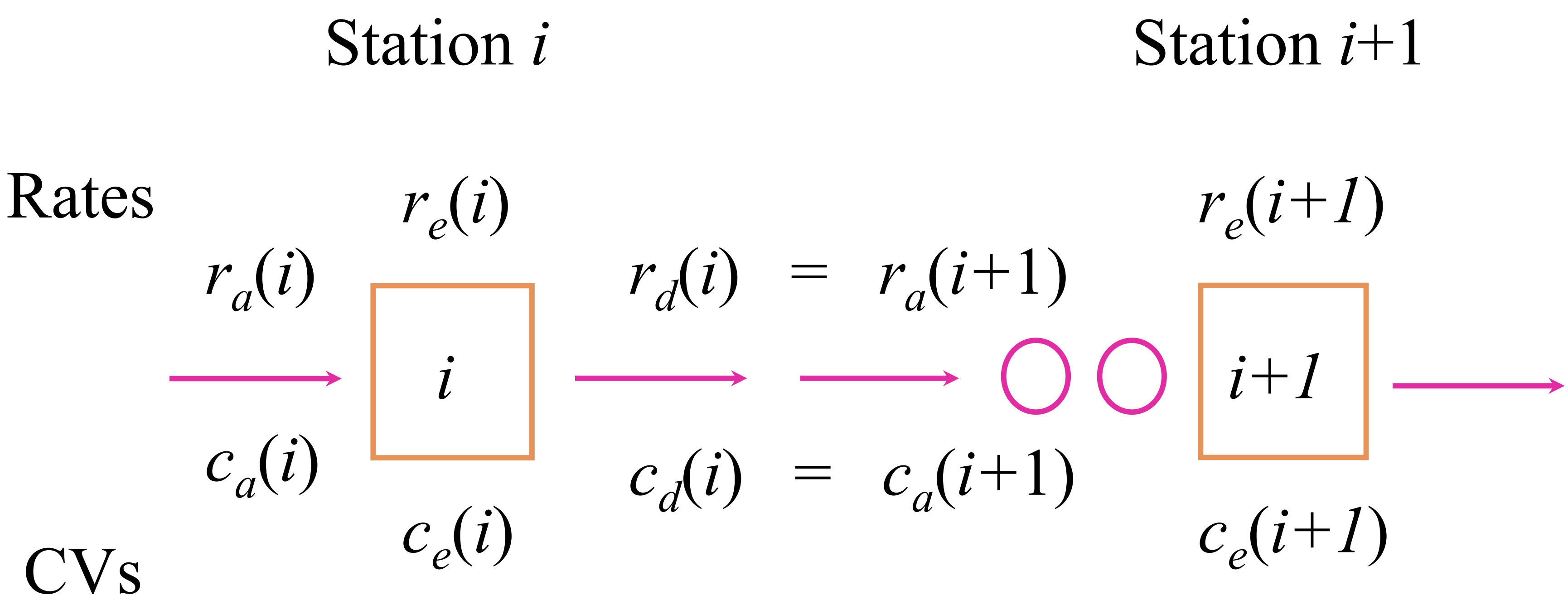
LEAN MANUFACTURING

Sanjay Sarma

2

Variations

Propagation of Variability



Variability Makes a Difference!

- Little's Law: TH = WIP/CT, so same throughput can be obtained with large WIP, long CT or small WIP, short CT. The difference? *Variability!*

- Penny Fab One: achieves full TH (0.5 j/hr) at WIP = W_0 = 4 jobs if it behaves like Best Case, but requires WIP = 57 jobs to achieve 95% of capacity if it behaves like the Practical Worst Case. Why? *Variability!*

Measuring Process Variability

$$t = \text{mean}$$

$$\sigma = \text{standard deviation}$$

$$c = \frac{\sigma}{t} = \text{coefficient of variation, CV}$$

$$c^2 = \frac{\sigma^2}{t^2} = \text{squared coefficient of variation, SCV}$$

Variability Classes

Variability Class	Coefficient of Variation	Typical Situation
Low (LV)	$c < 0.75$	Process times without outages
Moderate (MV)	$0.75 \leqq c \leqq 1.33$	Process times with short adjustments (e.g., setups)
High (HV)	$c \geqq 1.33$	Process times with long outages (e.g., failures)

Natural Variability

- **Definition**: variability without explicitly analyzed cause, variability inherent in natural process time.

- Sources:
  - operator pace
  - material fluctuations
  - product type (if not explicitly considered)
  - product quality

- Observation: Natural process variability is usually in the LV category.

Machine Downtimes

- Preemptive outages: downtimes that occur whether we want them to or not (e.g., they can occur right in the middle of a job).
  - Examples: machine breakdowns, power outages,..
- Nonpreemptive outages: downtimes that will inevitably occur but for which we have some control as to exactly when.
  - Example: process changeovers (setups)

Down Time – Mean Effects

Definitions:

t_0 = mean of natural process time

σ_0 = standard deviation of natural process time

c_0 = coefficient of variability of natural process time

r_0 = natural capacity (rate)

m_f = mean time to failure (MTTF)

m_r = mean time to repair (MTTR)

σ_r = standard deviation of repair time

c_r = coefficient of variability of repair time, $c_r = \frac{\sigma_r}{m_r}$

Down Time – Mean Effects (cont.)

Availability: Fraction of time machine is up

$$A = \frac{m_f}{m_f + m_r}$$

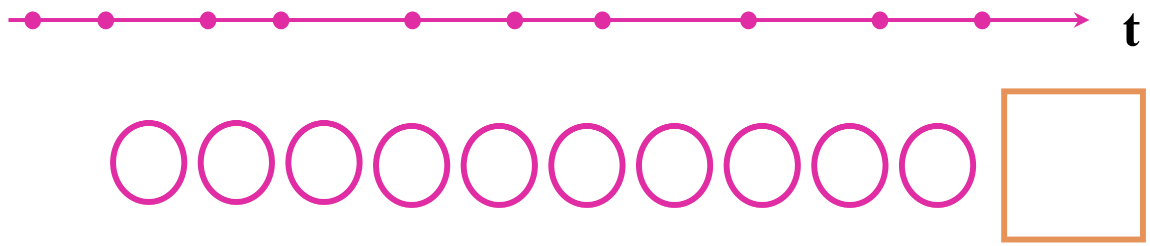
Effective mean process time: $t_e = \frac{t_0}{A}$

Effective capacity (rate): $r_e = \frac{1}{t_e} = Ar_0$

m = number of machines

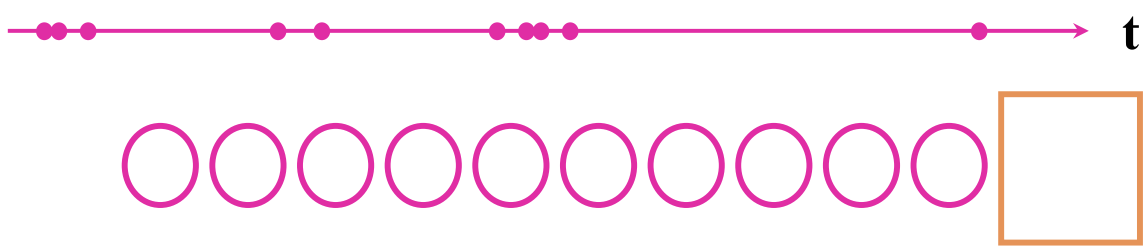
Flow Variability

Low variability arrivals



smooth!

High variability arrivals



bursty!

Measuring Flow Variability

t_a = mean time between arrivals

r_a = average arrival rate

σ_a = standard deviation of the time between arrivals

c_a = CV of interarrival time

$$r_a = \frac{1}{t_a}$$

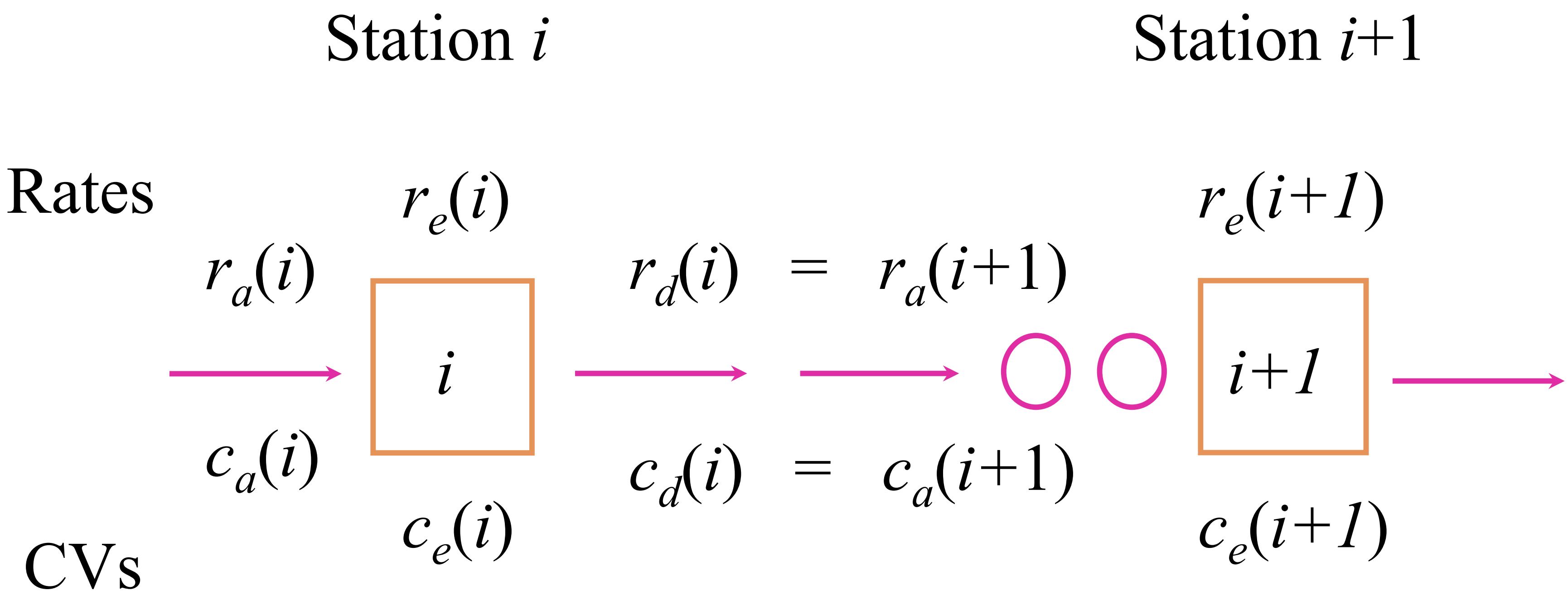
t_d = mean time between departures

r_d = average departure rate

c_d = departure CV

$$c_a = \frac{\sigma_a}{t_a}$$

Propagation of Variability



Characterizing Variability in Flows

- Utilization : fraction of time a workstation is busy over the long run..

