MSBA 7004
Operations Analytics

Tutorial 1: Process Flow Analysis

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Learning Objectives

- Compare and clarify the concepts in class
- Review the process analysis
- Identify the key components in process analysis
- Learn to draw a process flow chart
- Identify how to improve a process

Warm-up True-or-False Question

1. Flow units in a process could be homogeneous or heterogeneous.
2. If a process has two bottleneck resources, then they must have the same capacity rate.
3. In any process the non-bottleneck resource always gets idled for some time.
4. Buffers could have values added.
5. In any process, the flow time cannot be smaller than the cycle time.
6. The total duration of the process is the time spent on the bottleneck resource.
7. Increasing the capacity of the non-bottleneck resources does not increase the capacity rate of the process.

Explanation for the warm-up questions

1. **Flow units in a process could be homogeneous or heterogeneous.**

   True.

2. **If a process has two bottleneck resources, then they must have the same capacity rate.**

   True. Bottleneck resource is the resource with the minimal capacity rate. So if there is more than one bottleneck resource, they must all have the minimal capacity rate and therefore their capacity rate must be equal.

3. **In any process the non-bottleneck resource always gets idled for some time.**

   True. Because the unit load on a non-bottleneck resource has to be smaller than the unit load of the bottleneck resource, which is also the cycle time. So in each cycle, the non-bottleneck resource must have some time idled.

4. **Buffers could have values added.**

   False

Explanation for the warm-up questions

5. In any process, the flow time cannot be smaller than the cycle time.

True. cycle time = time spent on the bottleneck resource, which must be smaller or equal to the flow time.

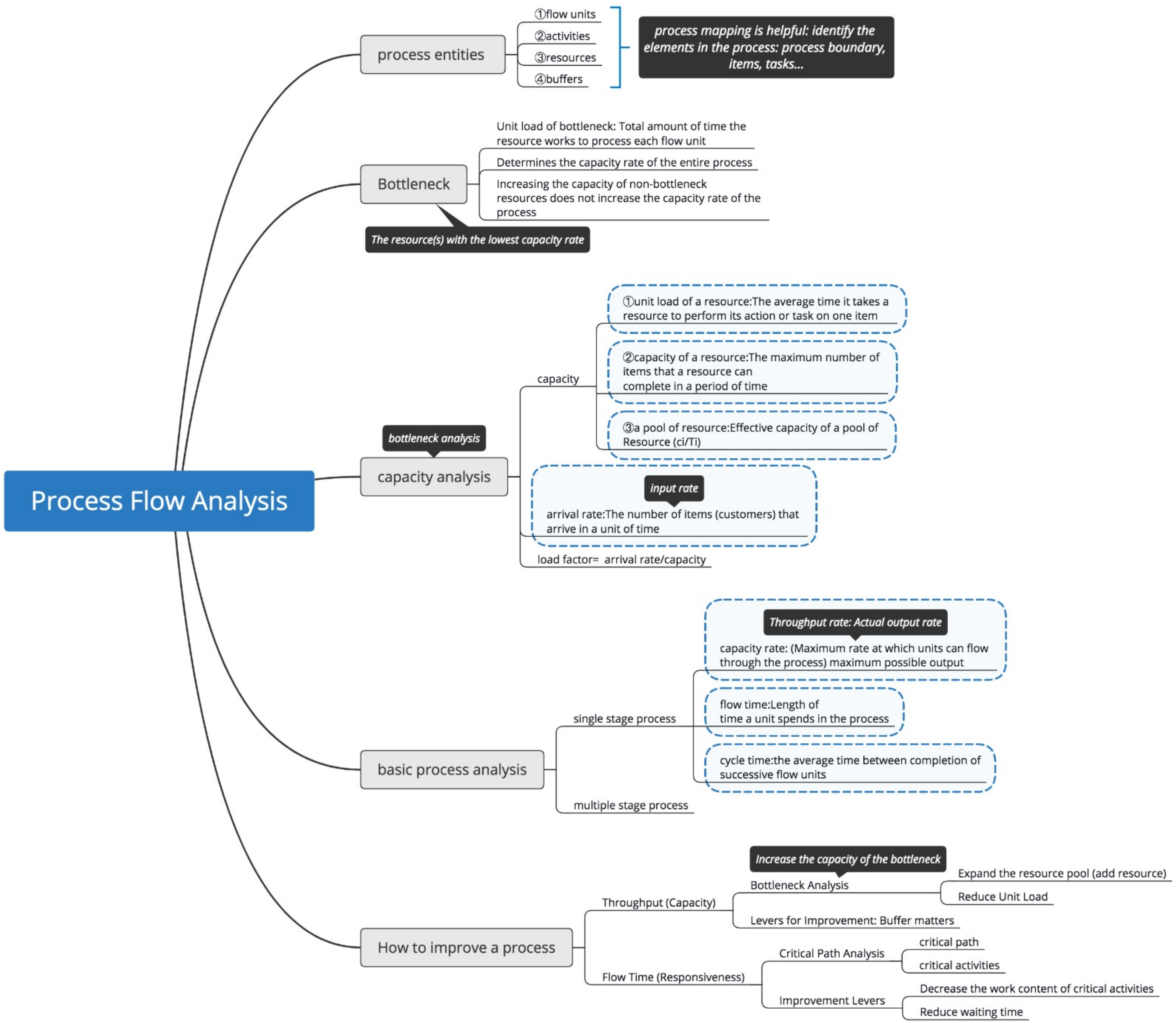
6. The total duration of the process is the time spent on the bottleneck resource.

False. The total duration (flow time) is the sum of the time along the critical path, has nothing to do with the bottleneck resource. The time spent on the bottleneck resource equals the cycle time, which determines the capacity rate for producing a large volume of identical products.

