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**MFS605/EE605**  
**Systems for Factory Information and Control**

Fall 2004

Larry Holloway  
Dept. of Electrical Engineering and  
Center for Robotics and Manufacturing Systems

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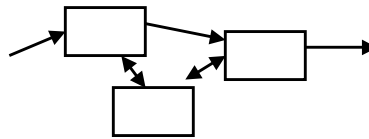
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- Collect info on name, major, MS/PhD, email

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## Overview

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- **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

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## Topics

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

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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?

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## Projects:

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- 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

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## Other Grades

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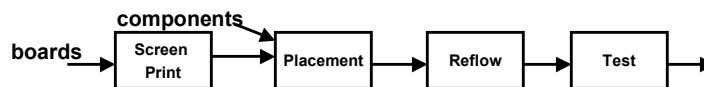
- **Homeworks (20%) (planned for 6 homeworks)**
  - Demonstrate understanding of material
  - May include mini-projects
- **Independent Readings (15%):**
  - 3 due over semester
  - Find an article relevant to course material
  - Write a brief summary and critique of the article
- **Quizzes (10% each – 30% total):**
  - 3 quizzes -- (not a full class period)
  - brief quizzes over material covered in class and on homeworks

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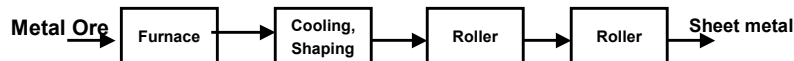
## Types of Manufacturing

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



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



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## Discrete Manufacturing

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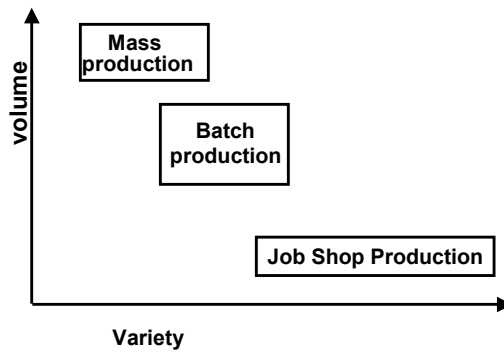
- **Structure issue:**
  - Layout
  - Product flow
  - Resources: people and equipment
  - Capacity
- **High-level control issue:**
  - What to make, when, how much
  - job sequencing
  - managing the needed materials and resources
- **Low-level control issue:**
  - low-level sequencing of steps
  - Actuation and sensing

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## Classification of Discrete Manufacturing

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- Mass Production
- Batch Production
- Job Shop



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## **Traditional Classification**

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- **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

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## **Complexity of control:**

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**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

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## Changing Marketplace

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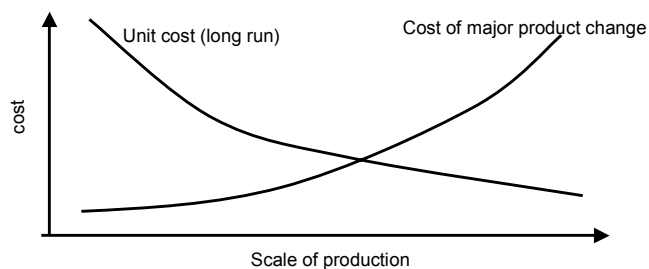
- **Global marketplace requires:**
  - **more variety of features**
    - regional customization, niche customization
    - Examples: Sony—30,000 watches, Phillips > 800 TVs
  - **new products faster**
    - technology races
    - responses to opportunities, changing tastes
  - **quality**
    - example: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

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## Productivity Paradox

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- **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**

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## Responsiveness

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### 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

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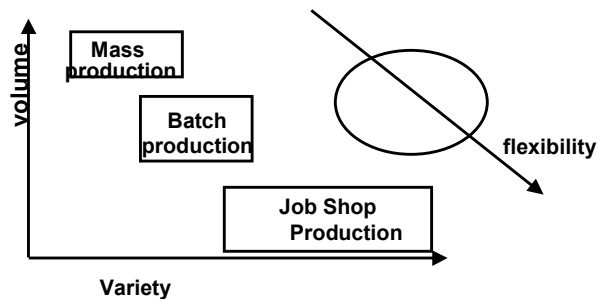
### **Problem: mass production isn't responsive**

- 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



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## How will we achieve better responsiveness?

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- 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) - ?