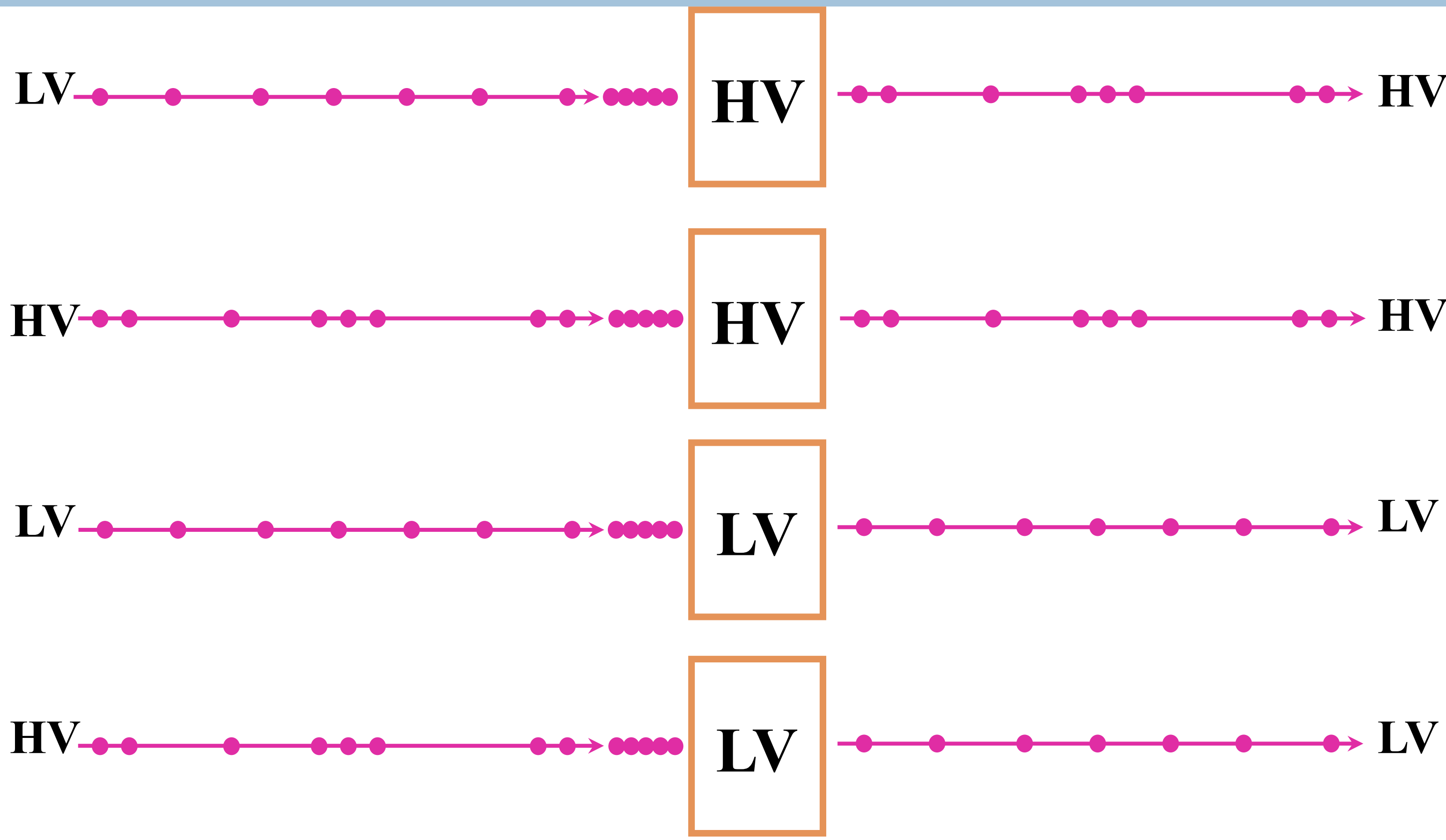
  u: utilization of a workstation consisting of m identical machines

  $$u = \frac{r_a t_e}{m} = \frac{r_a}{r_e}$$

  $$0 < u < 1 \quad \Rightarrow \quad r_e > r_a$$

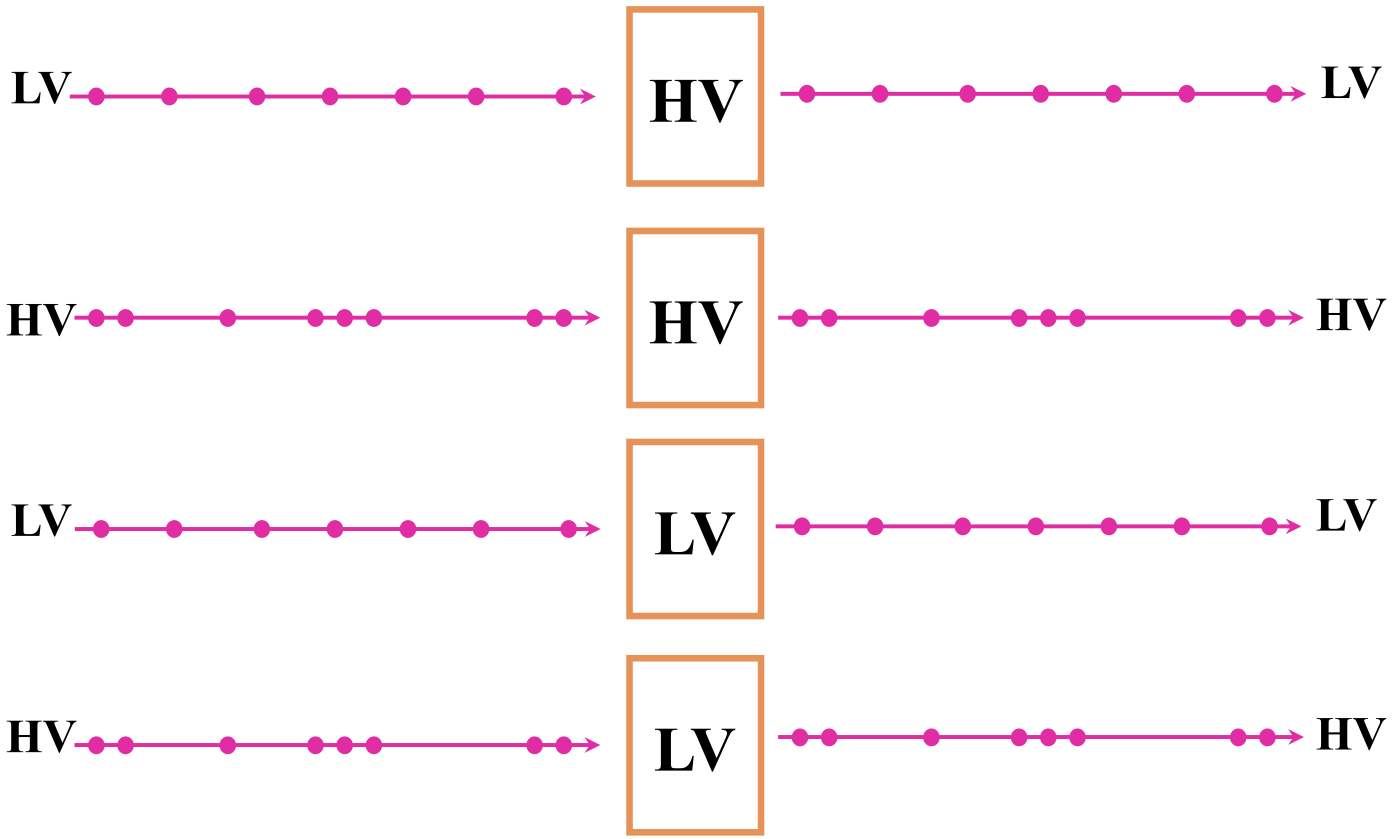
Single Machine Station: $c_d^2 = u^2 c_e^2 + (1 - u^2) c_a^2$

High Utilization Station



<u>Conclusion:</u> flow variability out of a high utilization station is determined primarily by process variability at that station.

Low Utilization Station



<u>Conclusion:</u> flow variability out of a low utilization station is determined primarily by flow variability into that station.

Average queue length

- **Formula:**

$$\mathrm{CT}_q \approx \underbrace{\left(\frac{c_a^2 + c_e^2}{2}\right)}_{V}\underbrace{\left(\frac{u}{1-u}\right)}_{U}\underbrace{t_e}_{T}$$

- **Observations:**
  - $\mathrm{CT}=\mathrm{CT}_q+t_e$
  - Refer to as Kingman's equation or *VUT* equation.
  - Separate terms for variability, utilization, process time.
  - CT_q (and other measures) increase with c_a^2 and c_e^2.
  - *Variability causes congestion!*

Example

Hare X19:

t_e = 20 minutes

c_e^2 = 6.25

c_a^2 = 1.0

u = 0.9583

$$\text{CT}_q = \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{u}{1-u}\right)t_e = \left(\frac{1+6.25}{2}\right)\left(\frac{0.9583}{1-0.9583}\right)20$$

$$= 1{,}667.5 \text{ minutes} = 27.79 \text{ hours}$$

$$c_d^2 = c_e^2 u^2 + c_a^2(1-u^2) = 6.25(0.9583^2) + 1.0(1-0.9583^2)$$

$$= 5.8216$$

The G/G/1 Queue —Example

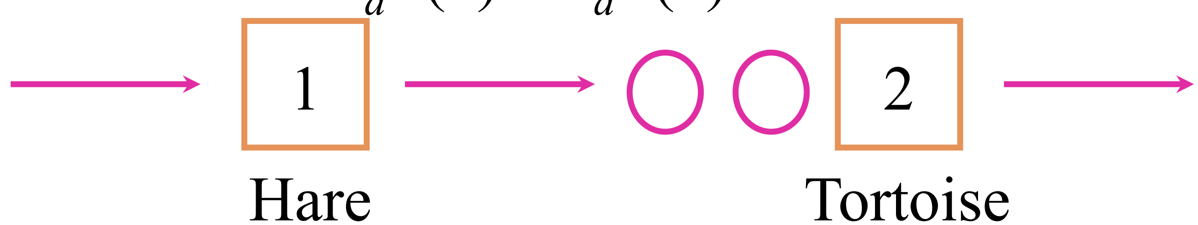
Assume the Hare feeds the Tortoise, then c_a^2 for the Tortoise is equal to c_d^2 for the Hare.

