16.660 / 16.853 / ESD.62J Introduction to Lean Six Sigma Methods
January (IAP) 2008

Teaching Lean Thinking Principles Through Hands-On Simulation

Hugh McManus
Metis Design

Eric Rebentisch and Earll M. Murman
MIT Lean Aerospace Initiative

Alexis Stanke
Eclipse Aviation

3rd International CDIO Conference
Cambridge, MA, June 13, 2007

Note for OCW viewers

- This talk presents an overview of the teaching simulation used in 16.660 / 16.853 / ESD.62J Introduction to Lean Six Sigma Methods
- It cannot replace the simulation experience, but outlines the goals, process, and basic lessons of the simulation
- It was written for a conference on "Conceive, Design, Implement, and Operate" (CDIO) teaching methods, and the second half of the talk relates the simulation experience (and this course in general) to the CDIO method.
- See Crawley E, Malmqvist J, Ostlund S, Brodeur D, 2007, *Rethinking Engineering Education: The CDIO Approach*, New York, Springer, for more information on CDIO.

Overview

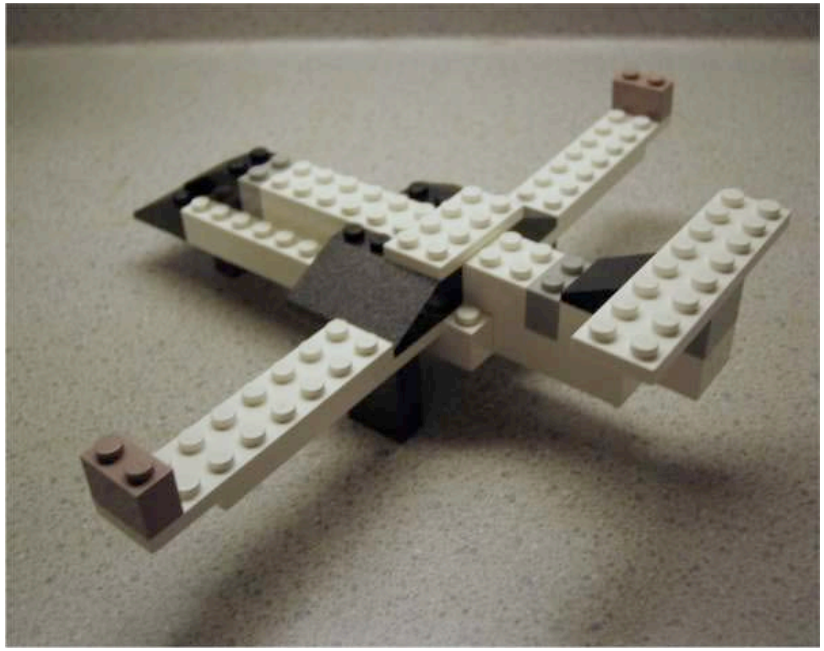
- Description of Lean Enterprise Simulation
- Use in Simulation-based learning
- Simulations as a CDIO practice field
- Evaluation of the simulation in the Lean Academy
- Caveats and Conclusions

Simulation Goals

- **Teaching Lean applied to complex enterprises challenges traditional teaching modes**
  - **Experience based**
  - **Depends strongly on complex context not familiar to students**
- **Use Simulation-based learning for:**
  - **Increased comprehension of the curriculum**
  - **Better understanding of context and holistic, system-spanning nature of lean changes**
  - **Learning through experience - a practice field for lean change**
  - **Increase student involvement and excitement**

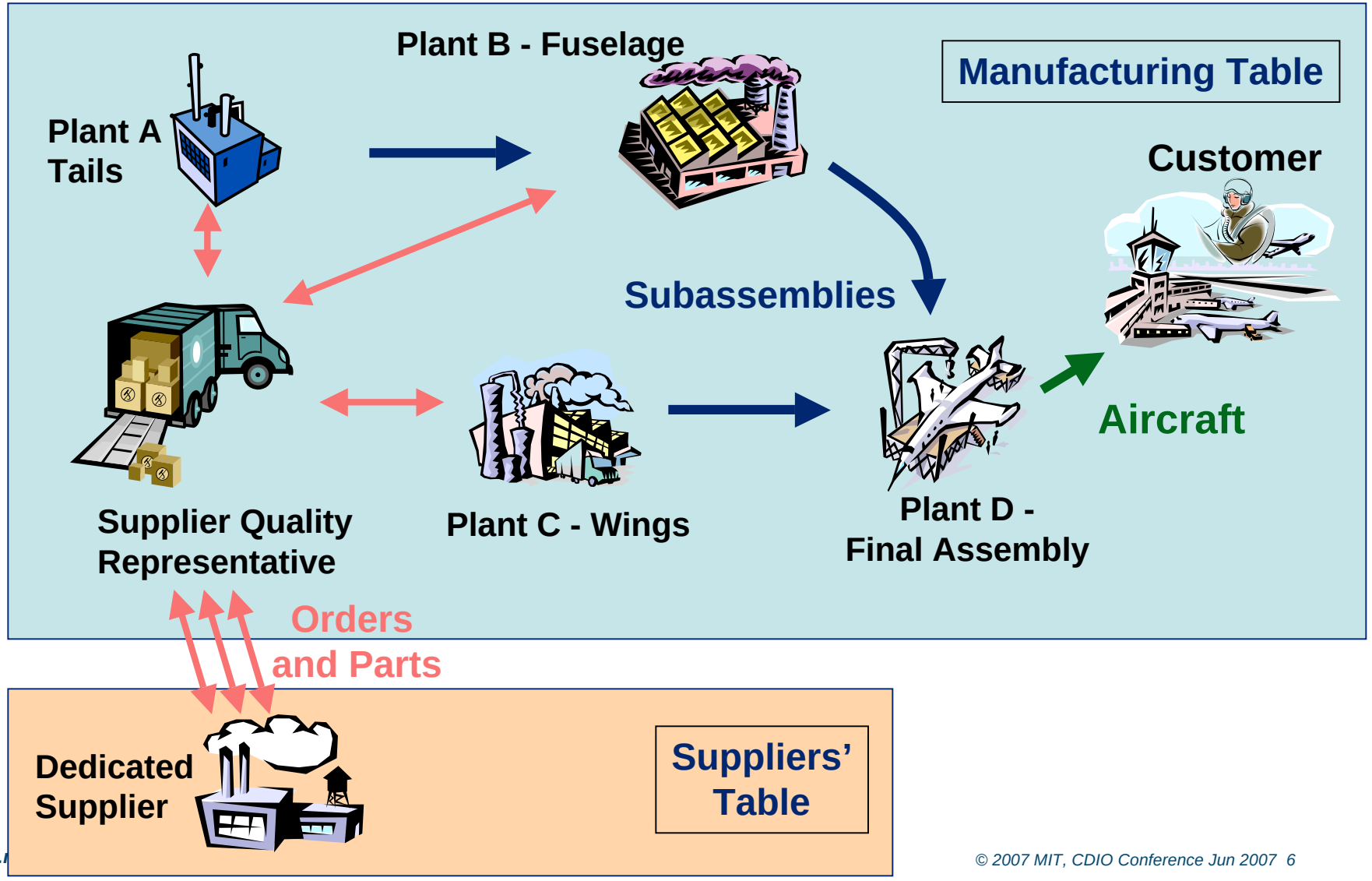
Simulation Objective: Build Lego Airplane

