Operations Management

Lecture 3:
Process flow analysis

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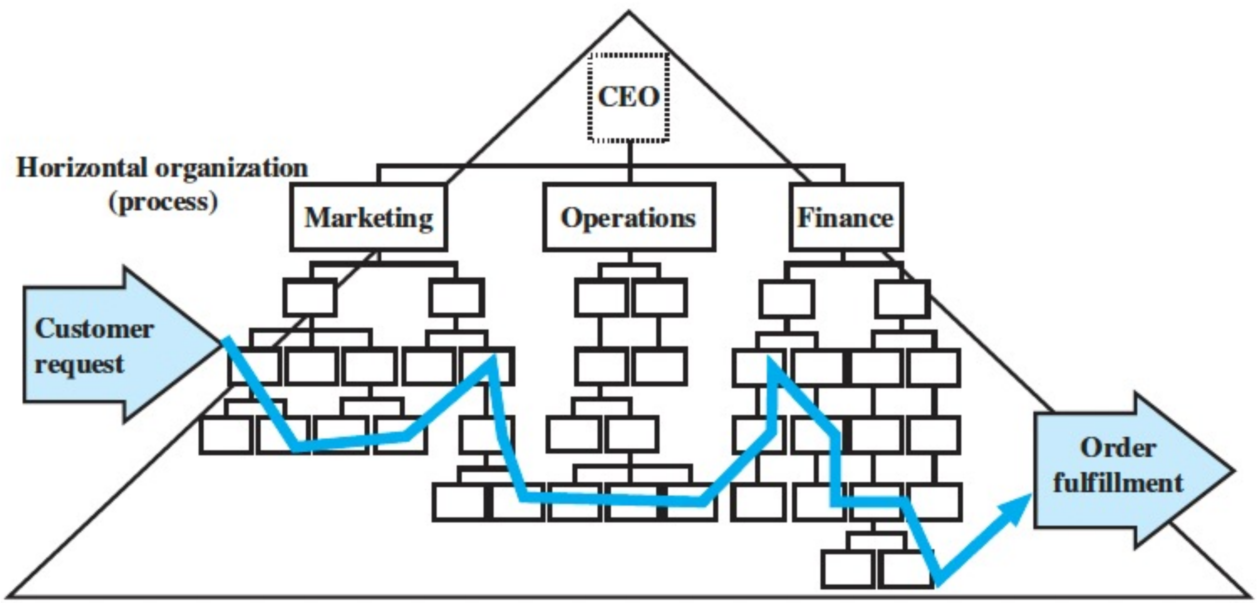
Process view

Operations

- Is any activity that transforms an input
- Are composed of a collection of activities that are purposeful, planned and coordinated.
- To perform activities, operations need resources

Processes

- A system of structured activities that use resources to turn inputs into valuable outputs.
- **Process thinking** is a way of viewing activities in an organization as a collection of processes (as opposed to departments or functional areas).



Process flow units

Principles of process performance: The Theory of Constraints

Theory of Constraints (TOC) is a philosophy that suggests that any system always has *at least one constraint*, otherwise it would generate an infinite amount of output, and that constraints generally determine the pace of an organization's ability to achieve its goal, which is profit.

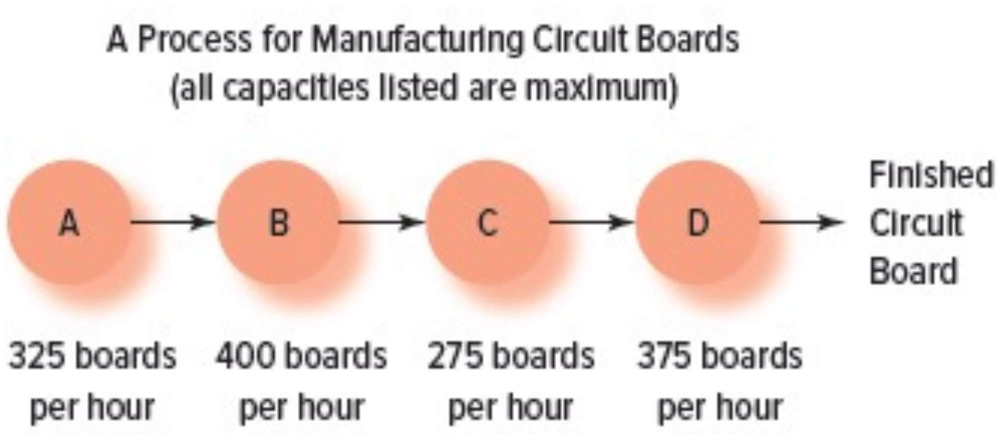
There are five basic principles at the heart of TOC:

1. Every process has a constraint.
2. Every process has variance that consumes capacity.
3. Every process must be managed as a system.
4. Performance measures are crucial to the process's success.
5. Every process must continually improve.