The expected queue time at the Tortoise:

$$CT_q = \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{u}{1-u}\right)t_e = \left(\frac{5.82 + 1.0}{2}\right)\left(\frac{0.9583}{1-0.9583}\right)20$$

$$= 1{,}568.97 \text{ minutes} = 26.15 \text{ hours}$$

$$c_d^2(1) = c_a^2(2) = 5.82$$



Conclusions

- Variability is a fact of life.
- There are many sources of variability in manufacturing systems.
- The coefficient of variation is a key measure of item variability.
- Variability propagates.
- Waiting time is frequently the largest component of cycle time.
- Limiting buffers reduces cycle time at the cost of decreasing throughput.
- Variability pooling reduces the effect of variability.

Lean Manufacturing

Plant layout

Job shop

Batch

Cellular

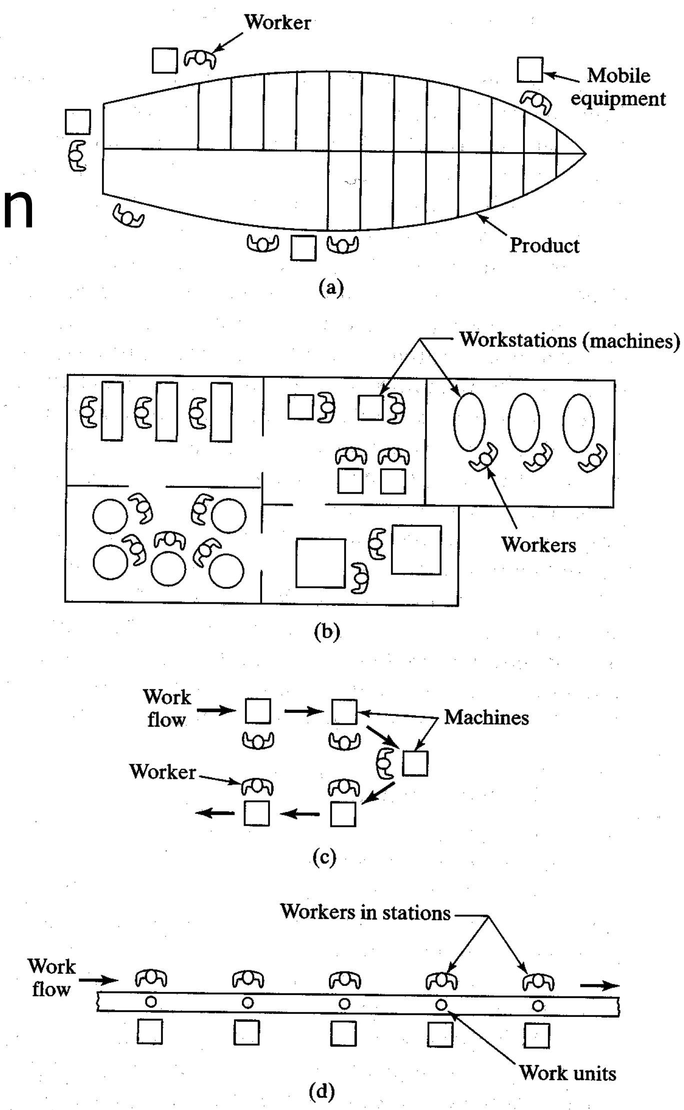
Mass production

Fixed position

Process

Cellular

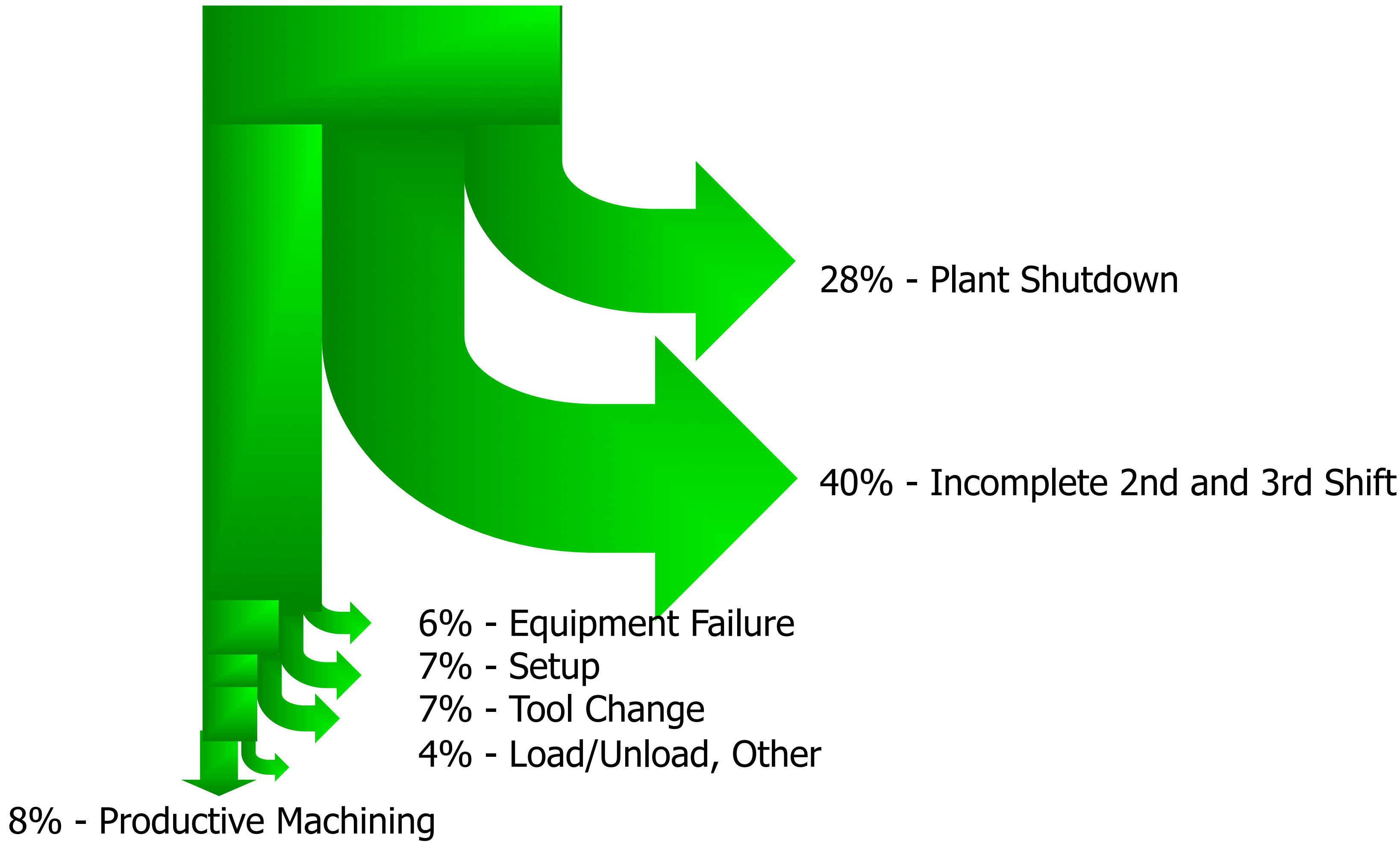
Product line



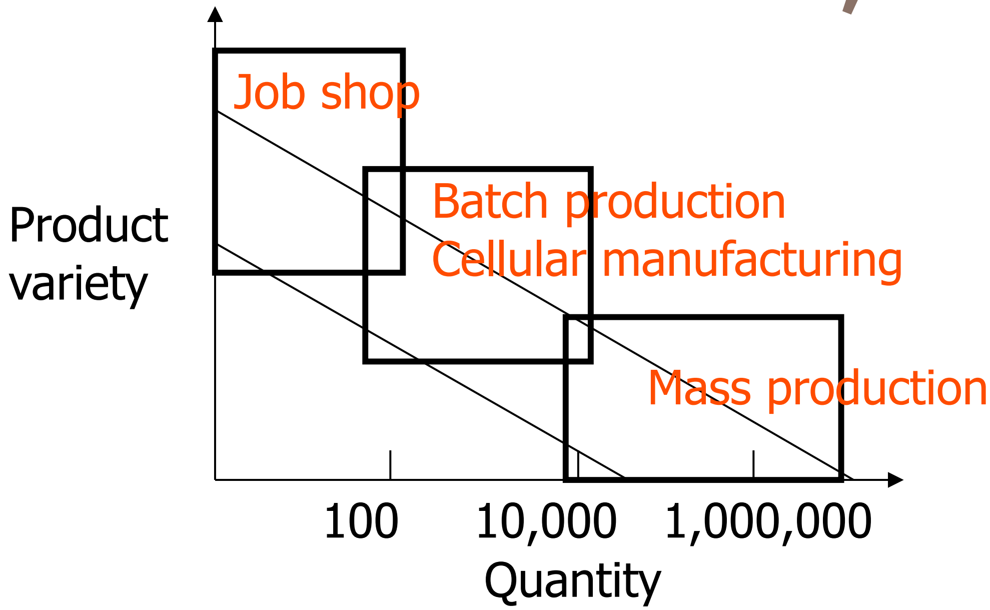
Performance Measures

- Capital cost
- Production rate or capacity
- Cycle time
- Lead time
- Machine utilization
- Work-in-process
- On-time deliveries

