MIT 2.852
Manufacturing Systems Analysis
Lecture 1: Overview

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Books

- Required
  - *Manufacturing Systems Engineering* (MSE) by Stanley B. Gershwin
  - ... obtainable from author.
- Optional
  - *Factory Physics* by Hopp and Spearman
  - *The Goal* by Goldratt
  - *Stochastic Models of Manufacturing Systems* by Buzacott and Shanthikumar
  - *Production Systems Engineering* by Li and Meerkov

Course Overview
Goals

- To explain important measures of system performance.
- To show the importance of random, potentially disruptive events in factories.
- To give some intuition about behavior of these systems.
- To describe some current tools and methods.

Problems

- Manufacturing systems engineering is not as well-developed as most other fields of engineering.
- Practitioners are encouraged to rely on gurus, slogans, and black boxes.
- There is a gap between theoreticians and practitioners.

Problems

- The research literature does not always focus on real-world problems
  - ... but practitioners are often unaware of what does exist.
- Terminology, notation, basic assumptions are not standardized.
- There is a separation of product, process, and system design.

Problems

- Confusion about objectives:
  - *maximize capacity?*
  - *minimize capacity variability?*
  - *maximize capacity utilization?*
  - *minimize lead time?*
  - *minimize lead time variability?*
  - *maximize profit?*
- Systems issues are often studied last, if at all.

Problems

- Manufacturing gets no respect.
  - *Systems not designed with engineering methods.*
  - *Product designers and sales staff are not informed of manufacturing costs and constraints.*
- Black box thinking.
  - *Factories not treated as systems to be analyzed and engineered.*
  - *Simplistic ideas often used for management and design.*

Problems

Reliable systems intuition is lacking. As a consequence, there is ...

- Management by software
  - *Managers buy software to make production decisions, rather than to aid in making decisions.*
- Management by slogan
  - *Gurus provide simple solutions which sometimes work. Sometimes.*

Observation

- *When a system is not well understood, rules proliferate.*
- This is because rules are developed to regulate behavior.
- But the rules lead to unexpected, undesirable behavior. *(Why?)*
- New rules are developed to regulate the new behavior.
- Et cetera.

Observation
Example

- A factory starts with one rule: *do the latest jobs first* .
- Over time, more and more jobs are later and later.
- A new rule is added: *treat the highest priority customers orders as though their due dates are two weeks earlier than they are.*
- The low priority customers find other suppliers, but the factory is still late.

Observation
Example

Why?

- There are significant setup times from part family to part family. If setup times are not considered, changeovers will occur too often, and waste capacity.
- Any rules that that do not consider setup times in this factory will perform poorly.

Definitions

- *Manufacturing:* the transformation of material into something useful and portable.
- *Manufacturing System:* A manufacturing system is a set of machines, transportation elements, computers, storage buffers, people, and other items that are used together for manufacturing. These items are *resources.*

Definitions

- *Manufacturing System:*
  - Alternate terms:
    - *Factory*
    - *Production system*
    - *Fabrication facility*
  - Subsets of manufacturing systems, which are themselves systems, are sometimes called *cells, work centers,* or *work stations* .

Basic Issues

- Increasingly, there are ...
  - frequent new product introductions, and
  - short product lifetimes, and
  - short process lifetimes.
- Consequently, ...
  - factories are built and rebuilt frequently, and
  - there is not much time to tinker with a factory. It must be operational quickly.

- Tools to predict performance of proposed factory design.
- Tools for optimal real-time management (control) of factories.
- Manufacturing Systems Engineering professionals who understand factories as complex systems.

- Quantity – how much and when.
- Quality – how well.

In this course, we emphasize *quantity*.

General Statement: Variability is the enemy of manufacturing.

General Statement: Know your enemy!