- **Lego aircraft starts as a non-lean product**
  - Excessive part count
  - Too many part types
  - Weak tail
- **Built in a non-lean way**
  - Unbalanced production system (bottlenecks, unused capacity)
  - Long supply chain
  - Excessive paperwork
  - Unclear communication



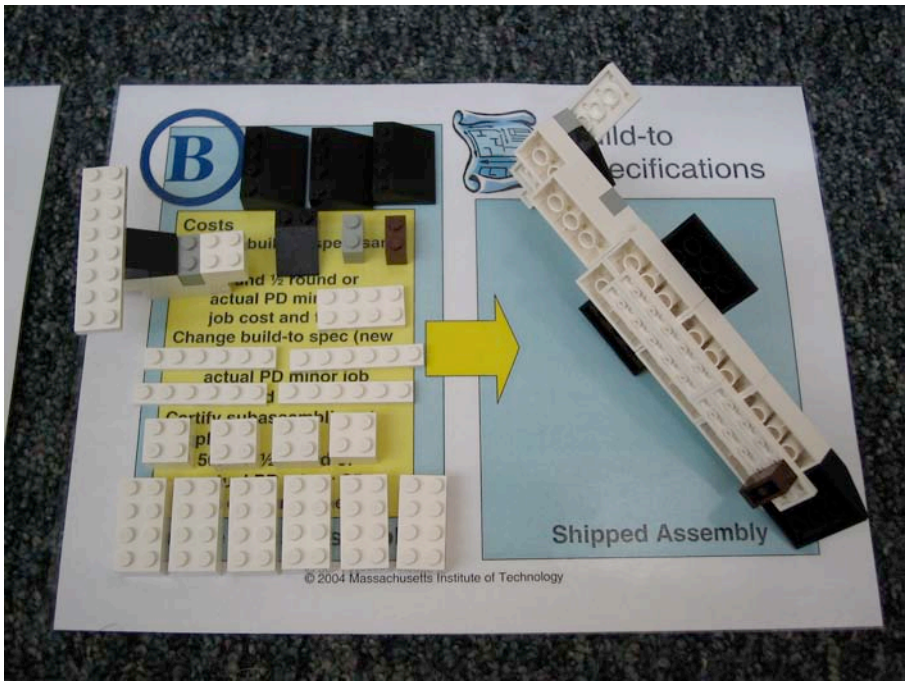
Lean Academy simulation is a subset of the Lean Enterprise Value (LEV) simulation

Simulated Production System



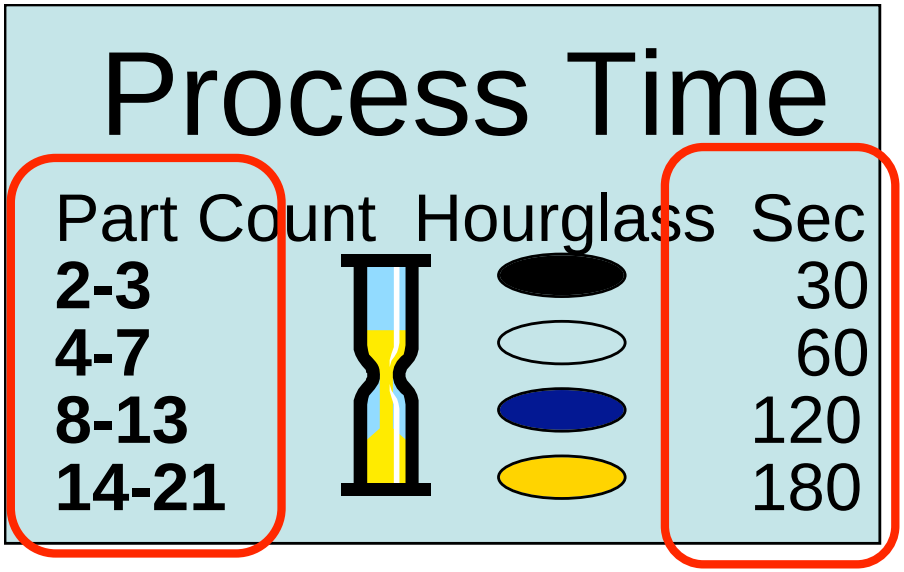
Simulation Features: Visual Instructions

