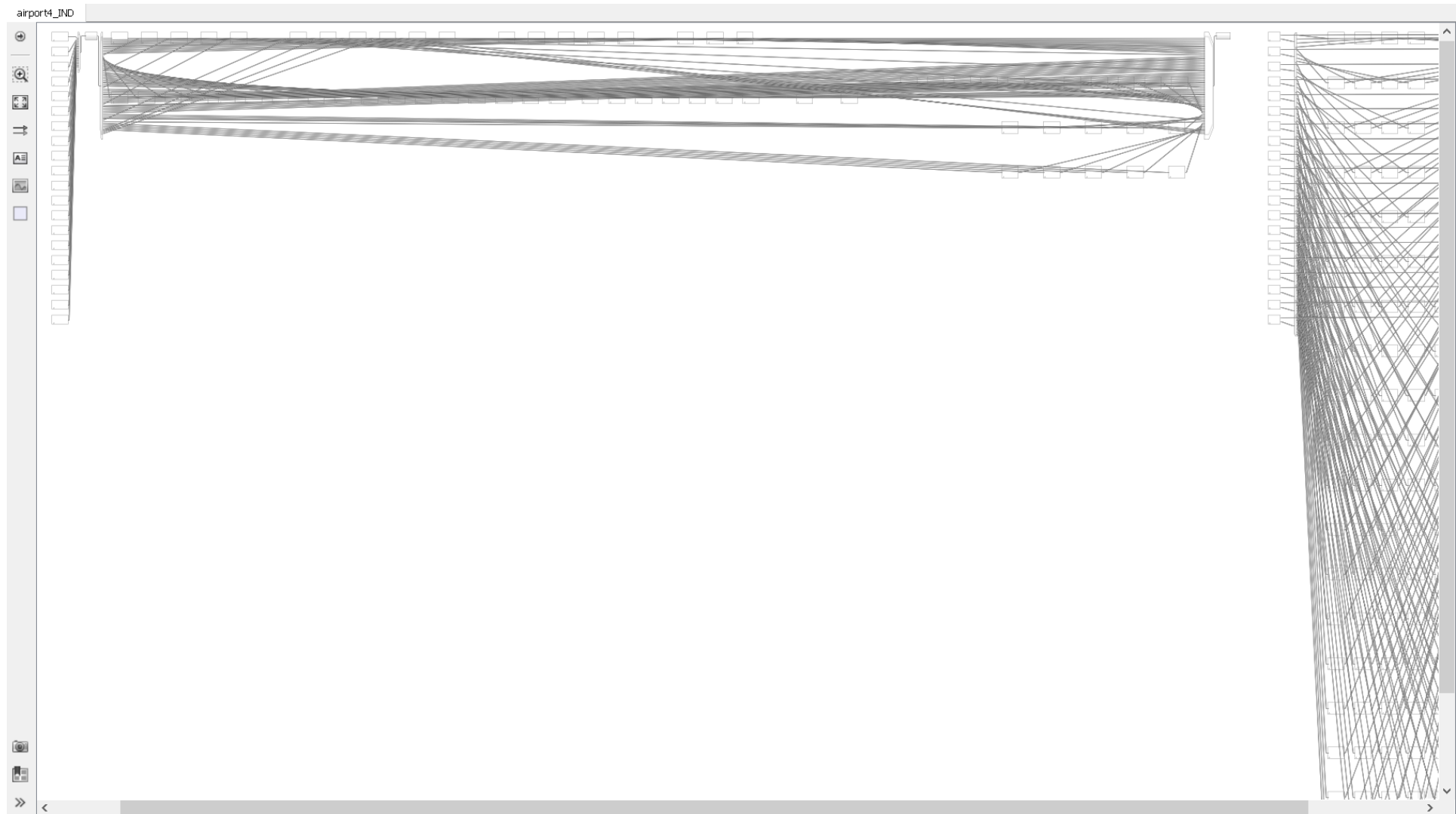
Question: PREDICT: What is the (expected) (Cycle Time Missed Due to Fuel Shortage) for Discrete Event Simulation tain (Ramp)? Solver:

MATLAB

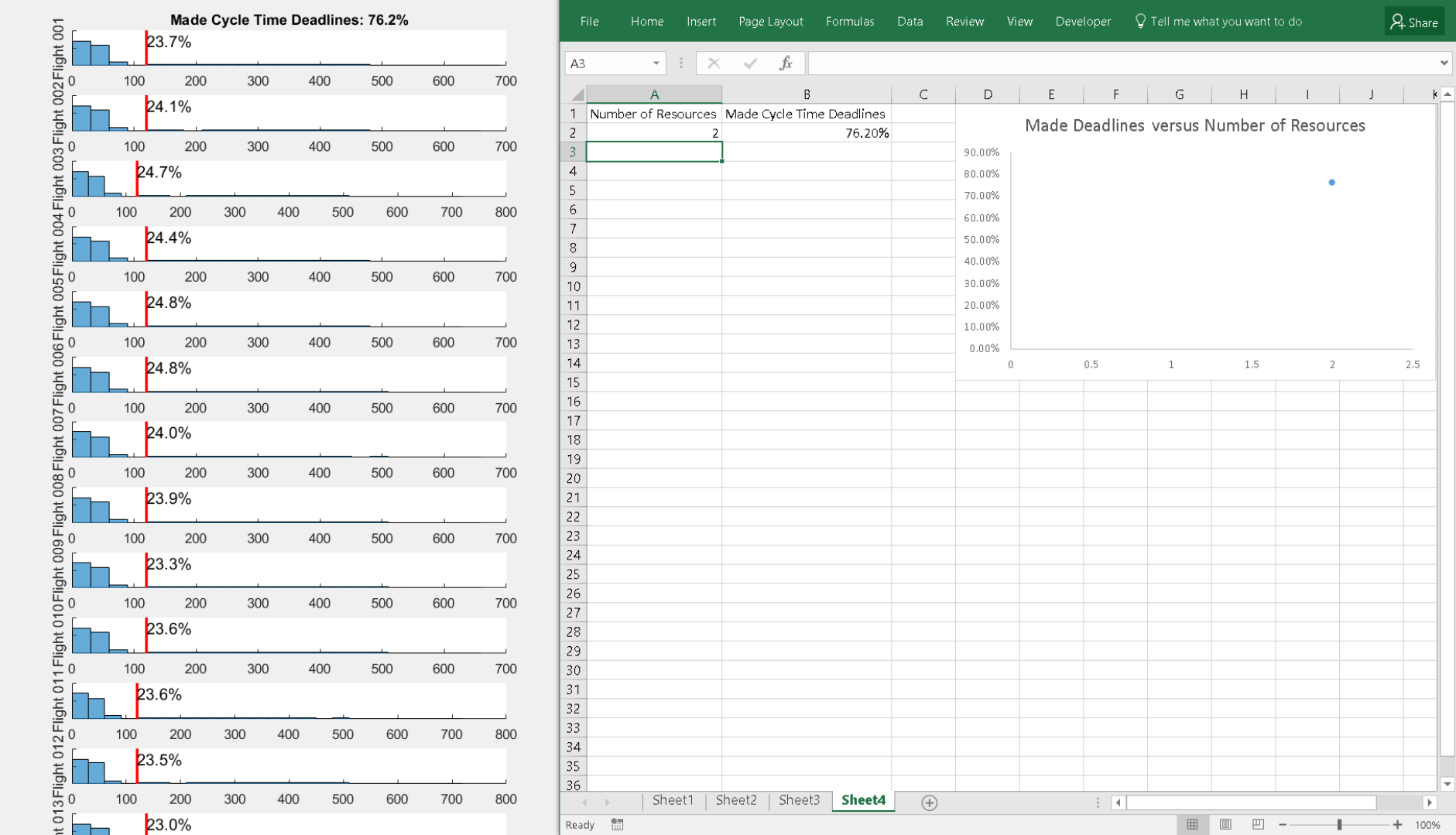
Formulate and Solve

Pose A New QuestionAnswers

Results: Air Cargo Sort Hub Demo

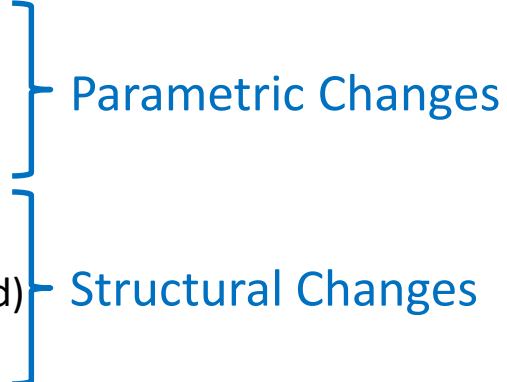


Results: Air Cargo Sort Hub Demo



Demonstration of Efficacy

To demonstrate that the methodology is *more general than just the manufacturing domain* and also *more general than any particular analysis solver*, use the same tool to quickly evaluate 50 different alternatives for an air cargo sort hub, and answer several questions about each:

- Change resource numbers
 - Change flight schedule
 - Change parking plan
 - Change airport
 - Change maintenance profile (more preventative = less unplanned)
 - Change maintenance rules
- 
- The diagram uses blue curly braces to group the list items. The first three items (Change resource numbers, Change flight schedule, and Change parking plan) are grouped under the label 'Parametric Changes'. The last three items (Change airport, Change maintenance profile (more preventative = less unplanned), and Change maintenance rules) are grouped under the label 'Structural Changes'.
- Parametric Changes
- Structural Changes

Results: Air Cargo Sort Hub Demo

FileTools

System Definition:

AirportEnvironment_v4

System Instance:

airport4_IND

Save System Instance

✚ AirportEnvironment

✚ Ramp

- gate : EReference [0..*]
- flight : EReference [0..*]
- asset : EReference [0..*]

✚ Gate

- locX : EAttribute [0..1]
- locY : EAttribute [0..1]

✚ AssetType

- numberAvailable : EAttribute [0..1]

✚ Flight

- scheduledArrivalTime-mean : EAttril
- scheduledArrivalTime-stdev : EAttrik
- time-units : EAttribute [0..1]
- scheduledDepartTime : EAttribute [0
- gateAssignment : EReference [0..1]
- requiredRefuelTime-mean : EAttribu
- requiredRefuelTime-stdev : EAttribu
- requiredRefuelAssets : EAttribute [0
- containerUnloadTime-mean : EAttril

AssetTypeFlightGateRampWorkCard

InstanceID	numberAvailable (int)
FuelTransferVehicle	50
HighLoader	80
MechanicLevel10	15
MechanicLevel11	10
MechanicLevel12	4

Question:

PREDICT: What is the (expected) (Cycle Time Missed Due to Fuel Assets for Discrete Event Simulation

How To Answer:

tain (Ramp)?