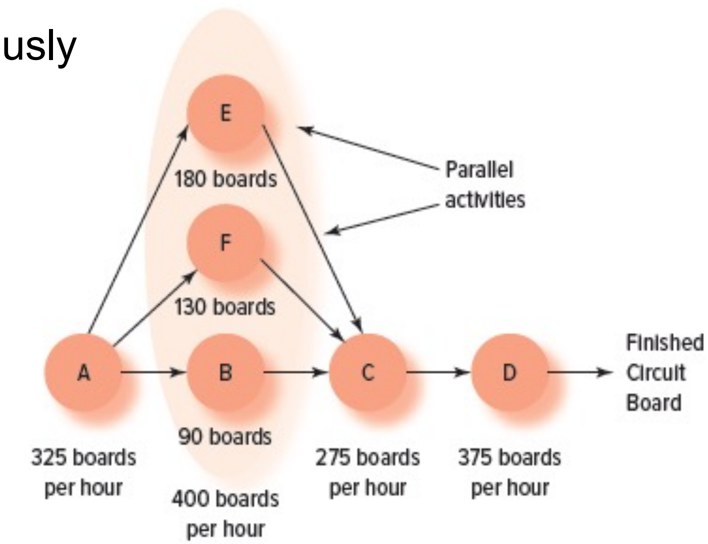
… a constraint will restrict the operation's capacity. If this constraint is reduced, or even removed, capacity will increase. A constraint can be reduced by increasing the resource in the bottleneck.

Theory of Constraints: Principle 1 – Every process has a constraint

- ***Bottleneck:*** any place where **demand ≥ capacity**; this limits the ability of the process to generate output
- A constraint or "scarce resource"
  - A facility, a department, a machine, a skill type, etc.
  - Demand
- Defines the maximum capacity of a *system*
- ***Serial/Sequential Structure:*** processes occur one after another
- ***Parallel Structure:*** two or more processes occur simultaneously