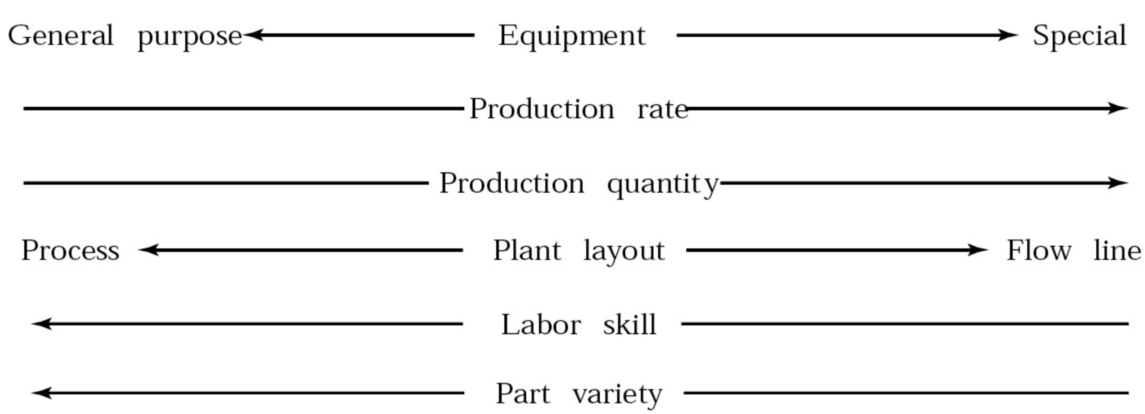
Where the Time Goes In Mid-Volume Metalworking



By production methods,…



Type of Production		
Job shop	Batch production	Mass production



Complexity

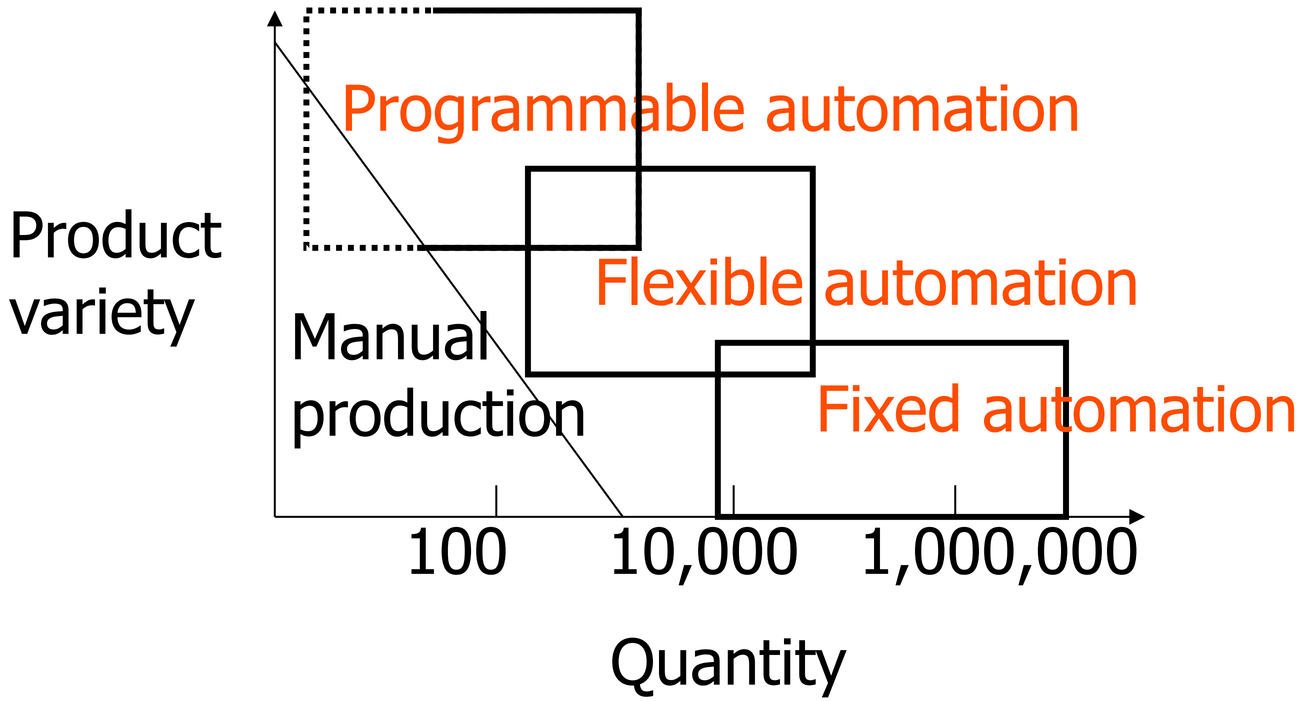
Product complexity

product	Number of components
Mechanical pencil	10
Rifle	50
Sewing machine	150
Bicycle	750
Automobile	20,000
Commercial airplane	1,000,000
Space shuttle	10,000,000

Part complexity

part	Number of operations	Typical operations
Injection molded part	1	Molding
Washer(steel)	1	Stamping
Washer(plated)	2	Stamping, electro-plating
Pump shaft	10	Machining
Coated carbide tool	15	Pressing, sintering, coating, grinding
Pump housing	20	Casting, machining
V-6 engine block	50	Casting, machining
IC chip	75-100	CVD, PVD, photo-lithography, etching, packaging

Types of automation



Transfer Line

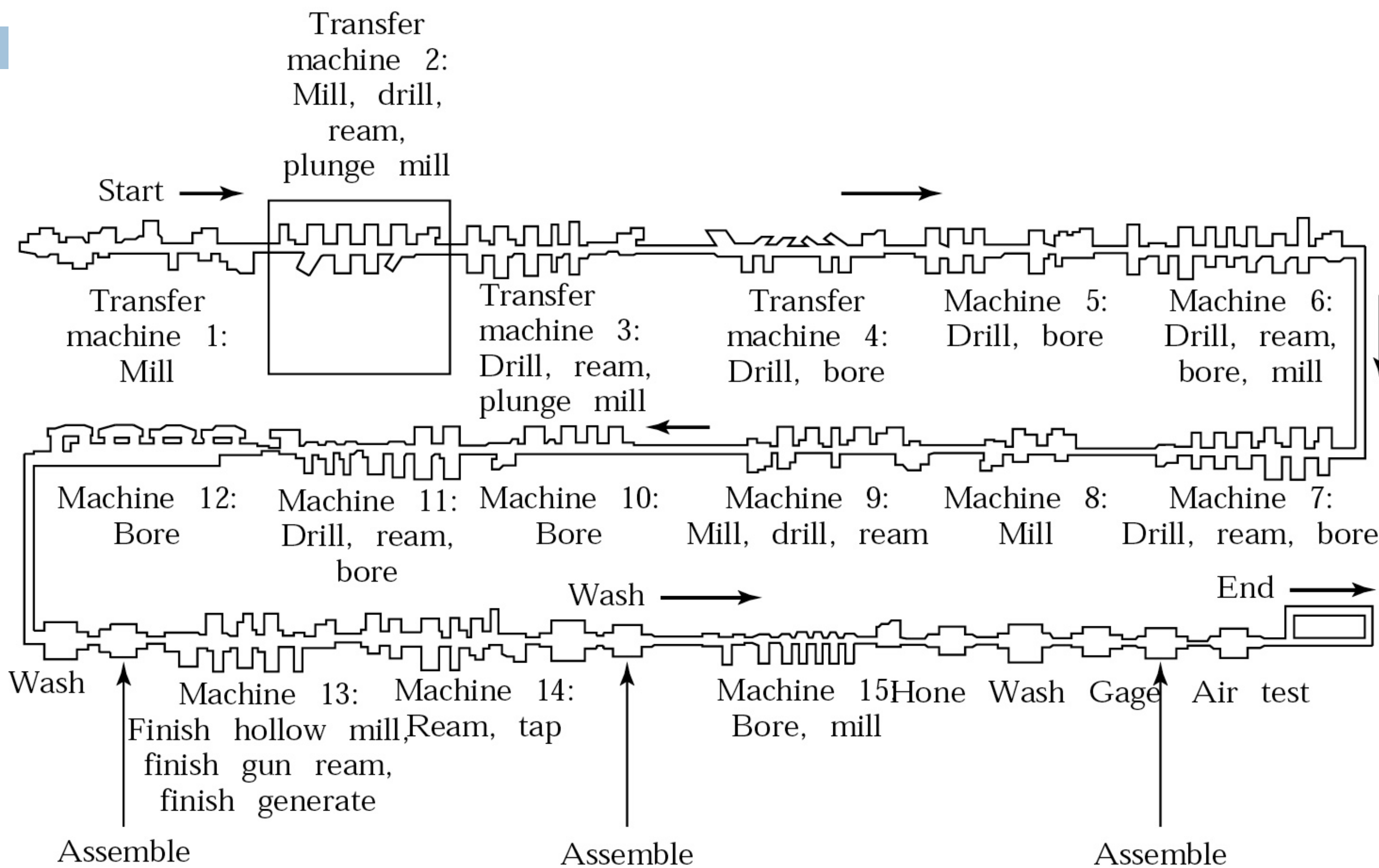
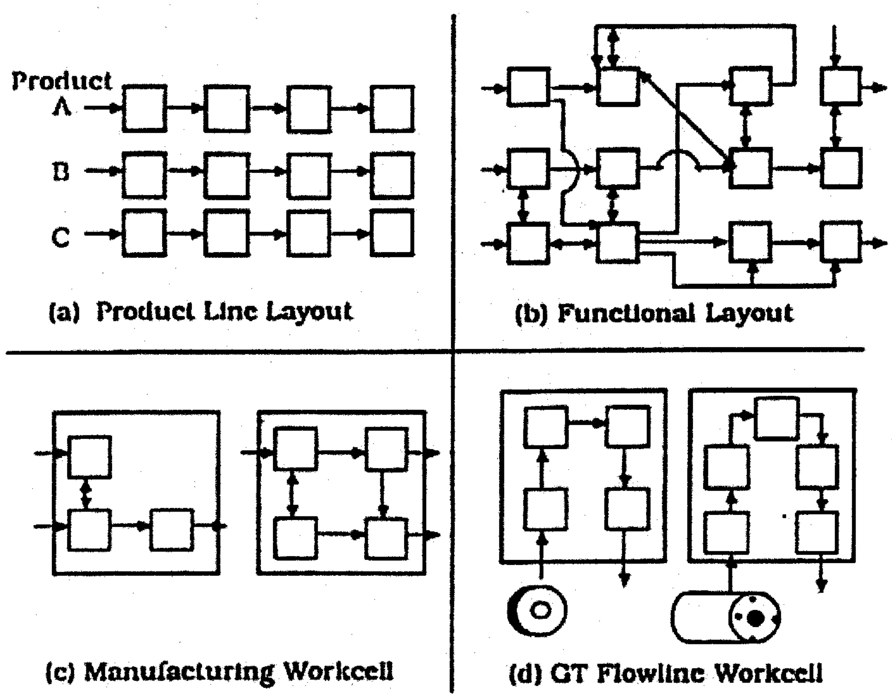
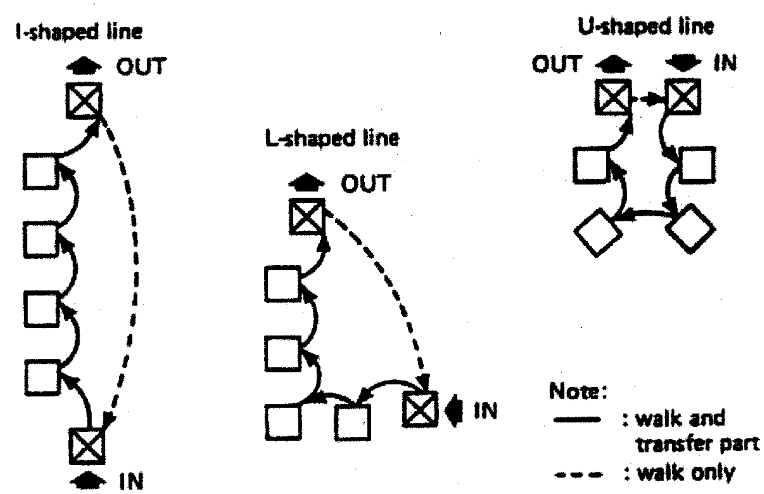


