DFA

- Goals of this class:
  - Place DFA in context
  - Learn basic principles of Design for Assembly
  - Understand background and history
  - Understand its strong and weak points

"The Multiplier" According to Ford and GM or: Why Is DFM/DFA Important?

- For every product part, there are about 1000 manufacturing equipment parts*
- Or, for every toleranced dimension or feature on a product part, there are about 1000 toleranced dimensions or features on manufacturing equipment
- Such "equipment" includes fixtures, transporters, dies, clamps, robots, machine tool elements, etc

*Note: Ford's estimate is 1000, GM's is 1800. Both are informal estimates.

A Few Quotes

- Just because you can make something doesn’t mean you can manufacture it.
- It’s very hard to make cheap [low cost] stuff - you get buried by your mistakes.
- I don’t understand why it won’t assemble. It passed inspection.
- Word came down that we couldn’t use screws. So we used snap fits. Then word came down that it had to pass a drop test. So we dropped it and it fell apart...

Goals of DFM/DFA

- Historically, conventionally
  - reduce costs, simplify processes
  - improve awareness of manufacturing issues during design
- More broadly (a goal of this course)
  - align fabrication and assembly methods to larger goals
    - ability to automate, systematize, raise quality, be flexible
    - access to assembly-driven business methods like delayed commitment
    - innovative designs, outsourcing (Siemens intake manifold)
- Broad view inevitably pushes DFM/DFA earlier into the product development process where it blends with architecture (see AITL Basic Issues and Product Architecture classes)

The Assembly from Heaven*

- Can be assembled one-handed by a blind person wearing a boxing glove
- Is stable and self-aligning
- Tolerances are loose and forgiving
- Few fasteners
- Few tools and fixtures
- Parts presented in the right orientation
- Parts asymmetric for easy feeding
- Parts easy to grasp and insert

*Dr Peter Will, ISI

The Assembly from Hell

- The opposite in each case from the previous slide

History of DFA

- Deep background in Group Technology
  - Coding and classification schemes
- European design tradition
- Value Engineering
  - each part must be justified
- Boothroyd
  - part feeding physics - 1960s
  - part handling and insertion experiments- 1970's
  - assertion that assembly cost = 30 - 50% of manufacturing cost
  - DFA methodology and software - 1970's-80's
  - switch to assertion that parts are the main cost and fewer parts = less cost, even if those parts are more complex

Sample Cost Breakdowns

- VCRs: 90% parts, 5% labor
- Car engines: 75% parts, 7% labor, 7% capital, 7% consumables*
- Mini computers: 65% parts, 25% labor
- Fighter planes: 50% parts and tooling, 40% labor
- Most of the above are pretty crude estimates because, for the most part, companies do not really know their costs
- Also, data look different depending on whether labor component of purchased items is visible or not (See class on Economic Analysis)

*Data from 27 engine lines, International Motor Vehicle Program

Characteristics of Traditional DFA

- Uses an easy to understand metrics-driven approach (metrics story about demurrage)
- Uses a *relative* cost and time metric
- *DFA in the small* simplifies each assembly step
  - single parts
  - manual assembly
  - small parts
  - uses many context-free metrics to assess difficulty levels of feeding and handling
- *DFA in the large* emphasizes part count reduction
  - It is essentially another force in product architecture
  - Advanced plastics make part count reduction more attractive

Traditional DFA

- The issues are: (Boothroyd except where noted)
  - assembling each part -estimating and reducing time
    - feeding/presenting
    - handling/carrying/getting into position (Sony exploded views)
    - inserting without damage, collisions, fumbling
  - reducing part count (originally driven by local economic analysis, now driven by part cost itself)
    - two adjacent parts of same material?
    - do they move wrt each other after assembly
    - is disassembly needed later (use, repair, inspection, upgrade...)
    - is the part a main function carrier?(Fujitsu, Lucas, (Pahl & Beitz))
    - if not, consider combining them (but see Architecture class)
    - are there too many fasteners?
  - identifying cost drivers (Denso)

