Lecture 04
Productivity Concept

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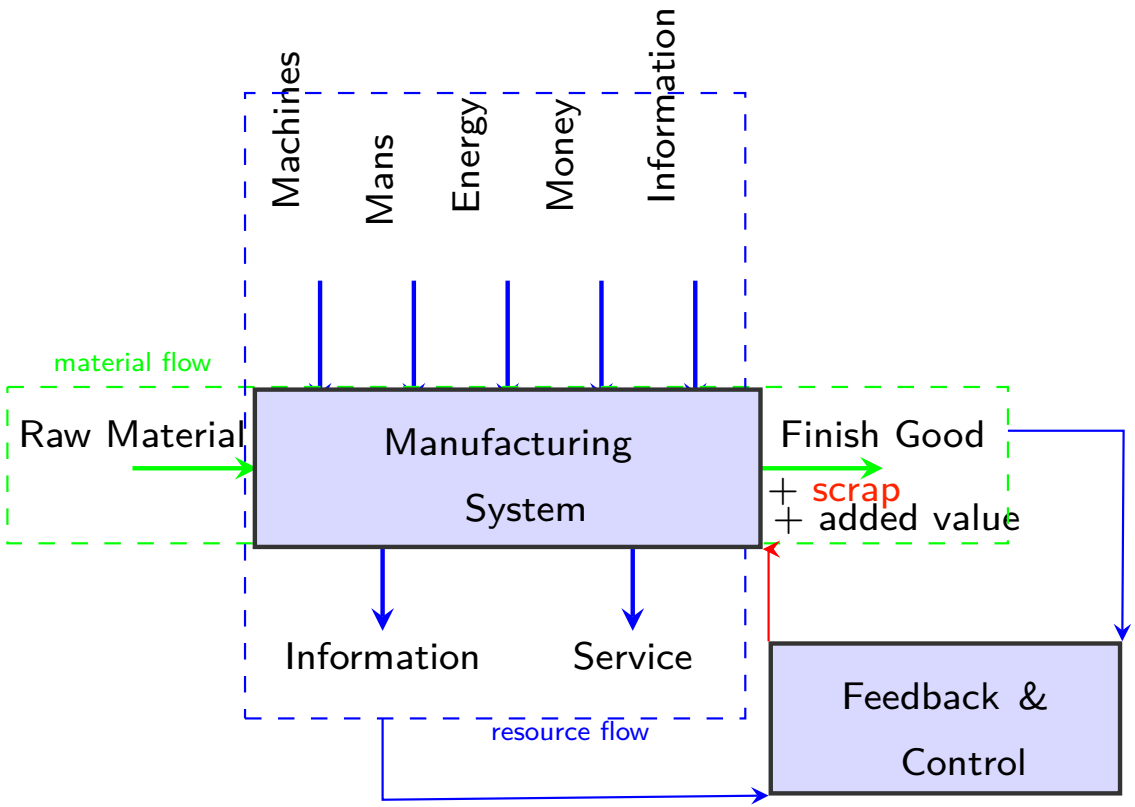
Outline

source: General references [Cha16, LZ11, SCJ10, MG06, Gri12]

Manufacturing System: What? and Why?

- **What:** transformation process of resources → products/services given criteria
- **Why:** multi-inputs & outputs, complex process, rapid changing of demand & environment



source: Cecelja. 2000. *Manufacturing Information & Data Systems.*

Resources and Goal Explanation

Internal: Resources

- **Man:** operators, supervisor, manager, owner, customer
- **Machine:** facility, equipment, MHE, IT, Energy
- **Material:** RM, WIP, FG, Scape/Waste, packaging
- **Method:** knowledge, patent, information, channel (bioPharma)
- **Money:** asset = equity + liability

External: Constraints

- **Environment:** regulation, geo-political, economic, nature
- **Paradigm:** believe, norm, circumstance, behavior, culture (dictionary)

Productivity

- **Effectiveness:** doing right decisions successfully implementing them to the extent of their values
- **Efficiency:** accomplishing of a given task with the least amount of effort/resources for plant/ peoples/ profits

What is productivity?

Productivity is ratio between the outputs generated from a system and the inputs that are used to create those outputs. it measures both effectiveness and efficiency

$$\text{productivity} = \frac{\text{output}}{\text{input}}$$

5 ways to improve productivity

$\frac{\text{output}\uparrow}{\text{input}\downarrow}$	$\frac{\text{output}\uparrow}{\text{input}\rightarrow}$	$\frac{\text{output}\Uparrow}{\text{input}\uparrow}$	$\frac{\text{output}\rightarrow}{\text{input}\downarrow}$	$\frac{\text{output}\downarrow}{\text{input}\Downarrow}$
a) ideal	b) motivate	c) tech web/saas	d) lean std oper	e) layoff

Variation in Measuring: Time & Factor

Static: measure one period snap shot, suitable for benchmark. i.e., $\frac{\text{output}}{\text{input}}$ (e.g., unit/man-hr)

Dynamic: measure static many periods; can compare change and improvement. ,i.e., $\text{prod}_1 = \frac{\text{output}_1}{\text{input}_1}$, $\text{prod}_2 = \frac{\text{output}_2}{\text{input}_2}$, $\frac{\text{prod}_2 - \text{prod}_1}{\text{prod}_1}$ (e.g., changing in sale/m^2 in same period)

Partial-Factor use single input, e.g., $\frac{\text{wt}_{out}}{\text{wt}_{in}}$, $\frac{\text{line}}{\text{man-hr}}$, $\frac{\text{piece}}{\text{machine-hr}}$

Multi-Factor use some inputs depending on topic, e.g., $\frac{\text{revenue}}{\text{direct labor}}$

Total-Factor: use all inputs typically monetary, e.g., $\frac{\text{return}}{\text{asset}}$

[VDO] what are good measurements of the wrapping line? how to trace 'defects'?

Example of Static Productivity

A health-check clinic has 5 employees and can process 200 patients per week. Each employee works 40 hours per weeks. The clinic's total direct labor cost is 4,500 USD and its total overhead expense are 1,500 USD per week. What is single-factor labor productivity and its multi-factor productivity.

- **What is output?** processed patients
- **What are inputs?** labour duration & money ## DL & FOH

- **Labor Productivity:** single factor
  - ***Patients by week:*** $\frac{\#\text{ patients}}{\#\text{ emplyoee}} = \frac{200}{5} = 40$ patients/employees/week
  - ***Patients by hour:*** $\frac{\#\text{ patients}}{\text{man-hour}} = \frac{200}{5\times 40} = 1.0$ patients/employees/hour

    ## which one is better? why?

- **Multi-factor Productivity:**
  - ***Patients by cost*** $\frac{\#\text{ patients}}{\text{wage+overhead}} = \frac{200}{4500+2000} = 0.333$ patients/USD

