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Introduction to Manufacturing Systems

Manufacturing Systems Overview

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HP Printer Case

Background

- In 1993, the ink-jet printer market was taking off explosively, and manufacturers were competing intensively for market share.
- Manufacturers could sell all they could produce. Demand was much greater than production capacity.
- Hewlett Packard was designing and producing its printers in Vancouver, Washington (near Portland, Oregon).

HP Printer Case

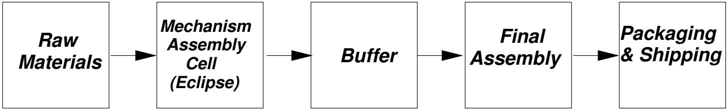
HP's needs

- Maintain quality.
- Meet increased demand *and* increase market share.
  - *Target: 300,000 printers/month.*
  - *Capacity with existing manual assembly: 200,000 printers/month.*
- Meet profit and revenue targets.
- Keep employment stable.

HP Printer Case

Printer Production

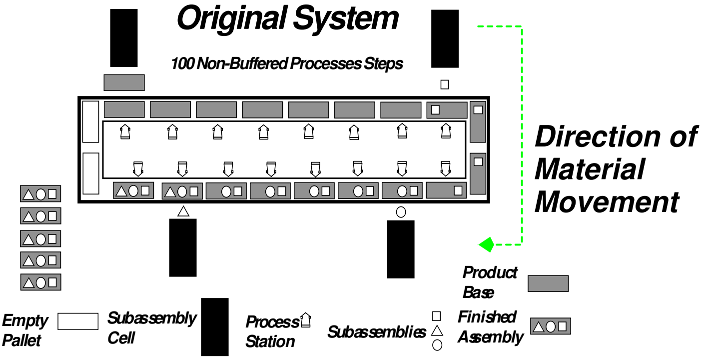
HP invested $25,000,000 in "Eclipse," a new system for automated assembly of the print engine.



Two Eclipses were installed.

HP Printer Case

Printer Production



Design philosophy: minimal — essentially zero — buffer space.

Images from "Hewlett-Packard Uses Operations Research to Improve the Design of a Printer Production Line," Interfaces, Volume 28, Number 1, January-February, 1998. pp. 24-26; (c) Copyright 2018 INFORMS. All Rights Reserved.

HP Printer Case

The Problem

- Machine efficiencies[1] were estimated to be about .99.
- Operation times were estimated to be 9 seconds, and constant.
  - ⋆ Consequently, the total production rate was estimated to be about 370,000 units/month.
- BUT data was collected when the first two machines were installed:
  - ⋆ Efficiency was less than .99.
  - ⋆ Operation times were variable, often greater than 9 seconds.

Actual production rate would be about 125,000 units/month.

[1] *(to be defined)*

HP Printer Case

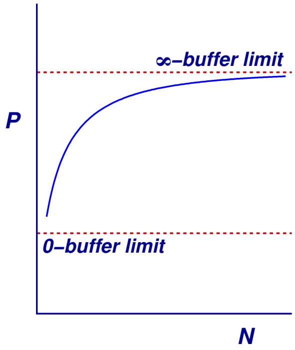
The Problem

- HP tried to analyze the system by simulation. They consulted a vendor, but the project appeared to be too large and complex to produce useful results in time to affect the system design.
  - ⋆ *This was because they tried to include too much detail.*
- Infeasible changes: adding labor, redesigning machines.

HP Printer Case

The Solution

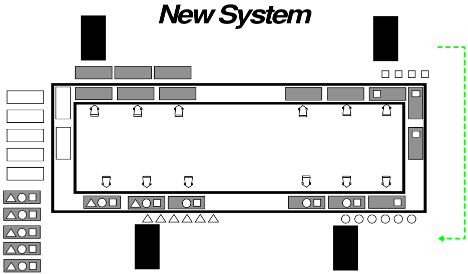
- Feasible change: visiting researcher proposed adding *a small amount* of buffer space within Eclipse.



