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:
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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Unit Cost Example

Unit Assembly Cost by Three Methods

\[ f_{AC} = 0.38 \]
\[ T = 2s \]
\[ L_H = $15/hr \]
\[ S$ = 50000 \]
\[ $/\text{tool} = $10000 \]
\[ N = 10 \text{ parts/unit} \]
\[ w = 0.25 \text{ workers/sta} \]

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Source:
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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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:
Typical Dial Machine

Same principle used by Gillette for Mach 3 razors

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Source:
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:
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

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

Source:
Serial Line with Multiple Stations

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Source:

(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:

(B) GROUPING WORK AT STATIONS IMPROVES BALANCE OF STATION TIMES
Multiple Paths Are Good and Bad

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Source:

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:
Sometimes it Isn’t Possible

Engine Block Machining

- 1.5 hours to make one block
- 3 weeks of finished blocks in about 30 varieties

Car Assembly

- 4 hours notice of need for a particular engine
- 1.5 hours to make one block

Engine Assembly

- ~18-20 hours
- ~1.5 hours

You can make a block quickly enough but not soon enough

400 other parts: 6 are made here. The rest are bought and arrive in boxes
Sub-Delayed Commitment in a Fish Bone Arrangement

DECOUPLING POINT FOR SUBASSEMBLY A

DECOUPLING POINT FOR SOMETHING THAT IS NOT IN ANY SUBASSEMBLY
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

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

- 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 of units / pallet)
- \varepsilon = 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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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:
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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