Flexible Manufacturing Systems

- Goals of this class:
- Understand goals of FMS
- Place FMS in context of manufacturing
- Understand the history
- Take some lessons about appropriate technology

Background

- Batch production - since the Egyptians?
- Mass production - 1880-1960
- Flexible production - ?
- Lean production - since 1970?

More Background

- Manually operated machine tools since 1700s
  - Roger Woodbury "History of the Milling Machine," 1960
- Steam and electric powered machines since 1820s
- Computer-controlled machines since 1960s
- Manufacturing systems awareness since Henry Ford or arguably much earlier

Computers and Manufacturing

- Numerical control of machine tools R&D at MIT, 1950s - see photo gallery along ∞ corridor
  - From WW II gun servos
  - Early 1950s Air Force SAGE system
- Computer-aided design R&D at MIT in the 1960s
  - "If the computer can guide the tool, then it can hold part shape in its memory"

Results of MIT NC Project

- Air Force funding aimed the project at complex parts requiring 5 axis machining
- MIT's response included complex implementation and abstract programming language
- Simple record playback solution rejected
- Useful output mainly benefited the defense industry and had little to offer small business with 2D or 2.5D needs
- Story documented (with exaggerated Marxist interpretation) by David Noble in "Forces of Production," Oxford Univ Press, 1986
- Market gap in small business making simple parts not filled for 2 decades

Numerical Control Technology

- Initially one computer for each machine
- Computer programmed in APT (Automatically Programmed Tool), a language like LOGO
- By the 1970s, a central computer controlled many machines - DNC (direct numerical control)
- By the 1980s each machine had its own computer, possibly loaded with instructions from a central computer - CNC (computer numerical control)

Job Shops and Flow Lines

- Ford style flow lines utilize equipment at a high level but are inflexible and costly
  - Big initial investment requires years to pay back
  - Dedicated to one part or a very limited family
  - At risk if the part is no longer needed
  - One failure stops the whole line
- Job shops are flexible but utilization is low
  - Some asserted that utilization is as low as 5%
  - Machine's time is lost due to setups made on the machine
  - Part's time is lost due to complex routing and queuing
  - Big WIP
- Flexibility can be defined several ways, including
  - Different part mix
  - Different production rate of existing parts
  - Different machines or routing if one breaks

Past Approaches to Utilization Improvement

- Faster changeover AKA SMED
- Reduction of setups
  - Standardization
  - Use of same setup for several parts
- Same setup: Group Technology
  - Classify parts and code them
  - Design generic tooling, fixtures, and processes for each class of part
  - Ignore the differences that do not matter

Ungrouped and Grouped Parts

Images removed due to copyright restrictions.

