Flow unit: Items that flow through the process (homogenous or hetero generous) → An order
Flow time: Time required to turn material into product or customer being served
Unit load: Total amount of time the resource works to process each flow unit

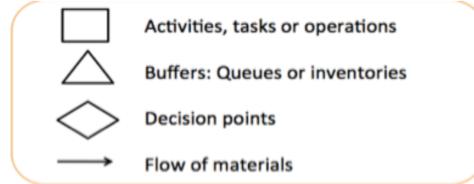
- Single type of flow units & **Multiple types of flow units**: The product mix needs to be considered

Capacity rate: Maximum units processed in a unit time; **EX: 60 /X per hour or 1/X per min**

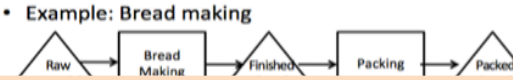
- Of a process: Maximum possible output rate → DETERMINED BY THE BOTTLENECK

Bottleneck: The resource with the lowest capacity rate

- "Slowest" resource or resource with the highest "unit load"
- Is FULLY utilized while *other* resources are not utilized = 100% UTLIZATION
- Shortening NON-BOTTLENECK tasks decreases flow time →Does NOT affect CAPACITY RATE



- Example: Bread making



$$\text{Utilization} = \frac{\text{Throughput Rate}}{\text{Capacity Rate}} = \frac{\text{Actual output rate}}{\text{maximum output rate}} \leq 100\%$$

How to increase the capacity rate of a bottleneck or a process

- Expand (Adding another) resource pool & reduce (faster resource) the unit load

**Be aware of bottleneck shift

Throughput (flow) rate = THE LOWER # {input rate, capacity rate}

- The amount of material or items passing through a process

Cycle time: Average time between completion of units → Paced by bottleneck

Implied utilization = Input rate / Capacity rate

- **Allows us to capture the idea of overtime**

Process Flow, Linear FChart, Swim-Lane FC, Gantt Chart
Inventory build-up diagram & Average inventory

Excess Capacity	INVENTORY BUILD-UP
23	0
2	0
0	3
23	0
	0.75

Average Inventory

- Continuous model: Assume continuous input and output processes

Instantaneous input rate, output rate, and inventory accumulation rate;
AVG inventory CONT:Area under the inventory curve / Length of time interval

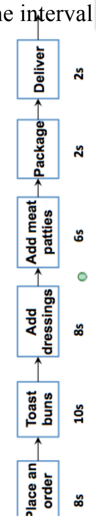
- **Discrete model**: Average inventory = Average height of the bars

Little's Law: $I = R \cdot T$ (inventory = throughput rate * flow time) →
Rate=Inventory/FlowTime → FlowTime=Inventory/Rate

	Production Process	Service Process
Flow Unit	Materials	Customers
Input Rate	Raw material releasing rate	Customer arrival rate
Capacity Rate	Maximum output rate	Maximum service completion rate
Throughput Rate	Finished goods output rate	Customers departure rate (service completion rate)
Flow Time	Time required to turn materials into a product	Time that a customer is being served
Inventory	Amount of work-in-process	Number of customers being served

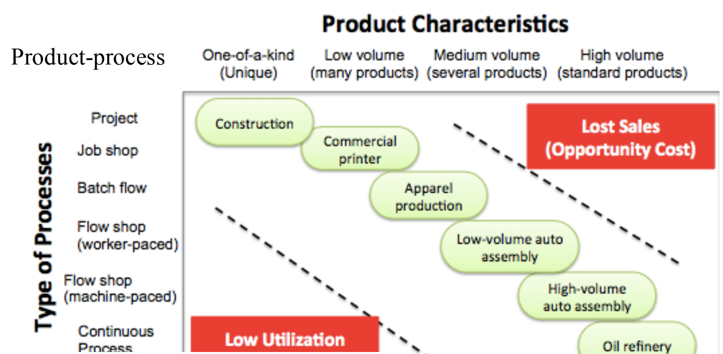
Short-Run vs Long-Run AVERAGE

Long-Run avg input rate must be **LESS** than the long-run avg capacity rate
Long-Run avg throughput rate **EQUALS** Long-run avg input rate if input is smaller than CAPACITY
Short-Run avg input rate **can be greate**r than the short-run avg capacity rate