- Design and analysis tools: *described in the second part of this course.*

HP Printer Case

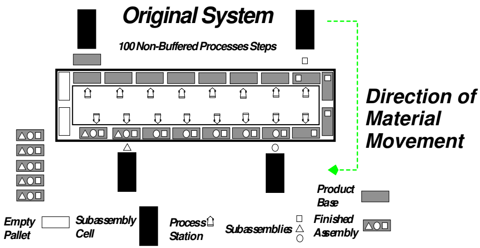
The Solution

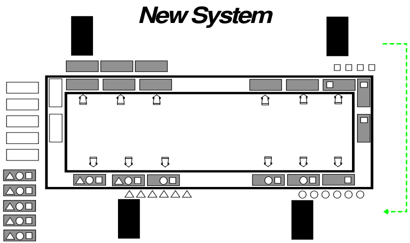


- Empty pallet buffer.
- WIP *(work in process)* space between subassembly lines and main line.
- WIP space on main line.
- Buffer sizes were large enough to hold about 30 minutes worth of material. This is a small multiple of the mean time to repair (MTTR) of the machines.

HP Printer Case

Comparison





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HP Printer Case

Consequences

- Increased factory capacity — to over 250,000 units/month.
- Capital cost of changes was about \$1,400,000.
- Incremental revenues of about \$280,000,000.
- Labor productivity increased by about 50%.

HP Printer Case

Reasons for Success

- Early intervention (before too much of the system was built).
- Rapid response by visiting researcher was possible because much research work had already been done.
- HP managers' flexibility.
- The new analysis tool was fast, easy to use, and was at the right level of detail.
  - ⋆ It only dealt with important features of the system.
  - ⋆ It did not require much data.

Course Overview

Message

- Manufacturing systems can be understood like any complex engineered system.

- Engineers must have intuition about these systems in order to design and operate them most effectively.

- Such intuition can be developed by studying the elements of the system and their interactions.

- Using intuition and appropriate design tools can have a big payoff.

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 and justify some quantitative tools and methods.
- But *not* to describe all current common-sense approaches.

Approach

- To focus on important factory phenomena that can be analyzed quantitatively.
- To develop or describe mathematical models of these phenomena.
- To study the required mathematics, only as deeply as needed.

Problems

- Manufacturing System Engineering (MSE) is not as advanced as other branches of engineering.

- Practitioners are sometimes encouraged to rely on slogans or black boxes.

- A gap exists between theoreticians and practitioners.

Problems

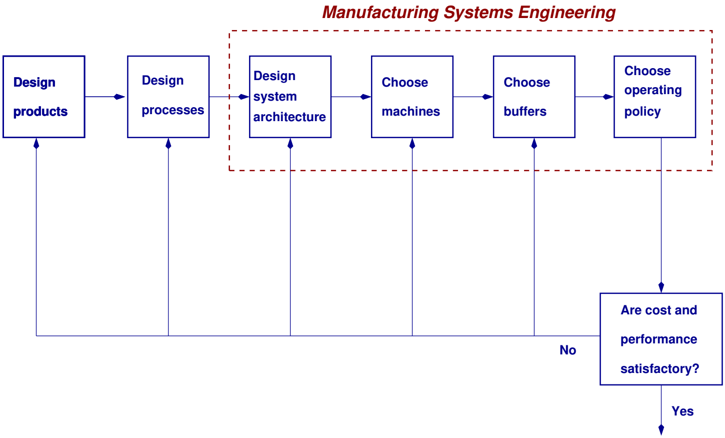
- The research literature is incomplete,
  - ... but practitioners are often unaware of what does exist.
- Terminology, notation, basic assumptions are not standardized.
- There is typically a separation of product, process, and system design.
  - They should be done simultaneously or iteratively, *not* sequentially.

Problems

- Confusion about objectives:
  - ⋆ *maximize capacity?*
  - ⋆ *minimize capacity variability?*
  - ⋆ *maximize capacity utilization?*
  - ⋆ *minimize lead time?*
  - ⋆ *minimize lead time variability?*
  - ⋆ *maximize profit?*

Product Realization

Products, Processes, Machines, Buffers,and Operating Policy



Rule proliferation

- *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.

Rule proliferation

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.
- *Why?*

Rule proliferation
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 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.*

  - 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

- Frequent new product introductions.
- Product lifetimes often short.
- Process lifetimes often short.

This leads to frequent building and rebuilding of factories.

There is little time for improving the factory after it is built; it must be built right.

Basic Issues

Consequent Needs

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

Basic Issues

Quantity, Quality, and Variability

- Design Quality – the design of products that give customers what they want or would like to have *(features).*
  - Examples: Fuel economy in cars. Advanced electronics, attractive styling in cell phones.

- Manufacturing Quality – the manufacturing of products to *avoid* giving customers what they *don't* want or *would not* like to have *(bugs).*
  - Examples: Exploding airbags in cars. Exploding batteries in cell phones.