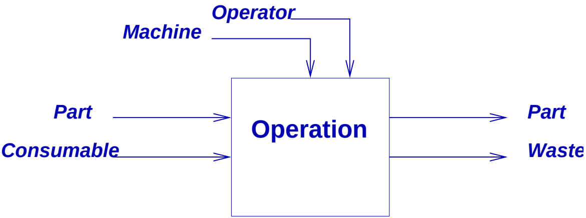
- Make to Stock (Off the Shelf):
  - items available when a customer arrives
  - appropriate for large volumes, limited product variety, cheap raw materials
- Make to Order:
  - production started only after order arrives
  - appropriate for custom products, low volumes, expensive raw materials

- Make to Stock:
  - large finished goods inventories needed to prevent stockouts
  - small finished goods inventories needed to keep costs low
- Make to Order:
  - excess production capacity *(low utilization)* needed to allow early, reliable delivery promises
  - minimal production capacity *(high utilization)* needed to to keep costs low

Basic Issues
Concepts

- *Complexity:* collections of things have properties that are non-obvious functions of the properties of the things collected.
- *Non-synchronism (especially randomness) and its consequences:* Factories do not run like clockwork.

Basic Issues
What is an Operation?



Nothing happens until <u>everything</u> is present.

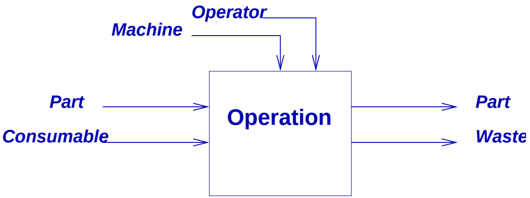
Basic Issues

Waiting

Whatever does not arrive last must wait.

- *Inventory:* parts waiting.
- *Underutilization:* machines waiting.
- *Idle work force:* operators waiting.

Basic Issues
Causes of Poor Performance

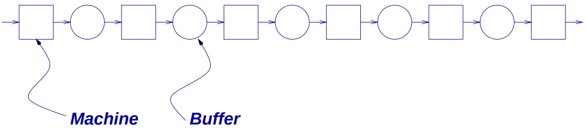


- *Reductions* in the availability, or ...
- *Variability* in the availability ...

... of any one of these items causes waiting in the rest of them and reduces performance of the system.

Kinds of Systems
Flow shop

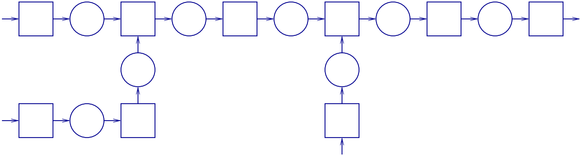
... or *Flow line* , *Transfer line* , or *Production line.*



Traditionally used for high volume, low variety production.

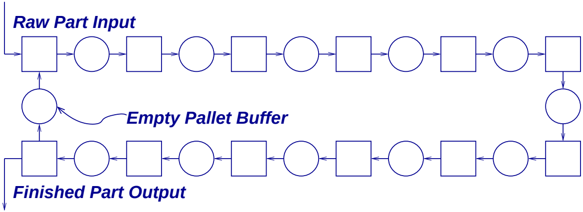
What are the buffers for?

Kinds of Systems
Assembly system



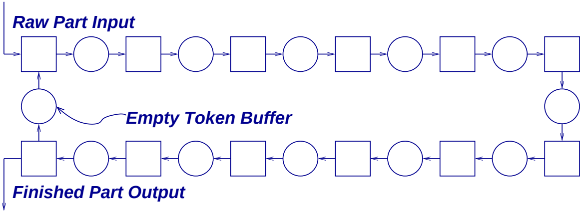
Assembly systems are *trees,* and may involve *thousands* of parts.

Limited number of pallets or fixtures:



- Pallets or fixtures travel in a closed loop. Routes are determined. The number of pallets in the loop is constant.
- Pallets or fixtures take up space and may be expensive.

Limited number of tokens:

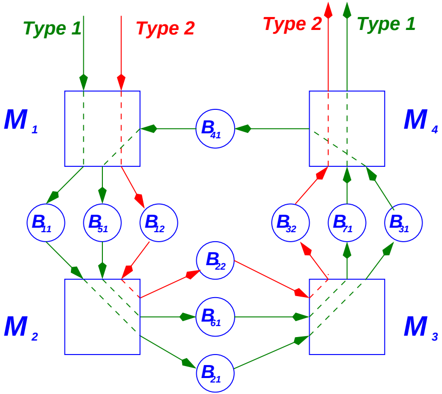


- Tokens travel in a closed loop. Routes are determined. The number of pallets in the loop is constant.
- Tokens take up *no space* and cost nothing.