Example of Dynamic Productivity

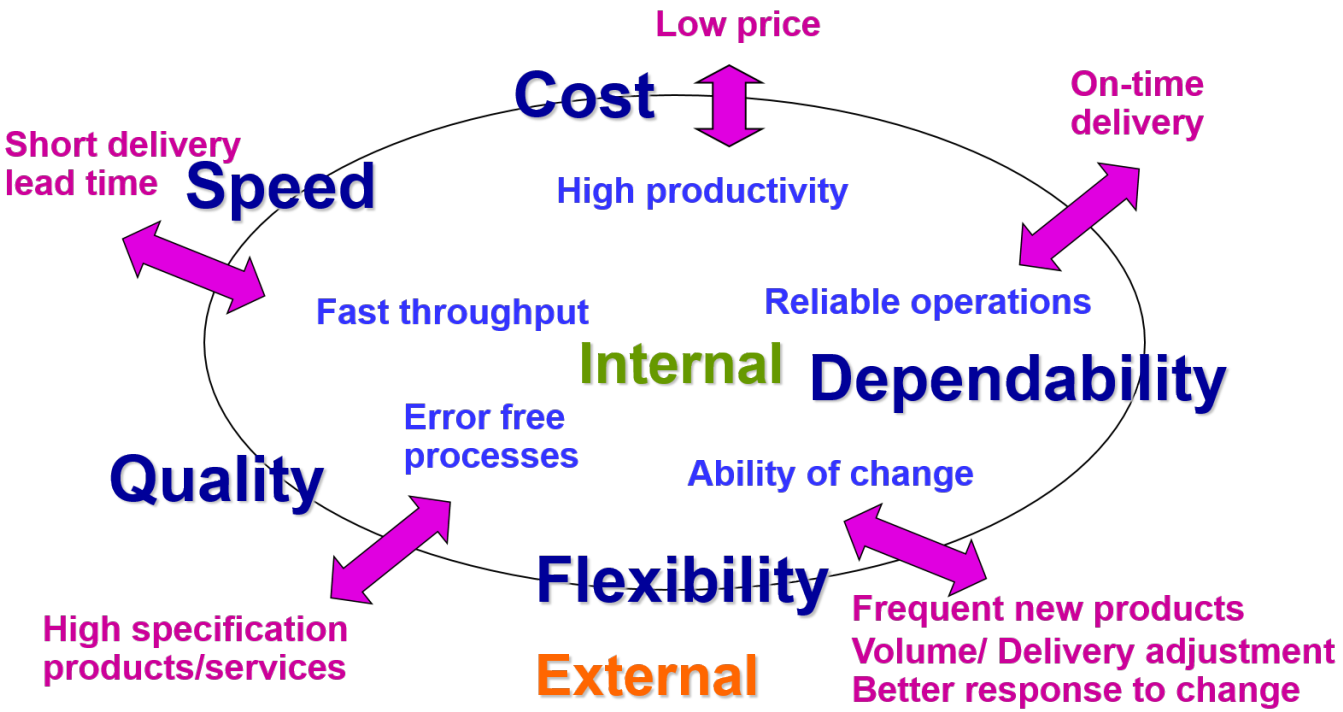
	2011	2010	2009	2008	2007
Walmart					
Revenue	418,952	405,046	401,244	374,526	344,992
Cost of Goods Sold	307,646	297,500	299,419	280,198	258,693
Inventory	36,318	33,160	34,511	35,180	33,685
Net Income	16,389	14,335	13,188	12,884	12,036

- **What is output?** net income ## which is net income?
- **What is input?** inventory ## area, # staff, asset are possible

	2011	2010	2009	2008	2007
Inventory	36,318	33,160	34,511	35,180	33,685
Net Income	16,389	14,335	13,188	12,884	12,036
$p_i \equiv \frac{\text{Net Income}}{\text{Inventory}}$	0.451	0.432	0.382	0.366	0.357
YoY $\frac{p_i - p_{i-1}}{p_{i-1}}$	0.044	0.131	0.043	0.025	

How to measure efficiency?

$$\text{efficiency} = \frac{\text{actual}}{\text{target/ideal}} \quad \text{xor} \quad \frac{\text{budget}}{\text{actual}}$$



source: Cecelja. 2000. *Manufacturing Information & Data Systems.*

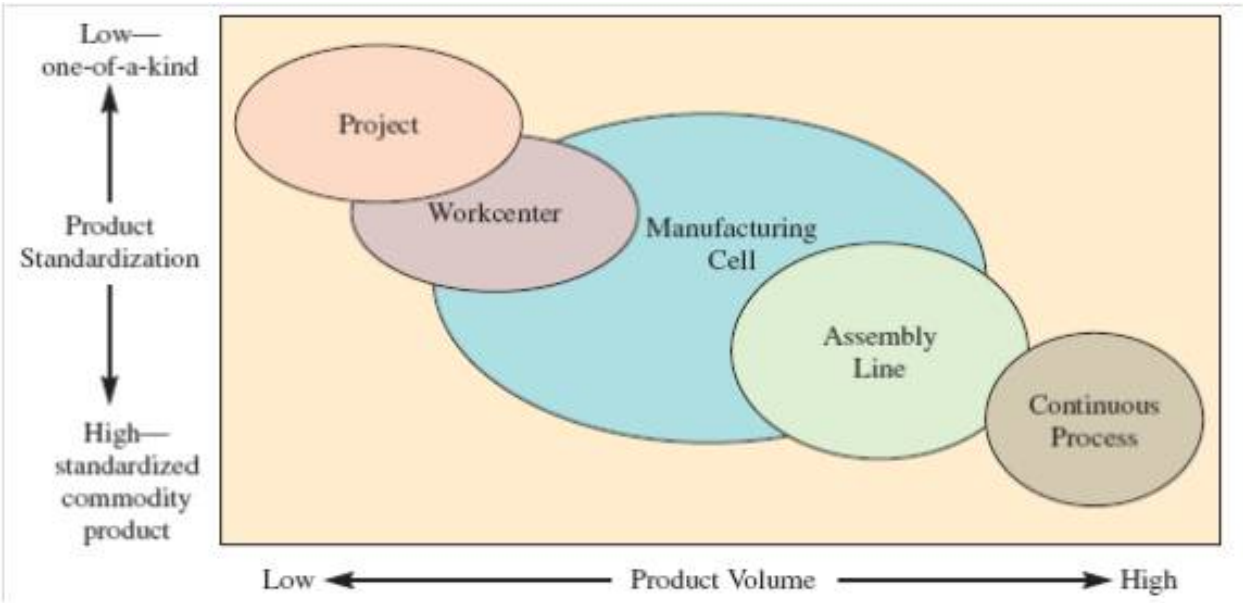
Example of Efficiency

An IE department contracts a construction company to renovated its 6FL classroom. The consultants estimates the cost of renovation at 7,500.0k THB and 120 days for the renovation. The contracted construction company bided the project at 6,785.0k THB and completed the project within 118 days with 5 minor defects. The correction requires additional 7 days. How does the department measure efficiency of the project?

Possible Measurement

- **Reliability:** missing deadline; 0.0
- **Flexibility:** no upside/downside changes; *NA*

Production Process



source: Chase & Jacabs. 2010. *Operation and Supply Chain Management*.