7. Increasing the capacity of the non-bottleneck resources does not increase the capacity rate of the process.

True

Summary of the concepts in lecture



Process Flow Analysis

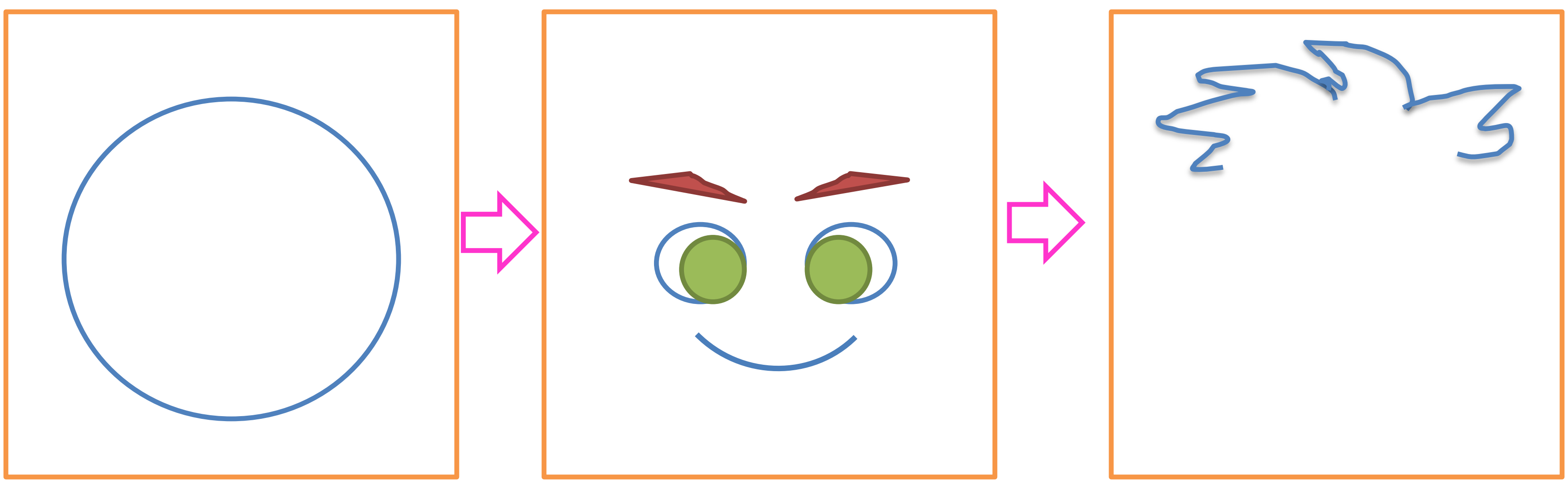
- **Key concepts**:
  - Flow Time *T,* Capacity Rate*,* Bottleneck
- Process Flow Diagram:
  - Elements: activities, buffers, decision points, flow of materials
  - Types: Standard, Linear, Swim-Lane, Gantt chart
- Improving a process
  - Throughput (Capacity)
  - Flow time (Responsiveness)

The Process: Drawing Faces

Step 1:
draw circle

Step 2:
draw features

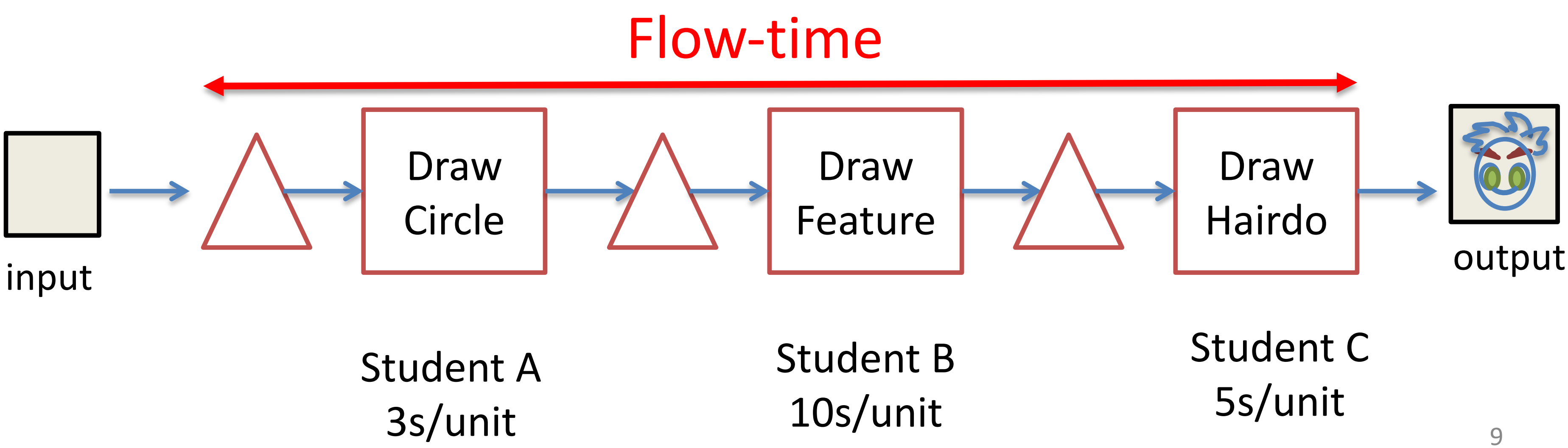
Step 3:
draw hairs



A Face!!

Definition: Flow-time

- **Flow-time (Raw process time):** The total time spent by a flow unit within process boundaries
  - Also known as “time in system”
  - Average flow-time: T
  - Units: hours, minutes, seconds



Definition: Theoretical flow time

- **Theoretical flow time:** The minimum amount of time required for a flow unit to go through the process without any waiting or interruptions.

- **Flow time**

$$= \sum \text{Activity time} + \text{Waiting(buffer) time}$$

$$= \text{Theoretical flow time} + \text{Waiting time}$$

Process Flow Diagram

How to Build a flow chart

- Determine objectives
- Define process boundaries
- Define flow units
- Observe process and collect data
- Map out process
- Validate chart

- Identify:

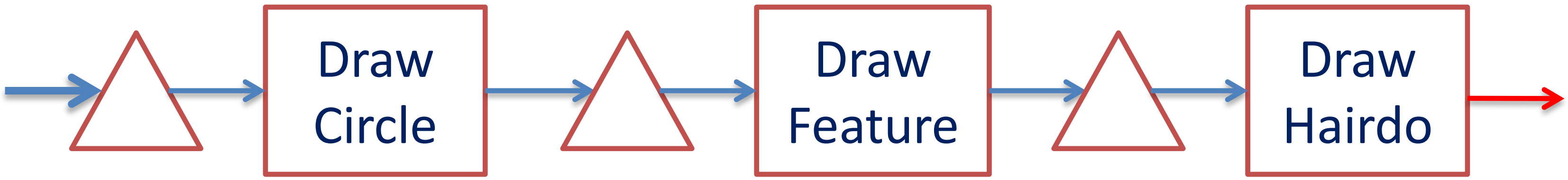
  Items (flow units)

  Tasks (steps)

  Resources (people or machine)

  Flows (movement or information exchange)