 Solver:

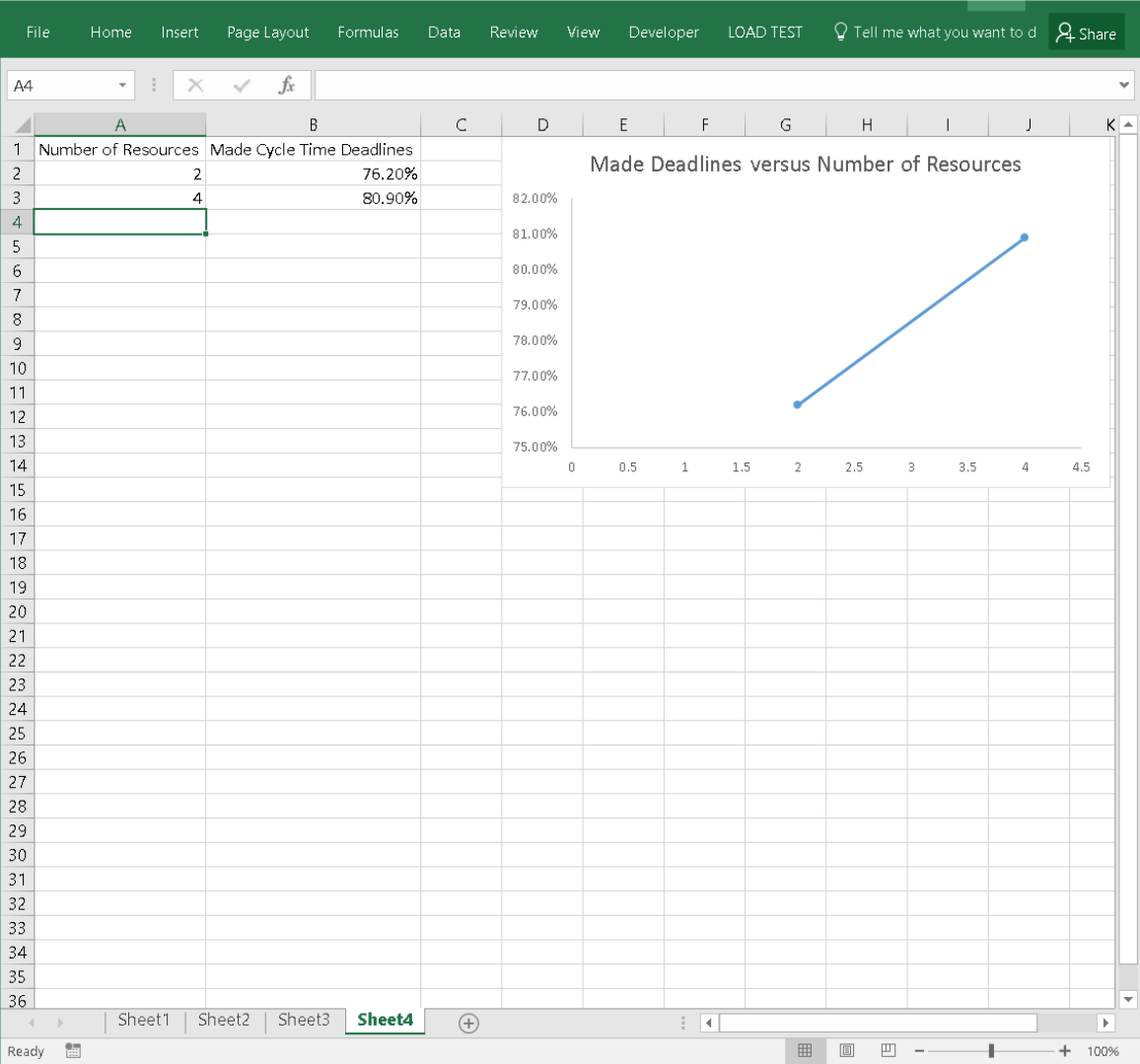
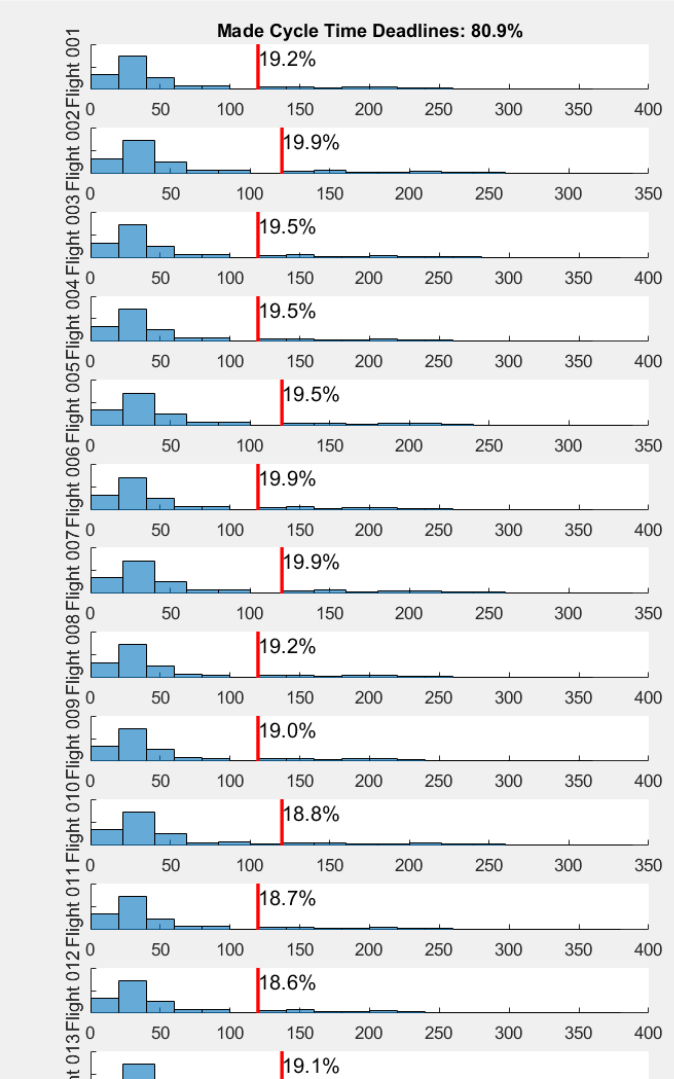
MATLAB

Formulate and Solve

Pose A New Question

Answers

Results: Air Cargo Sort Hub Demo



Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_IND

Save System Instance

✚ AirportEnvironment

✚ Ramp

- gate : EReference [0..*]
- flight : EReference [0..*]
- asset : EReference [0..*]

✚ Gate

- locX : EAttribute [0..1]
- locY : EAttribute [0..1]

✚ AssetType

- numberAvailable : EAttribute [0..1]

✚ Flight

- scheduledArrivalTime-mean : EAttril
- scheduledArrivalTime-stdev : EAttrik
- time-units : EAttribute [0..1]
- scheduledDepartTime : EAttribute [0
- gateAssignment : EReference [0..1]
- requiredRefuelTime-mean : EAttribu
- requiredRefuelTime-stdev : EAttribu
- requiredRefuelAssets : EAttribute [0
- containerUnloadTime-mean : EAttril