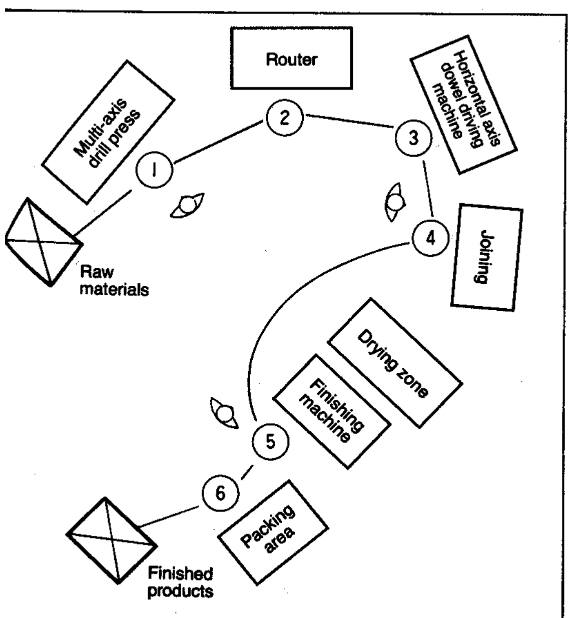
Figure 38.5 A large transfer line for producing engine blocks and cylinder heads. *Source*: Ford Motor Company.

Cell Manufacturing





U-cell production



A woodworking assembly cell

- This is an assembly and packaging line for wooden doors.
- There is no in-process inventory within the cell.
- The workers perform multi-process handling.
- To reduce the number of operators, machines have been equipped with *jidoka* or automation with a human touch. The machines can complete the cycle initiated by the operators.
- Unlike the traditional batch system, doors are processed one at a time. This requires less space.

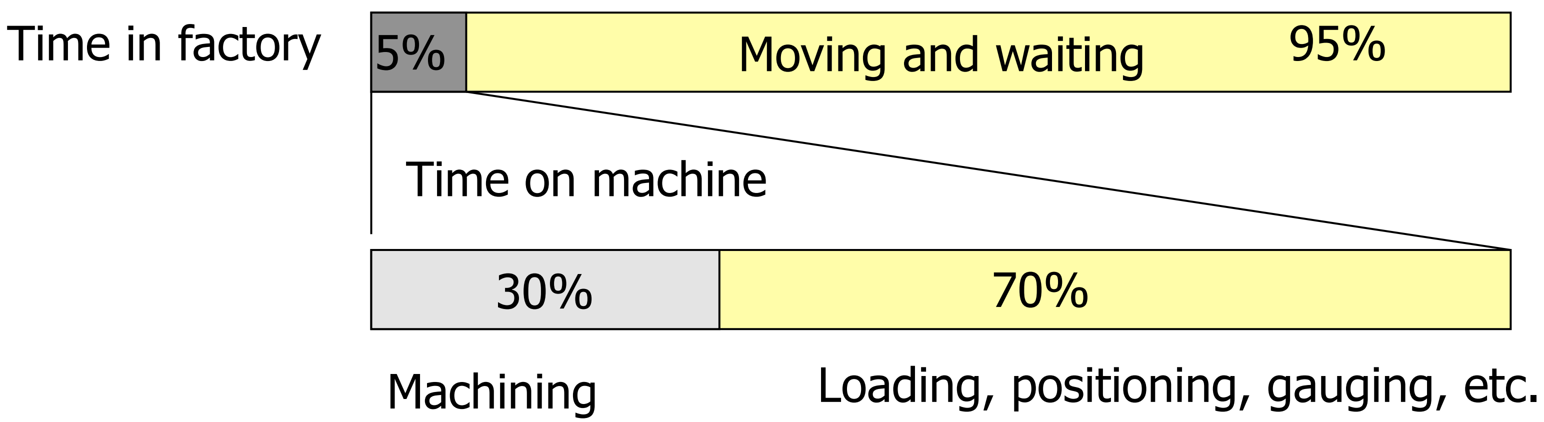
Improving Material Flow

Cellular Manufacturing

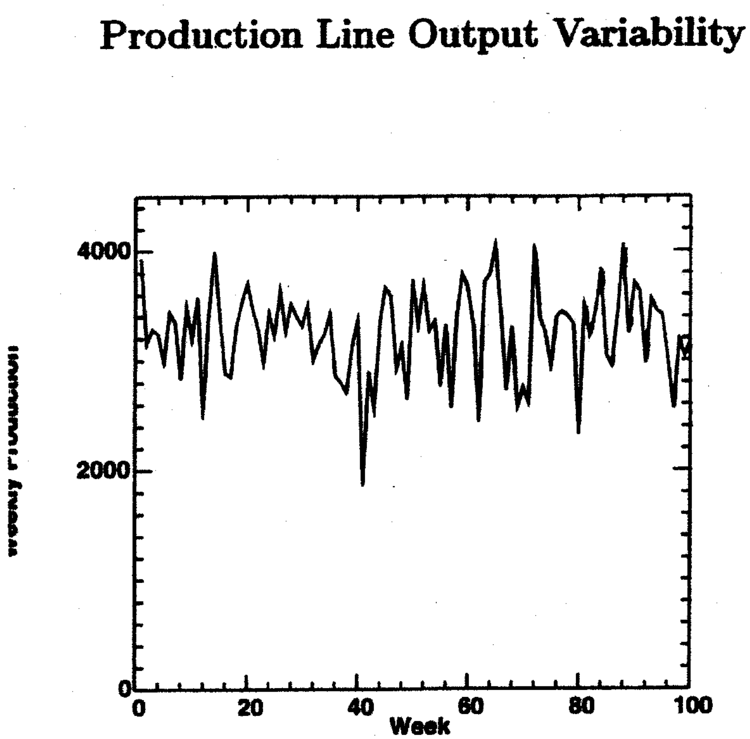
- Benefits
  - Reduce MLT (Mfg Lead Time) normally 75%
  - Reduce footprint
  - Improve quality, productivity, visibility
- Challenges
  - Less machine utilization
  - Vulnerability to machine failures

Manufacturing operations

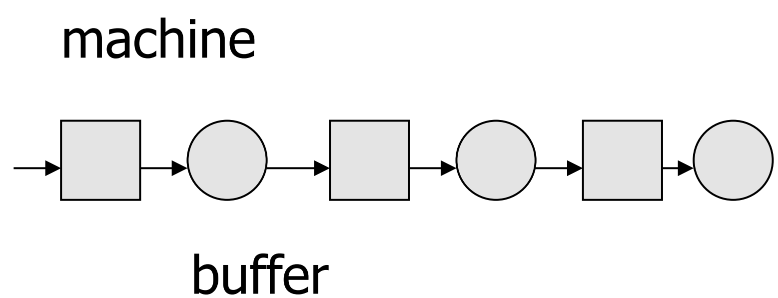
- Processing and assembly
- Material handling
- Inspection and test
- Coordination and control