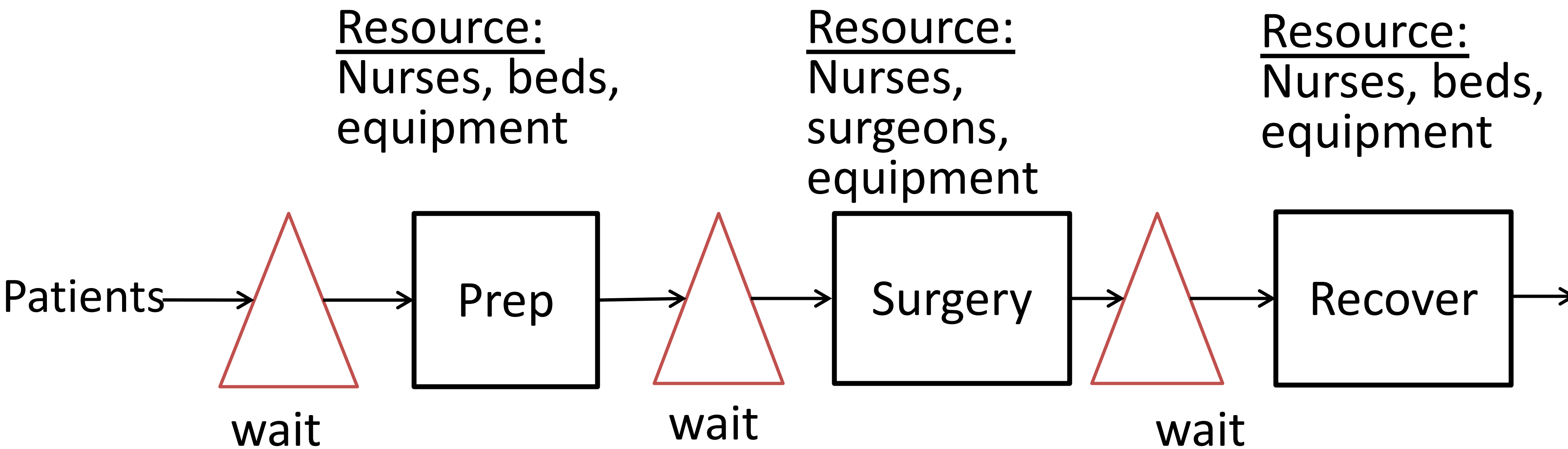
  Storages (waiting, inventory)



Example: Surgical Center

Flow units (items)	Patients
Start and end of system	From patient entering to leaving
Flow rate / Throughput (items/hr)	patients left/hour
Flow-time (hours)	from patient arrival to release
Inventory (items)	patients, in prep, in surgery, in recovery, waiting, etc.
Tasks	prep, surgery, recovery time, etc.

Surgical Center: Flow Chart



<u>Items</u>

<u>Tasks</u>

<u>Resources</u>

<u>Flows</u>

<u>Storages/inventory</u>

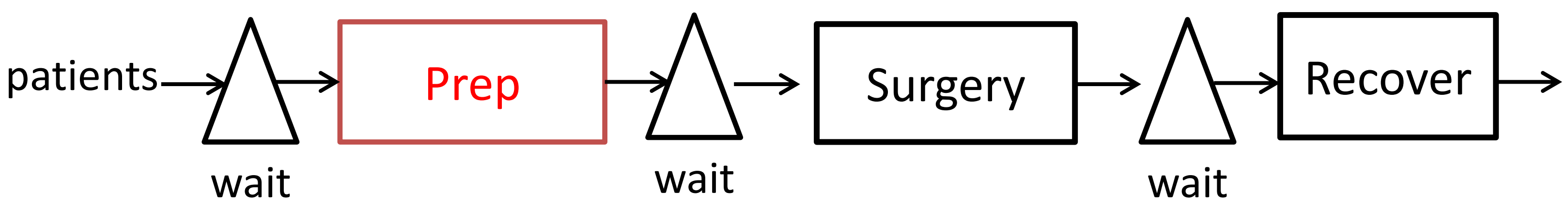
Capacity Analysis (Bottleneck Analysis)

- **Capacity of a Resource:**
  - Unit load (T_i), Resource Capacity (1/ T_i), Resource pool(n / T_i)
- **Bottleneck :** The resource with lowest capacity rate, can be multiple in a process
- **Capacity of a Process:**
  - =The capacity rate of the bottleneck resource
- Definitions needs to distinguish:
  - Arrival rate (input rate):
    - The number of flow units that arrive in a unit of time
  - Capacity rate:
    - Maximum rate at which flow units can flow through the process
  - Throughput rate (output rate):
    - Min {Arrival rate, Capacity rate}
  - Implied utilization (Load factor):
    - = Arrival rate/capacity
  - Utilization:
    - = Throughput rate/capacity <=1
  - Cycle time
    - = 1/ capacity rate of the process

Capacity Planning Example: Surgical Center Again

- A nurse can prepare a patient for surgery in 10 minutes. Can the nurse handle the load of 5 patients per hour?

- Question: Can the nurse handle the load?
- Flow-units: (items) patients
- Steps or tasks or actions prep for surgery
- Resources nurses, beds, equipment.
- Process flow diagram

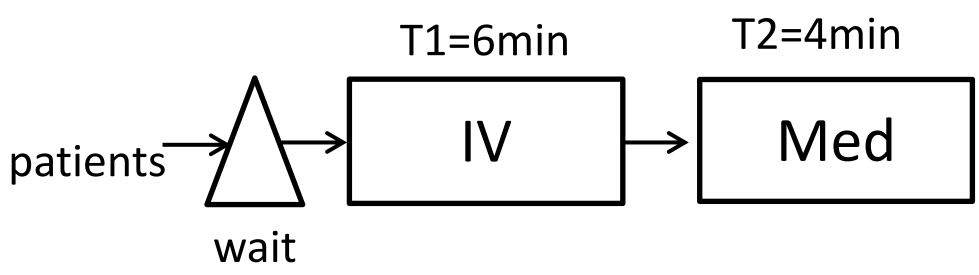


- Arrival rate: *Ri* 5 patients per hour
- Capacity: *Rp* 60/10 = 6 patients per hour

Series of Tasks (One Resource)

A nurse needs to do two tasks to prepare a patient: Put in an IV(infusion) which takes 6 minutes and give the patient medications which takes 4 minutes. Can the nurse handle a demand of 7 patients per hour?

- Question: Can the nurse handle the load?
- Flow-units: (items) patients
- Steps or tasks or actions Put an IV and then give medications
- Resources Nurse
- Process flow diagram

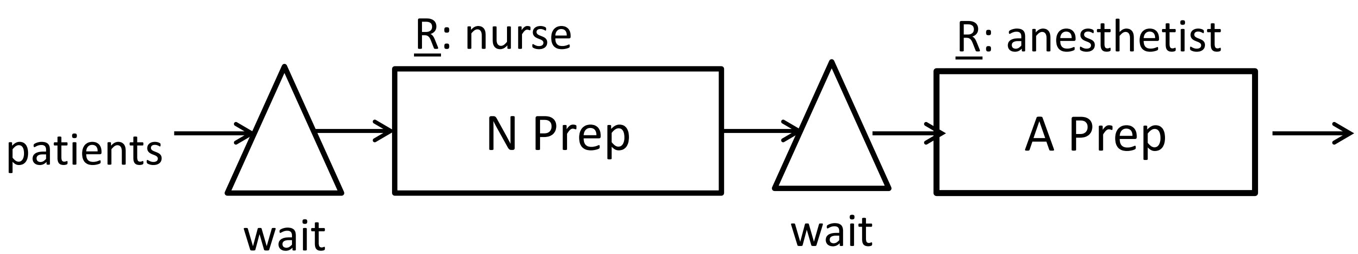


- Arrival rate: *Ri* 7 patients / hour
- Capacity: *Rp* 60/(6+4) = 6 patients/hour

Series of Tasks (Multiple Resources)

A nurse can prepare a patient in 10 minutes for surgery and an anesthetist can prepare a patient in 15 minutes. Can these two handle a demand of 5 patients per hour?