AssetTypeFlightGateRampWorkCard

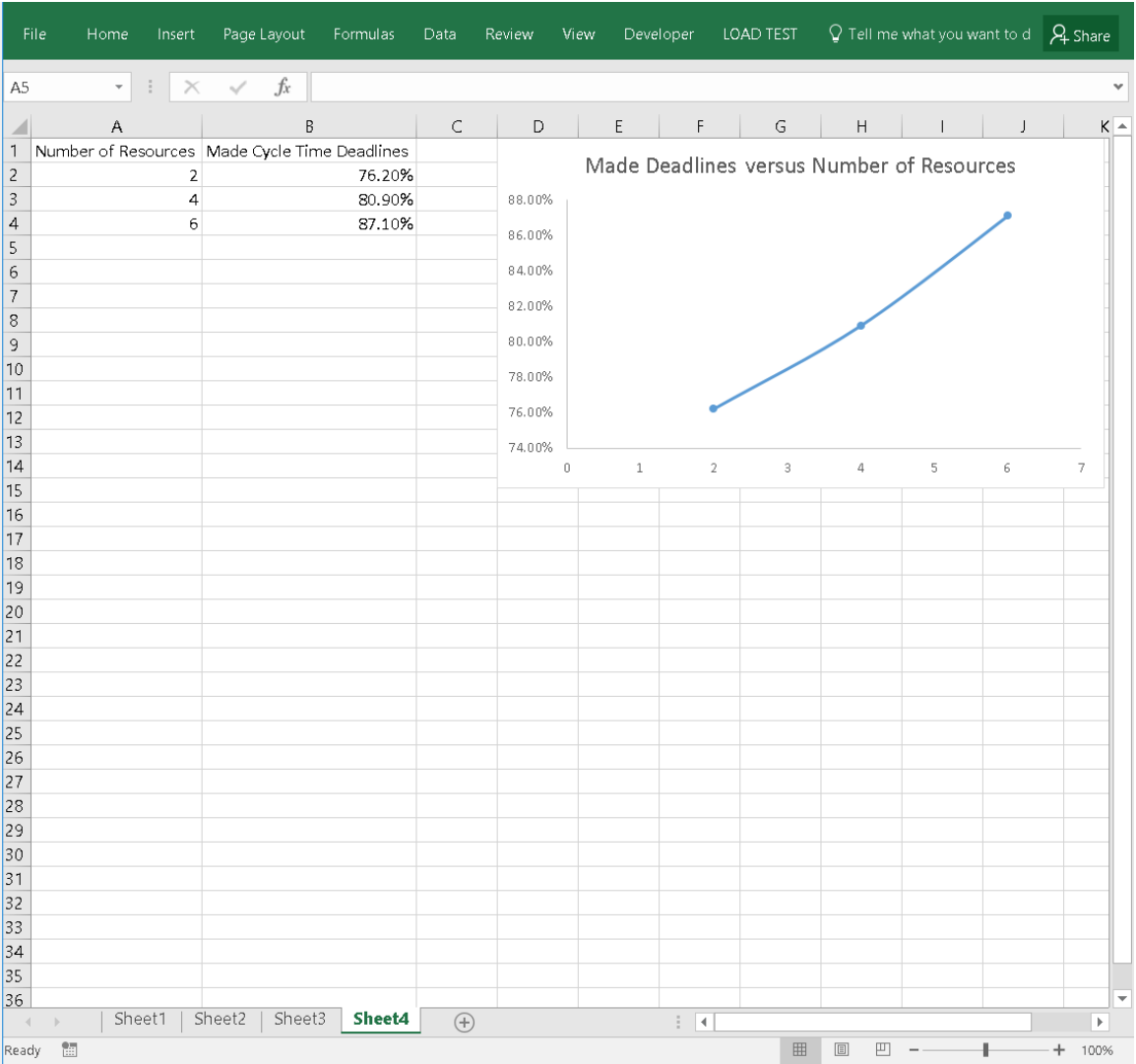
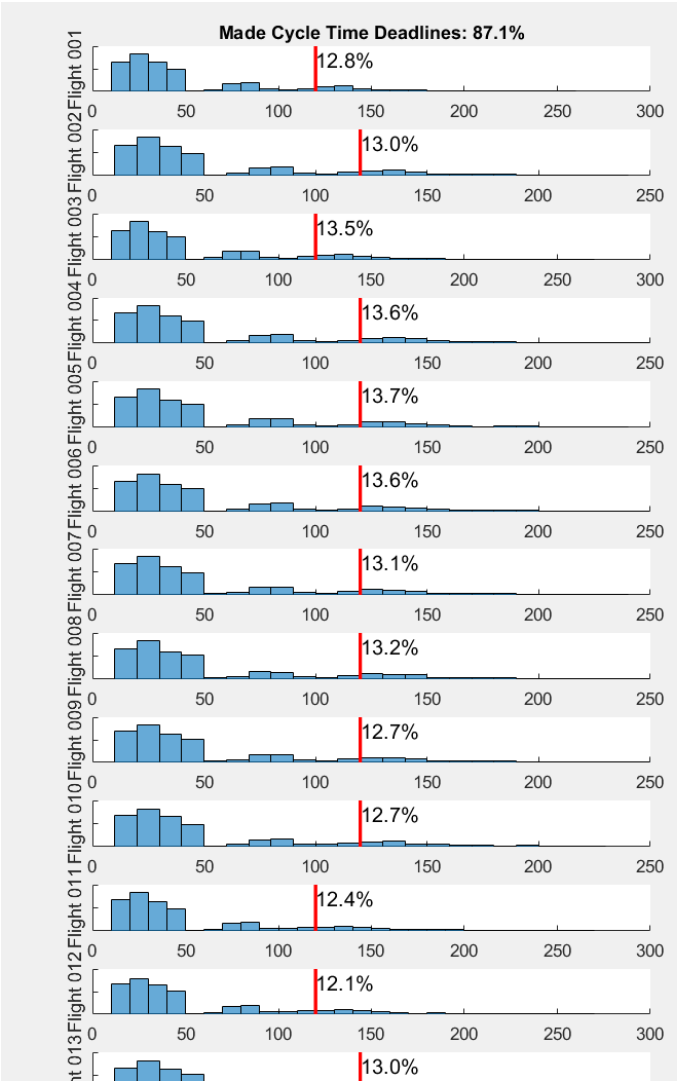
InstanceID	numberAvailable (int)
FuelTransferVehicle	50
HighLoader	80
MechanicLevel10	15
MechanicLevel11	10
MechanicLevel12	6

Question: PREDICT: What is the (expected) (Cycle Time Missed Due to Fuel Assets for Discrete Event Simulation ? tain (Ramp)? Solver: MATLAB

Formulate and Solve

Pose A New QuestionAnswers

Results: Air Cargo Sort Hub Demo



Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_IND

Save System Instance

AirportEnvironment

- Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- AssetType
 - numberAvailable : EAttribute [0..1]
- Flight
 - scheduledArrivalTime-mean : EAttribute [0..1]
 - scheduledArrivalTime-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0..1]
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribute [0..1]
 - requiredRefuelTime-stdev : EAttribute [0..1]
 - requiredRefuelAssets : EAttribute [0..1]
 - containerUnloadTime-mean : EAttribute [0..1]

AssetTypeFlightGateRampWorkCard

InstanceID	scheduledArrivalTime-mean (float)	scheduledArrivalTime-stdev (float)
Flight1	60	15
Flight2	70	15
Flight3	80	15
Flight4	90	15
Flight5	100	15
Flight6	110	15
Flight7	120	15
Flight8	130	15
Flight9	140	15
Flight10	150	15
Flight11	60	30
Flight12	70	30
Flight13	80	30
Flight14	90	30
Flight15	100	30
Flight16	110	30
Flight17	120	30
Flight18	130	30
Flight19	140	30
Flight20	150	30

Question: PREDICT: What is the (expected) (Cycle Time Missed Due to Fuel Shortage) for Discrete Event Simulation? (Ramp)?

Solver: MATLAB

Formulate and Solve

Pose A New Question

Answers

Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4

System Instance: airport4_IND

Save System Instance

AirportEnvironment

- Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- AssetType
 - numberAvailable : EAttribute [0..1]
- Flight
 - scheduledArrivalTime-mean : EAttribute [0..1]
 - scheduledArrivalTime-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0..1]
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribute [0..1]
 - requiredRefuelTime-stdev : EAttribute [0..1]
 - requiredRefuelAssets : EAttribute [0..1]
 - containerUnloadTime-mean : EAttribute [0..1]

AssetTypeFlightGateRampWorkCard

InstanceID	scheduledArrivalTime-mean (float)	scheduledArrivalTime-stdev (float)
Flight1	100	15
Flight2	100	15
Flight3	100	15
Flight4	100	15
Flight5	100	15
Flight6	110	15
Flight7	120	15
Flight8	130	15
Flight9	140	15
Flight10	150	15
Flight11	60	30
Flight12	70	30
Flight13	80	30
Flight14	90	30
Flight15	100	30
Flight16	110	30
Flight17	120	30
Flight18	130	30
Flight19	140	30
Flight20	150	30

Question: PREDICT: What is the (expected) (Cycle Time Missed Due to Fuel Shortage) for Discrete Event Simulation ? tain (Ramp)?