What are the tokens for?

Loops

Reentrant *(2)*



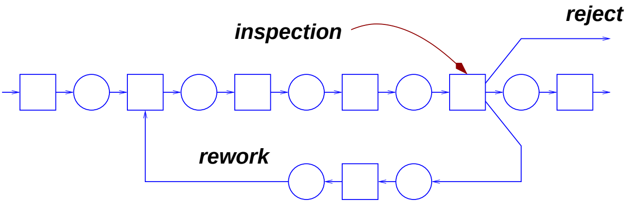
System with reentrant flow and two part types

Routes are determined. The number of parts in the loop varies.

Semiconductor fabrication is highly reentrant.

Loops

Rework loop *(3)*



Routes are random. The number of parts in the loop varies.

Kinds of Systems
Job shop

- Machines not organized according to process flow.
- Often, machines grouped by department:
  - mill department
  - lathe department
  - etc.
- Great variety of products.
- Different products follow different paths.
- Complex management.

Two Issues

- Efficient design of systems;
- Efficient operation of systems after they are built.

Time

- Most factory performance measures are about time.
  - *production rate:* how much is made in a given time.
  - *lead time:* how much time before delivery.
  - *cycle time:* how much time a part spends in the factory.
  - *delivery reliability:* how often a factory delivers on time.
  - *capital pay-back period:* the time before the company get its investment back.

Time

- Time appears in two forms:
  - delay
  - capacity utilization
- Every action has impact on both.

Time
Delay

- An operation that takes 10 minutes adds 10 minutes to the *delay* that
  - a workpiece experiences while undergoing that operation;
  - every other workpiece experiences that is waiting while the first is being processed.

- An operation that takes 10 minutes takes up 10 minutes of the available time of
  - a machine,
  - an operator,
  - or other resources.
- Since there are a limited number of minutes of each resource available, there are a limited number of operations that can be done.

- *Operation Time:* the time that a machine takes to do an operation.
- *Production Rate:* the average number of parts produced in a time unit. (Also called *throughput.*)

If nothing interesting ever happens (no failures, etc.),

$$\text{Production rate} = \frac{1}{\text{operation time}}$$

... but something interesting *always* happens.

- *Capacity:* the maximum possible production rate of a manufacturing system, for systems that are making only one part type.
    - *Short term capacity:* determined by the resources available right now.
    - *Long term capacity:* determined by the average resource availability.
- Capacity is harder to define for systems making more than one part type. Since it is hard to define, it is *very* hard to calculate.

- *Uncertainty:* Incomplete knowledge.
- *Variability:* Change over time.
- *Randomness:* A specific kind of incomplete knowledge that can be quantified and for which there is a mathematical theory.

Randomness, Variability, Uncertainty

- Factories are full of random events:
  - machine failures
  - changes in orders
  - quality failures
  - human variability
- The economic environment is uncertain
  - demand variations
  - supplier unreliability
  - changes in costs and prices

Randomness, Variability, Uncertainty

Therefore, factories should be

- designed as reliably as possible, to minimize the *creation* of variability;
- designed with shock absorbers, to minimize the *propagation* of variability;
- operated in a way that minimizes the *creation* of variability;
- operated in a way that minimizes the *propagation* of variability.

Randomness, Variability, Uncertainty

- Therefore, all engineers should know probability...
  - *especially manufacturing systems engineers* .

- Probability is an important prerequisite for this course.

- *Reading:* Mainly Chapters 2–9 of *MSE* . (Chapter 9 up to 9.3.)
- *Grading:* project and class participation.
- Homework optional.

The Course
Topics

- Probability
  - Basics, Markov processes, queues, other examples.
- Transfer lines
  - Models, exact analysis of small systems, approximations of large systems.
- Extensions of transfer line models
  - Assembly/disassembly, loops, system optimization
- Real-time scheduling
- Quality/Quantity interactions
- New material

The Course

- Emphasis on mathematical modeling and analysis.
- Emphasis on intuition.
- *Comparison with 2.854:* Narrower and deeper.

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