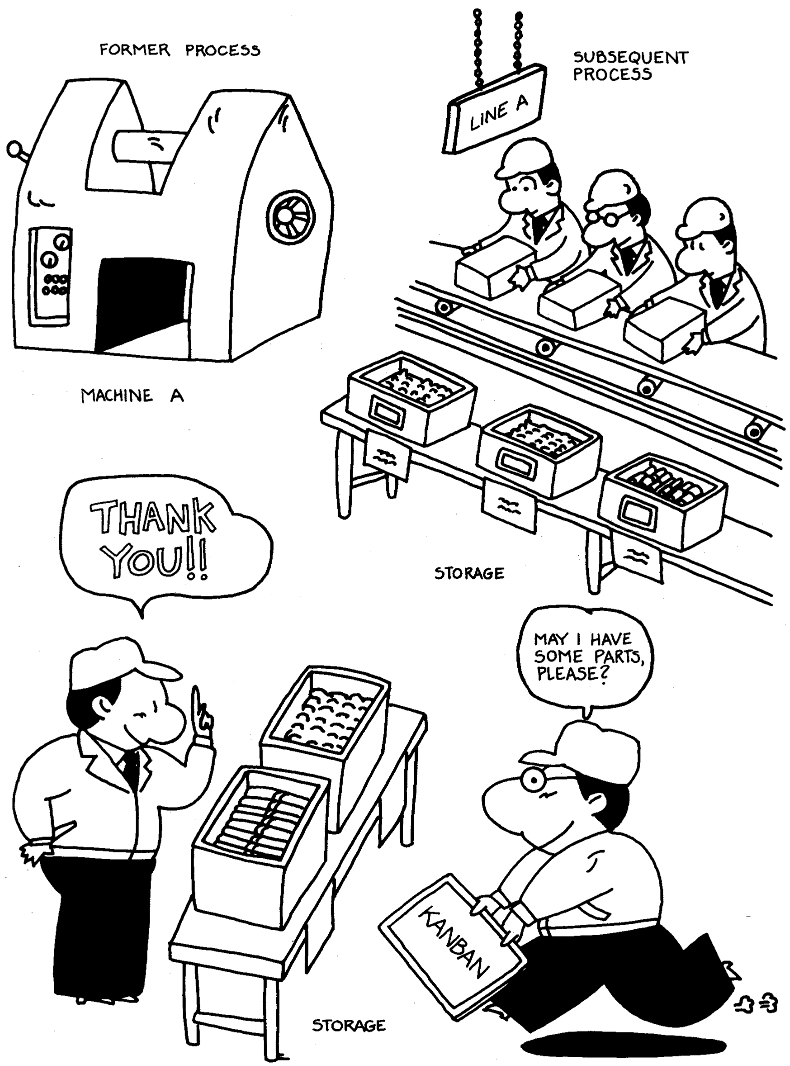
Production Line Control

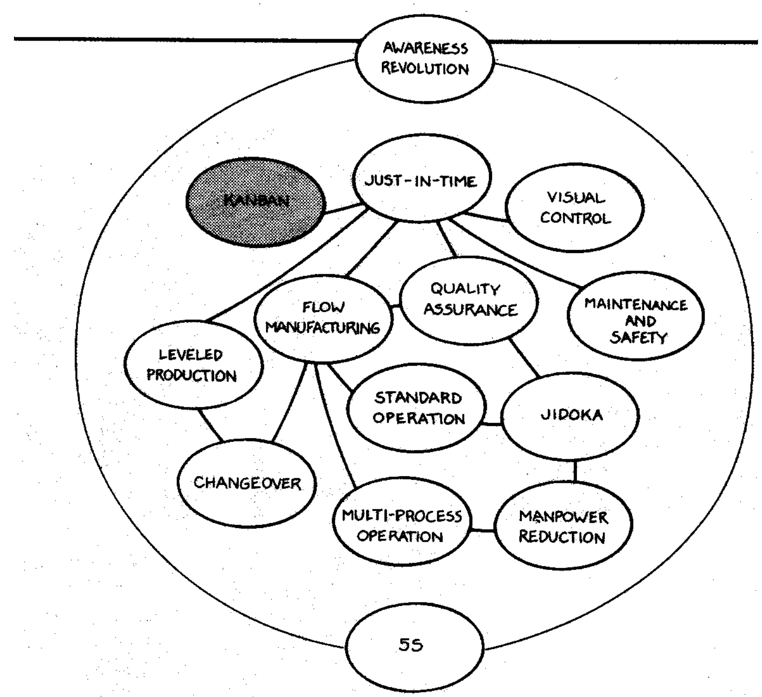


Machines are unreliable
Buffers are finite
Average production rate
Average inventory



Toyota Manufacturing System





TPS: Features & Elements

- Fast response, flexibility
- Product variety
- Production schedule stability
- Supply/chain integration
- SMED (Fast Die Change)
- Highlighting problems
- Gradual elimination of waste
  - Continuous
  - Root cause analysis
  - Fool proofing remedy
- Worker training
- Just-in-Time production
- Stable production schedules

Value: Would someone pay for this? If no, then it's Waste.

Lean Manufacturing

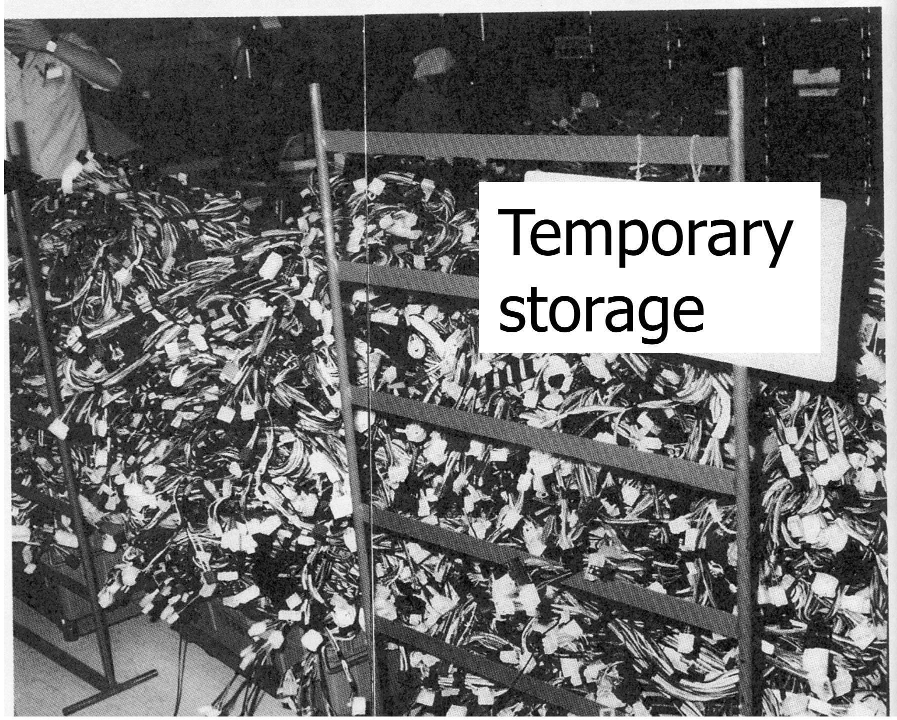
- Identifying and eliminating non-value-added effort, resources and wastes of
  - Overproduction
  - Waiting time
  - Transportation
  - Processing
  - Inventory
  - Motion
  - Defects

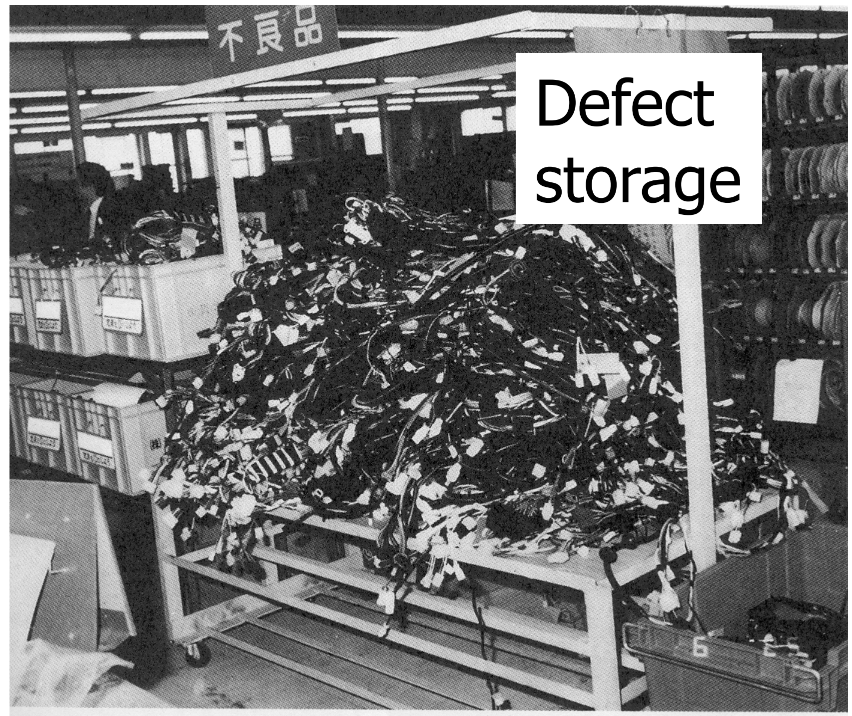
The ten rules of lean production

1. Eliminate waste
2. Minimize inventory
3. Maximize flow
4. Pull production from customer demand
5. Meet customer requirements
6. Do it right the first time
7. Empower workers
8. Design for rapid changeover
9. Partner with suppliers
10. Create a culture of continuous improvement

You've seen this before.

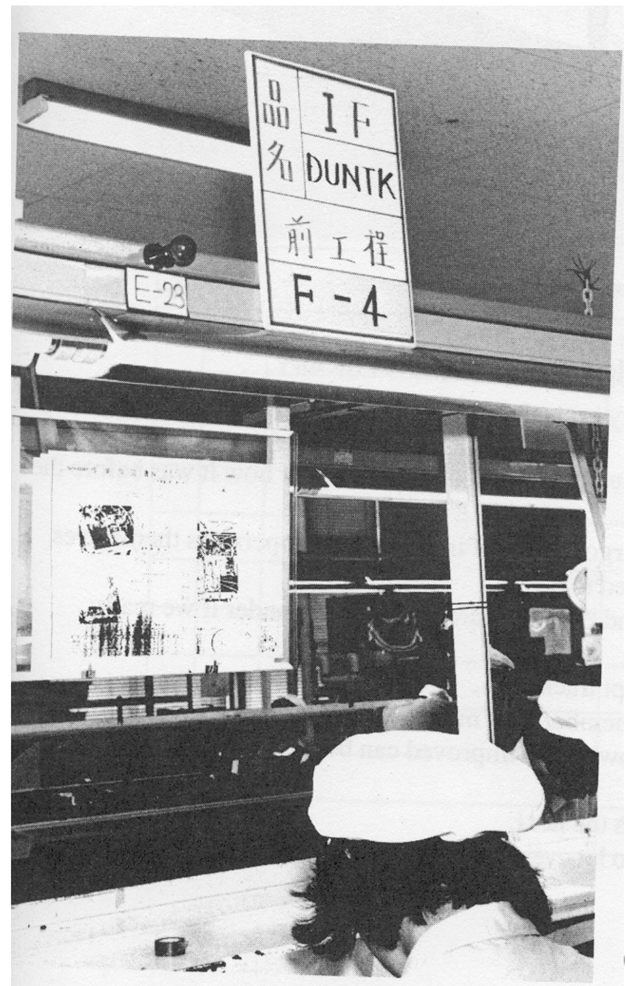
Temporary storage of wire harnesses: Is it really temporary? When will these quasi products be moved?





Storage for wire harness defectives: Profits are impossible with so many defectives.