- Question: Can they handle the demand?
- Flow-units: (items) Patients
- Steps or tasks or actions Nurse prep and anesthetist prep
- Resources Nurse and anesthesiologist
- Process flow diagram



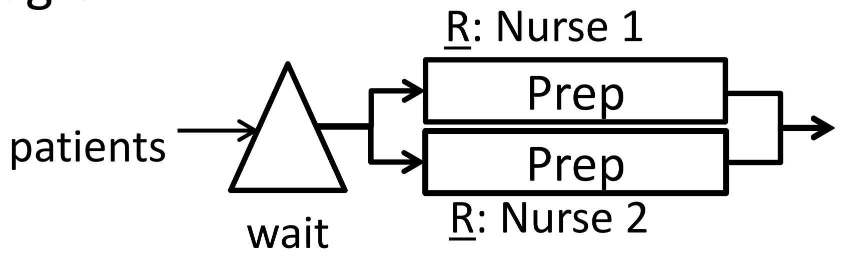
- Arrival rate: *Ri* 5 patients/hour
- Capacity: *Rp* Nurse = 6 patients/hour

Anesthetist = 4 patients/ hour

Multiple (Parallel) Resources

There are two nurses and each can prepare a patient in 10 minutes for surgery. Can these two nurses handle a demand of 10 patients per hour?

- Question: Can the two nurses handle?
- Flow-units: (items) Patients
- Steps or tasks or actions Prep
- Resources Nurse 1 and Nurse 2
- Process flow diagram

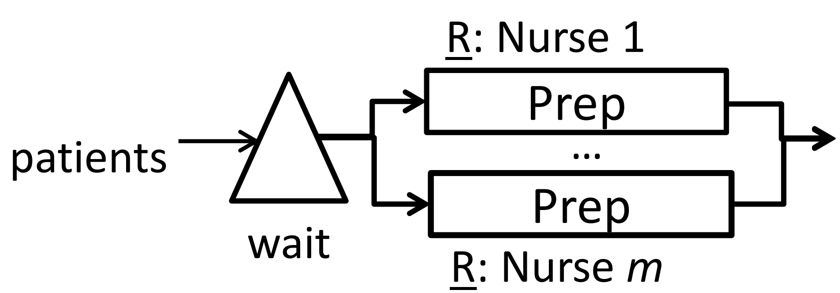


- Arrival rate: Ri 10 patients/hour
- Capacity: Rp 6+6 = 12 patient/hour

Capacity Planning

Each nurse can prepare a patient for surgery in 10 minutes. The ASU(Ambulatory surgical unit) expects a demand of 25 patients per hour. How many nurses does the ASU need to meet demand?

- Question: How many nurses do we need?
- Flow-units: (items) Patients
- Steps or tasks or actions Prep
- Resources Nurses
- Process flow diagram



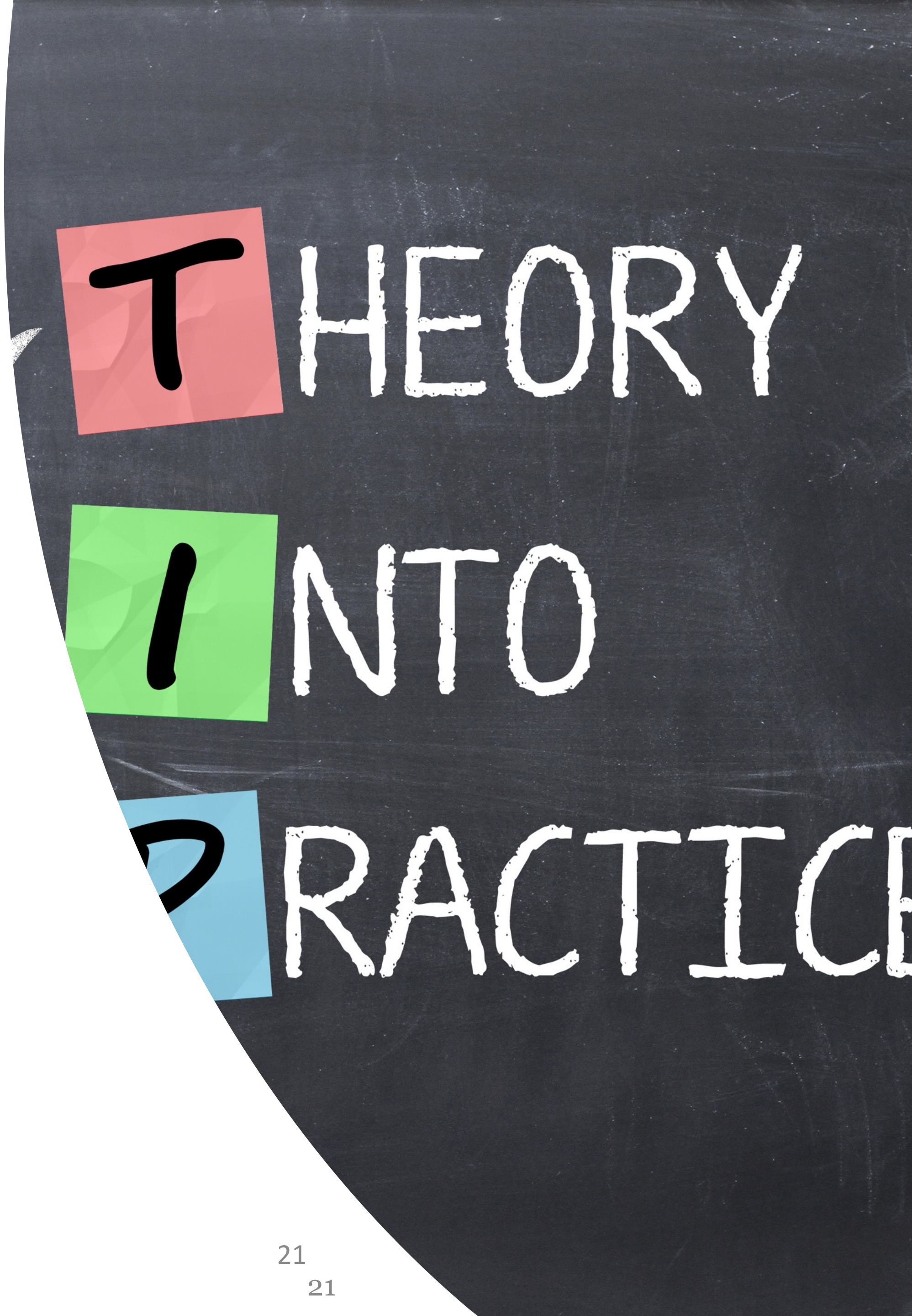
- Arrival rate: *Ri* 25 patients
- Capacity: *Rp* $Rp = m \times 6 \geq Ri$; $m \geq 25/6$
- *and hence* $m=5$

