MFS605/EE605
Systems for Factory Information and Control

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• Collect info on name, major, MS/PhD, email
Overview

• **Systems for Factory Information and Control:**

• **Systems:** High-level / abstract view.
• We will:
  – view mfg. as interacting equipment and people
  – examine how to model, analyze, predict, control
  – examine how elements of a manufacturing system
    • interact
    • coordinate
    • communicate

• We will not:
  – consider details of individual machines or processes

Topics

• Introductory Material 1 week
• Mfg Systems: 6 weeks
  – Deterministic Analysis
  – Queuing Analysis
  – Simulation Analysis
• Equipment Control 3 weeks
  – PLCs, Ladder Logic, SFC
• Production and Inventory Control: 2 weeks
  – MRP, JIT/Kanban, OPT
• Communication and Info Topics 1 week
• Student Presentations 1 week
• Total: 14 weeks
Goals for Class

1. Introductory understanding of current issues/methods/technologies
   - wide range of topics
   - mostly emphasis on working familiarity
   - other classes give more depth:
     • production control, simulation, networks, queuing

2. Learn to think critically about material
   - What are pro’s and cons of methods?
   - What would you do better?

Projects:

Semester Project (15%):
   - Report (and possibly oral presentation)
   - Explore in depth some topic relevant to class
   - Examples:
     • Survey literature or methods in depth
     • Do analysis or empirical study
     • Explore alternatives

• Simulation Project (15%):
  - Model, analyze, and simulate system
  - Explore alternatives

• PLC Project (10%)
  - Program and demonstrate a manufacturing control system
Other Grades

- Homeworks (20%) (planned for 6 homeworks)
  - Demonstrate understanding of material
  - May include mini-projects

- Independent Readings (15%):
  - 3 due over semester
  - Find an article relevant to course material
  - Write a brief summary and critique of the article

- Quizzes (10% each – 30% total):
  - 3 quizzes -- (not a full class period)
  - brief quizzes over material covered in class and on homeworks

Types of Manufacturing

- Discrete Manufacturing
  - Parts industries
  - Discrete parts and discrete steps
  - Examples:

- Continuous Manufacturing
  - Process industries
  - Continuous flow of product
  - Examples:
Discrete Manufacturing

• Structure issue:
  – Layout
  – Product flow
  – Resources: people and equipment
  – Capacity

• High-level control issue:
  – What to make, when, how much
  – Job sequencing
  – Managing the needed materials and resources

• Low-level control issue:
  – Low-level sequencing of steps
  – Actuation and sensing

Classification of Discrete Manufacturing

• Mass Production
• Batch Production
• Job Shop
Traditional Classification

- Mass Production:
  - “hard automation”, “Detroit-style automation”
  - low variety, high volume
  - requires specialized equipment, low labor skills
  - low cost production (relatively)

- Batch production:
  - general purpose equipment
  - mid volume

- Job-Shop:
  - low volume (even one-of-a-kind), high variety
  - general purpose equipment, versatile labor

Complexity of control:

Control of production, inventory, equipment

- Mass production: relatively simple
  - make one product, sequence through dedicated equipment

- Batch production:
  - how do we manage use of multiple products and orders flowing through system?
  - How to route materials, product, people?
  - Common problems: high WIP, long lead times

- Job-shop:
  - even more challenging
Changing Marketplace

- Global marketplace requires:
  - more variety of features
    - regional customization, niche customization
    - Examples: Sony—30,000 watches, Phillips > 800 TVs
  - new products faster
    - technology races
    - responses to opportunities, changing tastes
  - quality
    - example: automobiles
      - quality threshold rises
  - value ($$)

- Market requirement: “produce a wide variety of products in a short time with little waste”
  - Requires rethinking of conventional mfg. wisdoms

Productivity Paradox

- Conventional wisdom: The need to cut costs conflicts with need to stay flexible (productivity paradox)
  - More efficiency means more standardization
    - fewer model changes
    - fewer number of models

- Issue: flexible equipment and methods eat away at this wisdom
Responsiveness

- Faster development of designs for changing markets
- Customization of product for increasingly fragmented markets
- Faster introduction of product to market
- Faster fulfillment of orders

• Responsiveness is powerful business tool:
  - example: Trane Corp.
    - Order used to take 30 shifts, now takes 10 hours
    - Premium can be charged for improved response time
  - example: High-tech:
    - new display technologies, new PCs, new disks, etc.
    - Almost no market for same product produced 5 years ago

Problem: mass production isn’t responsive
  - specialized equipment
Problem: job shop is responsive, but only suitable for low volume
Ideal:
  - flexibility of job shop
  - efficiencies of mass production
  - responsiveness to market
How will we achieve better responsiveness?