Project: product remains in a fixed location or one-of-the-kind, e.g., vessel

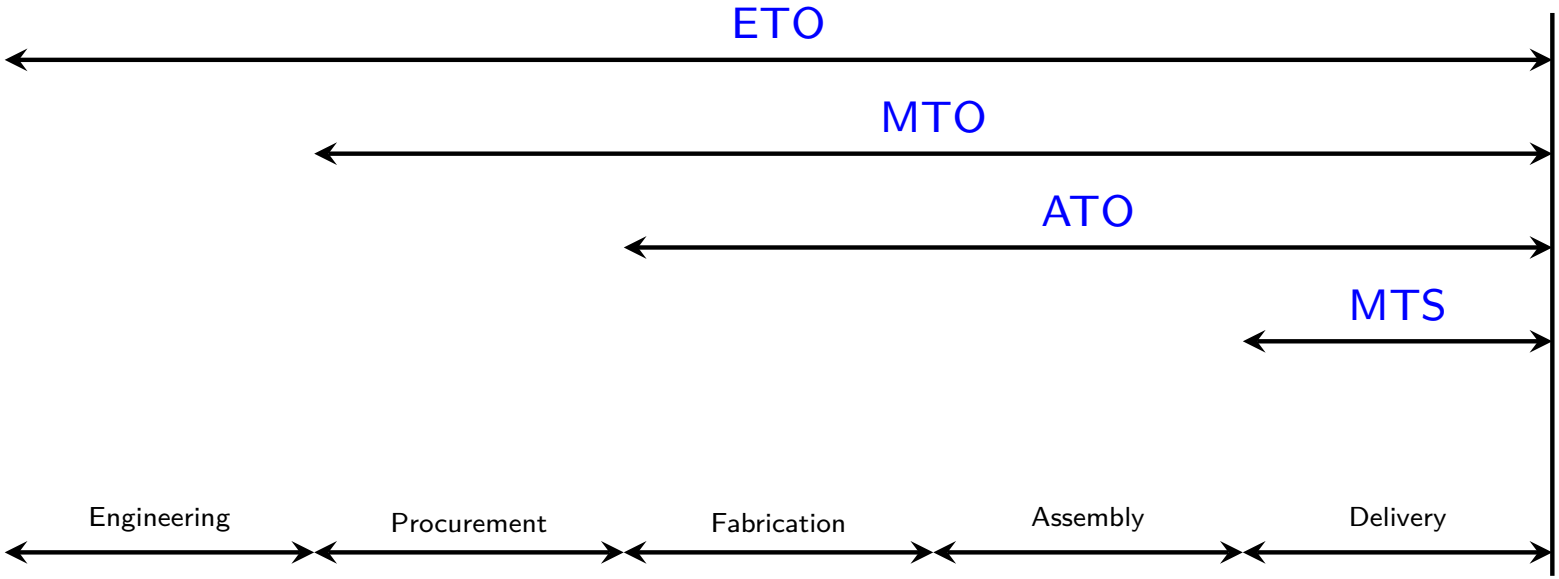
Work center/ Job shop: similar equipment are grouped together, e.g. paint shop, fine dining

Manuf. Cell/Batch: similar products are grouped in same area, e.g. coffee shop

Assemble line: processes are arranged according to the progressive steps

Continuous process: assembly line only the flow is continuous, e.g., water bottle

Inventory Position



source: Adopted from *Smith, S.* 1989.

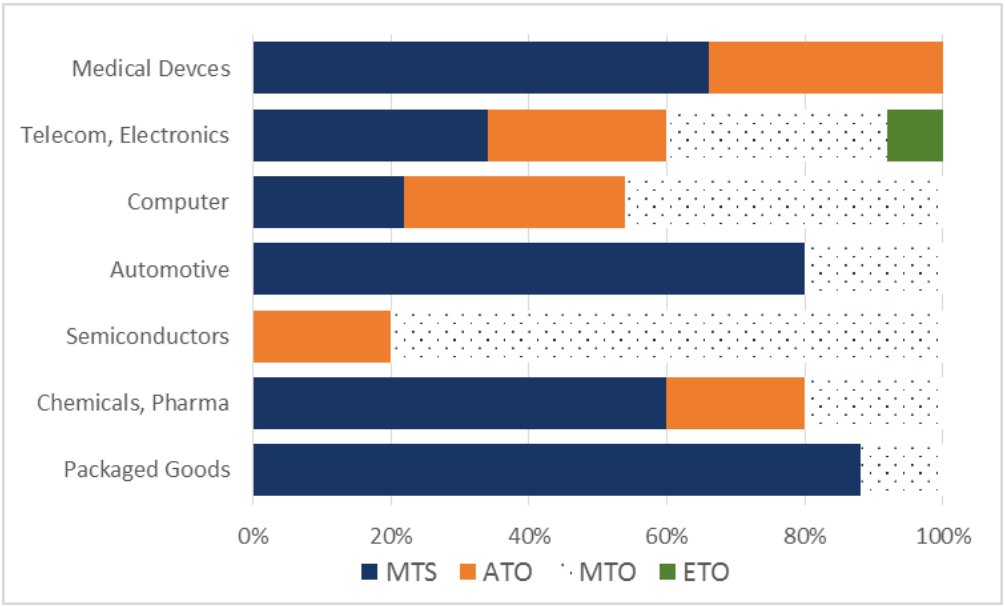
Engineer to Order (ETO): work with the customer to design and then make the product

Make to Order (MTO): make the customer's product from raw mat'

Assemble to Order (ATO): combine a number of preassembled modules to meet customer's specifications

Make to Stock (MTS): serve customers from finished goods inventory

Which operation strategy?



source: Performance Measurement Group, 2004

Type	Condition	Key benefits
MTS	standard product w/ high volume	cost & response
ATO	product w/ high variation	reduce inventory
MTO	customized or infrequent demand product	low FG, many option
ETO	complex product w/ unique customer	response to requirement

Important Productivity Concepts

- **Time-Motion Study:** scientifically measure & break human activities into smaller to eliminate inefficient & increase productivity (manual repetitive) $\rightarrow$ standard time & cost reduction
- **Overall Equipment Effectiveness (OEE):** framework to measure an individual machine $\rightarrow$ sources of waste
- **Lean management:** activity based , *kaizen* $\rightarrow$ 7 wastes, value stream mapping

History of Time-Motion Study

1881 **Frederick W. Taylor** developed time study to measure how long it takes a worker to complete a task

1885 **Frank B. & Lillian M. Gilbreth** developed motion study to determine the best way to complete a job

Time Study

- **What:** determining how long it takes for an average worker to complete a task at a normal pace
- **Benefit:** calculate standard cost, track performance, input for planning
- **Equipment:** pen, form, stop watch
- **Note:** define work element,

$$\text{std.time} = \frac{\text{observed time} \times \text{rating}}{(1 - \text{allowance})}$$

How to calculate std.time?

- **observed time:** avg.time (clear start-stop, rep?, trial time)
- **perf.rating:** $\frac{\text{operator speed}}{\text{normal speed}}$
- **allowance:** due to fatigue, environment, resting, delay in MHE,

Example of Standard time

$$\text{std.time} = \frac{\text{observed time} \times \text{rating}}{(1 - \text{allowance})}$$

Step 0 introduce and explain purposes

Step 1 observing operation/ element and compute average cycle time

- **avg.of total:** continue operation for many cycles, e.g., $\frac{400(\text{minutes})}{100(\text{cycles})} = 4.0$ minutes/cycle
- **avg.of lapse:** stop watch each cycle, e.g., $\frac{3.7+4.0+4.2+4.8+3.3}{5} = 4.0$ minutes/cycle, (5 sufficient?)