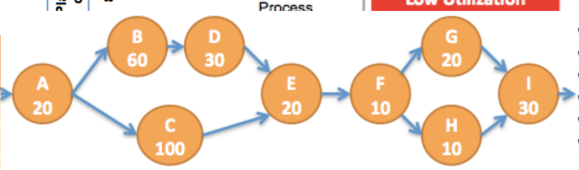
Identify all paths between the start node and the end node
(Enumeration Method)

- The maximum path /time required to finish the project is called **critical path**
- All activities on the critical path are critical activities
- Allows us to allocate resources among activities to find appropriate tradeoffs between project duration and project cost



Crashing: Reducing the time it takes to complete the activity
Crash Time: The minimum possible time to complete an activity (smaller than the *normal* time)
Crash Cost: Cost associated with the crash time (in place of the *normal* cost) Cost per week
(Crash Cost– Normal Cost)/(Normal Time- Crash Time)

Activity	Preceding Activities	Normal Time	Crash Time	Normal Cost	Crash Cost	Cost per Week	Weeks
A	-	4	2	10,000	11,000	500	2
B	A	3	2	6,000	9,000	3,000	1
C	A	2	1	4,000	6,000	2,000	1
D	B	5	3	14,000	18,000	2,000	2
E	B, C	1	1	9,000	9,000		0
F	C	3	2	7,000	8,000	1,000	1
G	E, F	4	2	13,000	25,000	6,000	2
H	D, E	4	1	11,000	18,000	2,333	3
I	H, G	6	5	20,000	29,000	9,000	1



How long will it take to complete the project?

Path	# Days
A-B-D-E-F-G-I	190
A-B-D-E-F-H-I	180
A-C-E-F-G-I	200
A-C-E-F-H-I	190

8AM-9AM: 0
9AM-12noon: Area = 3 · 60 / 2 = 90
12 noon-1PM: Area = (60 + 50) / 2 = 55
1PM-3PM: Area = 2 · (50 + 60) / 2 = 110
AVG Inv = 255. Dividing it by 7 hours (8AM to 3PM) = 255/7 = 36.43.
The total number of customers who showed up is 30 · (5 hours) + 45 · (2 hours) = 240. "Throughput" Rate = 240/7 = 34.29 customers/hour
Avg Flow Time = AVG Inventory/ Throughput Rate

Flow Shop	Job Shop
- High volume - Standardized product - Compete on cost - Fixed path - Resource specialization (high utilization)	- Low volume - Custom orders - Compete on servicing specific needs - Independent work stations (human judgment) - Resource flexibility (low utilization)

To compute the CAP.R of each resource: 1/(5 + 2) orders/min for A; 1/(5 + 10) orders/min for B; and 1/15 orders/min for C. Both B&C are the bottlenecks, and the capacity rate is 1/15 orders/min or 4 orders/hr. Profit per unit is (25%) · ($40) = $10, the current profit rate is ($10) · (4) = $40 per hour.

Increase Type B by 10%--> New input mix is: 0.5 unit of A per hour and 2.2 units of B per hour, for a total of 2.7 units per hour. An hour's input requires for Category *I*, 2.7 · 10 + 0.5 · 10 + 2.7 · 10 = 59 min < 60 min; for Category *II*, 2.2 · 30 = 66 min < 120 min (there are two units of Category *II*). The new input mix can be accommodated under the current resource capacities. Since the marginal profit of B is $110 per unit, the extra profit rate is 0.2 · $110 = $22/hour.