- How will we get improved responsiveness and variety with reasonable efficiencies?
  - Improved Organization and Control?
    - Layout
    - Organization
    - Production Control
  - Improved coordination?
    - Information technologies - ?
  - Automation?
    - Flexible manufacturing systems (FMS) - ?
    - Computer Integrated Manufacturing (CIM) - ?

Outline Revisited – what we have seen so far

Outline
- Classification of manufacturing:
  - Discrete vs. continuous
  - Mass vs. batch vs. job shop
    - Issues of control, inventory, complexity
- Market demands in manufacturing
  - Cost
  - Quality
  - Responsiveness
  - Variety
  - Tradeoffs among these
- Next – How does the design of a manufacturing system affect these?
Manufacturing as a system

- Cost
- Quality
- Throughput rate
- Lead Time (throughput time)

Demand, Orders → material, machine, man → Product

Manufacturing Terminology

- Basic Terms:
  - Lead time, Throughput rate, WIP, Availability…
  - Bottlenecks, Capacity…

- Layout Classifications
  - Product
  - Process
  - Group Techn.
  - Fixed-position
Manufacturing Lead Time

Manufacturing Lead Time – also called throughput time

- Average total time a product takes to go through our manufacturing system.
- This is the average time from release of a job at the beginning of a routing until it reaches the end.

- Includes:
  - Time in operations
  - Time waiting in Queues
  - Times in non-value operations…

Are non-operation times significant?

- Figures are from late 70’s, but still true in many companies today.
- One of the challenges in manufacturing is to reduce this non-value-added time.
Capacity and Throughput Rate

- **Capacity**: The maximum rate of output that a manufacturing system is able to produce.
  - Example: parts/day, parts/hour, ...

- **Throughput or Throughput rate**: The avg. output of a process per unit time. *Capacity* is the upper limit of this.

- **Utilization (%)** = \( \frac{\text{Throughput rate}}{\text{Capacity}} \)

Utilization of machine vs of system...

Question: Why isn’t Utilization always 100%???

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Example

- A machine can make 10 units per hour. A typical week at this plant has 37 hours of production time. During a typical week, the machine produces 300 good parts.

  - What is the production capacity?

  - What is the throughput rate?

  - What is the utilization?
**Bottlenecks**

- **Bottleneck**: The portion of the system that constrains capacity for the system (least long term capacity).

- What is the system capacity?

- (Additional Terms: Blocking and Starvation)

**Manufacturing Availability**

- Availability indicates the percent of time that a machine is expected to be available for use.

- MTBF = Mean Time Between Failures = average time between breakdowns
- MTTR = Mean Time to Repair = how long before equipment is repaired and back in service

\[
\text{Availability} = \frac{\text{MTBF} - \text{MTTR}}{\text{MTBF}} = \frac{E(\text{uptime})}{E(\text{uptime}) + E(\text{downtime})}
\]

- Example: On average, Machine A operates for 10 hours and is then down for 15 minutes.
  \[\text{Availability} = (10.25 - .25)/10.25 = 97.5\%\]
- Example: Machine B operates for 100 hours before being down for 2.5 hours for repair.
  \[\text{Availability} = (102.5-2.5)/102.5 = 97.5\%\]

What is missing here?
Work In Process

- **Work in process:** Inventory between the start and end points of a process.
  - Includes material in stations and between stations
  - Excludes raw material and finished goods inventory

![Diagram of process flow with stations M1, M2, M3]

- **Need for some WIP:**
  - Parts being processed on machines
  - “Buffer” (isolate) machine interactions
    - Starvation
    - Blocking
    - (more discussion in later class)

Problems with WIP

- **Problems with too much WIP**
  - Ties up capital
  - Long manufacturing lead times (discussed later)
  - Feedback delays
    - Quality issues
    - Example: (Drilled electronic boards)
  - Potential obsolescence
  - Spoilage
    - Example: (Primed engine brackets)

Hinders Responsiveness
Adds Waste
Law 1. Little’s Law:
WIP = Production Rate x Manufacturing Lead Time

Example:
- Production rate is 8 parts/hr. It takes 15 hours (avg.) for part to come through. The avg. WIP is $8 \times 15 = 120$ parts.

Another Example:
- Production rate is 8 parts/hr. It takes 15 hours (avg.) for part to come through. What is the average WIP?
  - The avg. WIP is $8 \times 15 = 120$ parts.
- Production rate is 10 parts/hr. The system has 300 parts in WIP. What is the lead time for a part?
  - Lead time = WIP/Rate = $300/(10/hr) = 30$ hours.
Implication of Little’s Law

\[ \text{WIP} = \text{Production Rate} \times \text{Manufacturing Lead Time} \]

Implications:
- If not near capacity, then increasing WIP increases rate without time increase. (Everything keeps busy).
- If near capacity, then rate cannot increase more – so increasing WIP increases throughput time!