- Shows you how to put a sub-assembly of the plane together
- If organized (as shown) provides a visual cue to obtain needed parts
- Easy to learn
- May be changed

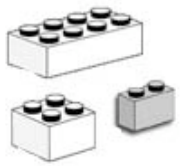
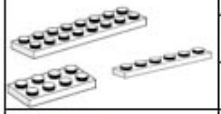


Timers Represent Process Times and Capacity

- Legos are assembled by the pace of an hourglass (time depends on part count)
- Prevents racing, dexterity contests
- Focuses attention on the *process*

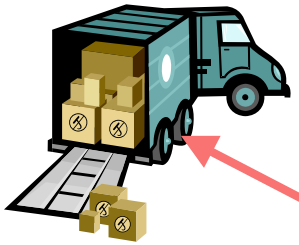


Parts Ordering: Clumsy Paper System, Long Supply Chain

Parts Order Form			Deliver to: A
Part Description			Quantity
Type	Color	Size	
Brick 	Light Grey	1x2	3
	Brown	1x2	2
	Sand Red	1x2	
	White	2x2	
	White	2x4	
	White	2x8	
Plate 	White	1x6	
	White	2x4	4
	White	2x8	
Slope 	Black	2x3	
	Black	4x3	

To be completed by supplier when order is fulfilled:

Total number of parts shipped:	9



Supplier Quality Representative

Supplier

Fulfillment Receipt	Delivered to: A
Invoice amount: 45	Fulfilled by: 1

Enterprise Accounting

- Complete cash-flow accounting system
- Tracks Revenue, Fixed and Variable Costs, OH
- Provides direct measure of effectiveness of simulated enterprise

Revenue

Costs

Overhead

BOTTOM LINE!

	Revenue									Profit	
Round	(A) Total Shipped Aircraft	(B) Price Received / aircraft	(C) Total revenue = A X B	(D) Total of purchased parts invoices	(E) Total Inventory (parts - all facilities)	(F) Carrying Costs (all facilities)	(G) Capital Improvements (all facilities)	(H) Engineering Overhead	(I) Total Costs = D+E+F+G+H	Net Profit = C - I	Cumulative Profit = sum(Net Profit)
1	2	450	900	380	55	540	0	200	1175	-275	-275
2		450						200			
3		450									
4		400									
5		350									
6		350						200			

Use of Simulation

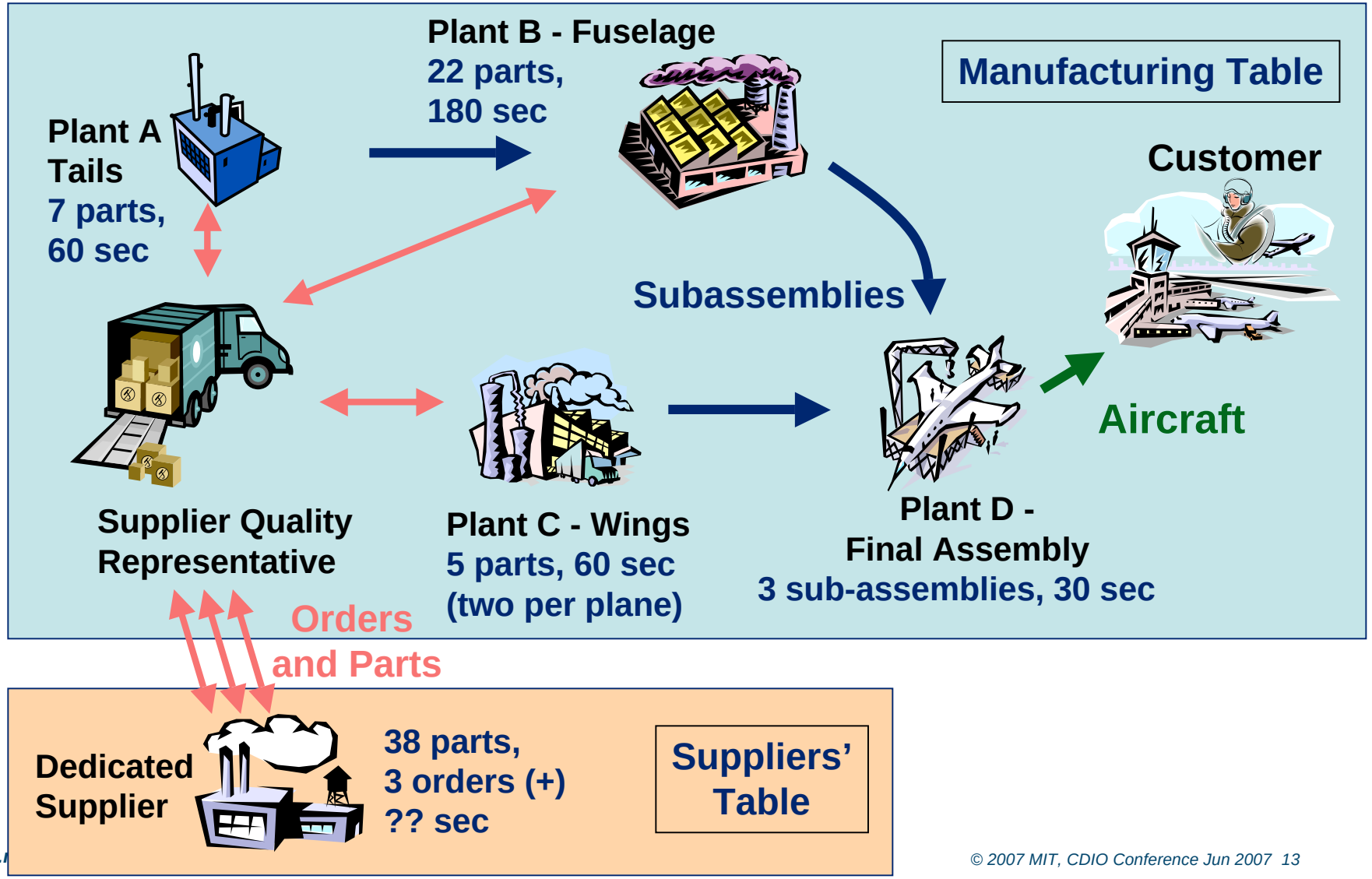
- One day (about 2/3s of the teaching time) dedicated to simulation
- Simulation played in 12 minute active rounds, interspersed with time for reflection, planning, and and analysis
- Round 1-2: Learn and Baseline
- Round 3-4: Process Improvements
- Round 5: Enterprise Lean

