Assembly System Design Issues

- Goals of this class
  - understand basic decisions in assembly system design
  - look at some typical lines for small and large products
  - different types of assembly machinery
  - example lines from industry

Basic Factors in System Design

- Capacity planning - required number of units/year
- Resource choice - assembly methods
- Task assignment
- Floor layout
- Workstation design
- Material handling and work transport
- Part feeding and presentation
- Quality
- Economic analysis
- Personnel training and participation

Basic Decision Process

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Source:
Figure 16-1 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.

Available Methods

- Seat of the pants
- The supplier's method, using his equipment
- Trial and error, using simulation to evaluate
- Analytical methods using math programming or heuristics
- Combination of technical and economic factors and inequality constraints make this a hard problem

The Basic Tradeoffs

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Source:
Figure 16-4 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.

Unit Cost Example

Unit Assembly Cost by Three Methods

f_{AC}=0.38

T=2s

L_H=$15/hr

S$=50000

$/tool = $10000

N = 10 parts/unit

w = 0.25 workers/sta

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Source:
Figure 16-5 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.

Characteristics of Manual Assembly

- Technical
  - dexterous, able to learn and improve, flexible
  - can overlap operations - move+flip+inspect
  - may be too innovative, or may be unable to repeat exactly the operation or the cycle time
- Economic
  - top speed dictates need for more people to get more output (called variable cost)

Cellular Assembly Line

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Source:
Figure 16-14 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.

One station | Whole line

Characteristics of Fixed Automation

- Technical
  - simple operations with few DoF and simple alternatives
  - each station is dedicated to one operation (place/fasten/confirm) built from standard modules strung together
  - small parts, relatively high speed
  - basic architectures include in-line and rotary
- Economic
  - the investment is in fixed increments regardless of required capacity (fixed cost)
  - the payoff is in keeping uptime high (many stories)

Typical Cam-operated Assembly Machine

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Source:
Figure 16-6 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.

Typical Dial Machine

Same principle used by Gillette for Mach 3 razors

Source:
Figure 16-8 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.

Characteristics of Flexible Automation

- Technical
  - multiple motion axes
  - motion (gross and fine) modulated by sensing and decisions
  - multiple tasks with or without tool change
- Economic
  - multiple tasks (within a cycle or next year)
  - investment scalable to demand (variable cost)
  - tools and parts presentation costly (fixed cost)

Sony VCR Assembly System

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Source:
Figure 17-22 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.

Line Architectures

- Single serial line (car or airplane final assembly)
- Fishbone serial line with subassembly feeder lines (transmissions, axles)
- Loop (common for automated lines)
- U-shape cell (often used with people)
- Rotary dial (used for very short production cycle work with a single long task cycle like filling bottles)
- Transport can be synchronous or asynchronous

Serial and Parallel Line Arrangements

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Source:
Figure 16-9 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.

How do they compare on tool cost, reliability, time, flexibility?

Serial Line with Multiple Stations

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Source:
Figure 16-10(a) 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.

(A) THREE COPIES OF STATION 3 ARE NEEDED BECAUSE ITS TASK TAKES SO LONG

Serial Line with Uneven Task Assignment

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Source:
Figure 16-10(b) 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.

(B) GROUPING WORK AT STATIONS IMPROVES BALANCE OF STATION TIMES

Multiple Paths Are Good and Bad

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Source:
Figure 16-11 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.

THERE ARE 6 POSSIBLE PATHS

Buffers - Conservative Design

- They insulate the line from stopped stations
- The only buffers that matter are the ones just ahead and after the bottleneck station (the one whose speed paces the line)
- But it is often hard to tell which station is the bottleneck
- Since a blocked buffer is as bad as a starved one, the ideal state of a buffer is half full
- Let a = the average number of cycles to fix a simple breakdown; b = buffer capacity
- Then if b/2=a, there will be enough parts in the buffer to keep everything going while a simple breakdown is fixed

Single Piece Flow

- Necessary for big things like airplanes
- Not necessary for little things
- The alternative is batch transport
  - This creates work in process inventory, takes up space, and seems associated with big inefficient factories (see research by Prof Cochran)
  - Errors can hide in the batch and the whole thing might have to be thrown away
  - Transport is infrequent so transport resources can be shared
  - Creates a transport mafia and finger pointing (VW engine plant story)