www.strategosinc.com/ group_technology.htm

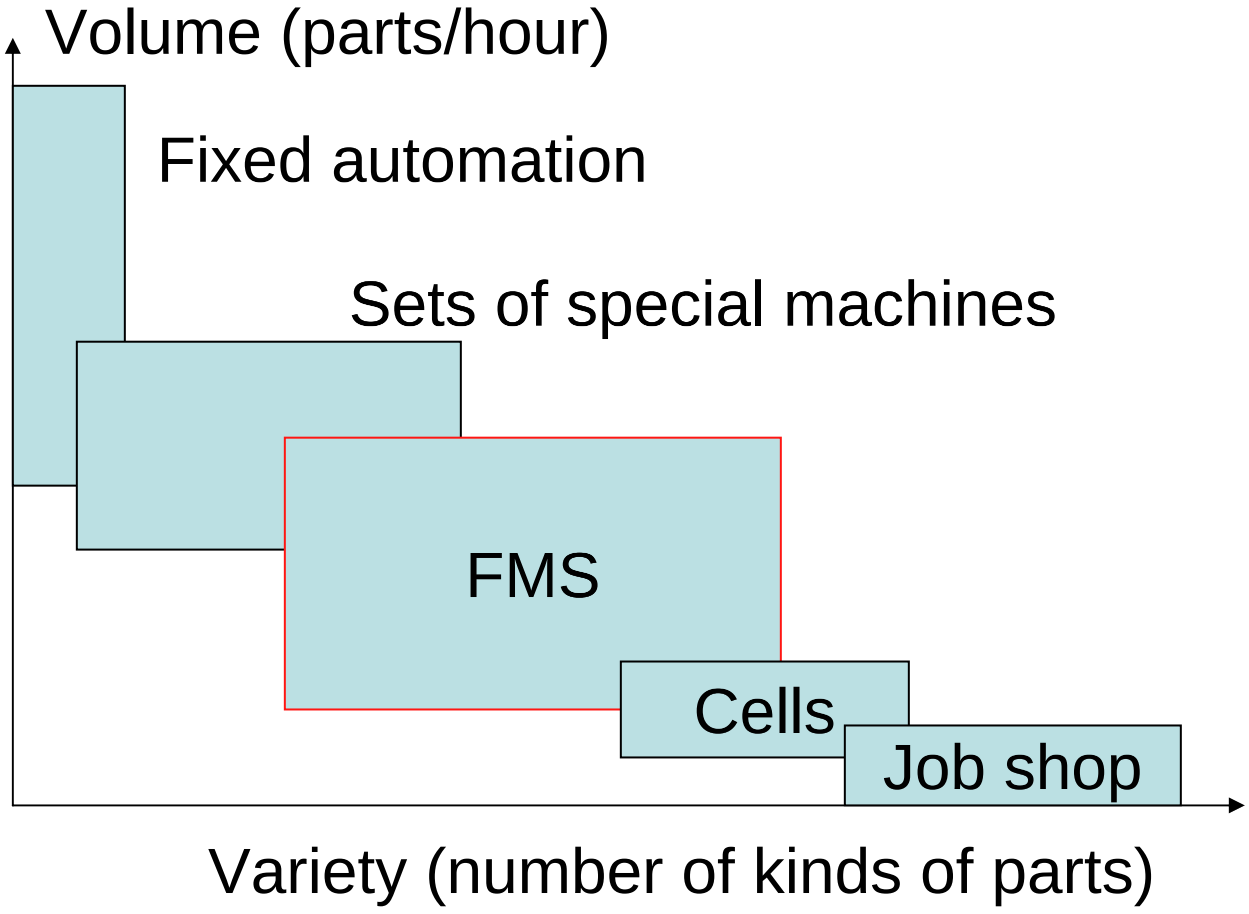
A Misplaced Effort: Adaptive Control

- Adaptive control speeds up a cutting process by adjusting the feed and speed corresponding to material hardness and cutter sharpness
- Without adaptive control the feed and speed have to be reduced to avoid random hard spots breaking the cutting tool
- But speeding up the cutting process just makes the machine finish sooner and makes the utilization gap even more obvious

The Flexible Manufacturing System Idea

- This idea sprang up in several places at once in the mid 1960s
- The basic idea was a computer-controlled job shop with flow line characteristics
- Group technology still important - system aimed at one kind of part, such as prismatic < 2 ft sq, or rotational < 6” diameter
- Computers perform scheduling, routing, and detailed cutter path control
- Pioneering developments by Molins (UK), Cincinnati Milacron and Kearney&Trecker (US), Gildemeister in W. Germany, Fritz Heckert Werkzeugmachinenkombinat in E. Germany
- Dueling patents between Molins and Milacron (Molins won)

Volume and Variety - The Claimed Niche



Early Customers and Partners

- Molins made cigarette-making machines
- Milacron partnered with Ford to make engine blocks in small quantities and many variants
- Gildemeister partnered with Heidelberg Druckmachinen to make printing presses
- Fritz Heckert made machine tools and partnered with its own internal business to make simple Bridgeport-style milling machines

Typical Big NC Machine

Images removed due to copyright restrictions.

http://www.hildebrandmachinery.com

Political/Historical Context

- Context overlays the technological revolution
- Challenge to US manufacturing from overseas, particularly Japan - several “national big projects” in IT and manufacturing in the 70s and 80s
- Defense mentality in politics and government-funded research
- Crisis approach to introducing FMS technology to get government and industry involved in supporting development
- Some hype
- “75% of all US manufacturing occurs in batches of 50 or less”, a “fact” still quoted 40 years later

Claimed FMS Capabilities

- Efficiency (high machine utilization based on off-line setup using optical comparators)
- Flexibility (could be reprogrammed for different parts)
- Capability (could process parts requiring many operations from many machines)
- Scope (could make many different kinds of parts)
- Automation (could be programmed remotely and operated without people)