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## Outline Revisited – what we have seen so far

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### Outline

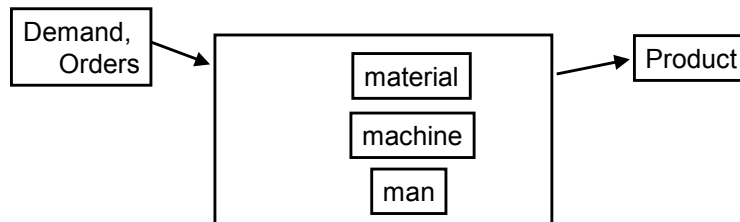
- Classification of manufacturing:
  - Discrete vs. continuous
  - Mass vs. batch vs. job shop
    - Issues of control, inventory, complexity
- Market demands in manufacturing
  - Cost
  - Quality
  - Responsiveness
  - Variety
  - Tradeoffs among these
- Next – How does the design of a manufacturing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

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## Manufacturing as a system

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



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## Manufacturing Terminology

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- **Basic Terms:**
  - Lead time, Throughput rate, WIP, Availability...
  - Bottlenecks, Capacity...
- **Layout Classifications**
  - Product
  - Process
  - Group Techn.
  - Fixed-position

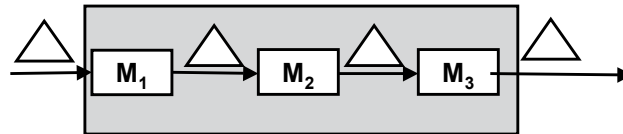
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## Manufacturing Lead Time

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**Manufacturing Lead Time** – also called throughput time

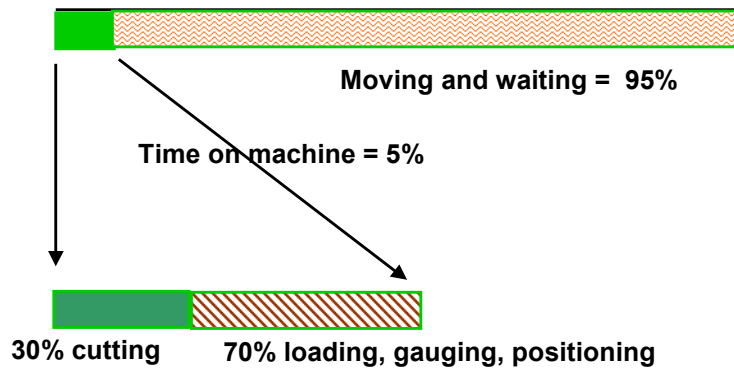
- Average total time a product takes to go through our manufacturing system.
- This is the average time from release of a job at the beginning of a routing until it reaches the end.
- Includes:
  - Time in operations
  - Time waiting in Queues
  - Times in non-value operations...



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## Are non-operation times significant?

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- 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.

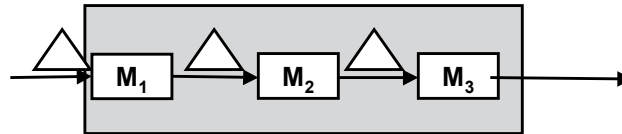
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## Capacity and Throughput Rate

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- **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

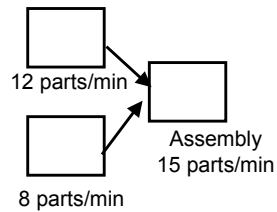
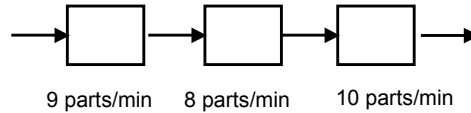
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- A machine can make 10 units per hour. A typical week at this plant has 37 hours of production time. During a typical week, the machine produces 300 good parts.
  - What is the production capacity?
  - What is the throughput rate?
  - What is the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

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## 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*)

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## 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.

$$\text{Availability} = (102.5 - 2.5) / 102.5 = 97.5\%$$

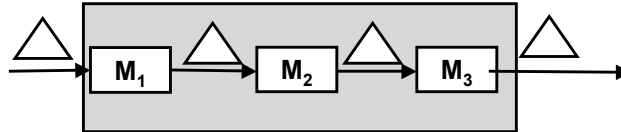
What is missing here?