Step 2 rating performance [by observer], e.g., work 85% slower than average, $4.0 \times .85 = 3.40$

Step 3 adding allowance [by policy], e.g, allow 5+5+8=18% break allowance, $\frac{3.4}{1-.18} = 4.14$ ## std.time

Motion Study: ECRS

- **What:** the best way (distance, movement) to complete a repetitive job; how much you get done in a period of time
- **Faster:** less movement, less task, less force
- **More Endurance:** better posture, better environment, consistent speed
- **How to calculate std.time?:**
  - eliminate unnecessary motions
  - combine activities
  - rearrange sequence of activity, environment
  - simplify tasks, invent tool or equipment
- **Story:** Nathan's Hot Dog Eating Contest

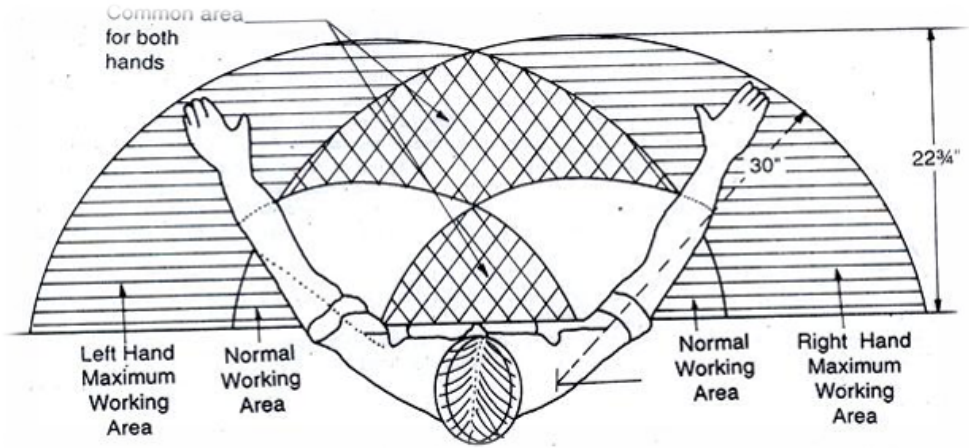
Therblig

Effective therbligs

- Transport empty/loaded
- Grasp
- Release load
- Use
- Assemble
- Disassemble
- Inspect
- Rest

Ineffective therbligs

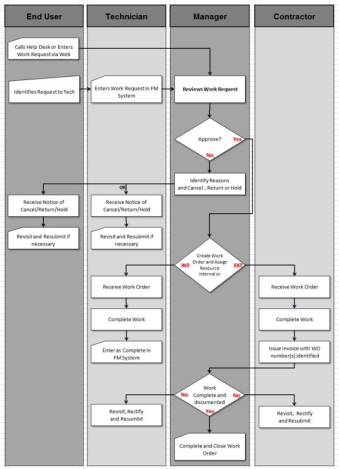
- Hold
- Pre-position
- Position
- Search
- Select
- Plan
- Unavoidable/Avoidable Delay



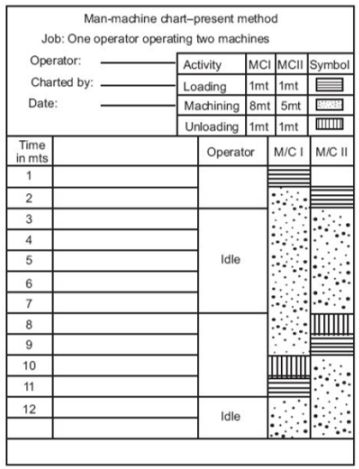
Selecting an Operation

- **Impact:** high frequency, high labor, repetitive tiring
- **Environment:** noisy, unpleasant, 3D (dirty, dangerous and demanding)

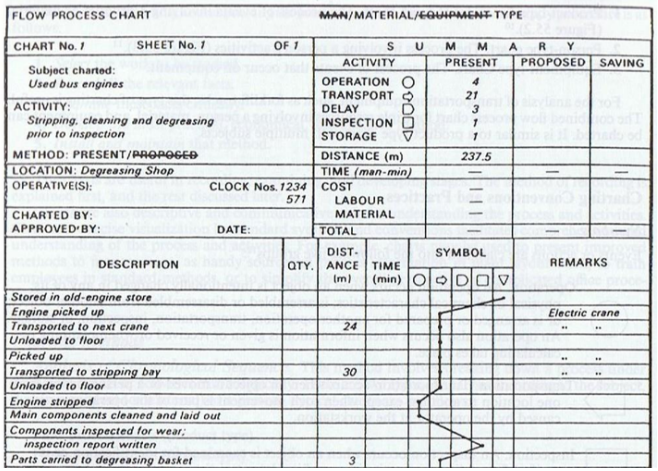
Tool to analysis of Operation



Swim lane diagram



Flow process chart



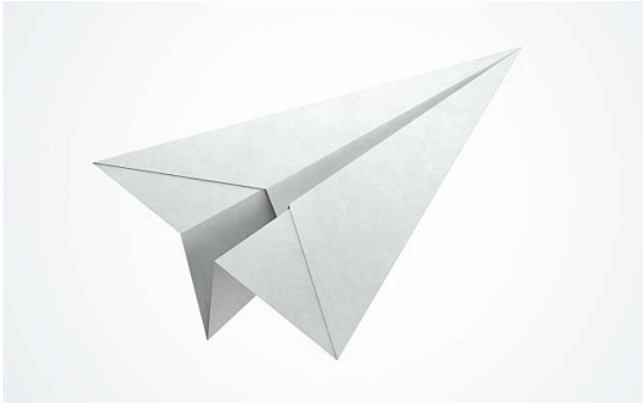
Man-Machine chart

- **How to select?:** Quick-Win VS High-Impact

Airplane Production Simulation

Setting

- **Volunteer:** 4 Operators + 4 IEs + 1 QC + 1 Timer
- **Other:** supervisor (all other students)
- **Timing:** 3 minute/round; 3 rounds + 2 minutes Preparing Time

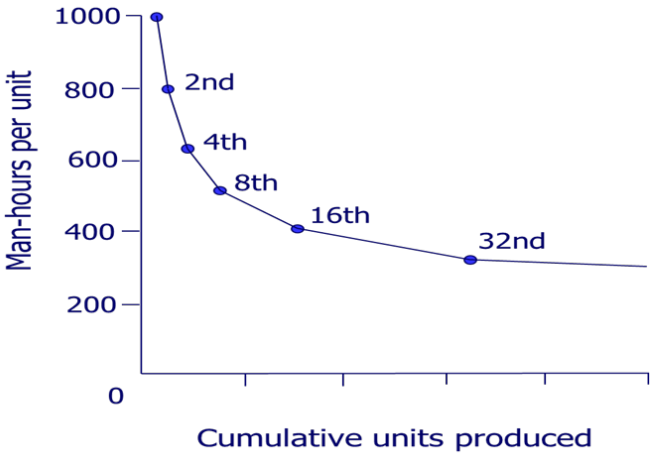


Question

- how to indicate bottleneck?
- what is the performance rating of each worker
- how to calculate standard time