Requirements to Support Claims

- Rapid programming
- Ability to set up tools and parts off line
- Ability to place parts and tools on machines accurately with respect to machine's coordinate system so that parts, tools, machine and NC program all align
- In general, these were achieved
- Effective scheduling and sequencing of work
- High reliability and uptime
- In general, these turned out to be unanticipated and proved to be serious impediments

Early FMS Implementations - 1970s

- These were big systems with big machines
- Several architectures were tried
- Vendors did not understand system architecture implications or control issues
- Only Milacron had both hardware and software capability
- Technical University of Stuttgart did software and system integration for Gildemeister - observed by Whitney in April, 1976

Molins FMS Patent

Content removed due to copyright restrictions.
Please see:
Williamson. *Automated machine tool installation with storage means*.
US Patent #4,369,563. Filed: October 29, 1970. Issued: January 25, 1983.

Milacron FMS Patent

Content removed due to copyright restrictions.

Please see:

Perry, et al. *Machine tool*.

US Patent #4,309,600. Filed July 5, 1979. Issued January 5, 1982.

Milacron "Circumferential" System

Content removed due to copyright restrictions.
Please see:
Fig 1. Perry, et al. *Machine tool*.
US Patent #4,309,600. Filed July 5, 1979. Issued January 5, 1982.

Tool Changing and Accurate Location of Tools on Machine

Content removed due to copyright restrictions.
Please see:
Fig 8. Perry, et al. *Machine tool*.
US Patent #4,309,600. Filed July 5, 1979. Issued January 5, 1982.

Accurate Coupling of Pallet to Machine

Content removed due to copyright restrictions.
Please see:
Fig 15. Perry, et al. *Machine tool*.
US Patent #4,309,600. Filed July 5, 1979. Issued January 5, 1982.

Control Architecture

Content removed due to copyright restrictions.
Please see:
Fig 20. Perry, et al. *Machine tool*.
US Patent #4,309,600. Filed July 5, 1979. Issued January 5, 1982.

Elements of a Process Plan for a Part

- Features to be machined
- Approach directions needed
- Rough and fine cuts needed to achieve required tolerances and surface finishes
- Sequence of cuts
- Cutting time (feeds and speeds)
- Required tools (kind, shape, size)
- Required machine(s) (dof, strength or stiffness, range of motion…)