Improve a process

- Throughput (Capacity)
  - Bottleneck Analysis(Capacity analysis)
    - Increase the capacity rate of a bottleneck
      - ☐ Increase resource pool for bottleneck
      - ☐ Reduce the unit load at the bottleneck
- Flow time (Responsiveness)
  - Critical Path Analysis
    - Reduce activity time on the critical path
      - ☐ Work faster
      - ☐ Move work content off the critical path
    - Reduce waiting (buffer) time

Practice Questions for today

- Quotable manufactures
- Bottlenecks
- Capacity for Cleaning and Sterilizing in a Surgical Suite
- Process Analysis with Different Types of Flow Units (optional)



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Practice 1: Quotable manufactures

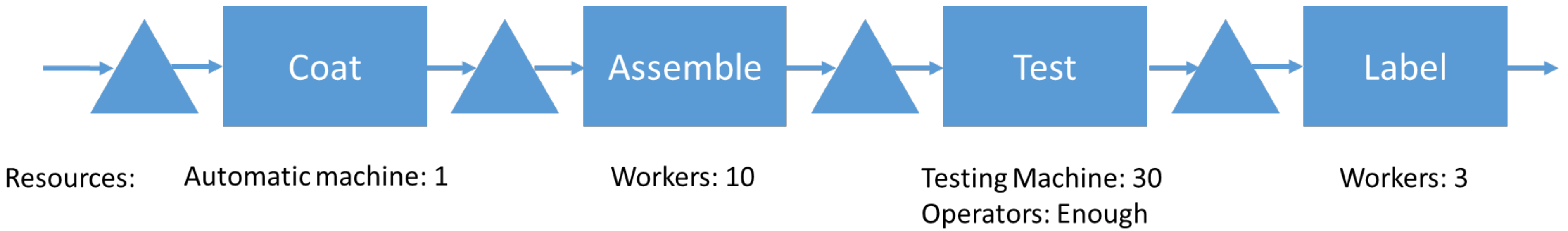
Quotable manufactures a removable disk for PC's. There are four major stages in its manufacture.

- The first stage is coating of disks. Coating is done by an automated machine that can run 24 hours/day. It produces 100 disks/hour.
- The second stage is assembly of the disk into the case. Assembly takes the average worker 2 minutes/disk. There are 10 workers at this stage.
- The third stage is testing, which catches defects from the coating operation. Each testing machine takes 5 minutes to test a disk. There are 30 machines and enough operators to keep these machines busy if necessary.
- The fourth stage is labeling the disk. Each worker here can do 2 disks/minute. There are 3 workers who do this task.

Assume the workforce completes <u>8 full hours of work each day</u>, and stages 2 through 4 <u>run 8 hours/day.</u> Demand is 2100 a day.

Assume all rates and times are deterministic (no variability in demand or production). Testing finds no defects.

(a) Draw the flow chart.



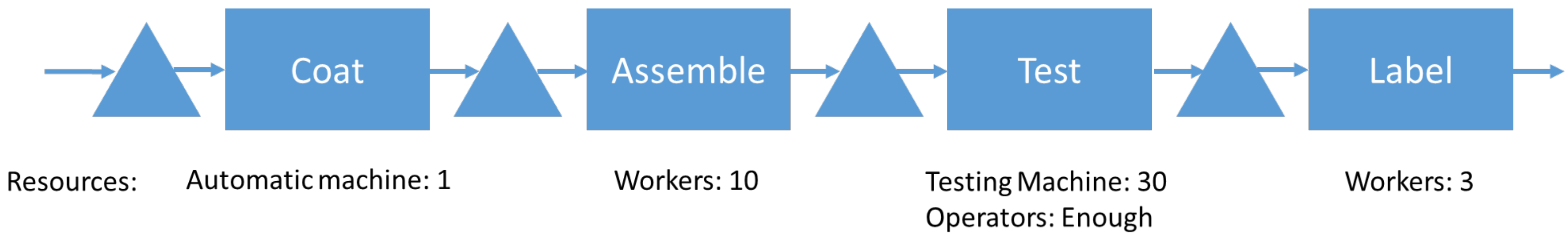
(b) Fill in the table below.

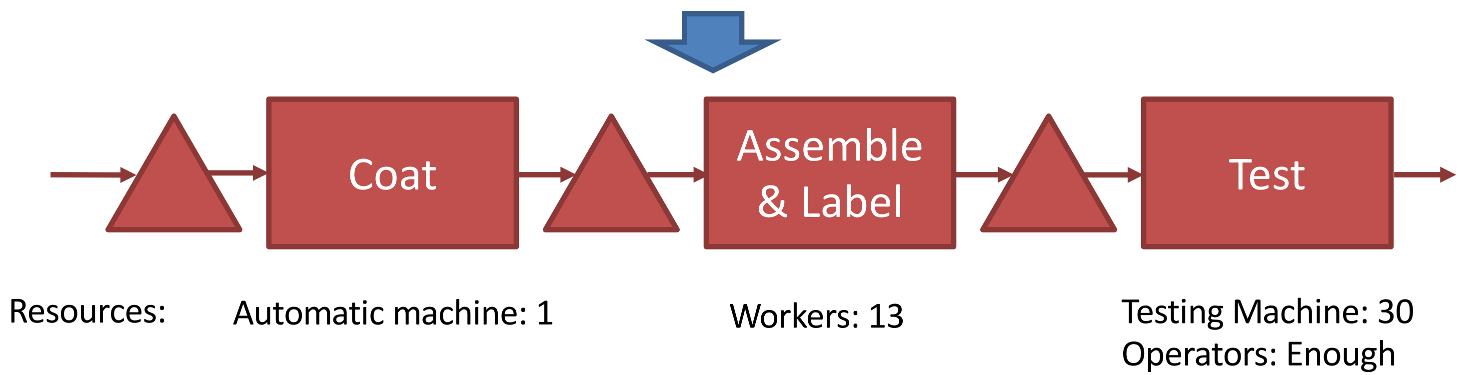
Stage	Resource	Time (Tp) (minutes/disk)	Rate for one resource (1/Tp) (disks/hour)	Number of resources	Rate for all resources at this stage (Rp=m/Tp) (disks/day)
1	Coating machine	0.6	100	1	2400/day
2	Assembly workers	2	30	10	300/hr=2400/day
3	Testing machines and operators	5	12	30	360/hr=2880/day
4	Labeling people	1/2	120	3	360/hr=2880/day

(c) Assume the demand is 2100 disks/day, explain why there is sufficient capacity to meet the demand.

- Bottleneck is either coating machine or employee at assembly at 2400/day.