Visual Control



02

JIT (Just-in-time)

Produce only what is needed, when is needed in just the amount needed.

Material → Parts→ sub-assemblies →finished goods→customers

- Inventory
- Defects
- Large Lot
- Rising Cost
- Delivery Delays

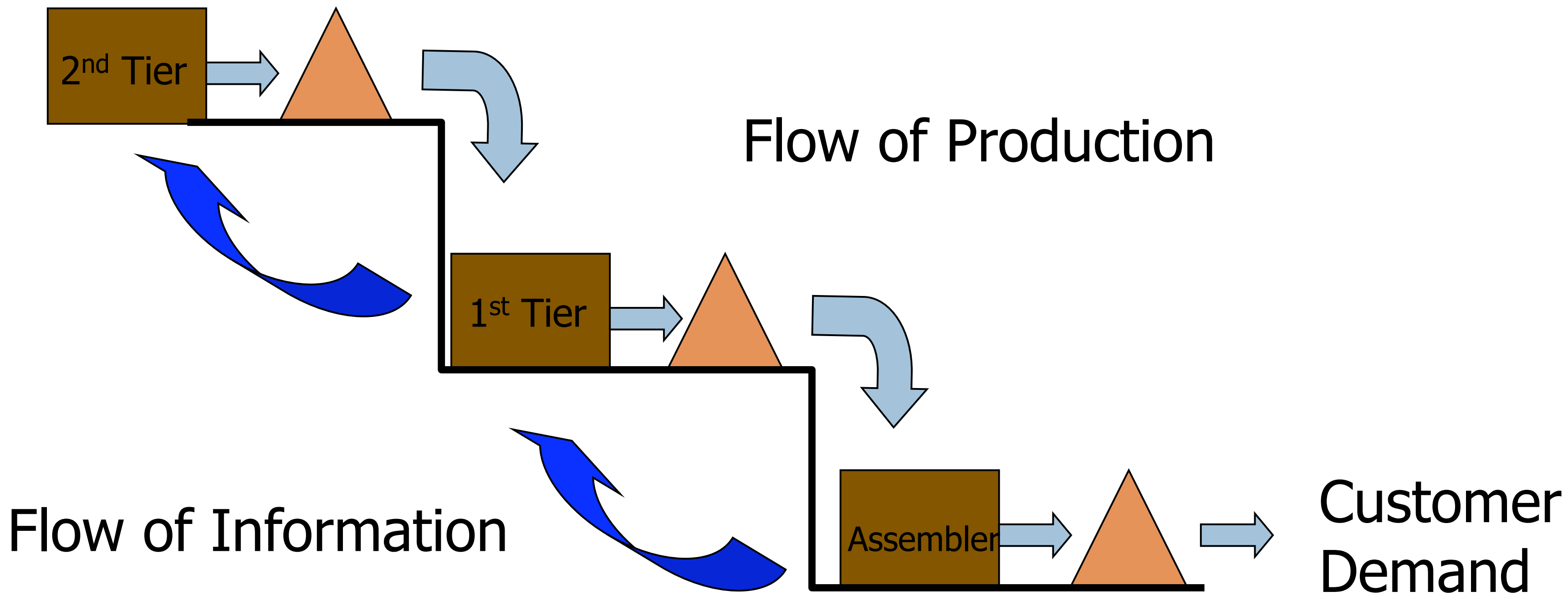
The Seven Zeros

- Zero Defects: **To avoid delays due to defects. (Quality at the source)**
- Zero (Excess) Lot Size: **To avoid "waiting inventory" delays. (Usually stated as a *lot size of one*.)**
- Zero Setups: **To minimize setup delay and facilitate small lot sizes.**
- Zero Breakdowns: **To avoid stopping tightly coupled line.**
- Zero (Excess) Handling: **To promote flow of parts.**
- Zero Lead Time: **To ensure rapid replenishment of parts (very close to the core of the zero inventories objective).**
- Zero Surging (sudden changes): **Necessary in system without WIP buffers.**

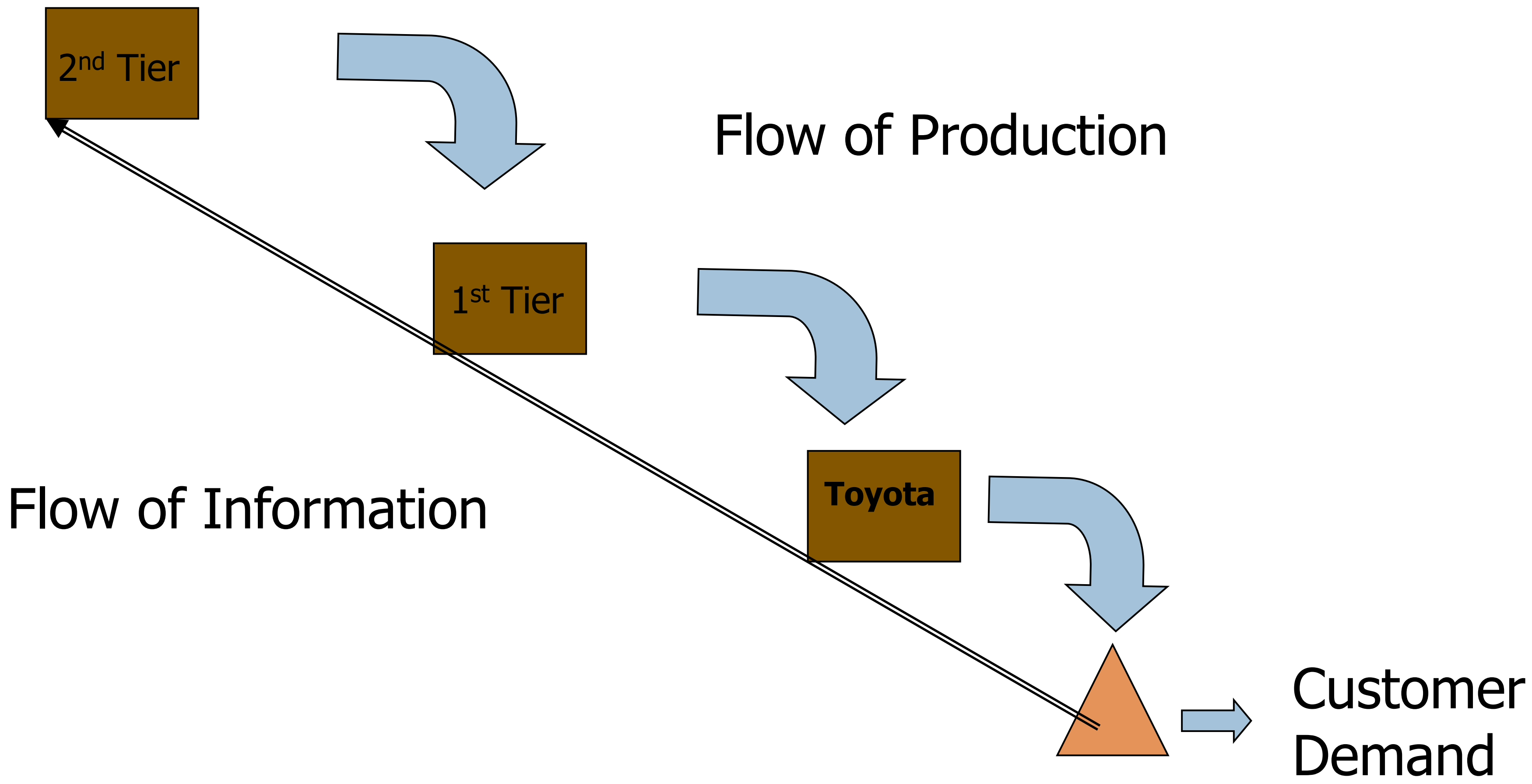
JIT implementation

- Awareness revolution
- Workplace improvements
  - Cleanness, orderliness, discipline
- Visual control
- Flow manufacturing
- Quality assurance
- Standard operation

Traditional “Buffered” Supply Chain

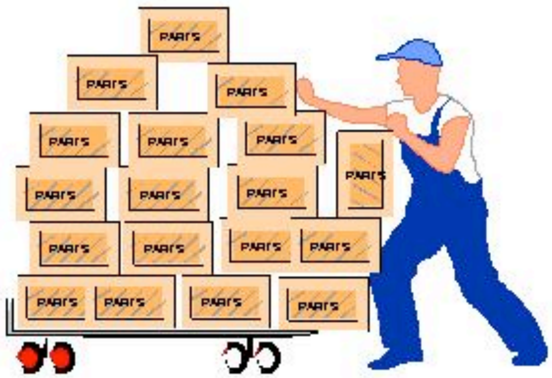


The Just-in-Time :No Stocks!



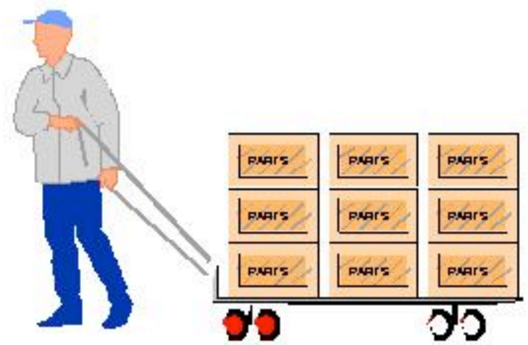
Push vs. Pull

Make all we can just in case.