Learning Curve

- **What** more experience → better performance
- **Implication:** capacity ↑, incentive & std.time?
- **Theory:** performance marginally improves as more unit produced
- **Example**



$$t(n) = 1000 \times (0.8)^{\log_2 n}$$

Suppose man-hour required to manufacture a produce reduced 20% every time that products are double production, how many units of products required to reduce man-hour from 1000.0 man-hour to less than 400.0 man-hour?
Let n number of time production double

n	$\log_2 n$	man-hour
1	0	1000.0
2	1	800.0
4	2	640.0
8	3	512.0
16	4	409.6
32	5	327.7

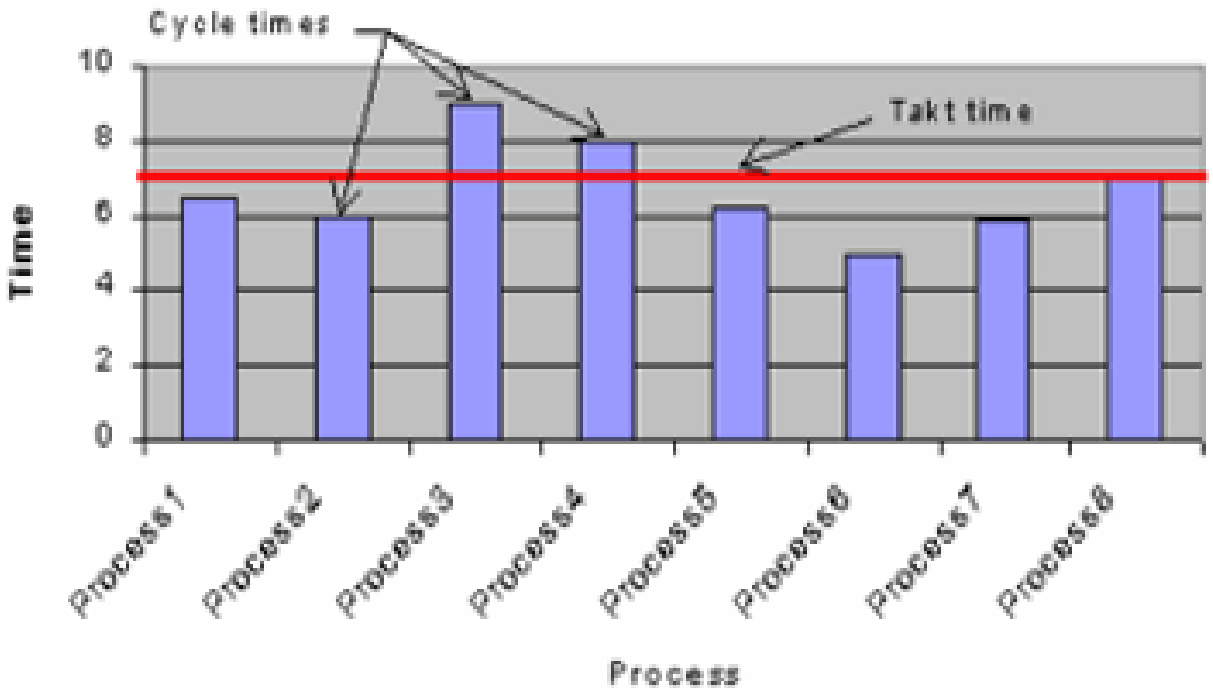
Cycle Time & Takt Time

Cycle Time

actual time to process one opeartation

- **Operation CT** time required for a worker to complete one cycle of an operation
- **Machine CT** time for a machine to finish one complete cycle, including loading and unloading

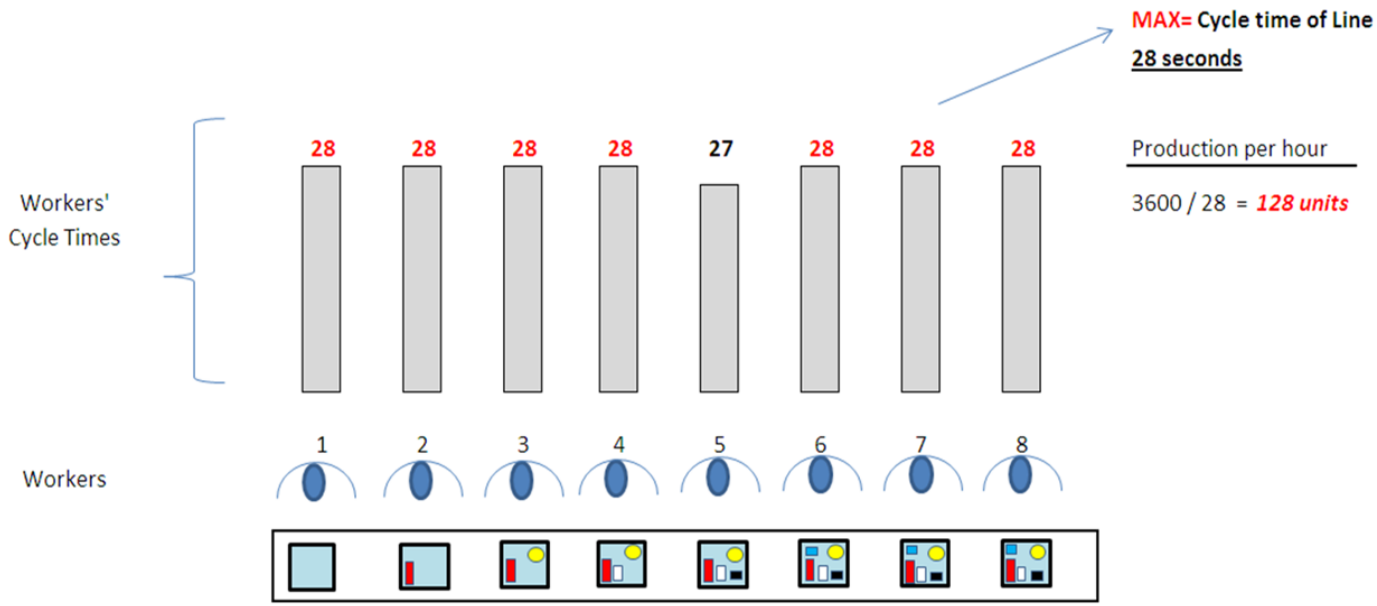
Takt Time



Line Balancing

- **What** shift some elements of a task to balance work
- **Requirement:** precedence constraints/ sequencing
- **Example:**

  Consider a tandem assembly line consisting of 8 identical worker, an engineer wishes to maximum productivity by line balancing. What are current and maximum of productivity?