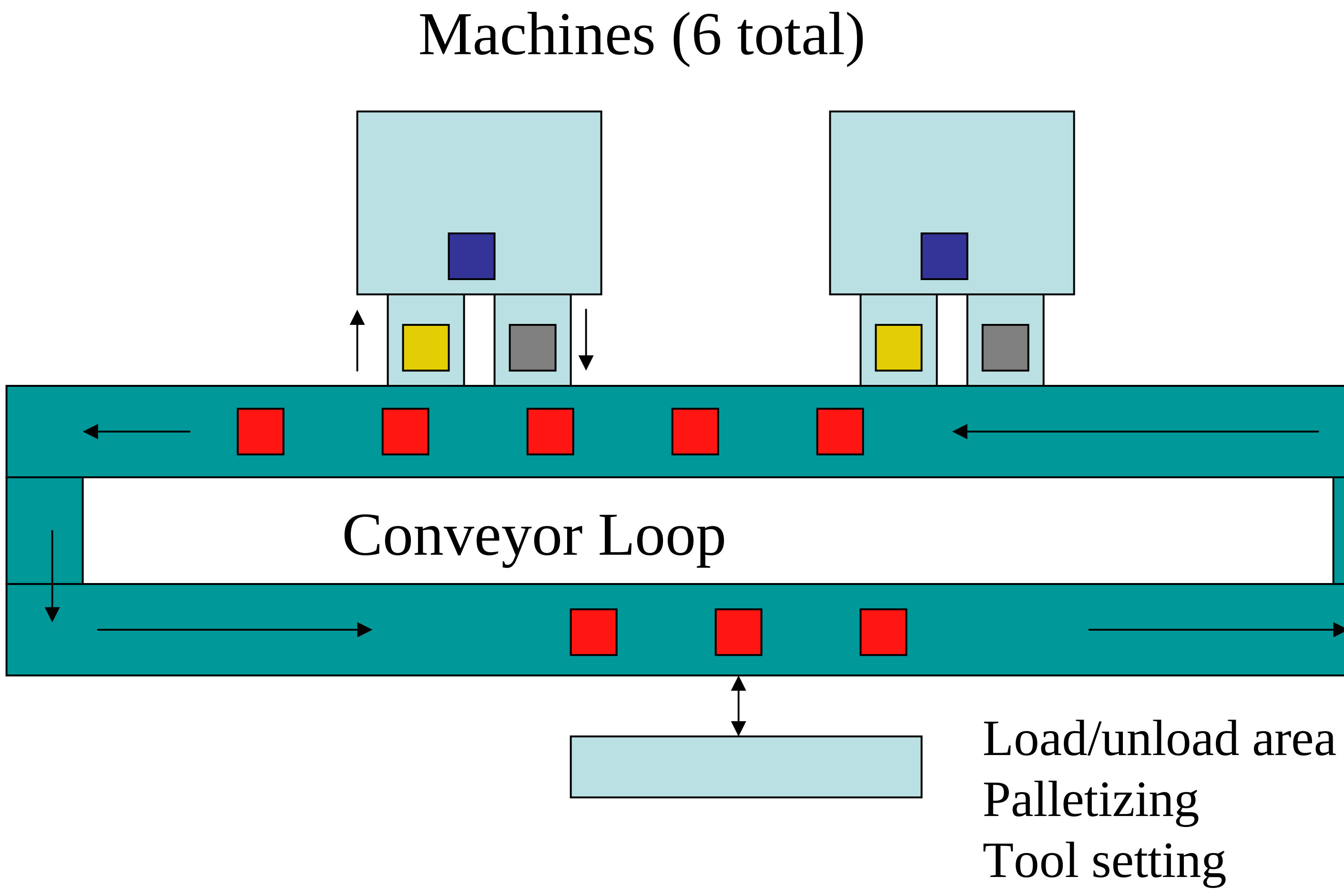
Elements of a Shift's Work

- Get all the parts made
- Keep all the machines busy
- Get the needed tools to the machines
- Get finished parts out and waiting parts into the machines quickly
- Plan the allocation of parts to machines over time
- Replan when a machine breaks or someone wants a special part made
- "We installed the FMS to stop the red telephone"

Successful Architecture

- Ingersoll-Rand system build by Sunstrand; their first FMS
- A loop architecture with traveling pallets
- One piece in-queue and one piece out-queue at each machine
- “The system basically ran itself”