- Production Approximation
- Anticipated Usage's
- Large Lots
- High Inventories
- Waste
- Management byFirefighting
- Poor Communication

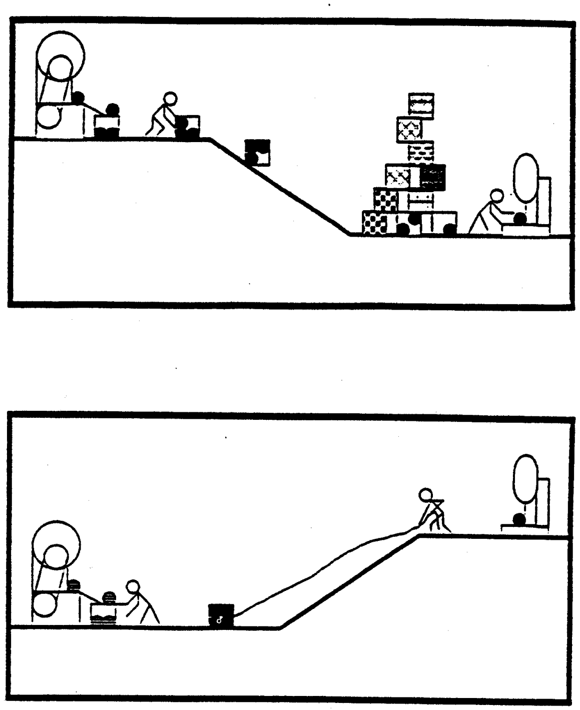
Make what's needed when we need it



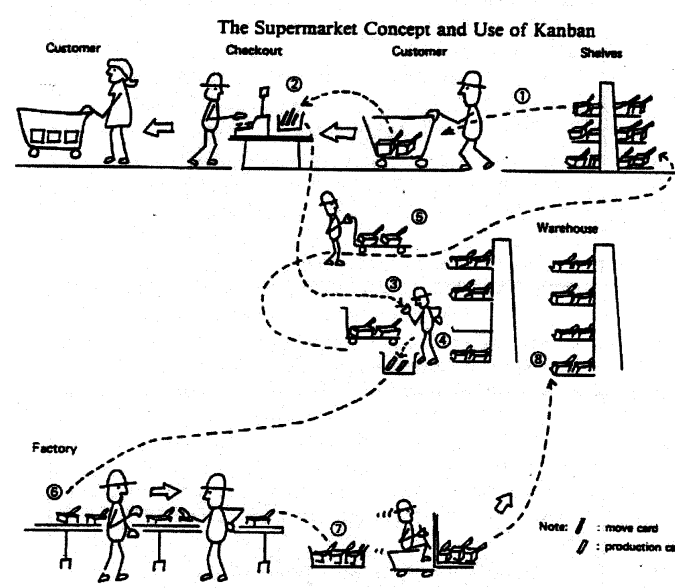
- Production Precision
- Actual Consumption
- Small Lots
- Low Inventories
- Waste Reduction
- Management by Sight
- Better Communication

Push vs. Pull

PUSH SYSTEMS VS. PULL SYSTEMS FOR
PRODUCTION PLANNING AND CONTROL



("Manufacturing in the Nineties" by Steudel and Desruelle, pp. 238-239)



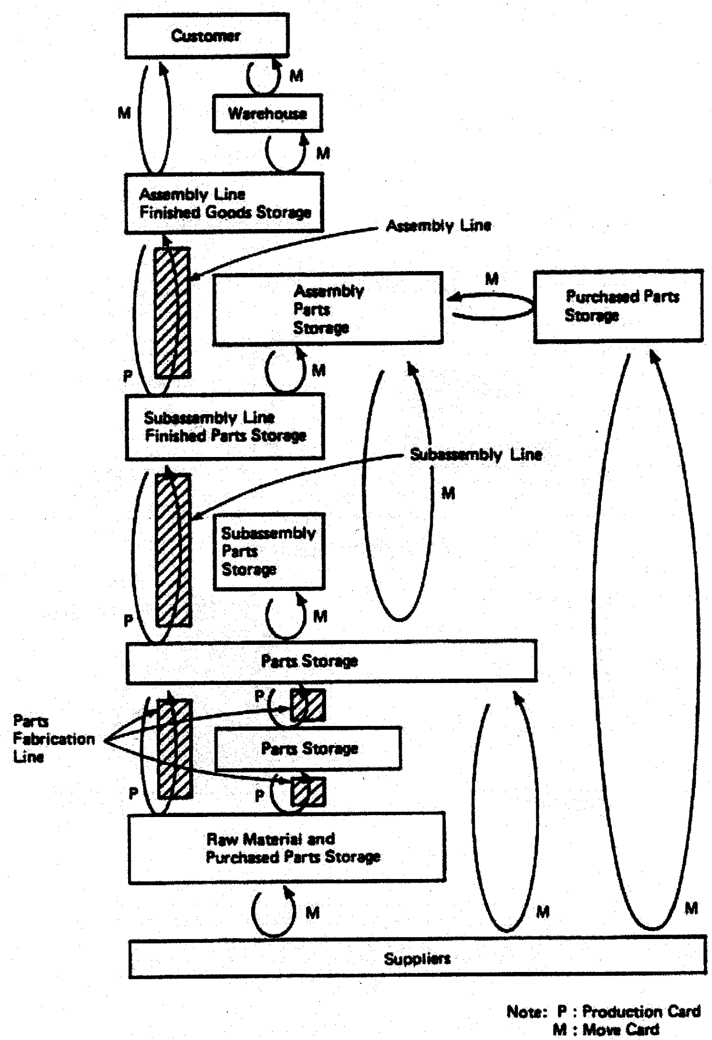
(From "The New Manufacturing Challenge" by K. Suzaki, pp. 149)

Kanban system

Two Kanbans

- Production card
- Move card

Kanban Routes in a Factory



(From "The New Manufacturing Challenge" by K. Suzaki, pp. 151)

Kanban system

Two Kanbans

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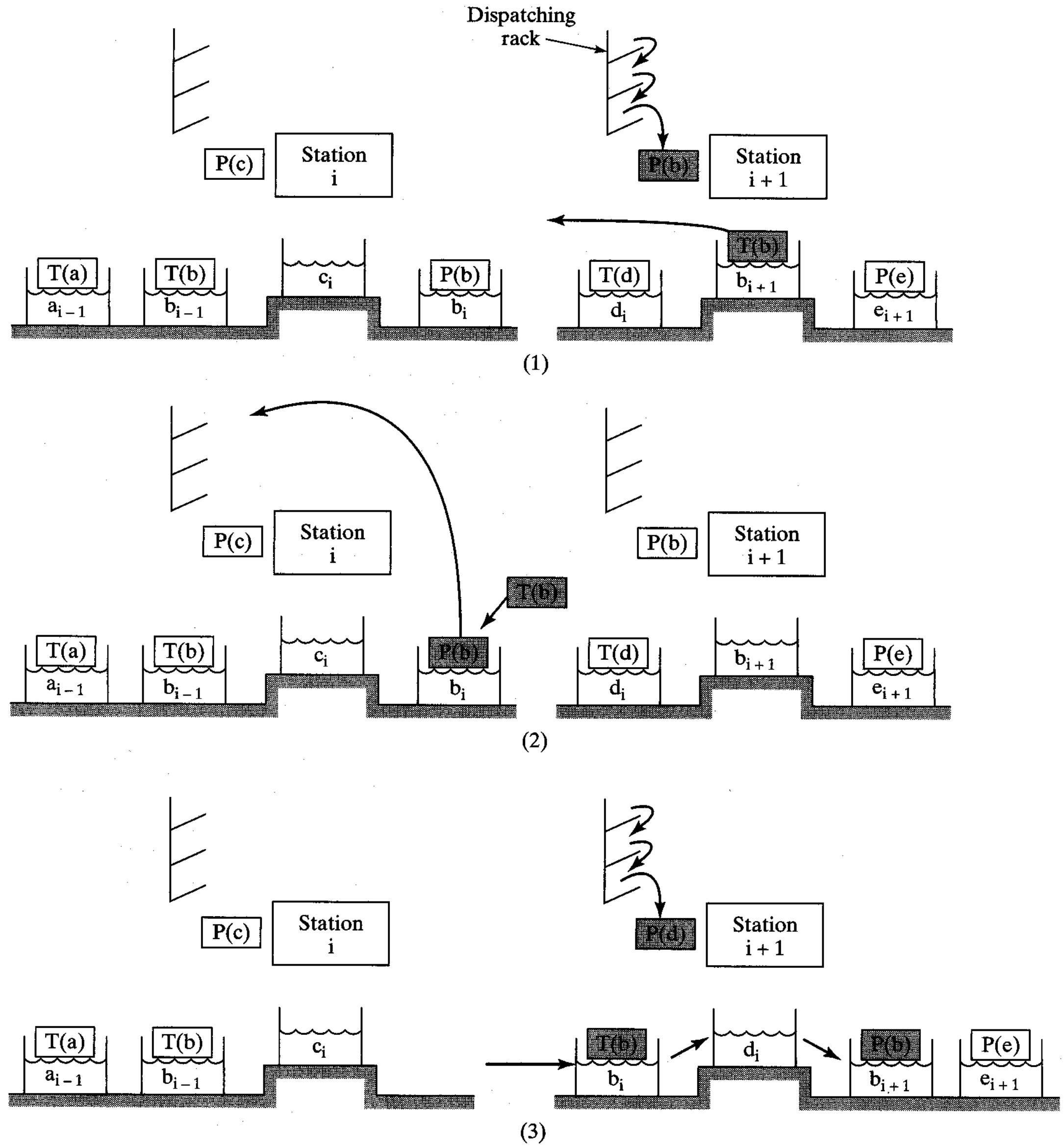


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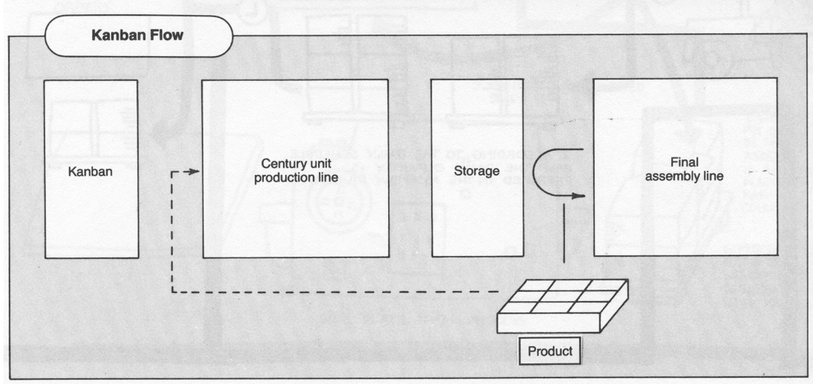
Kanban Flow
Kanban
Century unit production line
Storage
Final assembly line
Product

Global Manufacturing Environment

- Customers want:
  - Innovation
  - quality and reliability, and
  - they want it NOW!
- Competitive firms have to deliver products:
  - that both sell and are produced globally,
  - using a work force with different experience and training, and
  - do it QUICKLY!

All in all, firms should produce good products that best satisfy customers while maximizing the value creation.