Glove Box Vibration Wielding

OEE Motivation

If you were told that your department was running flat out you might reasonably assume that the equipment was running efficiently and effectively. However,

- What if the equipment only ran for 75% of the time? → availability
- What if when it ran it ran at 80% of its speed ? → productivity
- What if only 90% of the parts it made are good? → quality

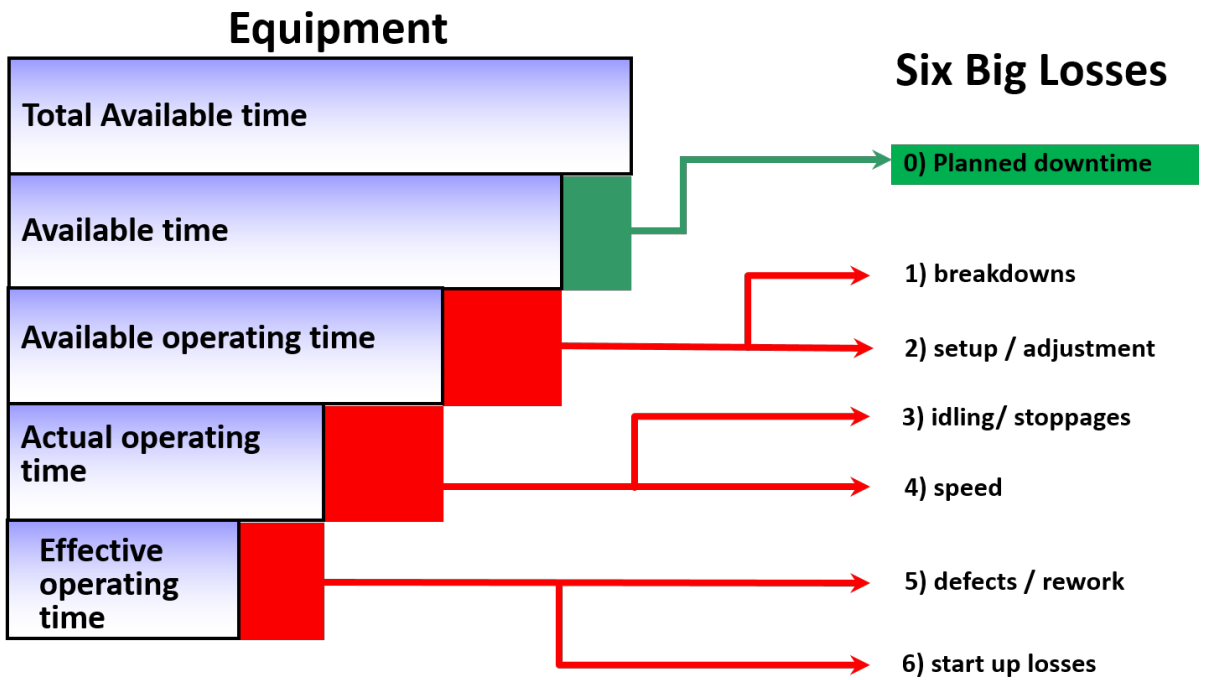
  Individually these performance measures seem be OK, but is it a true picture?

What's impacting on these performance figures?

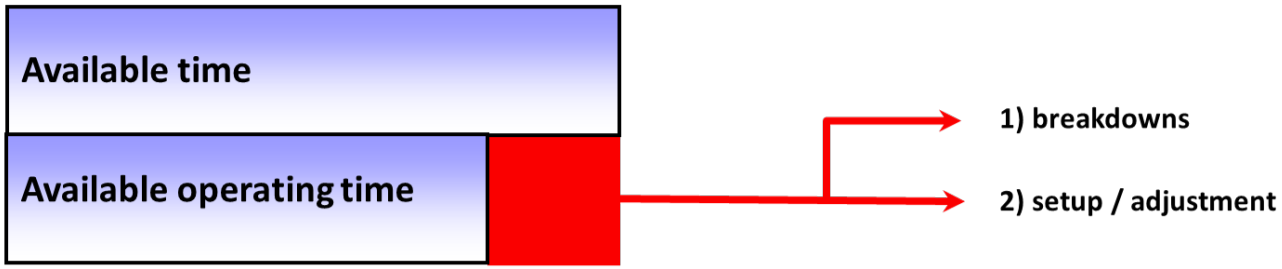
Overall Equipment Efficiency

- **What:** total measure of process/ machine not operator
- **Benefit:** identification of process improvement
- **Note:** focus on six big loss, not comparable across factory

$$\text{OEE} = \text{Availability} \times \text{Productivity} \times \text{Qualtiy}$$



Availability: Scheduled Time

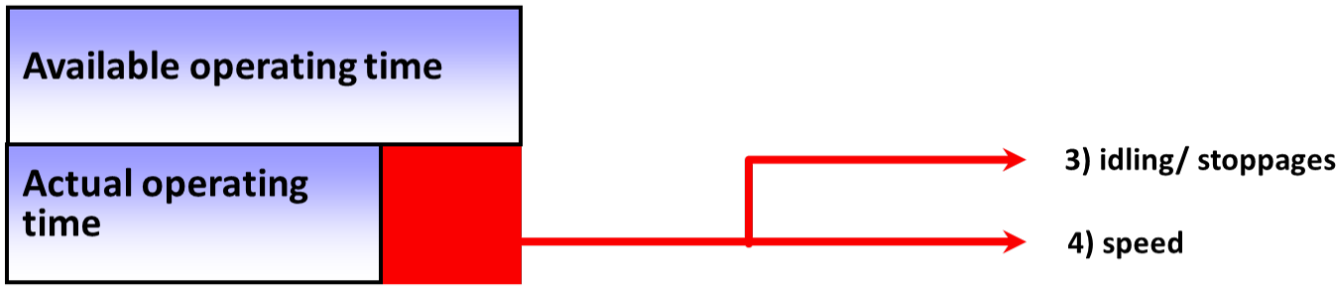


- **Availability:** ratio of scheduled time available to operate (Uptime)

$$\text{Availability} = \frac{\text{available time} - \text{unplaned down time}}{\text{available time}}$$

- **Big Losses**
  - *Breakdown:* time lost through key equipment breaking down (10+)
  - *Setup/ Adjustment:* time lost through product change over or adjustment

Productivity: Ideal Production Time



- **Productivity:** ratio of time that machine at its designed speed.

$$\text{Productivity} = \frac{\text{ideal cycle time} \times \text{actual output}}{\text{available oper.time}}$$

- **Big Losses**
  - *ideal/minor stoppage:* time lost through not operating or not added value
  - *speed:* time lost through not operating at its optimum rate

Quality: Meaningful Production Time

- **Quality:** ratio of time that good units produced (first pass yield)

$$\text{Quality} = \frac{\text{parts good}}{\text{part made}}$$

- **Big Losses**
  - *defect/rework:* time lost through producing poor quality or reworking
  - *start-up loss:* time lost through not reaching controllable environment

Example of OEE calculation

During an eight hours shift (8:00 - 16:00) a body press machine is scheduled to run with a single worker who typically has two 15 minutes break beginning at 10:30 and 14:30 as well as 30 minute lunch at noon. In the ideal condition, it should produce 20 units per hour, but the machine ran poorly during shift. Several jams were encountered, and the maintenance report showed detail as follows:

11:15 received breakdown call

11:30 arrived to machine CPMA056

12:00 replaced canning press

12:30 closed maintenance task

During this shift, the total of 100 units were produced with 25 damaged units. Calculate OEE of this canning press machine