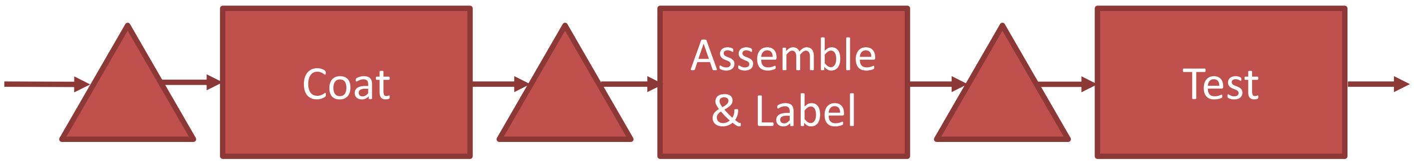
(d) If assembly and labeling are combined into a single step, can the process handle the demand? The raw processing time for one disk when assembly and labeling are combined into a single step equals to the sum of the original times. That is 2.5 minutes for one disk. Assume testing is done after this new combined step.





Tp= 2.5 minutes/disk
Rp= 1/Tp = 24 disks/hour or 192 disks/day (8 hours per day)
Capacity of workers in combined stage: 192*13 = 2496 disk /day
Bottleneck resource is coating machine
Capacity rate of the process still 2400 > 2100 disk/day (demand)
Hence the process can handle the demand.

(e) How many people do we need in the combined stage in order to satisfy the demand?



Resources: Automatic machine: 1 Workers: 13 Testing Machine: 30

Operators: Enough

Tp= 2.5 minutes/disk

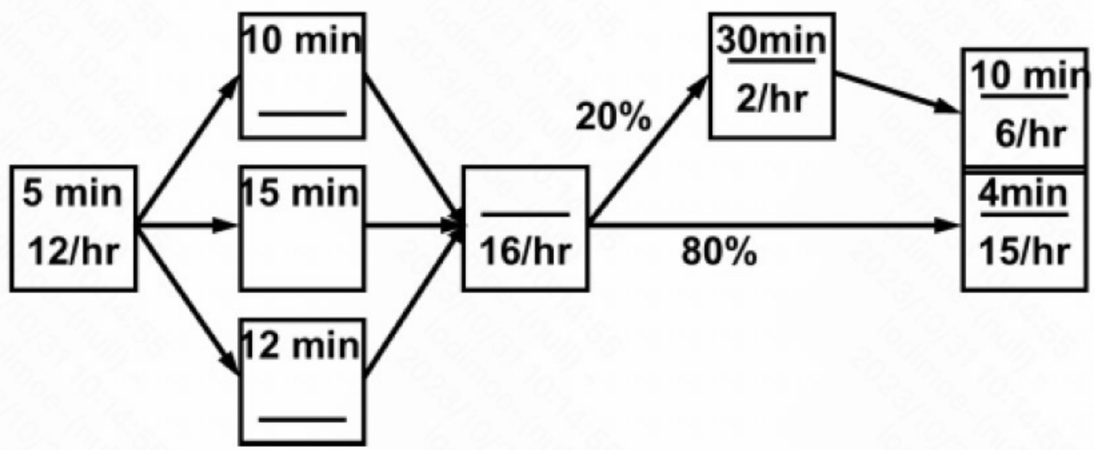
Demand 2100 disks/day

Rp= 1/Tp = 24 disks/hour or 192 disks/day (8 hours per day)

We need 2100/192 = 10.93, or at least 11 workers in order to handle the demand.

Practice 2: Bottlenecks

- For this problem assume all times and rates are deterministic and there is a reasonable amount of buffer between stages.
- Stage 1 has a single resource.
- Stage 2 has 3 servers. The job needs to **<u>visit only one of them</u>**, so these three work in parallel. The times the individual resources require are given.
- Stage 3 has a single resource
- Stage 4 is only required of 20% of the units.
- Stage 5 is **<u>a single resource</u>** that **<u>handles both</u>** the 20% of the units that go through stage 4 at the rate of 6/hr and the 80% of the units that don't use stage 4 at a rate of 15/hour.