Process Improvements

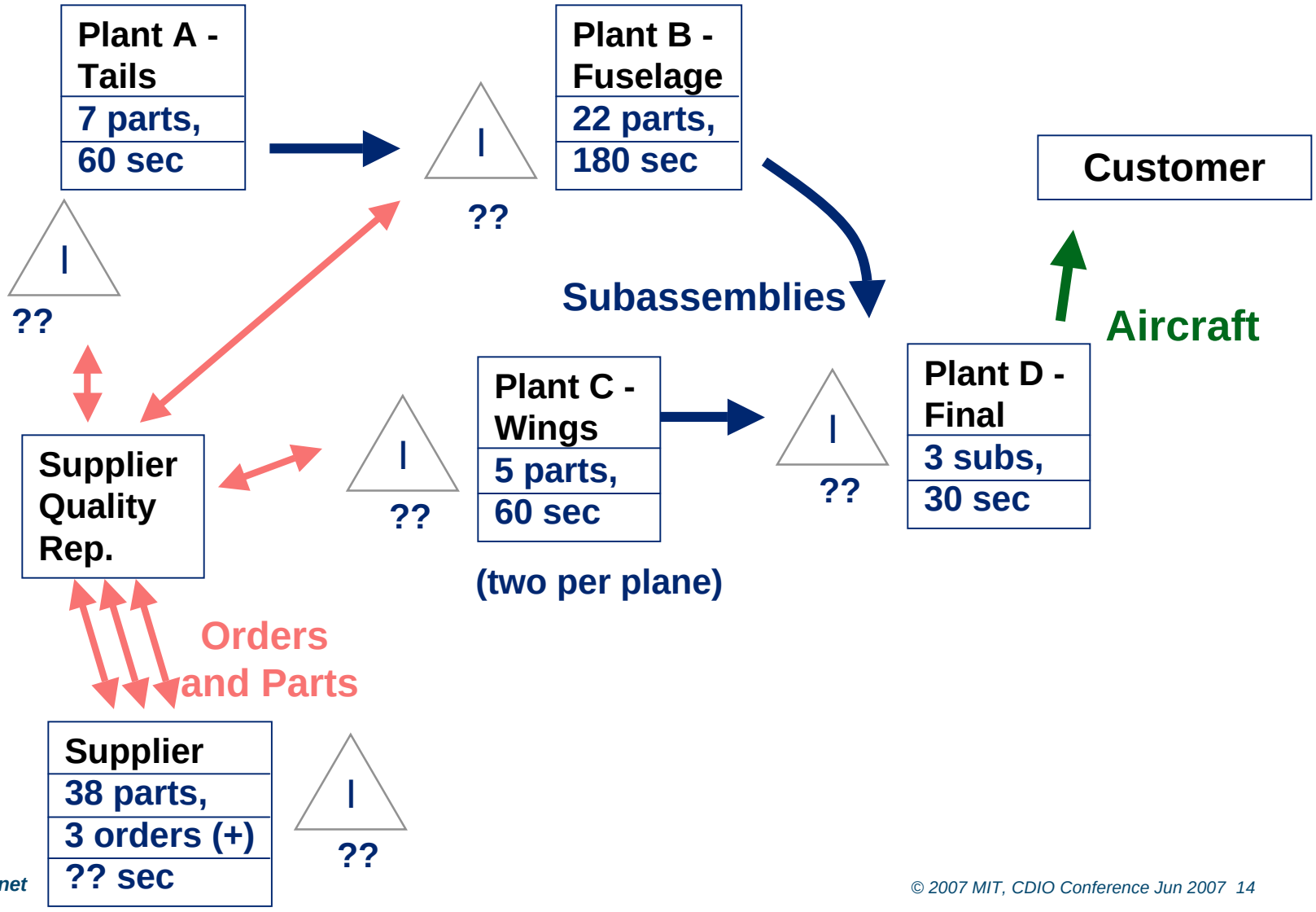
Simulation Improvements	Lean Principles	Typical Student Actions
Organize Activity	5S, Visual Control, Standard Work	Clean up worksite, organize inventory, standardize sequence of ordering, assembly, and paperwork
Balance Workload between Facilities – this requires an "engineering request" (approved by instructor)	*Takt* time, Single-piece Flow, Balanced Work	Move work between plants to balance work at 120 sec and 12-13 parts
Change (improve, eliminate, or move) facilities – this requires "corporate approval" (also by instructor)	Eliminate Unnecessary Tasks, Single-piece Flow, Just-in-Time Delivery	Demolish "warehouse;" freed student moves orders and parts
Modernize parts order system by eliminating paperwork – requires "corporate approval"	Eliminate Unnecessary Tasks, Standard work	Upgrade parts ordering system and standardize orders to single-plane sets