Template of OEE calculation

Availbility			
Gross Time	.	(in minutes)	(A)
Planned Down Time	.	(in minutes)	(B)
Net Available Time	.	(in minutes)	$(C) := (A) - (B)$
Non Planned Stoppages	.	(in minutes)	(D)
Operating Time	.	(in minutes)	$(E) := (C) - (D)$
Availability	.		$(F) := (E)/(C)$
Productivity			
Output	.	(units)	(G)
Std Cycle Time	.	(minutes/unit)	(H)
Productivity	.		$(I) := \frac{1}{(E)}\,[(G) \times (H)]$
Quality			
Defected	.		(J)
Quality	.		$(K) := \frac{1}{(G)}\,[(G) - (J)]$
OEE	.		$(L) := (F) \times (I) \times (K)$

Apply OEE: data & example

Machine No.				No. operators				A B C D		Day / Night		Date /	
Hour of the Day	Tape No.	Machine Downtime											
		Programme change inc. test piece	Tooling problem please specify cause	Machine problem - please specify cause	Cartridge Change	Calibration	Meetings (inc. team brief)	Clean up & SAP up	Post / fixture problem	Slaving Up	Other - please specify cause	Specified causes of machine downtime	Total Downtime every 3 hrs
7-8													
8-9													
9-10													
10-11													
11-12													
12-1													
1-2													
2-3													
3-4													
4-5													
5-6													
6-7													
TOTAL													
Hand Over Notes:													

- **Data collection:** not hindrance, unit of time (1 min or 30 min), automatic?
- **Responsibility:** involve operators, ownership, stage of machine
- **Limitation:** OEE for equipment or process, not operators

OEE In Class Exercise

Calculate the OEE given that: operation time is 460 min/day; downtime is 100 min; ideal cycle time is 10 min/product; actual cycle time is 15 min/product; the number of products scheduled for production is 22; and the number of products actually produced is 20 with no defect or rework. If the value turned out to be significantly less than you "benchmark" value, what step would you take to correct the situation?

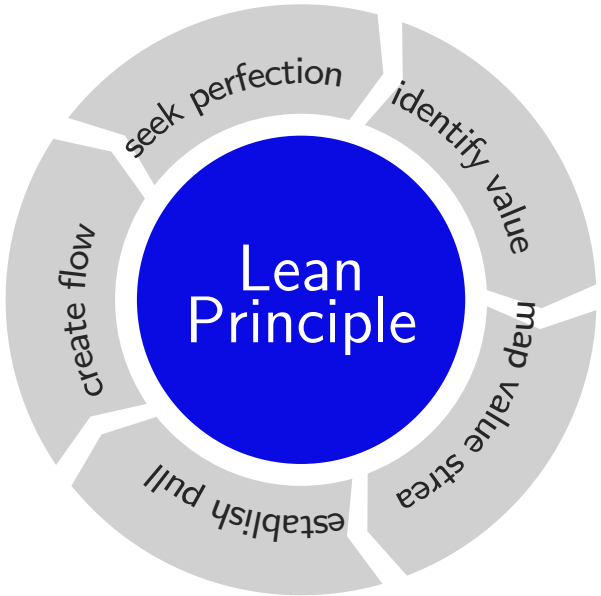
source: 'Systems Engineering and Analysis', *Blanchard, B.S. and Fabrycky, W.J.*

- **Availability:** $\frac{\text{oper.time - downtime}}{\text{oper.time}} = \frac{460-100}{460} = 0.7826$
- **Producibility:** $\frac{\text{output} \times \text{ideal.CT}}{\text{oper.time - downtime}} = \frac{20\times10}{360} = 0.5556$
- **Quality:** $\frac{\text{part good}}{\text{part made}} = \frac{20}{20} = 1.0$
- **OEE:** $0.7826 \times 0.5556 \times 1.0 = 0.4348$

  Further Analysis: planning problem

- **Schedule$_{idealCT}$/Oper.Available:** $\frac{\text{scheduled.num} \times \text{ideal.CT}}{\text{oper.time - downtime}} = \frac{22\times10}{360} = 0.6111$
- **Schedule$_{actualCT}$/Oper.Available:** $\frac{\text{scheduled.num} \times \text{actual.CT}}{\text{oper.time - downtime}} = \frac{22\times15}{360} = 0.9167$

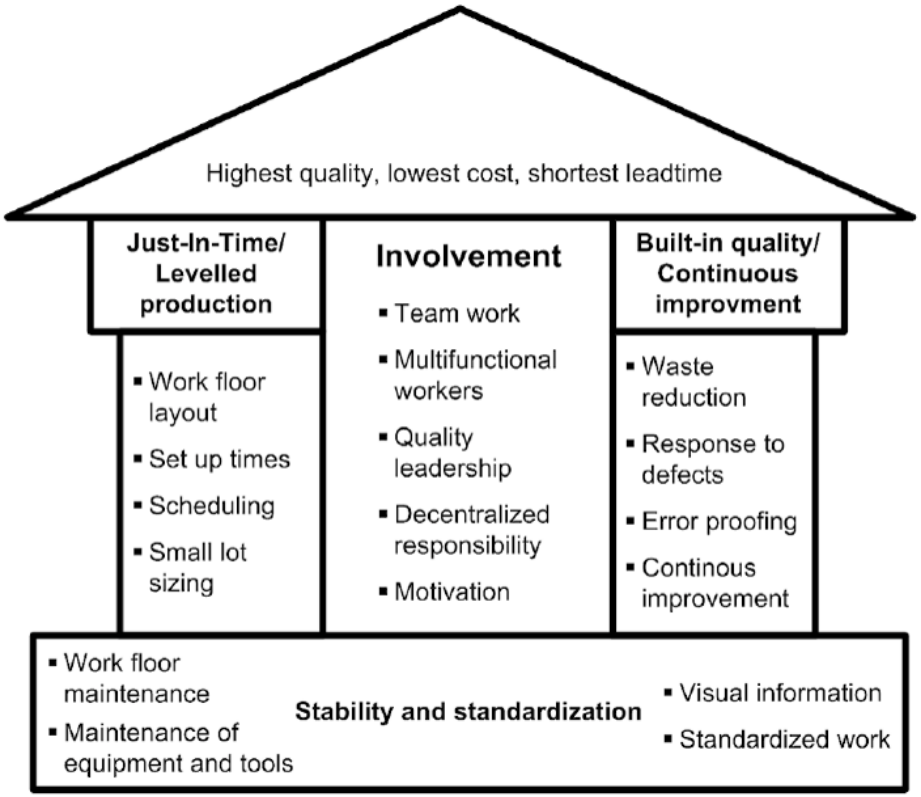
Principles of Lean Supply Chain



source: www.lean.org

- **Lean101:** superior form of Just-In-Time (JIT) system
- **History:** kaizen (bottom-up) & JIT VS TQM → Lean
- **Principle:** eliminating wastes by marginal gain, bottom up, training
- **Adaptation:** Manuf → Office → logistic & service

House of Lean



source: Lean principles in industrialized housing production: The need for a cultural change, *Hook, M and Stehn,L.*

Highlight: lean is way of life, not project

- **Everyday concept:** one piece flow, Error Proofing (Poka Yoka)
- **Interest Tools:** 7Wastes, Value Stream Mapping,