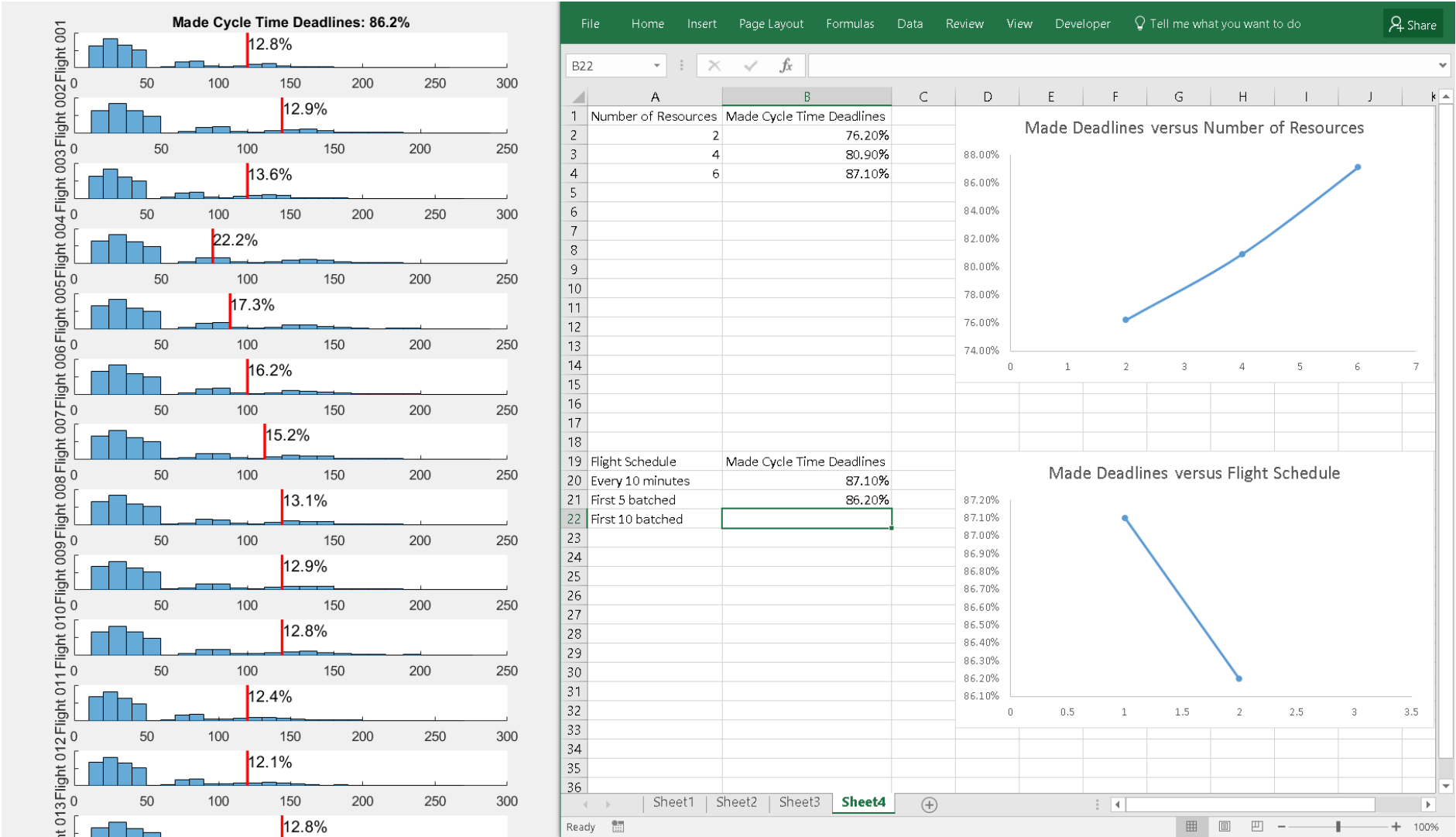
Solver: MATLAB

Formulate and Solve

Pose A New Question

Answers

Results: Air Cargo Sort Hub Demo



Results: Air Cargo Sort Hub Demo

FileTools

System Definition: AirportEnvironment_v4System Instance: airport4_IND

Save System Instance

AirportEnvironment

Ramp

- gate : EReference [0..*]
- flight : EReference [0..*]
- asset : EReference [0..*]

Gate

- locX : EAttribute [0..1]
- locY : EAttribute [0..1]

AssetType

- numberAvailable : EAttribute [0..1]

Flight

- scheduledArrivalTime-mean : EAttribute [0..1]
- scheduledArrivalTime-stdev : EAttribute [0..1]
- time-units : EAttribute [0..1]
- scheduledDepartTime : EAttribute [0..1]
- gateAssignment : EReference [0..1]
- requiredRefuelTime-mean : EAttribute [0..1]
- requiredRefuelTime-stdev : EAttribute [0..1]
- requiredRefuelAssets : EAttribute [0..1]
- containerUnloadTime-mean : EAttribute [0..1]

AssetTypeFlightGateRampWorkCard

InstanceID	scheduledArrivalTime-mean (float)	scheduledArrivalTime-stdev (float)
Flight1	150	15
Flight2	150	15
Flight3	150	15
Flight4	150	15
Flight5	150	15
Flight6	150	15
Flight7	150	15
Flight8	150	15
Flight9	150	15
Flight10	150	15
Flight11	60	30
Flight12	70	30
Flight13	80	30
Flight14	90	30
Flight15	100	30
Flight16	110	30
Flight17	120	30
Flight18	130	30
Flight19	140	30
Flight20	150	30

Question: PREDICT: What is the (expected) (Cycle Time Missed Due to Fuel Constraints) (Ramp)?

How To Answer for Discrete Event Simulation

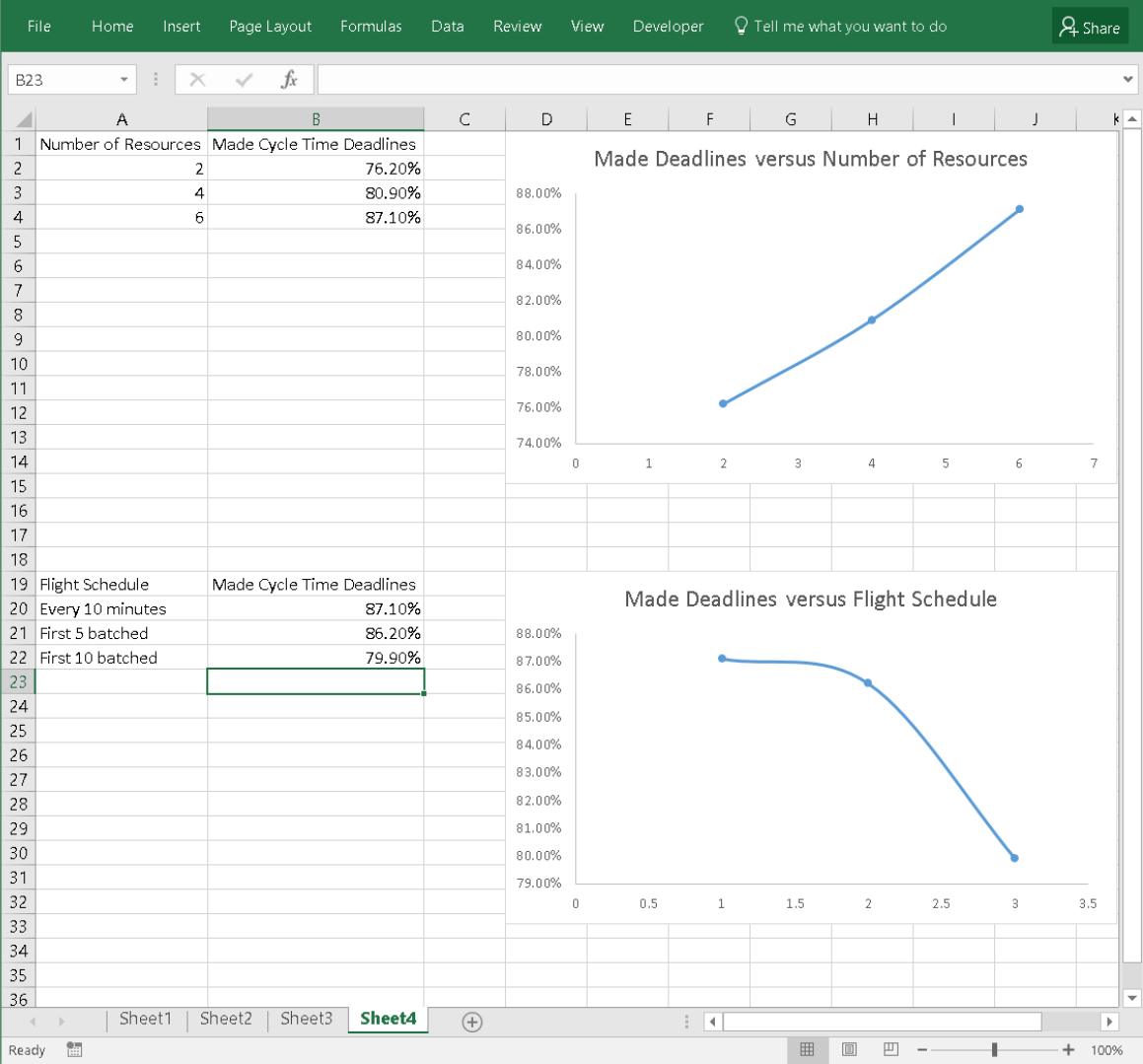
Solver: MATLAB

Formulate and Solve

Pose A New Question

Answers

Results: Air Cargo Sort Hub Demo



Results: Air Cargo Sort Hub Demo

FileTools

System Definition:

AirportEnvironment_v4

System Instance:

airport4_IND

Save System Instance

✚ AirportEnvironment

- ✚ Ramp
 - gate : EReference [0..*]
 - flight : EReference [0..*]
 - asset : EReference [0..*]
- ✚ Gate
 - locX : EAttribute [0..1]
 - locY : EAttribute [0..1]
- ✚ AssetType
 - numberAvailable : EAttribute [0..1]
- ✚ Flight
 - scheduledArrivalTime-mean : EAttribute [0..1]
 - scheduledArrivalTime-stdev : EAttribute [0..1]
 - time-units : EAttribute [0..1]
 - scheduledDepartTime : EAttribute [0..1]
 - gateAssignment : EReference [0..1]
 - requiredRefuelTime-mean : EAttribute [0..1]
 - requiredRefuelTime-stdev : EAttribute [0..1]
 - requiredRefuelAssets : EAttribute [0..1]
 - containerUnloadTime-mean : EAttribute [0..1]

AssetTypeFlightGateRampWorkCard

InstanceID	numberAvailable (int)
FuelTransferVehicle	50
HighLoader	80
MechanicLevel10	15
MechanicLevel11	10
MechanicLevel12	6

Flight_plannedWorkItem_WorkCard (RefTable)		
Flight_requiredLoadAssets (GenericTypeTable)		
Flight_requiredRefuelAssets (GenericTypeTable)		
Flight_requiredUnloadAssets (GenericTypeTable)		
Flight_unplannedInboundWriteup_WorkCard (RefTable)		
Ramp_asset_AssetType (RefTable)	Ramp_flight_Flight (RefTable)	
Ramp_gate_Gate (RefTable)	WorkCard_requiredAssets (GenericTypeTable)	
(WorkCard) InstanceID	requiredAssets (int)	requiredAssets (AssetType)
PlannedWorkItem1	1	MechanicLevel10
PlannedWorkItem2	1	MechanicLevel10
PlannedWorkItem3	1	MechanicLevel12
UnplannedWorkItem1	1	MechanicLevel11
UnplannedWorkItem2	1	MechanicLevel12

Question:

PREDICT: What is the (expected) (Cycle Time Missed) (How Late For Arrival) (Discrete Event Simulation) (Main (Ramp))?