Students use Lean Process Improvement Tools to make Simulation Process Effective

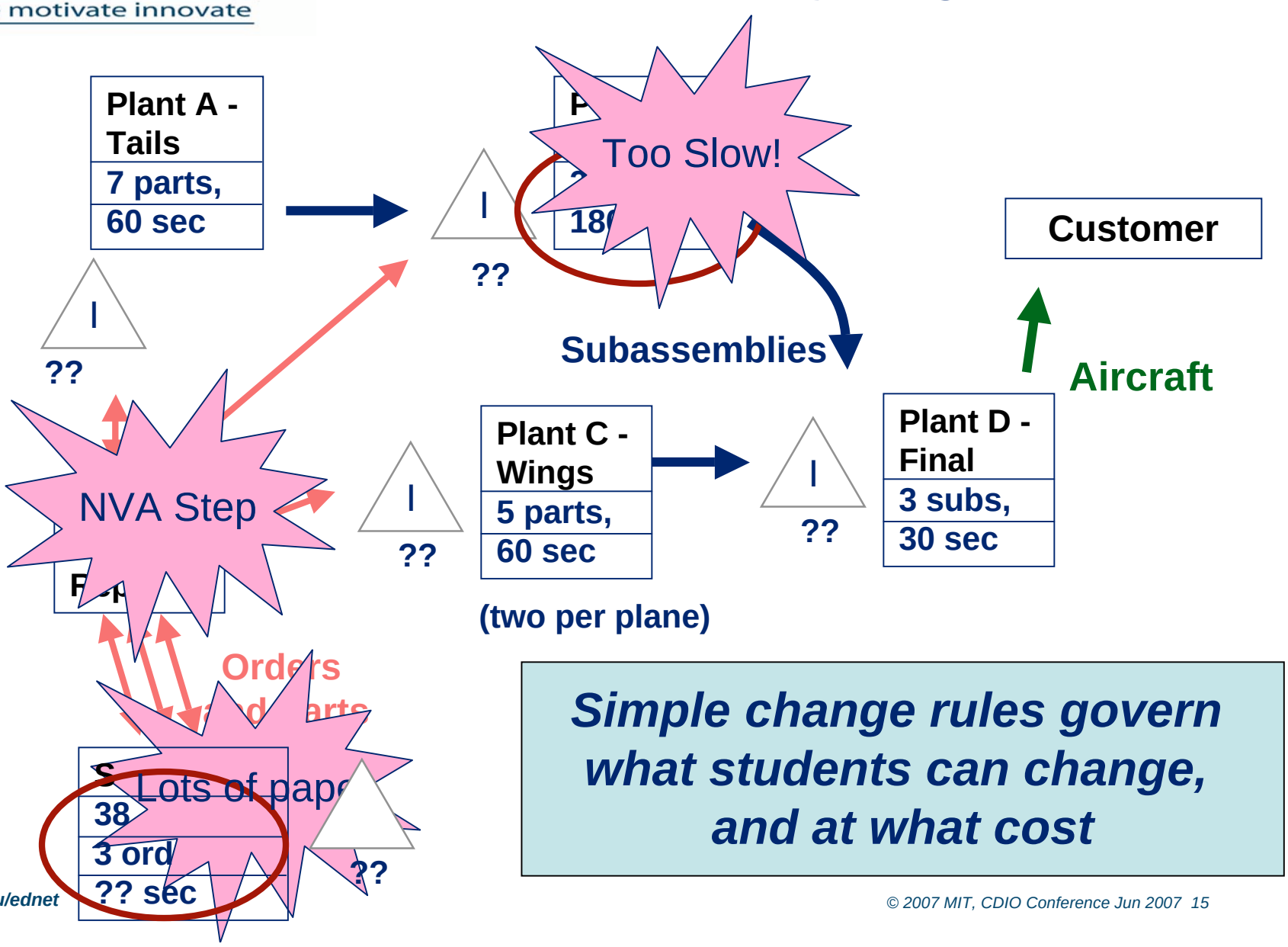
Adding Data



Using standard symbols - a simple VSM



Analyzing the VSM



Simple change rules govern what students can change, and at what cost

Lean Enterprise

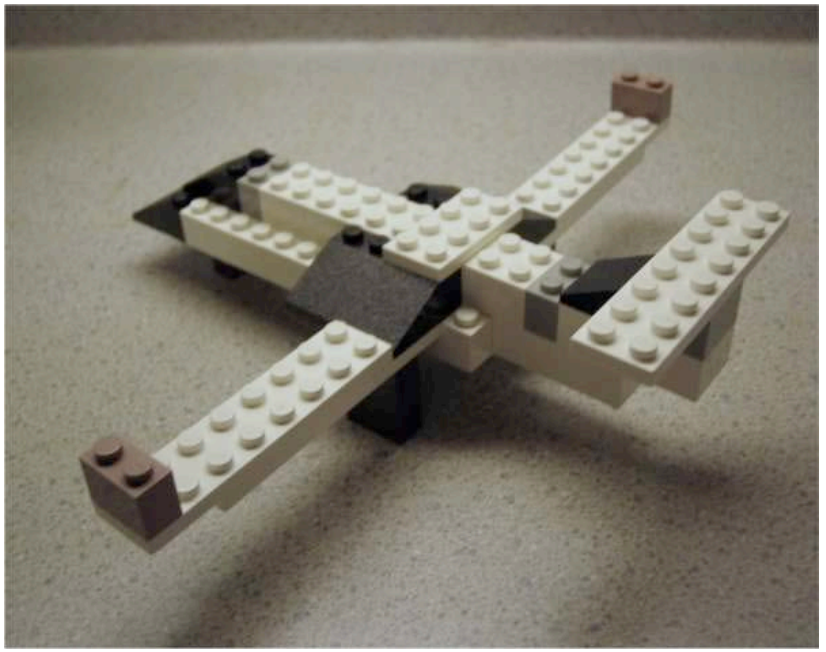
Simulation Improvements	Lean Principles	Typical Student Actions
Airplane may be redesigned within a constant exterior mold-line	Lean Engineering, DFMA, Supplier Integration	Reduce part count by 10 (to 28 per plane) using large Lego blocks available to suppliers
Balance Workload between Facilities (again)	*Takt* time, Single-piece Flow	Move work between plants to balance work at 60 sec and 7-9 parts, including using excess capacity at final assembly to install some exterior parts (e.g. landing gear)