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## Work In Process

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- **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



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

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## Problems with WIP

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- **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

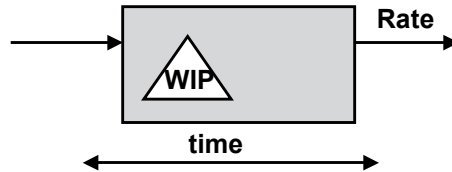
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## Basic Laws of Manufacturing Systems

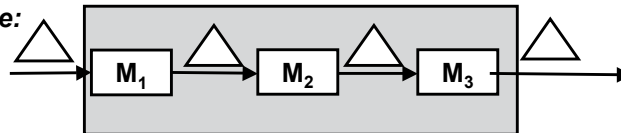
(Askin, Standridge 1993)

### Law 1. Little's Law:

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



### 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.

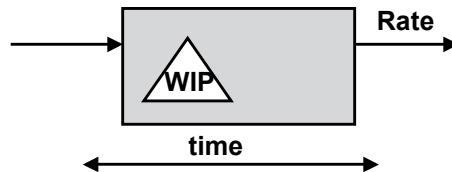
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## Basic Laws of Manufacturing Systems

(Askin, Standridge 1993)

### Law 1. Little's Law:

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



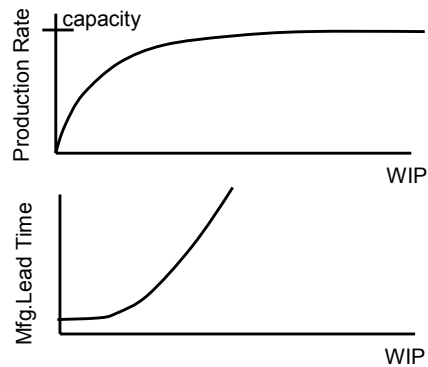
### Another Example:

- 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 =  $\text{WIP}/\text{Rate} = 300/(10/\text{hr}) = 30$  hours.

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## 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!

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## 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 ( $T_0$ )

$$W_0 = r_b T_0$$

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??)

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## Basic Laws of Manufacturing Systems

(Askin, Standridge 1993)

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### 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.



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## Basic Laws of Manufacturing Systems

(Askin, Standridge 1993)

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### 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.

→ 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).

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## **Basic Laws of Manufacturing Systems**

(Askin, Standridge 1993)

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### **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**

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## **Problems with Complexity**

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- **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.

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**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

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• **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.

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## Manufacturing Terminology

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- **Basic Terms:**
  - Throughput, WIP, Availability...
  - Bottlenecks, Capacity...
- **Layout Classifications**
  - Product
  - Process
  - Group Techn.
  - Fixed-position

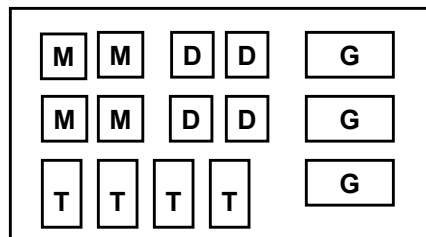
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## Layout

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Mixture of variety and volume may influence layout

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



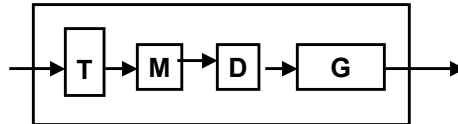
- **Problem:** Large transportation and handling times
- **Appropriate only if variety so large that there is little commonality between parts flows (job shop).**

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## Product Layout / Flow Lines:

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



- Effects on inventory, time, ...

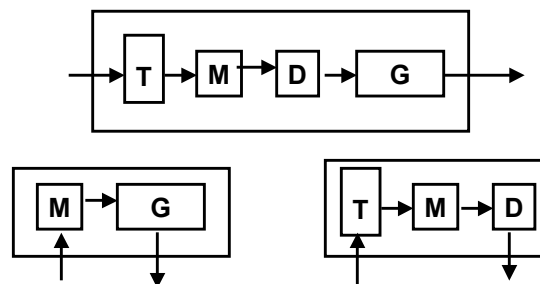
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## Group Technology Layout:

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### Group Technology Layout:

- Different workcells for different parts with common routings
- Issues: Which parts to group?



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## General Characteristics of Layout Types

(Askin, Standridge 1993)

Characteristic	Product	Process	Group	Fixed Pos.
Throughput time	Low	High	Low	Medium
WIP	Low	High	Low	Medium
Skill level	Choice	High	Med. High	Mixed
Product Flexibility	Low	High	Med. High	High
Demand Flexibility	Medium	High	Medium	Medium
Machine Utilization	High	Med-low	Med-High	Medium
Worker Utilization	High	High	High	Medium
Unit cost	Low	High	Low	High

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## Outline

### 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
- **Manufacturing Terminology**
  - WIP, Bottlenecks, Throughput rate, lead time, ....
- **Relationship between WIP, Rate, Time**
- **Basic laws/principals to consider**
- **Layout basics: product, process, group technology**

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