How to Do Traditional DFA

- Make a structured bill of materials
- Identify every part mate and understand it
- Choose a reasonable assembly sequence
- Use the tables to estimate handling and mating times
- Label theoretically necessary parts, *excluding* all fasteners
- Calculate

$$assembly\ \ efficiency = \frac{3*\ \#\ \ of\ \ theoretically\ \ needed\ \ parts}{total\ \ predicted\ \ assembly\ \ time}$$

- This ranges from 5% for kludges to 30% for good designs

DFA Spreadsheet

- On SoanSpace there is a folder called DFA Software
- In it is DFA.xls with the handling and insertion data from the previous two slides
- Enter your code numbers and labor rate ($/sec) and the sheet will calculate times and costs

DFA Spreadsheet

Cost per sec
$0.04

Type cost per second in cell B2

Type handling codes in column E

Type insertion codes in column K

If you type a non-existent code, the value will be #N/A

Don't change values in yellow cells

Boothroyd-Dewhurst Data ©
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Handling	Code	Time, sec	Product handling codes	Product handling time values	Handling Cost	Product Insertion codes	Product insertion times	Insertion Cost	Total time
	0	1.13	0	1.13	$0.05	1	3	$0.12	2.13
	1	1.43	71	#N/A	#N/A	11	5.2	$0.21	#N/A
	2	1.69	11	1.8	$0.07	10	3.7	$0.15	11.8
	3	1.84	15	3	$0.12	11	5.2	$0.21	14
	4	2.17	11	1.8	$0.07	11	5.2	$0.21	12.8
	5	2.45	0	1.13	$0.05	33	#N/A	#N/A	34.13
	10	1.5		1.13			1.5		
	11	1.8		1.13			1.5		
	12	2.06		1.13			1.5		

Make Each Step Easier

- Add chamfers and lead-ins
- Make the assembly point visible and reachable
- Design parts so that they do not tangle
- Make assembly happen from above
- Design the product to assemble in layers
- Make the parts easy to assemble the right way
  - Symmetric if orientation does not matter
  - Obviously asymmetric if orientation matters

Heavy Duty Staple Gun

Image removed for copyright reasons.
Source:
Figure 15-25 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Assembly efficiency = 17% before improvements
= 25% after improvements
= 30% with some functional risk

Low Cost Staple Gun

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Source:
Figure 15-30 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Assembly efficiency = 31%
Contains many of the suggested improvements
But is it a better staple gun?

Part Count Tradeoffs

ONE PART PER μ FUNCTION	PARTS CONSOLIDATION: FEWER PARTS AND LESS FASTENING
MANY SIMPLE PARTS	FEWER BUT MORE COMPLEX PARTS
LOTS OF INTERFACES IN ASSEMBLY	MORE FUNCTION SHARING
EXTRA WEIGHT, EXTRA FAULT OPPORTUNITIES	
EXTRA CHANCES FOR ERRORS	PARTS TAKE LONGER TO DESIGN AND PROTOTYPE
LOTS OF LOGISTICS, FAB ACTIVITY, & ASSY ACTIVITY	MORE ACTIVITY DURING FAB, LESS DURING ASSEMBLY
EXTRA "SUPPORT" COST	PARTS COST MORE
FLEXIBILITY IS POSSIBLE DURING ASSEMBLY	FEWER OPPORTUNITIES FOR ON-LINE FLEXIBILITY
QUALITY IS CREATED DURING ASSEMBLY	QUALITY CREATED DURING FAB

PART COUNT TRADEOFFS

A Few Conceptual Questions

- What's a "base part?"
  - remember the alternator - the nut is the "base" in the only assembly sequence family that achieves assembly without reorientation
  - different types of "product structure" exist (Arch. class)
- What do you mean "difficult?"
  - for manual assembly, Boothroyd has some time-based data (originally derived from grad students)
- Why avoid screws?
  - 25 years ago's reasons may not apply any more
  - see Blonder video