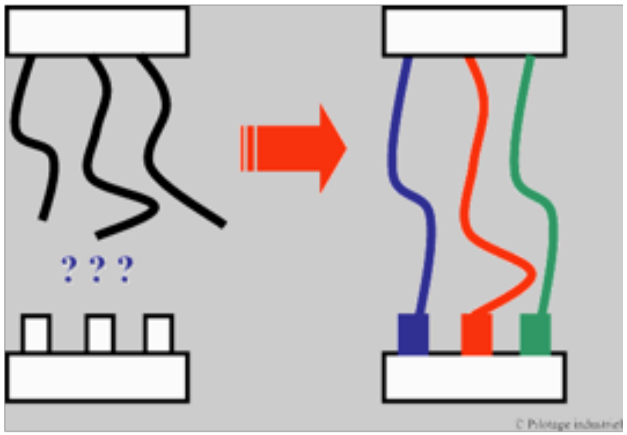
5S: Basic of Basic

Example of Poka Yoke: Fool Proof

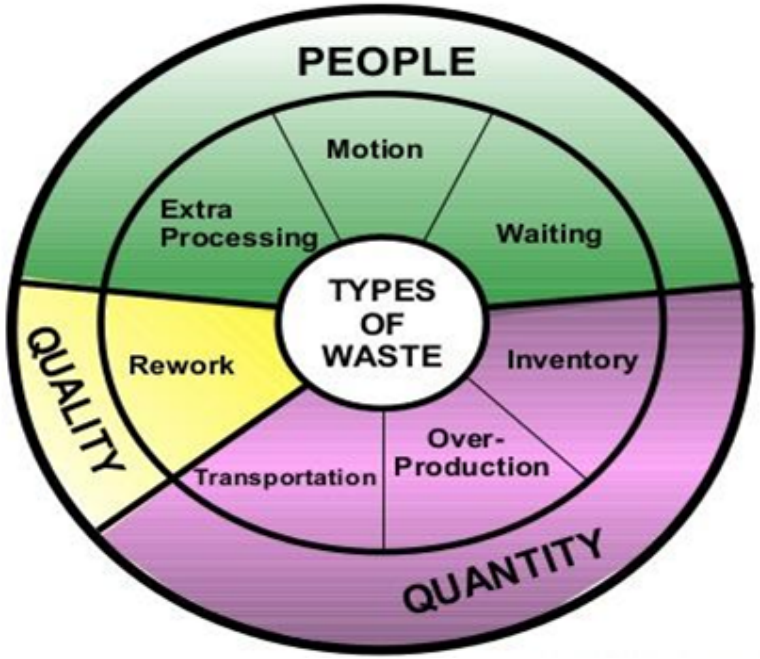
Error is inevitable, but it should be eliminated.

Before Poka Yoke

After Poka Yoke



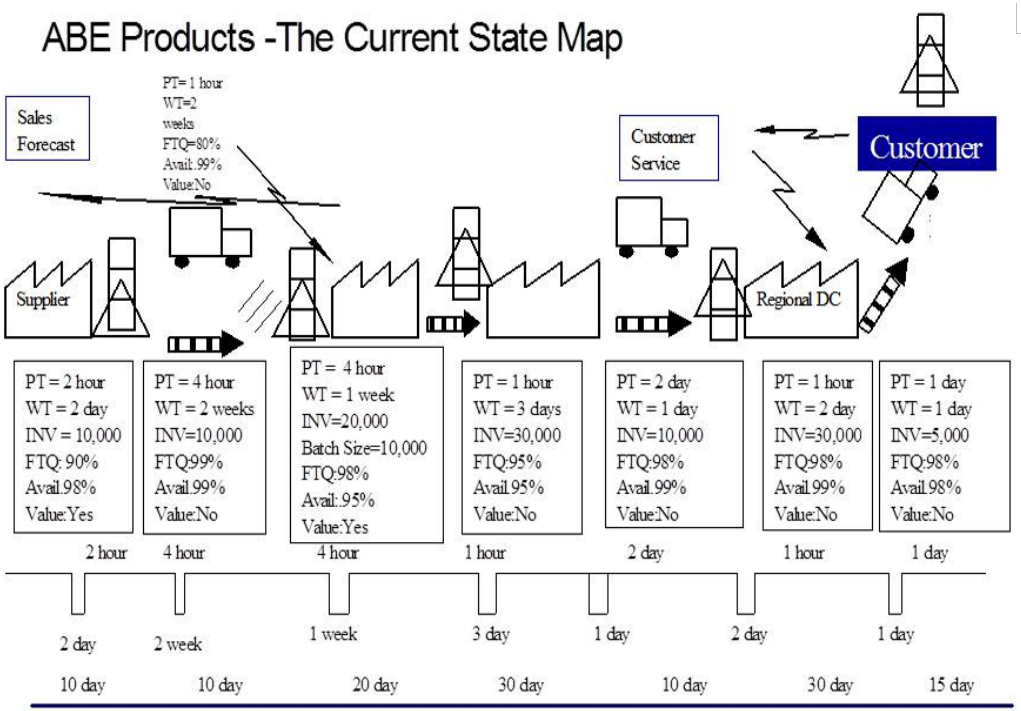
7Wastes (Muda): TIM WOOD



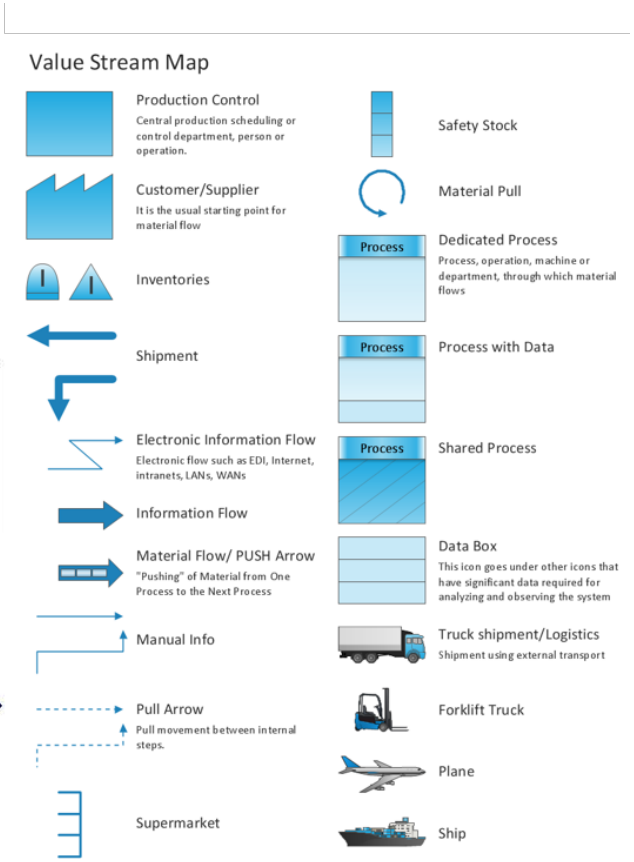
source: Chopra and Meindl 2010 [**?**]

- **Transportation:**
- **Inventory:**
- **Motion**
- **Waiting**
- **Overproduction**
- **Overprocess**
- **Defect**

Value Steam Mapping



Summary of Current State Value Stream Map			
Total Process Time	85 Hours	First Time Quality	62%
Total Wait Time	30 Days	First Time Availability	83%
Total Inventory	125 Days	Total Value Add Time	5 hours
		Total Process / Total Lead Time	2.40%
Total Lead Time	160 Days	Total Value / Total Lead Time	0.15%



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