Kanban and Just in Time Systems

- The kanbans are like money
- Work is done when a ticket (“kanban”) arrives
  - Unwanted work is not done, WIP is controlled
  - Machines are not used just to use them (misplaced cost idea)
- “The whole factory operates, as much as possible, like one big conveyor.”
- “You never don’t make the same thing every day.”
- It doesn’t work unless the suppliers are doing it too
- Kanban + single piece flow means piece rate = takt time
- See “To pull or not to pull: What is the question?” by Hopp and Spearman, Mfr & Service Ops Mgt, v 6 #2, Spring 2004, pp 133-148

Toyota Georgetown KY Plant

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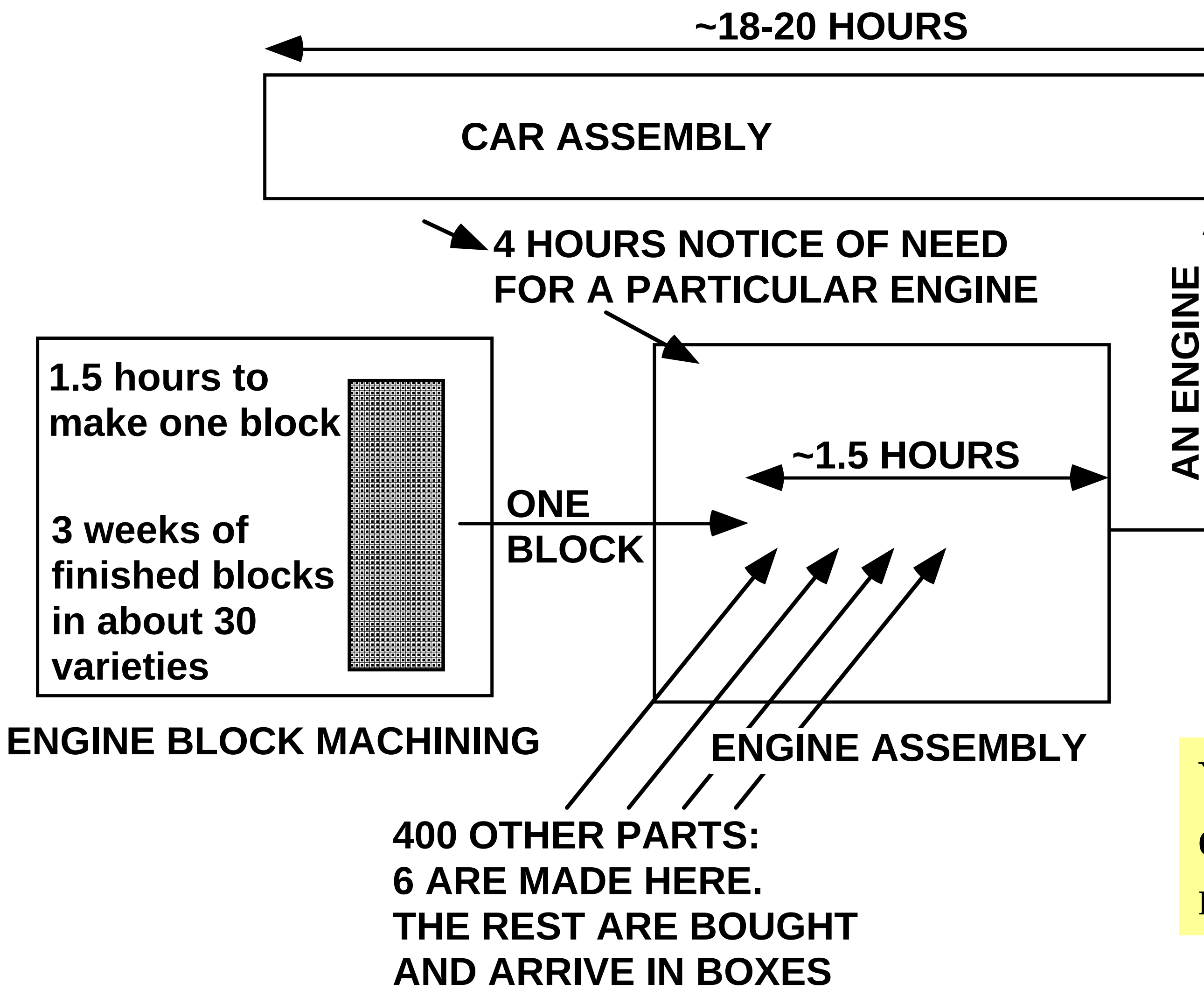
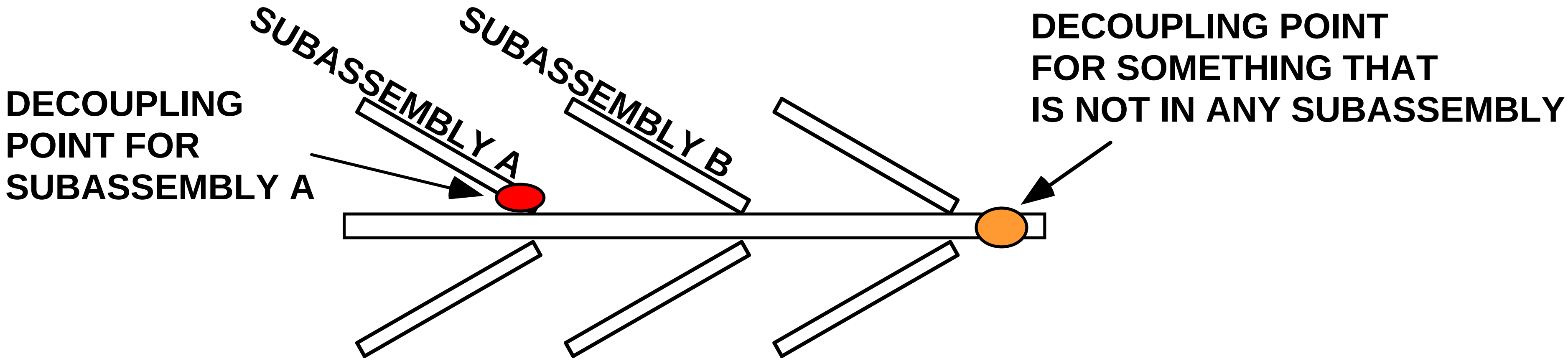
Source:
Figure 16-17 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Sometimes it Isn't Possible