Manual vs Automatic Assembly DFA

- What's easy for a person
  - reorienting the assembly
  - quickly eyeballing the part (story about bad filament)
- What's easy for a machine
  - picking up little parts
  - using tools that are like tweezers
- Part jams occur most often in feeder tracks
  - Denso: perfect parts don't jam!
- A different balance between gross motion and fine motion times
- Different ways of "inspecting"

Complex Molded Part

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Source:
Figure 15-11 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Home Hot Water System Family Parts

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Source:
Figure 15-14 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Poschmann AG

Melt-Core Technology for Water Heater Parts

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Source:
Figure 15-15 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Poschmann AG

Regression Model for Mold Cost and Time

- \$Cost = 22500 + .82*Size, cc + 30*#Dimensions + 2940*#Actuators + 7630*High finish + 5470* High tolerance ($R^2 = 0.911$)
- Time (weeks) = 13 +0.000055*Size + 0.007*#Dimensions ($R^2 = 0.7$)
- Ref A. Fagade and D. Kazmer, "Optimal Component Consolidation in Plastic Product Design," ASME DETC/DFM-8921, 1999.
- Boothroyd's model includes a complexity factor that drives cost $C = (number\ \ of\ \ \ features)^{1.24}$

Questions of Scope

- When can DFA be applied?
- When should DFA be applied? When is DFA not the right approach?
- What information is needed before DFA can be applied?
- What should the designers' priorities be?
- Can/should DFA be separated from "the rest" of product design?

DFM-DFA Strategies

	Low Lifetime Production Volume	High Lifetime Production Volume
Development Time Critical	Example Products: High performance computers Telecommunications equipment DFM Strategy: Avoid long lead time tooling Use standard components Minimize production risk	Example Products: Notebook computers, Toys DFM Strategy: Minimize complexity of most complex part For complex parts, use processes with fast tool fab Apply traditional DFM to less time-critical parts
Development Time Not Critical	Example Products: Machine tools Electrical distribution equipment DFM Strategy: Avoid expensive tooling Use standard components Other issues likely to dominate	Example Products: Blank videocassettes Circuit breakers DFM Strategy: Use traditional DFM-DFA Combine and integrate parts Consider automatic assembly

Source: Ulrich, Sartorius, Pearson, Jakiela, "DFM Decision-making", Mgt Sci, v 39 no 4, Apr 1993.

The Pneumatic Piston Redesign*

- Was the original function completely understood?
- Was it preserved in the redesign?

*Product Design for Assembly by Boothroyd and Dewhurst, workbook 1991

The Water Pump Redesign

- What are the differences between the old and new designs?
  - from the POV of product function
  - from the POV of assembly
- What are we looking at in this example?

Redford-Chal Pump Redesign

Image removed for copyright reasons.
Source:
Figure 15-16 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

DFA at Sony

- Applied to products like Handicams
- “Our designers take assembly into account early.”
- Method:
  - concept designs are sketched in exploded views
  - each concept is subjected to DFA analysis and scored
  - concept selection criteria include DFA score
- A Sony engineer made a complete exploded view drawing of a Polaroid camera in 20 minutes!

Sony Walkman II Mechanism

Image removed for copyright reasons.
Source:
Figure 14-15 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Sony Exploded View

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Source:
Figure 15-7 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Hitachi Assembly Reliability Evaluation Method

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Source:
Figure 15-5 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Source: Hitachi; Suzuki, Ohashi, Asano, and Miyakawa

Design for Recycling and Reuse

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Source:
Figure 15-18 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Source: Kanai, Sasaki, and Kishinami

Web Sites from Google

http://www.intel.com/design/quality/pcdesign/assembly.htm

http://www.engineer.gvsu.edu/vac/ (class notes)

http://www.dfma.com/ (Boothroyd-Dewhurst company)

http://www.johnstark.com/pb18.html (a list of books)

http://www.munroassoc.com/design.htm (consulting, training)