Change (improve, eliminate, or move) Facilities	*Takt* time, Single-piece Flow	Students find they must *increase* capacity at some manufacturing plants (but can now justify it economically)
Further Modernize Supply Chain	Standard work, Just-in-Time, *Kanban*	Implement a two-bin *Kanban* inventory management system throughout enterprise

Students use Lean Enterprise Tools to make Simulation Process Outstanding

Key: Redesign Airplane

Practice Lean Engineering:

- **Cut part count**
- **Reduce part types**
- **Fix weak tail**
- **Easy to assemble**
- **Obeys constraint of unchanged moldline**

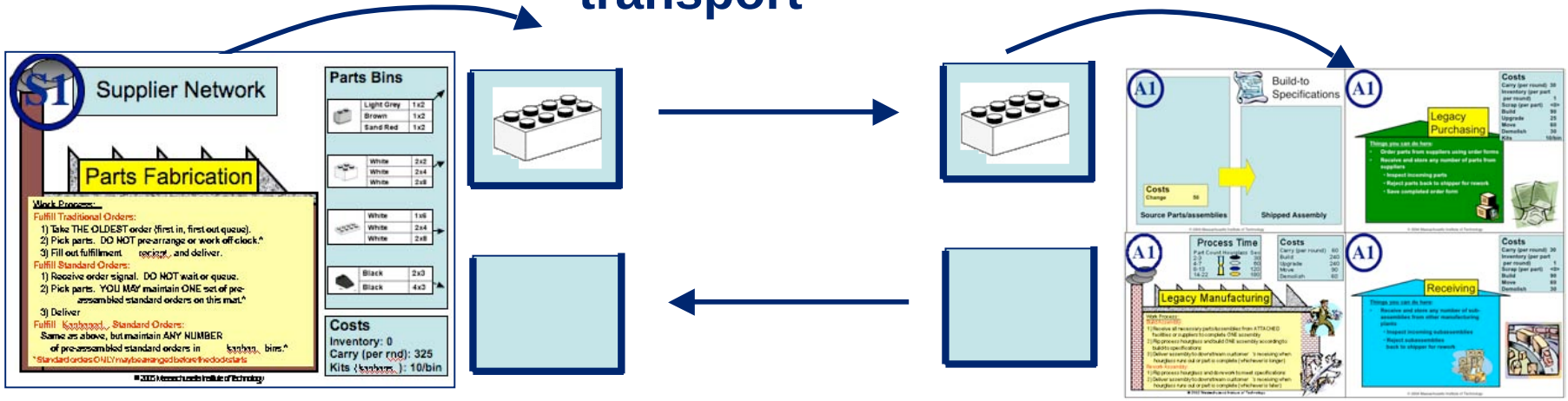


Example learning by doing: Kanban System

- Implement pull inventory and production control system
- Learn complex, context-dependent tool through simulated exerience