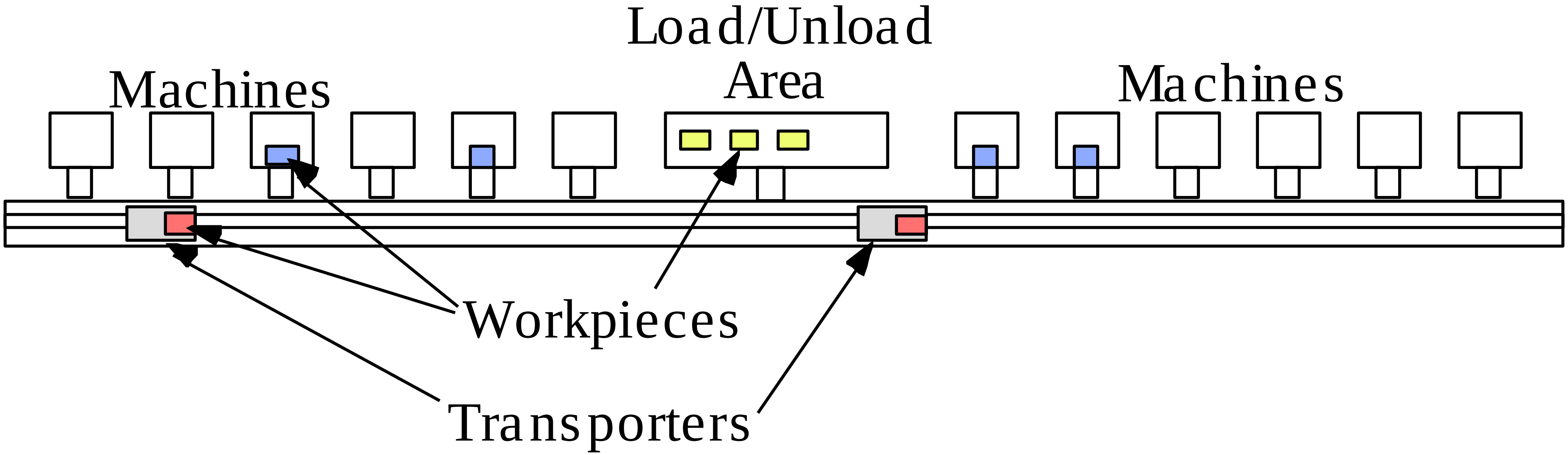
I-R System


Machines (6 total)
Conveyor Loop
Load/unload area
Palletizing
Tool setting

An Unsuccessful Architecture

- In-line system for Caterpillar built by Sunstrand, their next one after the I-R system
- 12 machines in a line
- Two handling carriers on a single rail
- Each carrier could hold one part
- No in- or out-queues, eliminated (@$75K each) to save money
- No idea what operational problems this would cause
- Gave Prof Richard Wysk his PhD in 1977

Caterpillar FMS ~ 1976



Two one-arm paper hangers sharing the same crutch

What Happened

- Early systems were too complex and too flexible
- Too many kinds of parts were tried on one system
- Too many operations were tried on one system
- Too many tools were needed (approx 10 per part at any one station)
- Problem of scheduling and dispatching tools was not anticipated
- Parts could not be inserted randomly but had to be batched - required complex software and optimization algorithms - called production smoothing or load leveling today

PRISMA

- East German system built between 1969 and 1974
- Highly touted by Milacron's chief marketer
- Visited by Nevins and Whitney April, 1976
- Porous partly machined parts on the floor
- Almost no raw castings at the input
- Stacks of finished parts at the output
- General Mgr: "What do you think?"
- Nevins: "Very impressive. Do you plan to make any more?"
- G. M: "No!"

What Happened - 2

- Systems were too expensive
- Systems did not achieve claimed productivity
- Sufficient reliability was not achieved until Japanese applied their methods in the 1980s and 90s
- High reliability -> lights out operation -> high productivity
- Typical FMS applications today are simple and have 3 to 5 machines doing a few operations on a few kinds of parts

Sheet Metal Bending System

Images removed due to copyright restrictions.

www.mt-muratec.com/ eg/p/fms/fms_yuatu.html

Yamazaki Mazak

- Built lights-out factory in mid 1980s to make its products (machine tools) - visited by Whitney in1991
- Addressed tool proliferation with “given tool method”
- Addressed system complexity by breaking up factory into many simple cells having identical tasks, identical machines, and identical tool sets
- Addressed reliability, in part, by reducing cutter depth and speed at night, eliminating tool breakage, the main failure preventing lights-out operation
- “American customers want 120-tool capacity in their tool carousels - ha ha. Japanese companies are happy with 60.”
- Some of this documented by the late Prof Jai Jaikumar of HBS in cases on Yamazaki

http://www.mazak.jp/english/

Fanuc

- Originally a motor company
- Built NC machine in 1956!
- Developed NC technology in 1960s and 70s
- Started building robots in the 1970s
- Applied robot controllers to simple CNC machines in late 1970s with low cost bubble memory and simple graphical controls for programming and simulating and monitoring operations
- Drove US NC controls makers (GE, Honeywell, A-B) out of the market
- Addressed needs of small manufacturers and simple machines for the first time
- Fanuc is still important in the controller and robot markets

http://www.fanuc.co.jp/en/profile/index.htm

Reconfigurable Manufacturing Systems

- Japanese demonstrator system in the 1970s included reconfigurable machine tools
- Current research looks at entirely reconfigurable systems consisting of reconfigurable machines and transport systems (see U of MI RFMS Center)
- Advances in machine design techniques are included
- Economic analysis includes system life cycle(s)

Current Status

- FMS is a niche technology, not the savior of US manufacturing
- It is effective when applied judiciously with limited aims, complexity, and scope
- This is in spite of Jaikumar's paper "Post-Industrial Manufacturing," HBR November-December 1986, which claimed that US firms made less flexible use of FMS than Japanese firms, and that this was bad for US manufacturing