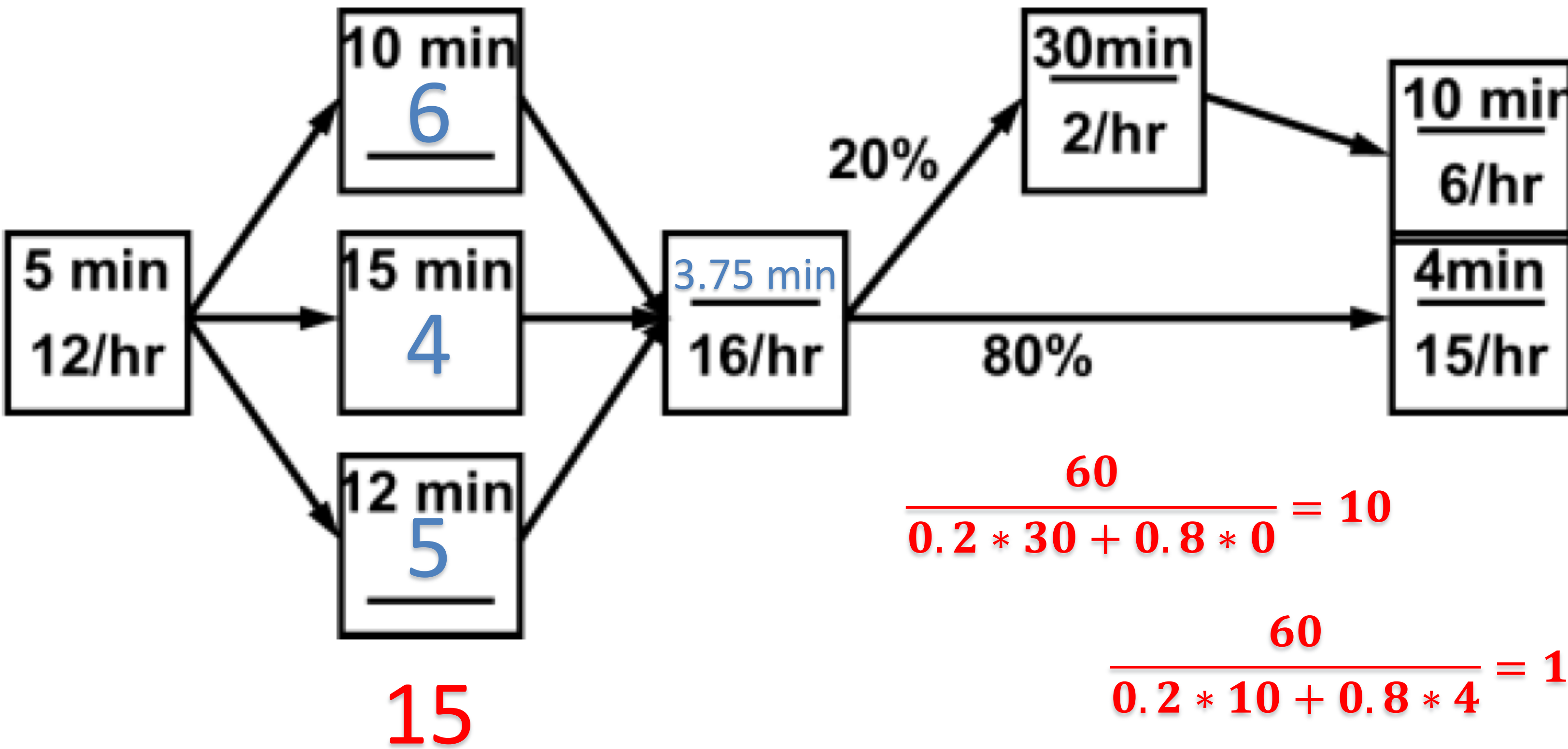


Capacity rate: S_1 _____ S_2______ S_3 ______ S_4 ______ S_5 ______

(a) Compute the capacity of each stage

- For stages 1 and 3 the rates are actually given.
- For stage 2, you need to convert each processing time to a rate.
  - e.g. 10 min/unit is equivalent to 1/10 unit/min or (60 min/hr) (1*10 unit/min) = 6 units/hr.)
  - Total should be 6+5+4 = 15units/hr
- For stage 4, only 20% of the units is handled, and therefore, the average rate is 60/(20%*30+80%*0) = 10 units/hr
- Let's consider stage 5 next. We know that 20% of the units will be processed at the rate of 6/hr and 80% will be processed at the rate of 15/hr. Thus:
  - Average time: 20% * (10 min/unit) + 80% * (4 min/unit)= 5.2 min/unit
  - Average rate is (60 min/hr)/(5.2 min/unit) = 11.54 units/hr.
  - Don't just simply add the capacity rate*proportion together

(b) Which stage is the bottleneck?



$$\frac{\mathbf{60}}{\mathbf{0.2*30+0.8*0}}=\mathbf{10}$$

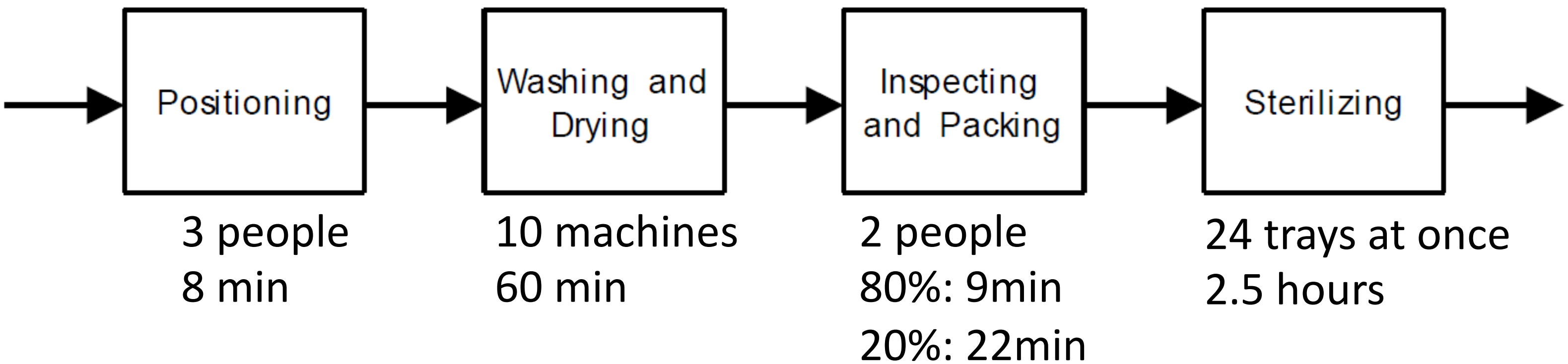
$$\frac{\mathbf{60}}{\mathbf{0.2*10+0.8*4}}=\mathbf{11.54}$$

(c) The maximum production rate of the system ?

- A system's maximum production rate is determined by its bottleneck

Practice 3: Capacity for Cleaning and Sterilizing in a Surgical Suite

Surgical instruments, when they are not in use, are stored in “trays” that are wrapped and kept sterile until they are needed. Once a tray of instruments has been used in surgery and returned to the supplies area the instruments must be 1) positioned for washing, 2) washed and dried, 3) inspected for damage and packed back in the tray, and 4) sterilized. The four-step process is shown below



Positioning is done by three people and a person can do one tray in 8 minutes.

The washing and drying is done by 10 automated machines. Each machine washes and dries a tray of instruments in 60 minutes. No labor is required except to place the instruments in the machine and take them out, which we will ignore for this problem.

Inspecting and packing can be broken into two cases. Everything is fine (80% of the trays) and some instrument is damaged (20% of the trays). When everything is fine it takes 9 minutes for one person to do. If any instrument is damaged, the average time to (1) repair or find a replacement and (2) inspect and pack is 22 minutes. Two people work at this stage, and both people do both steps.

The sterilizing step is like a baking or kiln operation that cannot be interrupted to add more trays. The sterilizing step takes 2.5 hours and the one “oven” can handle up to 24 trays at once.

(a) Use the table below and compute the capacity of each resource pool.

Resource Pool	Calculation step	Capacity of Resource pool (tray/hour)

Resource pool	Calculation	Capacity of Resource pool (trays/hour)
Positioning people	$R_p = m(1/T_p) = 3(1/8\text{ min}) \times (60\text{ min/hour})$	22.5 trays/hour
Washing and Drying machines	$R_p = m(1/T_p) = 10(1/60\text{ min}) \times (60\text{ min/hour})$	10 trays/hour
Inspecting and Packing people	$T_p = 80\%(9\text{ min}) + 20\%(22\text{ min})$ $= 7.2 + 4.4 = 11.6\text{ min}$ $R_p = m(1/T_p) = 2(1/11.6\text{ min}) \times (60\text{ min/hour})$	10.3 trays/hour
Sterilizing "oven"	(24 trays/batch) / (2.5 hours / batch)	9.6 trays/hour

(b) Capacity of this system?