Full Kanban bin cues transport

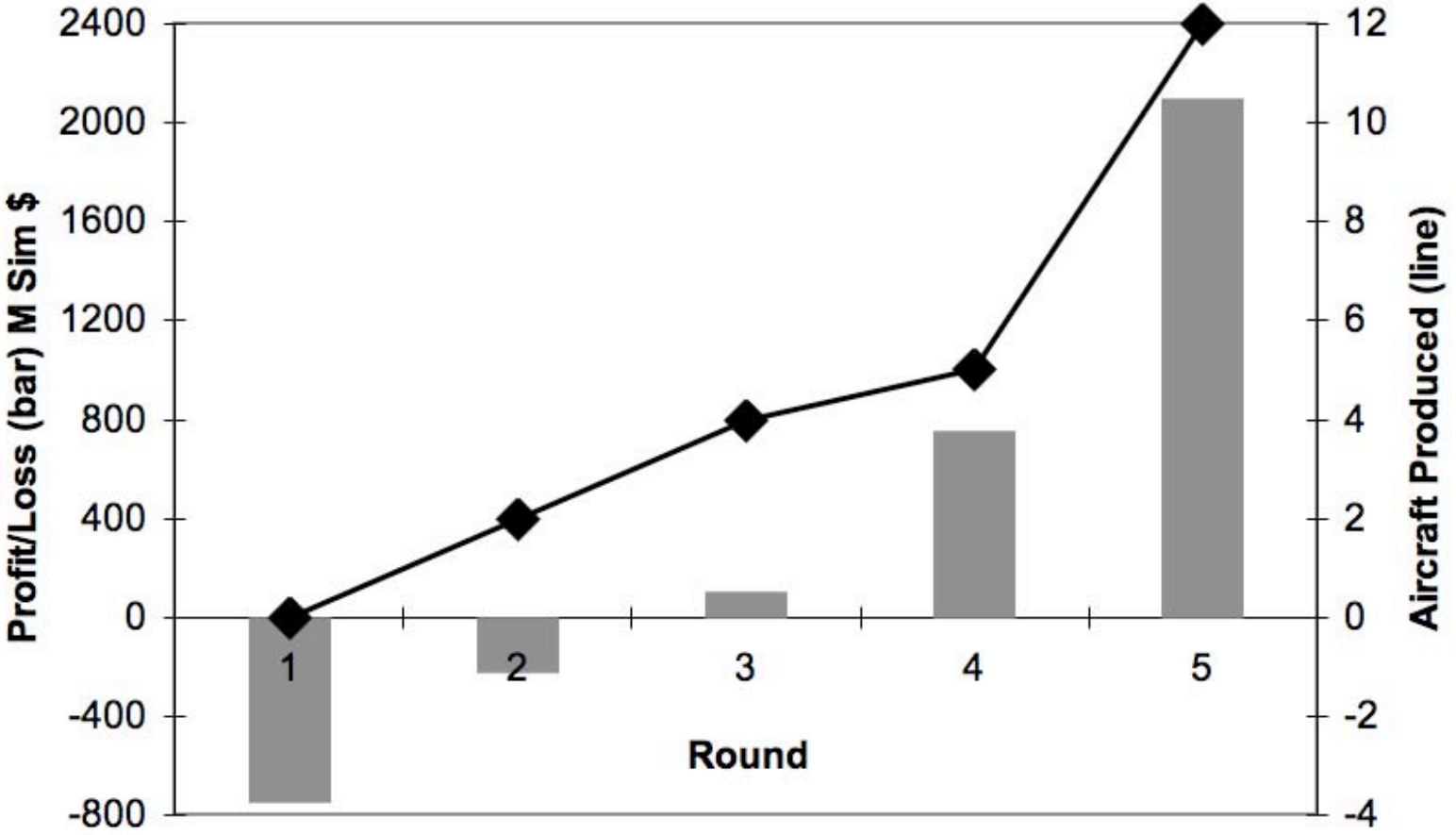
Empty receiving cues emptying Kanban bin



Empty Kanban bin cues order fulfillment

Empty Kanban bin cues transport

Results



Students get simulated experience of process improvement

Simulation-Based Learning and our Learning Objectives

- **Increased comprehension of the curriculum**
  - **Controlled studies show increased comprehension using "games" vs. lectures or static web-based learning**
  - **Controlled studies also show improved outcomes measured by behavior**
- **Better understanding of context and holistic, system-spanning nature of lean changes**
- **Learning through experience - a practice field for lean change**
  - **Supported as *goals*, improved outcomes unproven**
- **Increase student involvement and excitement**
  - **Observed!**

Most literature on computer-based simulations

Non-computer Peer Efforts

- **Simple simulation to make one learning point**
  - **Beer game**
  - **Dot games**
  - **Dice games**
- **Lean Manufacturing Simulations**
  - **Timewise clock manufacturing**
  - **Various lego games - cars, etc.**
  - **Lean Shipbuilding**
- **Design and Analysis Simulations**
  - **Requirements and concept design**
  - **Engineering processes**

Mostly simple systems designed to teach specific lessons

CDIO and Continuous Process Improvement

- **Typical Continuous Process Improvement methods have structures very similar to CDIO!**
  - **Plan-Do-Check-Act (PDCA)**
    - **Shewhart, Deming**
  - **Define-Measure-Analyze-Improve-Control (DMAIC)**
    - **Six-Sigma**
  - **Mobilization-Diagnosis-Redesign-Transition**
    - **Hammer (Re-Engineering)**
- **CPI is about designing and operating business systems!**
- **We avoid favoring any one camp**

Course CONTENT resembles CDIO

CDIO and Simulation-Based Learning

- **Course methods puts students through a CDIO cycle *in the simulated world***
  - ***Comprehend:*** **the existing system and its weaknesses, using lean tools and quantitative data found in the simulation**
  - ***Design:*** **the new system, using standard design techniques, and constrained by the "physics" and finances of the simulation**
  - ***Implement:*** **the new system; facing practical challenges (mostly organizational) above and beyond the design**
  - ***Operate (and Iterate):*** **keep the new system working, face new practical challenges and start the process over again to take it to the next level**