You can make a block quickly enough but not soon enough

Sub-Delayed Commitment in a Fish Bone Arrangement



Basic Nominal Capacity Equations

operations/unit * # units/year = # ops/yr

ops/sec = # ops/yr * (1 shift/28800 sec)*(1 day/n shifts)*(1 yr/280 days)

cycle time = 1/(ops/sec) = required sec/op

equipment capability = actual sec/op

actual sec/op < required sec/op -> happiness

required sec/op < actual sec/op -> misery (or multiple resources)

Typical cycle times: 3-5 sec manual small parts
5-10 sec small robot
1-4 sec small fixed automation
10-60 sec large robot or manual large parts

Basic Cycle Time Equation

$$\text{Cycle time /unit} = \frac{1}{\varepsilon}\left[\text{assy time} + \frac{\text{in – out time}}{\text{\# units / pallet}} + \frac{\text{tool ch. time * \#ch. / unit}}{\text{\# units / tool ch.}}\right]$$

cycle time = net avg time per assembly

in – out time = time to move one pallet out and another in

tool ch. time = time to put away one tool and pick up another

ch. / unit = number of tool changes needed to make one unit

units / tool ch. = number of units worked on before tool is changed (cannot be larger than number units / pallet)

ε = station uptime fraction: $0 < \varepsilon < 1$

Example Lines from Industry

- First Sony Walkman Line (~1981)
- Four programmable robots with XYZ motions
- Parts on trays, tools on robot frame
- Assembly visits two stations, then person puts it on a second tray upside down
- Assembly then visits the other two stations

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Source:
Figure 16-28 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.

Example Lines from Industry - 2

- Denso Alternator Line (~1986)
  - ~ 20 parts installed
  - loop arrangement
  - 20 home-made robots
  - able to switch size of alternator
  - brushes retained by throw-away pin
  - cycle time perhaps 10 sec, two or three shifts
  - inspired by Draper movie of alternator assembly shown in 1980

Denso Robotic Alternator Assembly Line

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Source:
Figure 16-29 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.

Example Lines from Industry - 3

- Boeing 777 Assembly (~ 1993)
  - whole airplanes from structural subassemblies
  - lots of outsourcing
  - basically single serial line
  - fuselage segments built upside down on floors, then flipped for installation of crowns
  - successive joining from front, rear and sides
  - a lot of systems installed before final body join
  - cycle time moving toward 3 days, 3 shifts/day

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Source:
Figure 16-33 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.

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Figure 16-34 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.