This course is about manufacturing, *not* product design.

Basic Issues
Quantity, Quality, and Variability

- Quantity – *how much* is produced and *when* it is produced.

- Quality – *how well* it is produced.

In this course, we focus *mostly* on *quantity*.

General Statement: Variability is the enemy of manufacturing.

Basic Issues

Styles for Demand Satisfaction

- 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

Basic Issues

Conflicting Objectives

- Make to Stock:
  - ⋆ large finished goods inventories needed to prevent stockouts
  - ⋆ small finished goods inventories needed to keep costs low

Basic Issues

Conflicting Objectives

- 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

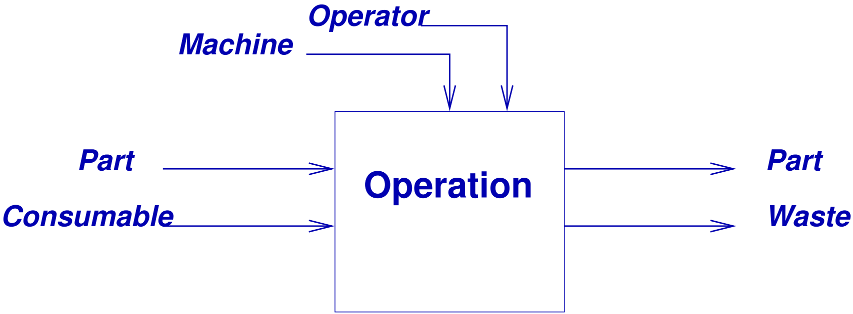
Concepts

- *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

Operation



Nothing happens until everything is present.

Basic Issues

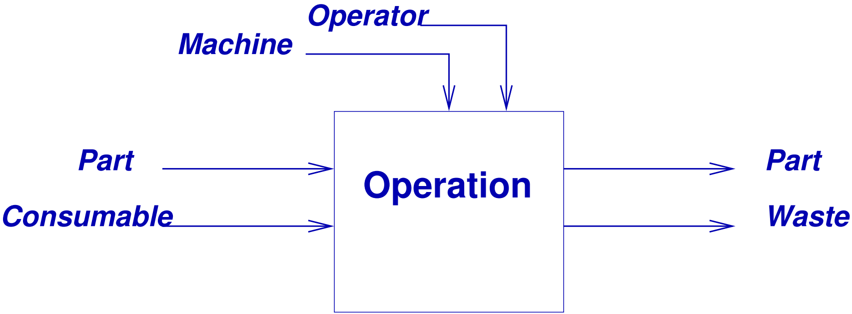
Waiting

Whatever does not arrive last must wait.

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

Basic Issues

Waiting



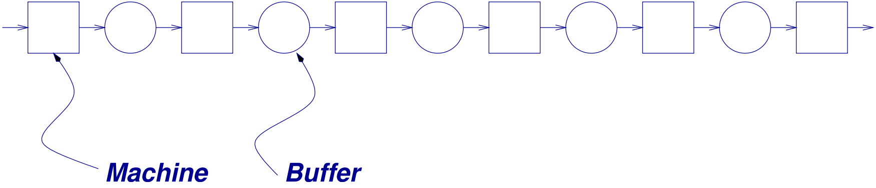
- *Reductions* in the availability, or ...
- *Increased variability* in the availability ...

... of any one of these items increases 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.*

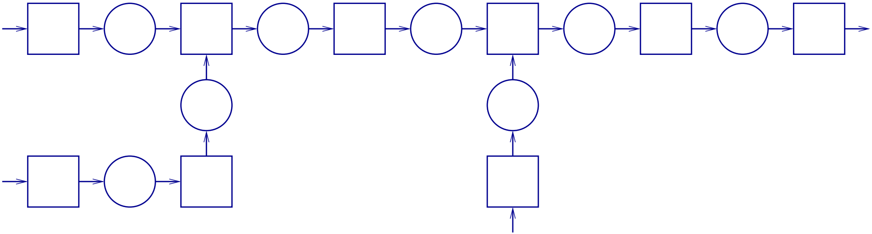


Traditionally used for high volume, low variety production.

What are the buffers for?