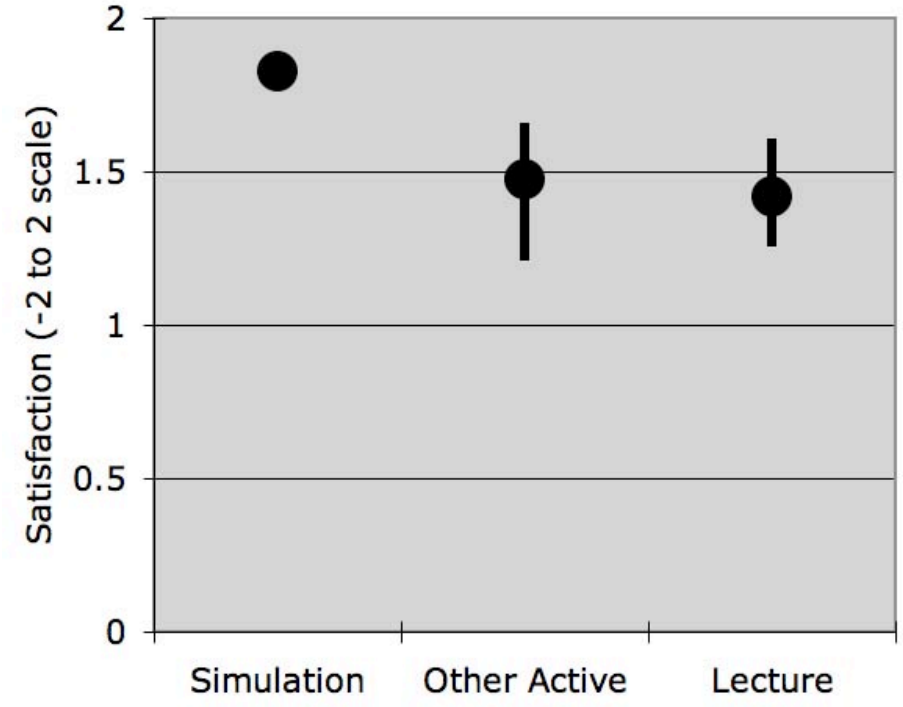
Course METHOD is CDIO

Simulations allow CDIO on complex systems

- **Most complex systems are not available for students to manipulate for teaching purposes**
- **Students can get a CDIO experience from manipulating a simulation if:**
  - **Complex enough to capture the key features of the emergent behavior of the system**
  - **Simple enough to have an acceptable learning curve**
  - **Fast enough to allow multiple change cycles within teaching period**
  - **Credible and Fun**

Simulation ENABLES CDIO

Evaluation



- Students asked if Lean Academy Modules "provided positive reinforcement of the concepts"
- Six academies, N=194
- Circle = 90% confidence
- Bars = extremes between means within categories

Simulation assessed significantly higher than other types of learning in ALL cases

Comments Indicate Simulation Goals Met

- **Increased comprehension of the curriculum**

  … helped with application of what we learned in lecture

  It took a while to get the concepts but it finally clicked during the 2nd segment [of the simulation]

- **Learning through experience - a practice field for lean change**

  Hands on – Excellent. Telling someone how something works is fine. Having someone do it teaches it

  LOVED the simulations. Figuring stuff out yourself makes things make much more sense

- **Increase student involvement and excitement**

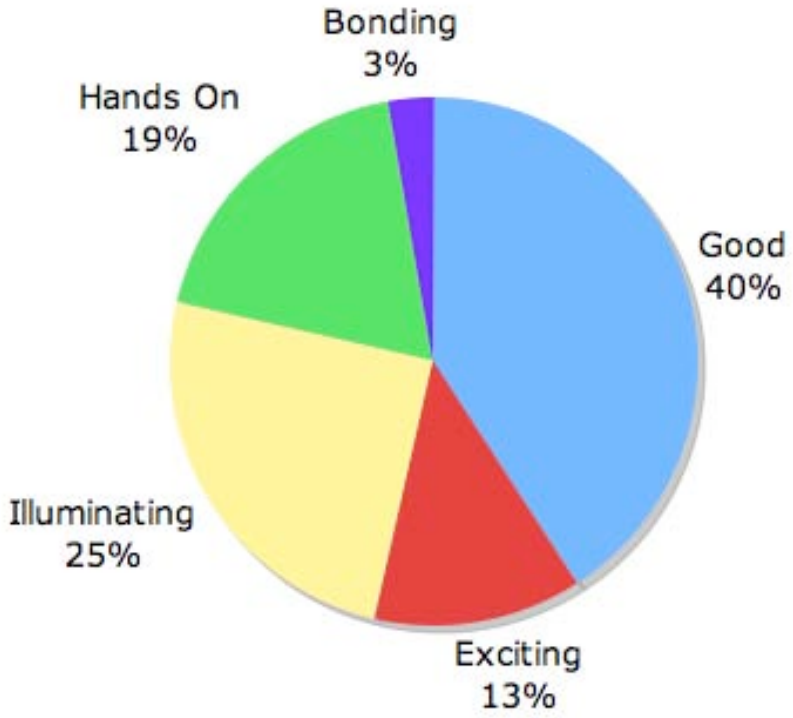
  I really enjoyed the simulations with the Legos. This made time fly.

  … SO good and SO cool. One of the most enlightening engineering experiences I've had.

- **Team Building**

  Created a good sense of camaraderie

Comment Categories



- Types of answers to open question “what did we do well today”
- 106 responses (out of 182) mentioned simulation
- Responses binned by category

Simulation well liked
Comments reflect learning objectives

Caveats

- **Evaluation based on satisfaction, not outcomes**
  - **Outcome data for Lean Academy positive, but does not differentiate between modules**
- **Cost and Time**
  - **Significant upfront expense (Legos, etc.)**
  - **Need 6 trained facilitators**
- **Simulations are vulnerable to disruption**
  - **Logistic and facilitation errors degrade experience**
- **Cannot satisfy all learning styles**
  - **Students asked for more *and less* simulation time**
  - **Real stress from *simulated* process difficulties, competition**

Typical issues for teaching simulations

Conclusions

- Unique simulation of an aerospace enterprise created
  - Subset used in Lean Academy
  - Teaches use of lean process improvement tools
  - Gives context and hands-on experience
  - Increases student involvement and enthusiasm
- Simulation provides a laboratory for CDIO of complex systems
  - CDIO teaching methods well aligned with material
  - Process improvement techniques have CDIO structure!
- Feedback indicates simulation is successful
- Caveats typical of learning simulations in general

A CDIO Success Story