Solver:

MATLAB

Formulate and Solve

Results: Value Stream Mapping Demo

File Tools

System Definition:

System Instance:

Save System Instance

Manufacturing_v12

AirportEnvironment_v4

ValueStreamMapping

Question:

How To Answer:

Solver:

Formulate and Solve

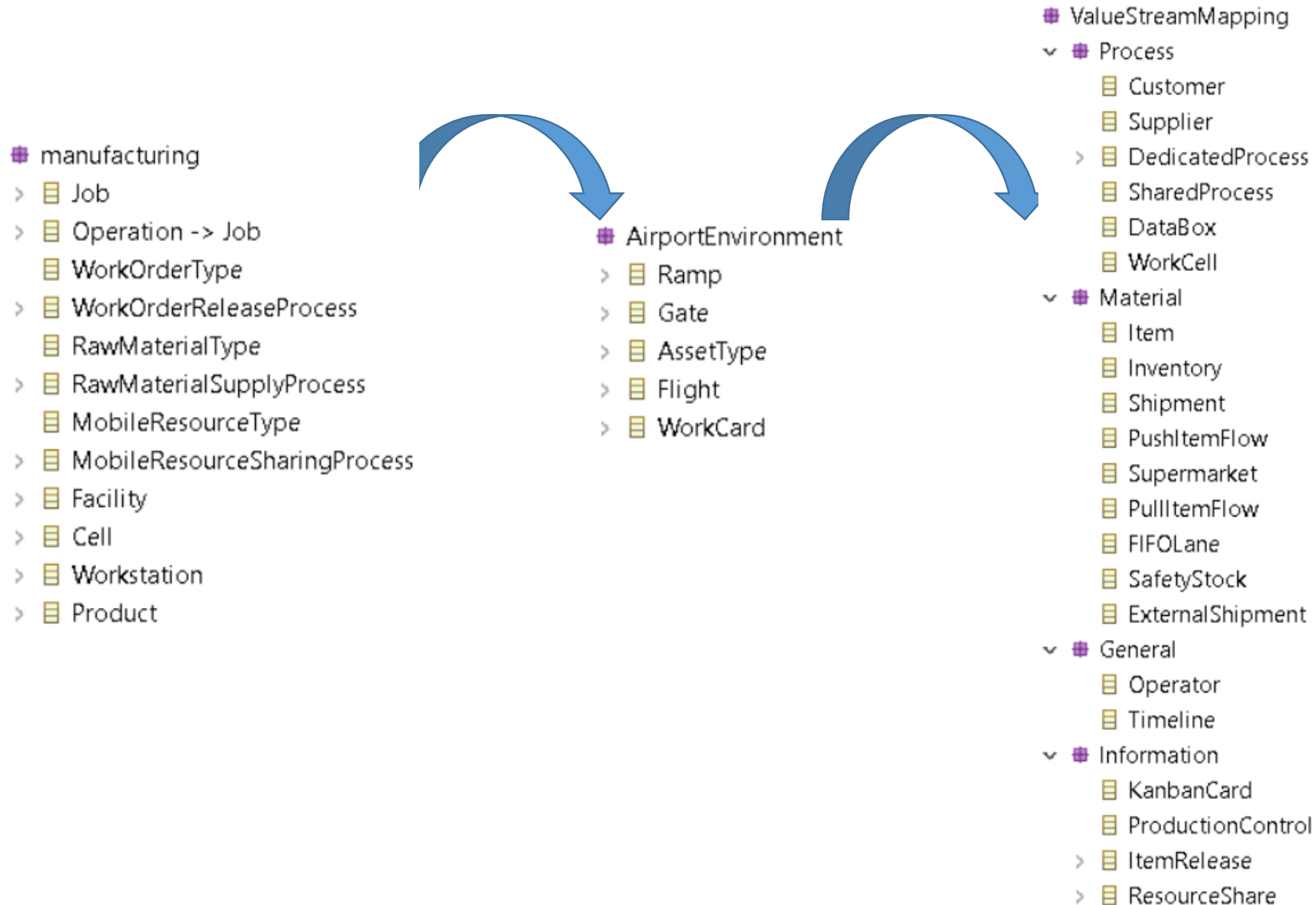
Pose A New Question

Answers

Results: Value Stream Mapping Demo

- ValueStreamMapping
 - Process
 - Customer
 - Supplier
 - > DedicatedProcess
 - SharedProcess
 - DataBox
 - WorkCell
 - Material
 - Item
 - Inventory
 - Shipment
 - PushItemFlow
 - Supermarket
 - PullItemFlow
 - FIFOLane
 - SafetyStock
 - ExternalShipment
 - General
 - Operator
 - Timeline
 - Information
 - KanbanCard
 - ProductionControl
 - > ItemRelease
 - > ResourceShare

Complete Domain Switch, Same Analysis Generators



Results: Value Stream Mapping Demo

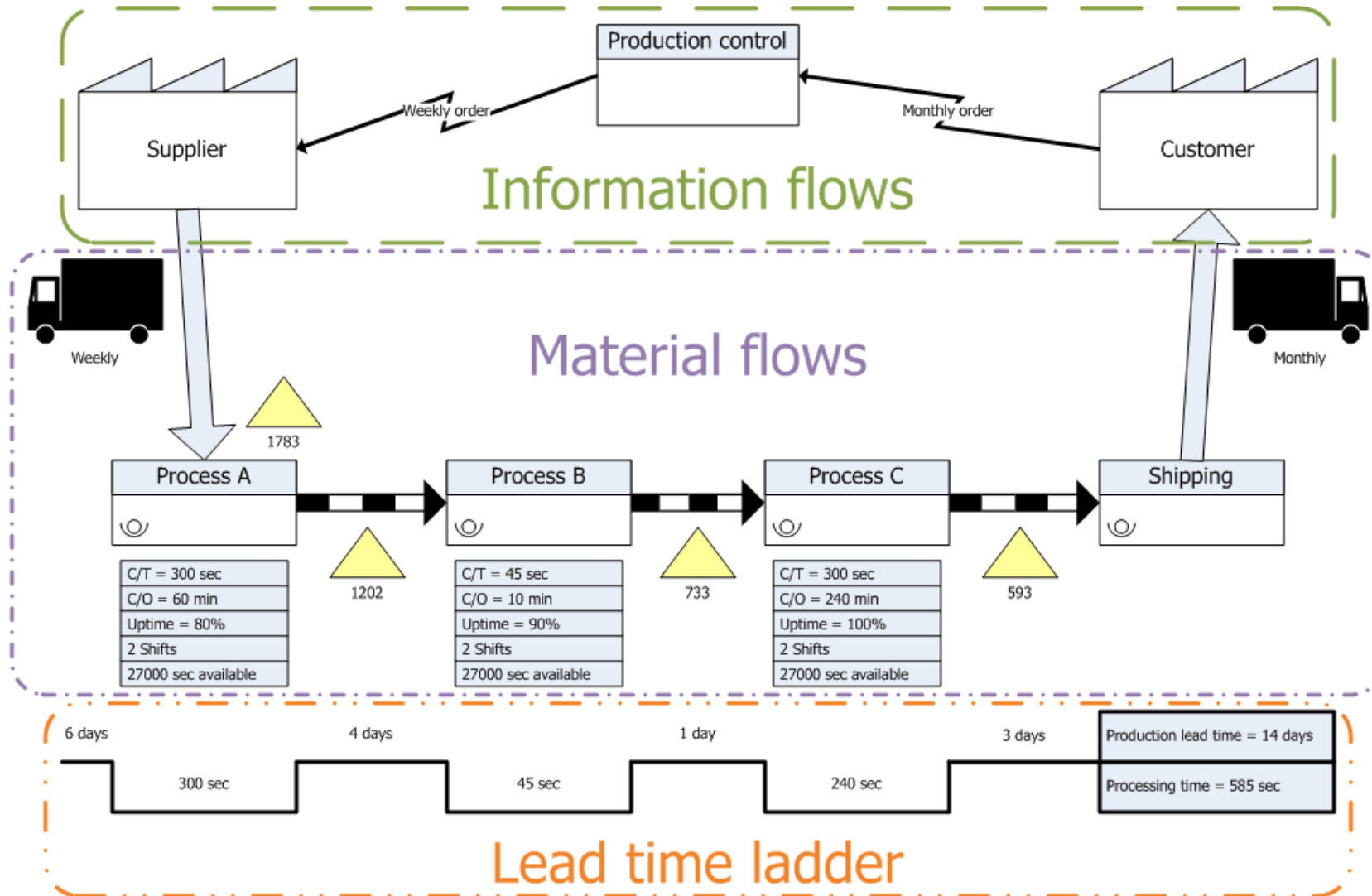
The screenshot displays the Value Stream Mapping (VSM) software interface. The window has a title bar with standard minimize, maximize, and close buttons. Below the title bar is a menu bar with 'File' and 'Tools' options.