Critical WIP

- **Bottleneck**: constrains capacity for the system (least long term capacity). Let its rate be \( r_b \).

- **Raw Process Time**: \( T_0 \): Sum of average process times of workstations along the line. (Note: this excludes the queue time). This is theoretical minimum Mfg. Lead Time.

- **Critical WIP**: \( W_0 \): WIP s. t. when no variability, we have maximum throughput (\( r_b \)) with minimum time (\( T_0 \))

\[ W_0 = r_b \times T_0 \]

Example (cont.) Suppose M1 takes 7.5 minutes (8 parts/hour), M2 takes 3 minutes, and M3 takes 4.5 minutes. Then, Raw Process Time is 15 minutes.

Critical WIP = \( 8 \times (15/60) = 2 \) parts
(why does this make sense??)
Law 2: Matter is conserved.

- Over time, input must equal output. Otherwise material accumulates, and system is unstable.
- Cannot push material through faster than the slowest process.

3. The Larger the System Scope, the Less Reliable the System.

Suppose each subsystem is available 90%.
If 2 components, then $90\%^2 = 81\%$ system availability.

$\Rightarrow$ To keep the 90% overall, the individual systems would need to be 95% available ---- so doubling system size meant halving downtime of each component!

If 10 components, then $90\%^{10} = 35\%$ system availability.

Suppose each subsystem is available 99%.
If 10 components, then $99\%^{10} = 90\%$ availability
If 100 components, then $99\%^{100} = 37\%$

4. Objects Decay
- Systems do wear, become obsolete, or become unworkable, (even the latest and greatest technologies).
Basic Laws of Manufacturing Systems
(Askin, Standridge 1993)

Law 4: Objects Decay
- Systems do wear, become obsolete, or become unworkable, (even the latest and greatest technologies).

Law 5: Exponential Growth in Complexity
Complexity grows faster than simple rate

Example: 4-state systems.
If we have 5 working together, then we have $4^5 = 1024$ states

Law 8: Limits of Rationality
- People have limits to the amount of complexity they can handle

Problems with Complexity

- Problems with Complexity:
  - Difficulty in maintaining and managing complexity
  - Decreased Reliability
  - “If you can’t make a simple machine work, then you can’t make a more complex one work.
    - -- Throwing technology at problems without understanding them first may be a costly mistake.
**Law 6: Technology Advances**
- We must continually improve and adapt

**Law 7: System Components Appear to Behave Randomly**
- Random times, Random failures, ...
- In this class, we will study both deterministic and random models of systems.
  - Random includes: Queueing analysis and simulations

**Law 9: Combining, Simplifying, and Eliminating Save Time, Money, and Energy**
- Many advantages of lean mfg. are due to simplifying approach.
- Problem: Current technology approaches (CIM) sometimes represent a battle against these laws.
Manufacturing Terminology

- Basic Terms:
  - Throughput, WIP, Availability...
  - Bottlenecks, Capacity...

- Layout Classifications
  - Product
  - Process
  - Group Techn.
  - Fixed-position

Layout

Mixture of variety and volume may influence layout

- Process Layout:
  - each part has unique routing
  - floor divided into functional areas

- Problem: Large transportation and handling times
- Appropriate only if variety so large that there is little commonality between parts flows (job shop).
**Product Layout / Flow Lines:**

- all parts follow same path
- appropriate for mass production, low variety

- Effects on inventory, time, ...

**Group Technology Layout:**

- Different workcells for different parts with common routings
- Issues: Which parts to group?
## General Characteristics of Layout Types

(Askin, Standridge 1993)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Product</th>
<th>Process</th>
<th>Group</th>
<th>Fixed Pos.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput time</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>WIP</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Skill level</td>
<td>Choice</td>
<td>High</td>
<td>Med. High</td>
<td>Mixed</td>
</tr>
<tr>
<td>Product Flexibility</td>
<td>Low</td>
<td>High</td>
<td>Med. High</td>
<td>High</td>
</tr>
<tr>
<td>Demand Flexibility</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Machine Utilization</td>
<td>High</td>
<td>Med-low</td>
<td>Med-High</td>
<td>Medium</td>
</tr>
<tr>
<td>Worker Utilization</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Unit cost</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

## Outline

- Classification of manufacturing:
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- Market demands in manufacturing
  - Cost
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  - Responsiveness
  - Variety
  - Tradeoffs among these
- Manufacturing Terminology
  - WIP, Bottlenecks, Throughput rate, lead time, ....
- Relationship between WIP, Rate, Time
- Basic laws/principals to consider
- Layout basics: product, process, group technology