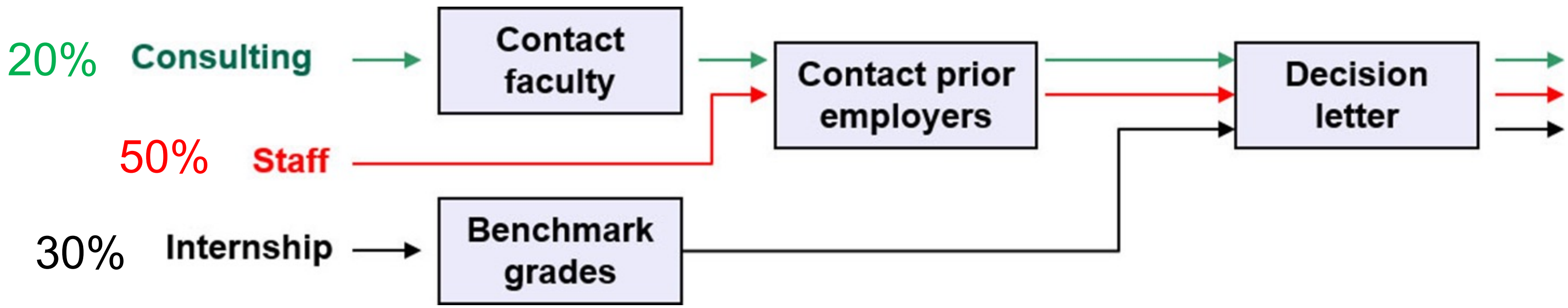
- Bottleneck, again
- The capacity of the system is the capacity of the bottleneck which is the slowest resource pool = 9.6 trays/hour

(c) An expansion of the OR (operating room) will require that trays be handled at the rate of 12/hour. What changes / additions need to be made to meet this demand?

- Theoretically, to achieve a capacity of the system of 12 trays/hour, we need to increase the rate of the second, third, and fourth steps.
  - For the second step, we need to purchase two more washing and drying machines to reach a rate of $12(1\ /\ 60min) * (60min/hour) = 12trays/hour.$
  - For the third step we need a third person, which will bring the rate to $3(1/11.6\ min)\ *\ (60\ min/hour)$ *=15.5 trays/hour*.
  - For the fourth step we will need to buy another sterilizing oven which would double the rate to *19.2 trays/hour.*
- Some improvements over this plan are possible:
  - Only two people are needed in the first step. →Moving one person from step 1 to step 3 may be possible depending on the skill requirements.
  - We may need a third additional washer/dryer since the rate for this resource pool is exactly the required rate.
  - It may be possible to buy a smaller sterilizer.

Practice 4: Process Analysis with Different Types of Flow Units

Three types of job applications need to be processed: “consulting,” “staff,” and “internship.” There are reasonable amount of inventory buffers in front of each resource/task (not shown).Each type of application has its own path through the process and does not necessarily visit all tasks. 20% of the arrived applications are consulting application, 50% are staff and 30% are internship. Unit load and numbers of workers for each task are given below:

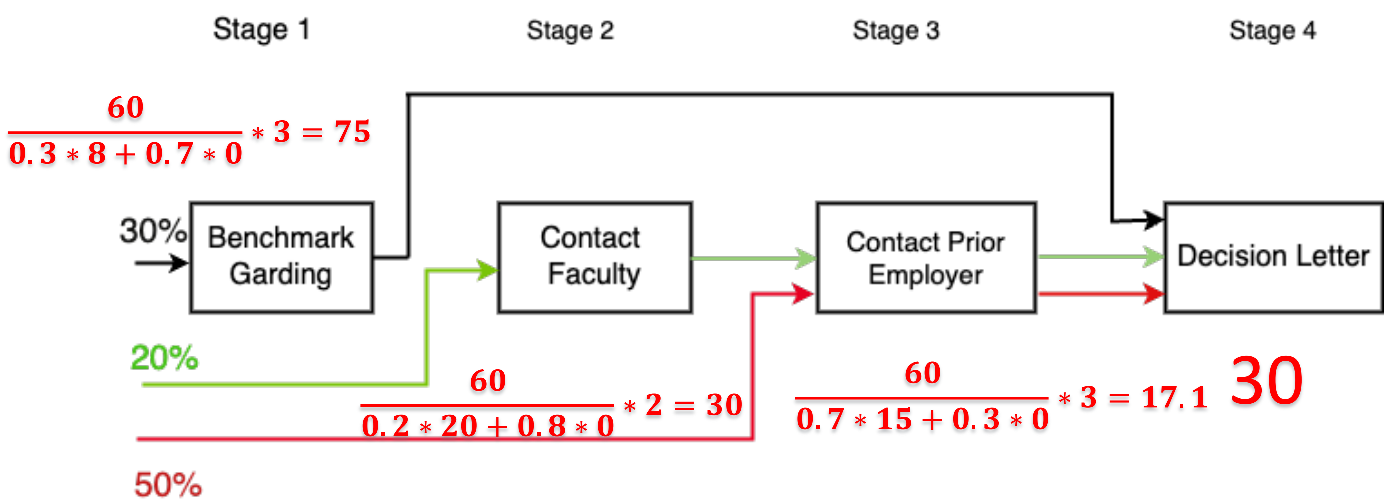


	Benchmark grades	Contact faculty	Contact employers	Decision letter
Data:				
Unit load(min/app)	8	20	15	2
Number of workers	3	2	3	1

Which step is the bottleneck? Contact employers

Can this process handle an arrival rate of 20 applications per hour?
No, as capacity rate of bottleneck =17.1<20

What is the capacity rate of this process? 17.1



	Benchmark grades	Contact faculty	Contact employers	Decision letter
Data:				
Unit load(min/app)	8	20	15	2
Number of workers	3	2	3	1

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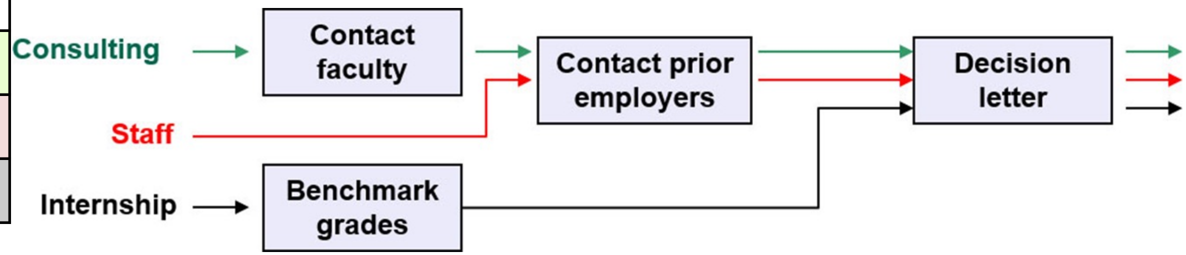
Another method: By calculating implied utilization.

Can this process handle an arrival rate of 20 applications per hour?

	Proportion	Arrival Rate
Consulting	20%	4/hour
Staff	50%	10/hour
Internship	30%	6/hour



	Contact faculty	Contact employers	Benchmark grades	Decision letter
Unit load(min/app)	20	15	8	2
Number of workers	2	3	3	1
Capacity rate (app/hour)	6	12	22.5	30
Arrival rate (app/hour)	4	14	6	20
Implied utilization	66.7%	116.7%	26.7%	66.7%

The resource with the highest implied utilization is the bottleneck: **Contact employers**.
As the implied utilization for this resource is higher than 100%, it **cannot** handle the demand of 20 applications per hour.
As 70% of the flow unit will flow through the bottleneck resource, the maximum output rate of this process is 12/70%=**17.1 units per hour**

Key take-aways

- Concepts clarification
- Key process characteristics
- Process Flow diagram
- Improving a process