The main interface is divided into several sections:

- System Definition:** A dropdown menu currently set to 'ValueStreamMapping'.
- System Instance:** A dropdown menu with '(Create New)' and 'VSM_Example1' (which is highlighted).
- Save System Instance:** A button located to the right of the System Instance dropdown.
- Left Panel (Tree View):** A hierarchical tree structure showing the components of the VSM model. The tree is expanded to show the following categories:
 - ValueStreamMapping**
 - Process**
 - Customer
 - Supplier
 - DedicatedProcess
 - SharedProcess
 - DataBox
 - WorkCell
 - Material**
 - Item
 - Inventory
 - Shipment
 - PushItemFlow
 - Supermarket
 - PullItemFlow
 - FIFOLane
 - SafetyStock
 - ExternalShipment
 - General**
 - Operator
 - Timeline
 - Information**
 - KanbanCard
 - ProductionControl

- Right Panel:** A large, empty workspace for creating and editing the VSM map.
- Bottom Section:**
- Question:** A dropdown menu.
- How To Answer:** A dropdown menu.
- Solver:** A dropdown menu.
- Formulate and Solve:** A button.
- Footer:** Two tabs labeled 'Pose A New Question' and 'Answers'.

Results: Value Stream Mapping Demo



Results: Value Stream Mapping Demo

FileTools

System Definition: ValueStreamMappingSystem Instance: VSM_Example1Save System Instance

ValueStreamMapping

- Process
 - Customer
 - Supplier
 - DedicatedProcess
 - SharedProcess
 - DataBox
 - WorkCell
- Material
 - Item
 - Inventory
 - Shipment
 - PushItemFlow
 - Supermarket
 - PullItemFlow
 - FIFOLane
 - SafetyStock
 - ExternalShipment
- General
 - Operator
 - Timeline
- Information
 - KanbanCard
 - ProductionControl

General/OperatorGeneral/TimelineInformation/ItemReleaseInformation/KanbanCardInformation/ProductionControlInformation/ResourceShareMaterial/ExternalShipmentMaterial/InventoryMaterial/ItemMaterial/PullItemFlowMaterial/PushItemFlowMaterial/SafetyStockMaterial/ShipmentMaterial/SupermarketProcess/CustomerProcess/DedicatedProcessProcess/SharedProcessProcess/SupplierProcess/Supplier

InstanceID	producesItem (Item)	cycleTime (float)	cycleTimeStdev (float)	timeUnits (nvarchar)
ProductionProcess	Widget1			
ProcessA		5	0.5	minutes
ProcessB		0.75	0.075	minutes
ProcessC		5	0.5	minutes
Shipping		120	12	minutes

Question:How To Answer:Solver:Formulate and Solve

PREDICT: What are a Process' predicted performance measures?Pose A New QuestionAnswers

Results: Value Stream Mapping Demo

FileTools

System Definition: ValueStreamMapping

System Instance: VSM_Example1

Save System Instance

ValueStreamMapping

- Process
 - Customer
 - Supplier
 - DedicatedProcess
 - SharedProcess
 - DataBox
 - WorkCell
- Material
 - Item
 - Inventory
 - Shipment
 - PushItemFlow
 - Supermarket
 - PullItemFlow
 - FIFOLane
 - SafetyStock
 - ExternalShipment
- General
 - Operator
 - Timeline
- Information
 - KanbanCard
 - ProductionControl

General/Operator

General/Timeline

Information/ItemRelease

Information/Kan

Information/ProductionControl

Information/ResourceShare

Material/ExternalShipment

Material/Inventory

Material/Item

Material/PullItemFlow

Material/PushIt

Material/SafetyStock

Material/Shipment

Material/Supermarket

Process/Custom

Process/DedicatedProcess

Process/SharedProcess

Process/Supplier

Process/

InstanceID	producesItem (Item)	cycleTime (float)	cycleTimeStdev (float)	timeUnits (nvarchar)
ProductionProcess	Widget1			
ProcessA		5	0.5	minutes
ProcessB		0.75	0.075	minutes
ProcessC		5	0.5	minutes
Shipping		120	12	minutes

Question: PREDICT: What are a Process' predicted performance measures?

How To Answer:

Discrete Event Simulation

Solver:

Formulate and Solve

Pose A New Question

Answers

Results: Value Stream Mapping Demo

FileTools

System Definition: ValueStreamMapping

System Instance: VSM_Example1

Save System Instance

ValueStreamMapping

Process

Customer

Supplier

DedicatedProcess

SharedProcess

DataBox

WorkCell

Material

Item

Inventory

Shipment

PushItemFlow

Supermarket

PullItemFlow

FIFOLane

SafetyStock

ExternalShipment

General

Operator

Timeline

Information

KanbanCard

ProductionControl

General/Operator

General/Timeline

Information/ItemRelease

Information/Kan

Information/ProductionControl

Information/ResourceShare

Material/ExternalShipment

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Question: PREDICT: What are a Process' predicted performance measures?

How To Answer: Discrete Event Simulation

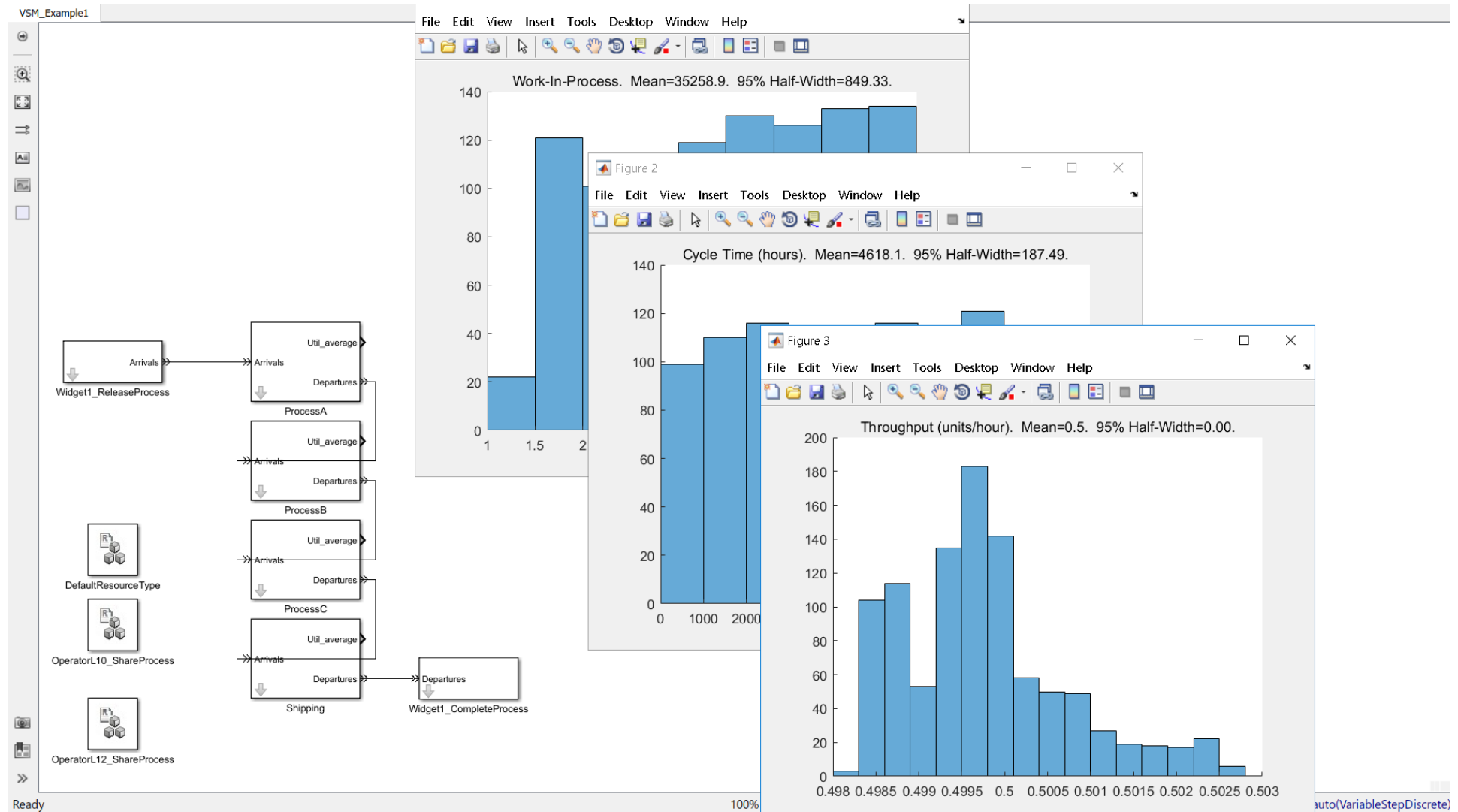
Solver: MATLAB

Formulate and Solve

Pose A New Question

Answers

Results: Value Stream Mapping Demo



Results: Value Stream Mapping Demo

FileTools

System Definition: ValueStreamMappingSystem Instance: VSM_Example1Save System Instance