Kinds of Systems

Assembly system

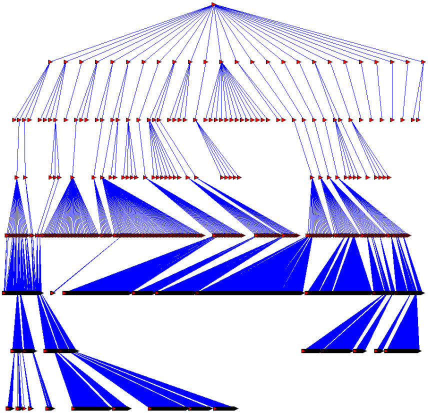


Assembly systems are *trees* , and may involve *thousands* of parts.

Kinds of Systems

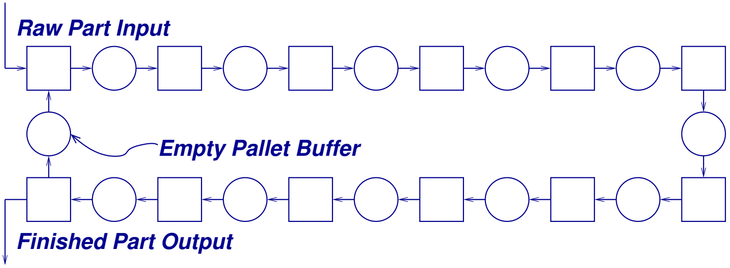
Assembly system

Bill of Materials of a large electronic product



Kinds of Systems — Loops

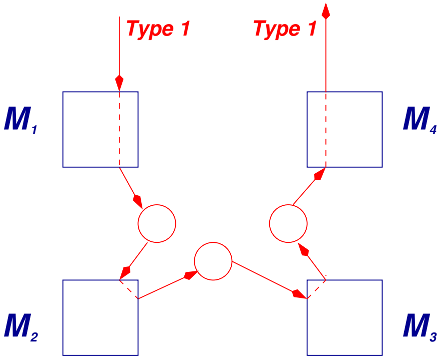
Closed loop *(1)*



Pallets or fixtures travel in a closed loop. Routes are determined. The number of pallets in the loop is constant.

Kinds of Systems — Loops

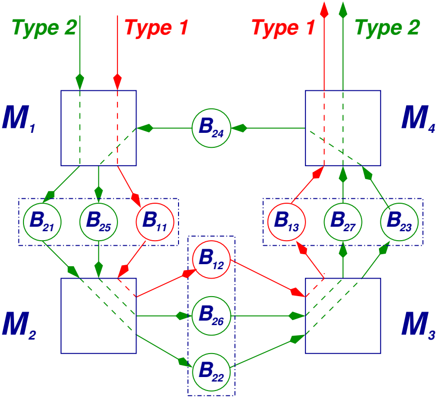
Reentrant loops *(2)*



Kinds of Systems — Loops

Reentrant loops *(2)*

System with reentrant flow and two part types

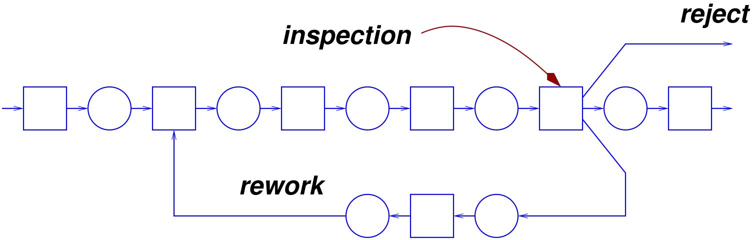


Routes are determined. The number of parts in the loop varies.

Semiconductor fabrication is highly reentrant.

Kinds of Systems — 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.

Time

- Many factory performance measures are about time, such as

  - *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

Even inventory can be described in time units:

"we are holding x weeks of inventory"

means

"customer demand could consume all our inventory in x weeks."

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.
- A machine stoppage that lasts 10 minutes adds 10 minutes to the delay that
  - ⋆ every workpiece that is waiting to be processed at that machine experiences.
  - ⋆ Machine stoppages are caused by failures, maintenance, blocking, starvation, set-up changes and other causes.
- The sum of all the delays that a part experiences during production is the extra time that a part spends in a factory beyond the time required for its operations.
  - ⋆ That is often between 10 and 100 times the total operation time.

Time

Capacity Utilization

- An operation that takes 10 minutes takes up 10 minutes of the available time of
  - a machine,
  - an operator,
  - or other resources.
- Similarly for machine stoppages.
- Since there are a limited number of minutes of each resource that are available in a day, there are a limited number of operations that can be done in a day.
- In other words, this is the limit on the factory's production rate.

Time

Production Rate

- *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.

Time

Capacity

- *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.