ValueStreamMapping

- Process
 - Customer
 - Supplier
 - DedicatedProcess
 - SharedProcess
 - DataBox
 - WorkCell
- Material
 - Item
 - Inventory
 - Shipment
 - PushItemFlow
 - Supermarket
 - PullItemFlow
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 - SafetyStock
 - ExternalShipment
- General
 - Operator
 - Timeline
- Information
 - KanbanCard
 - ProductionControl

General/OperatorGeneral/TimelineInformation/ItemReleaseInformation/KanbanCard

Information/ProductionControlInformation/ResourceShareMaterial/ExternalShipmentMaterial/InventoryMaterial/ItemMaterial/PullItemFlowMaterial/PushItemFlowMaterial/SafetyStockMaterial/ShipmentMaterial/SupermarketProcess/CustomerProcess/DedicatedProcessProcess/SharedProcessProcess/SupplierProcess/Supplier

InstanceID	producesItem (Item)	cycleTime (float)	cycleTimeStdev (float)	timeUnits (nvarchar)
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Question: PREDICT: What are a Process' predicted performance measures?How To Answer: Discrete Event SimulationSolver: MATLABFormulate and Solve

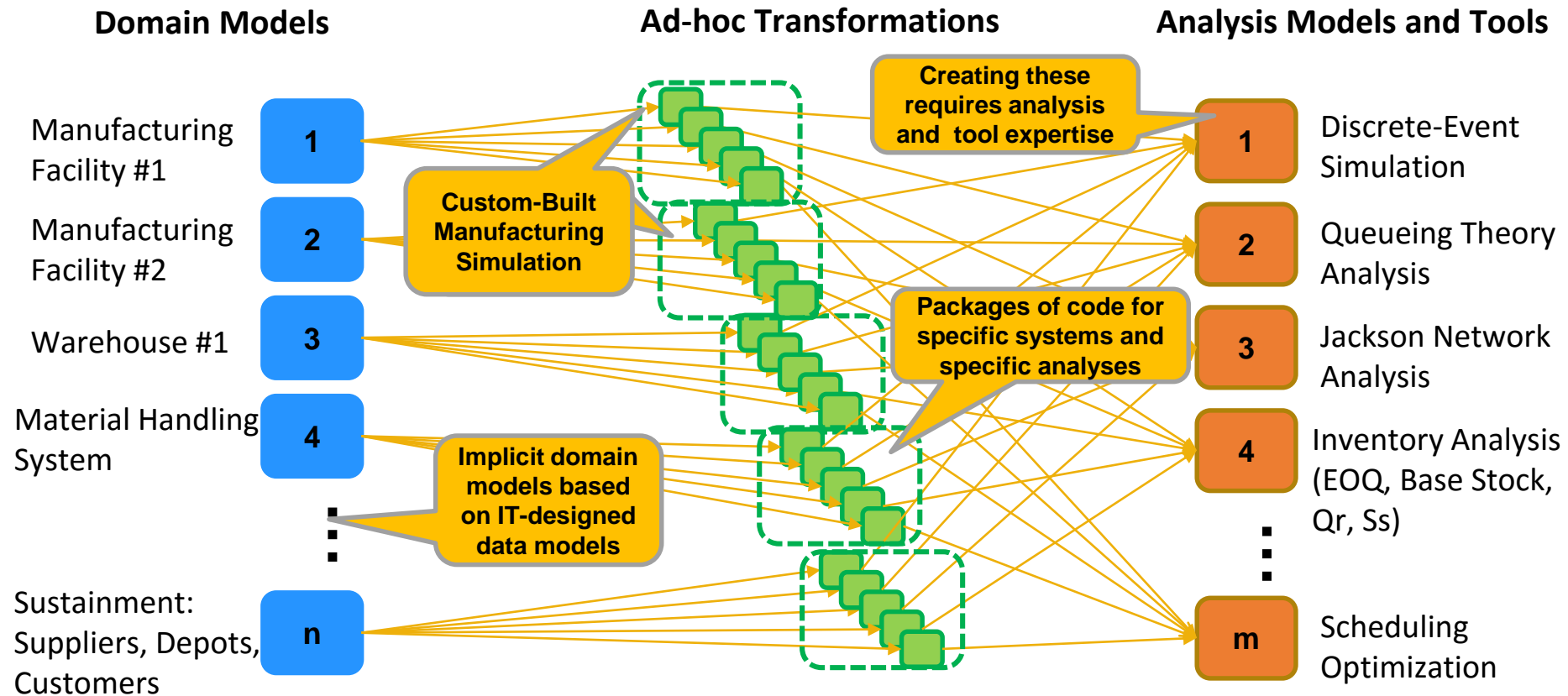
Pose A New QuestionAnswers

Summary

- Industrial Engineering is a domain that can benefit from improved tool support, we're creating it, and MATLAB and Simulink are an integral part of the solution.
 - **Minimum:** MATLAB, Simulink, SimEvents.
 - **Recommended:** Statistics Toolbox, Stateflow, Parallel Computing Toolbox.
 - **Advanced:** Global Optimization Toolbox.
- Our contribution is Industrial Engineering domain knowledge, and expertise with modeling and model transformations. The MathWorks' contribution is analysis languages, solvers, and interpretation and visualization of results.
- Should you expect an "Evaluate Produceability" button to appear in your CAD tools in the next few months? This tool is a big step in that direction, although other puzzle pieces are needed to make it truly push-button.

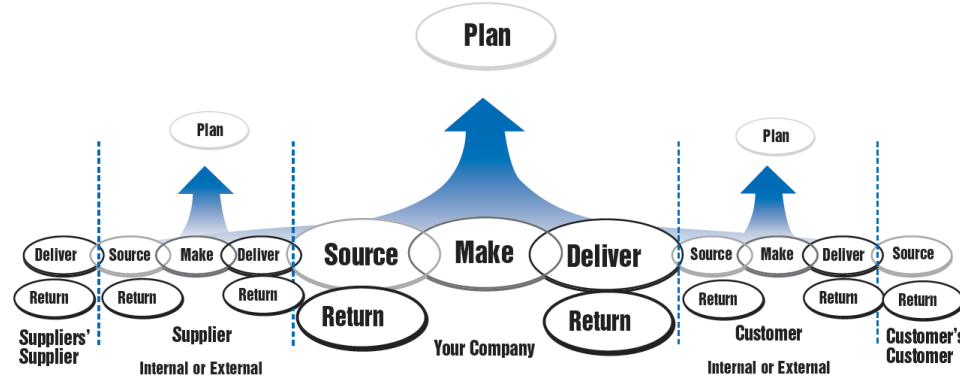
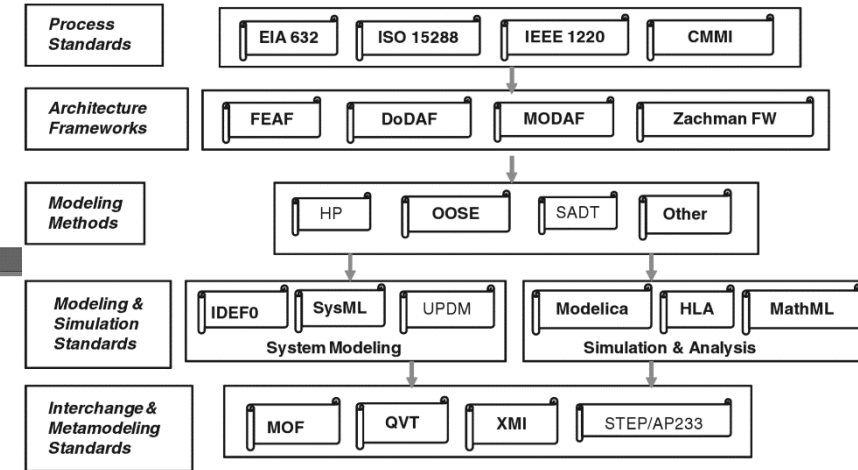
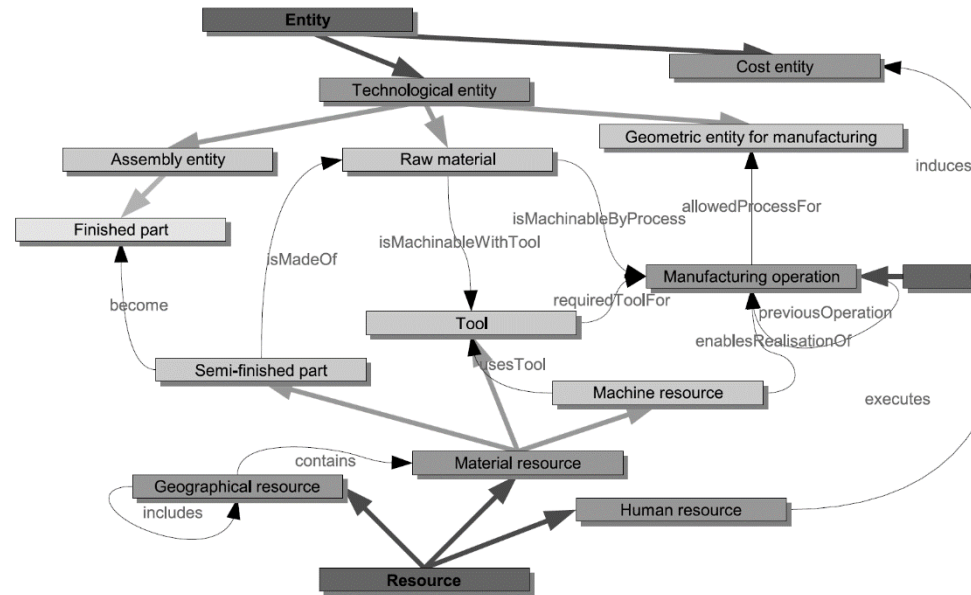
Q & A

Status Quo of Automation: Manual and Ad-Hoc



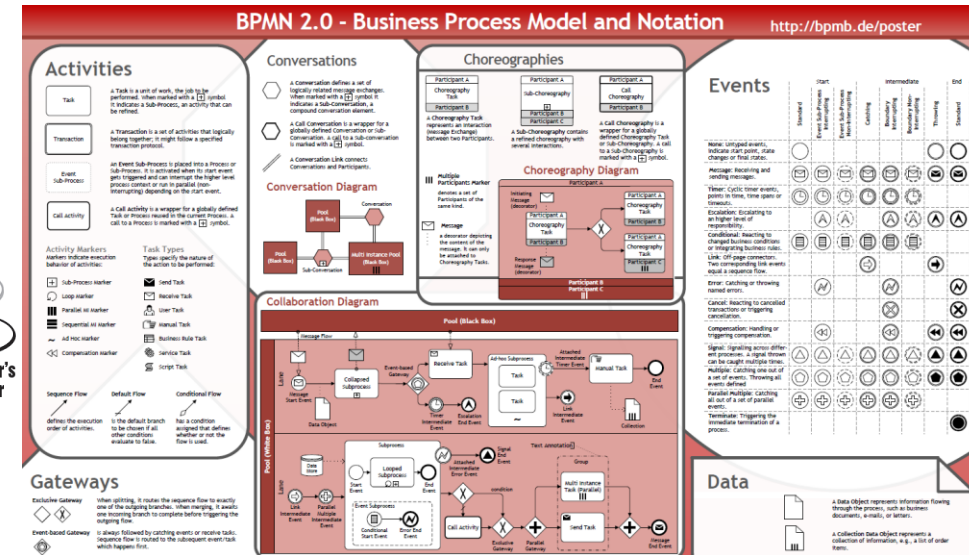
In the status quo, analysts commonly **hand-build custom analysis** to answer specific questions about specific systems. Automation can be added to make the formulations repeatable, but the issue remains that there is a unique transformation for every (domain, analysis) pair, severely limiting ROI of writing and maintaining each one.

We spent years searching for a perfect Industrial Engineering system model:



SCOR does not attempt to describe every business process or activity, including:

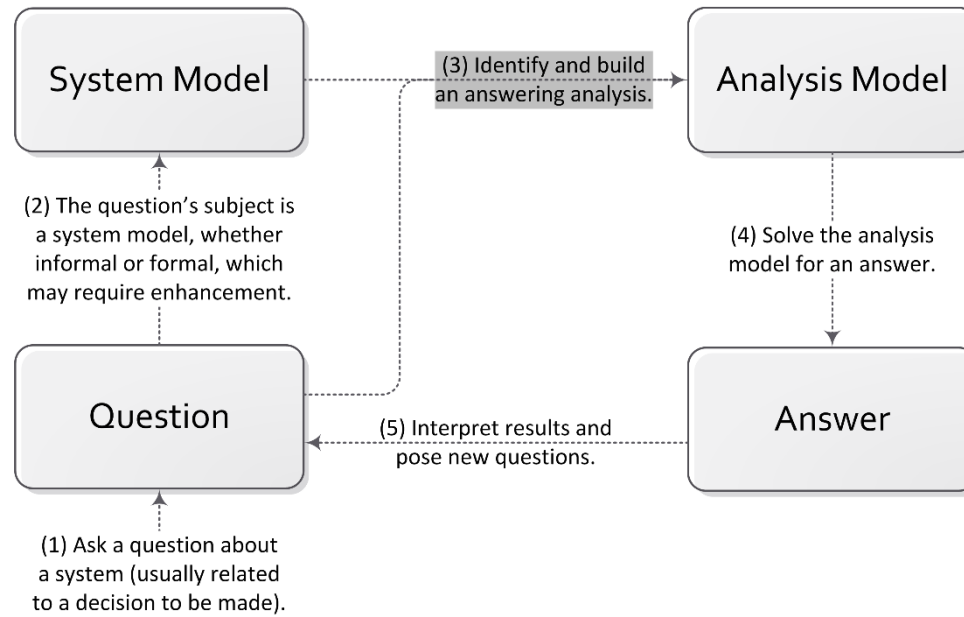
- Sales and marketing (demand generation)
- Research and technology development
- Product development
- Some elements of post-delivery customer support



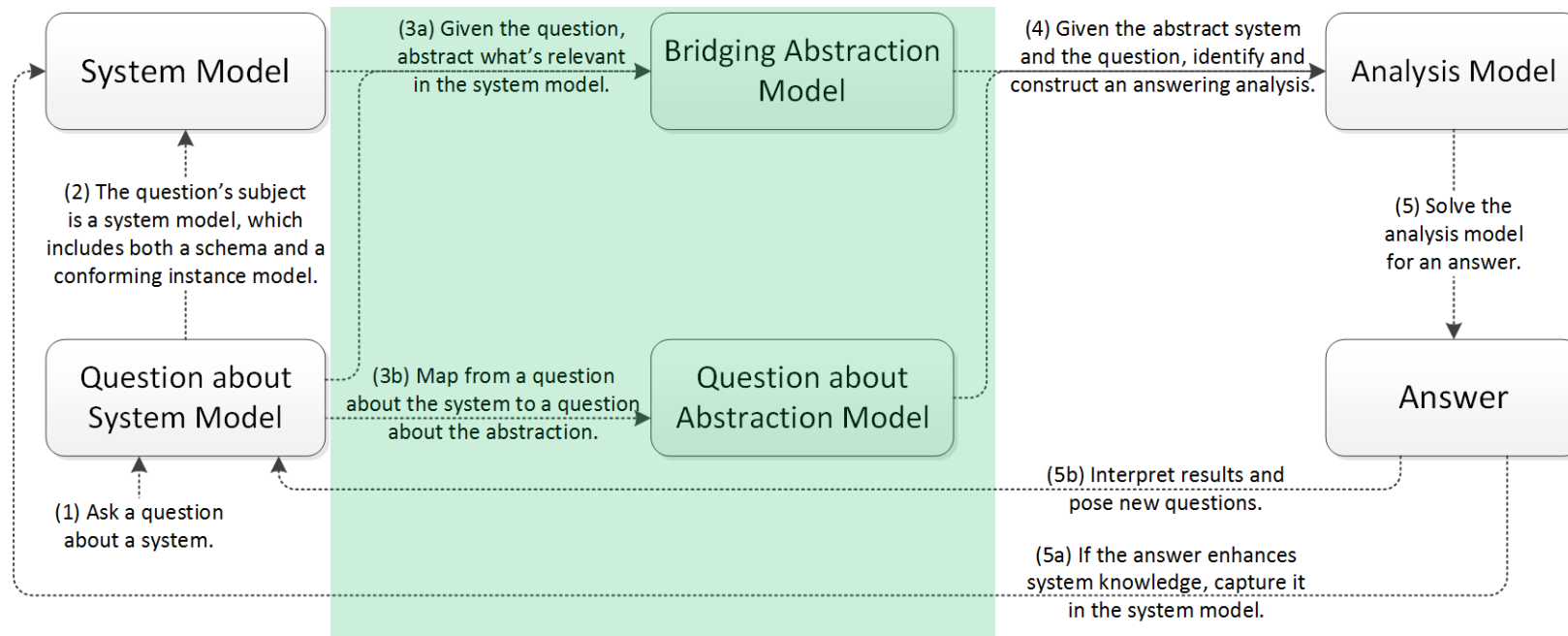
How to make a model robust and reusable? **Make it abstract.**

How to make a model user-friendly and accessible? **Make it concrete.**

The Solution



The Solution



MBSE for Industrial Engineering (versus Mechanical & Aerospace)

- The behavioral model is fundamentally different.
- We care a lot more about instance data. An aircraft or satellite has a controlled number of subsystems (which can each be quite complex; it's the number we care about) - one avionics system, one guidance and control system, one power system, ... A manufacturing system may have dozens of facility instances, hundreds of process plan instances, thousands of workstations, and tens of thousands of resource instances.

Issues with Process Modeling in SysML

- The subset of the language for activity modeling is very abstract, similar to the *Process Network* definition in our back-end bridging abstraction model. However, we never intended end-users to author directly in our bridging abstraction model, just map to it.
- There's no facility for user customization, e.g. define a language within the language, as SysML structural modeling permits.
- It stores information at the wrong levels of abstraction. A specific process structure is stored at schema-level, and also elements' parameterization are stored at the schema-level, for example actions' token types and quantities input & output.
- SysML has limited capabilities for modeling structure-behavior integration. In version 1.3, a *Block's* links to behavior are *Classifier Behavior*, *Owned Behavior*, and *Owned Operation*. How to express capability, assignment (both static and time-varying, the latter sequencing and scheduling)?