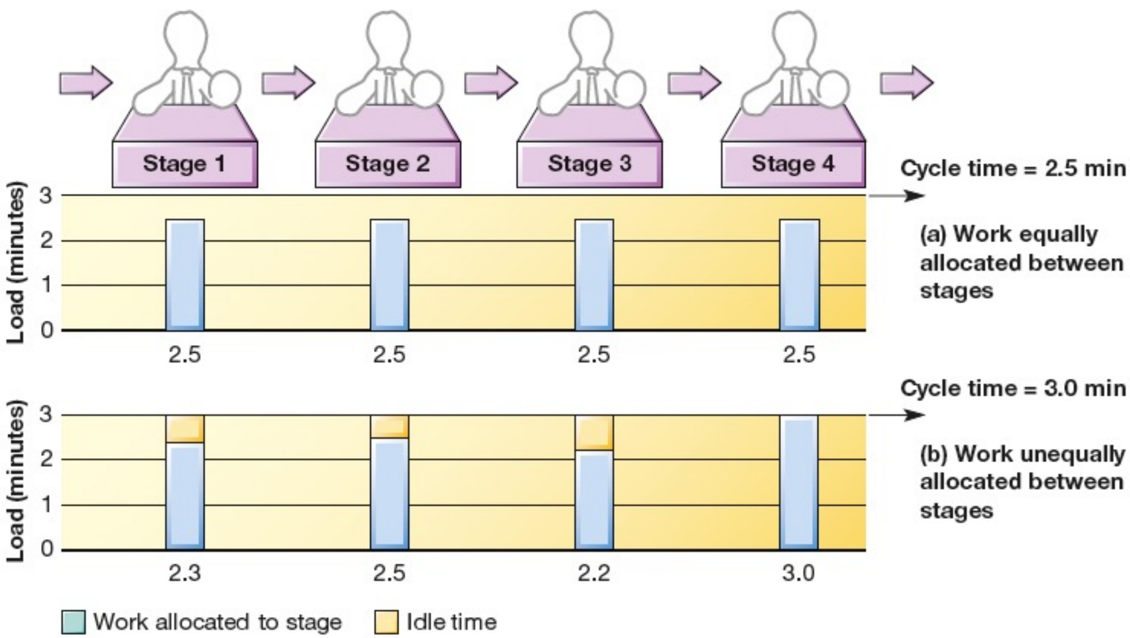
Maximum Capacity in a Serial Process



Maximum Capacity in a Parallel Process

Bottleneck operation

- Each activity has an associated flow rate and cycle time
- The activity with the smallest flow rate is called the bottleneck activity
- Alternatively, the bottleneck is the activity with the longest cycle time If there are multiple such activities then they are all bottleneck activities
- An operation in a sequence of operations whose capacity is lower than that of the other operations



The bottleneck is that part of the process that is the most overloaded relative to its capacity

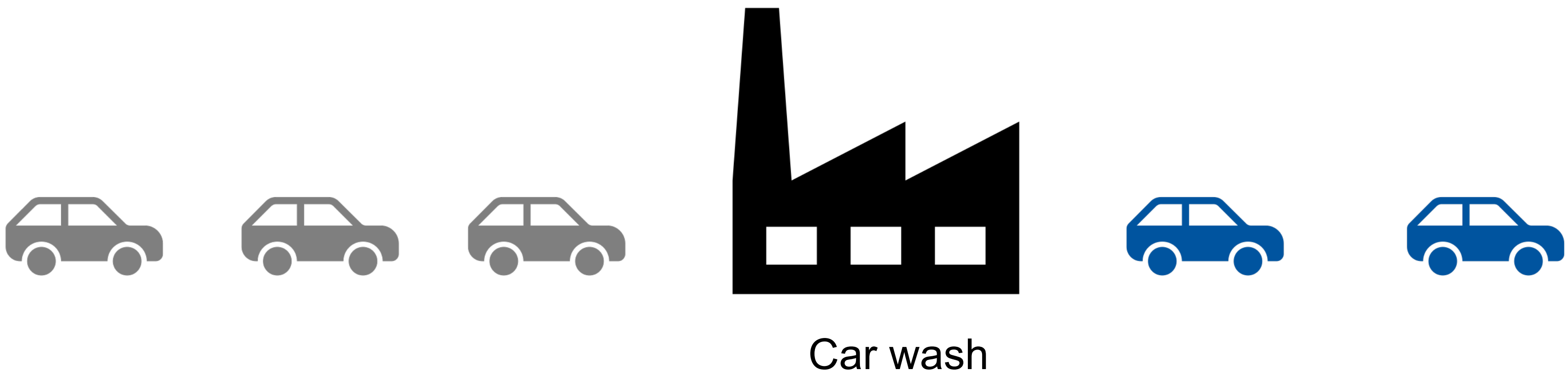
Questions to ask in process flow analysis

- **Flow:** Is it balanced? Where is the bottleneck? Are all steps necessary? How jumbled is the flow?
- **Time:** How long to produce one unit? Can it be reduced? Is set-up time excessive? Is waiting time excessive?
- **Quantity:** Theoretical production amount? How easy to change? How many units actually produced?
- **Quality:** Historical defect rate? Which steps contribute to defects? Where do errors occur?
- **Cost:** How much to produce one unit? What are cost buckets for one unit? Can some cost buckets be reduced or eliminated?

Process flow performance metrics

Cycle Time	▪ Is the reciprocal of throughput rate; time between items emerging from the process. ▪ Time between two consecutive units departing the process ▪ Time it takes to process one unit at an operation in the overall process
Takt Time	▪ Can be defined as the time allocated to each unit for making a product or providing a service in order to meet the customer *demand*. ▪ This is the rate at which the customer requires the product, and should be used to define the rate of delivery.
Throughput Rate (flow rate)	▪ Is the rate at which items emerge from the process, that is the number of items passing through the process per unit of time. ▪ Rate at which units depart the system ▪ Flow Rate = 1/(Cycle Time)
Throughput Time (flow time)	▪ Is the average elapsed time taken for inputs to move through the process and become outputs ▪ The time it takes a flow unit to go through the entire process - from the time it enters to the time it departs the process ▪ time for one unit to get through a process
Number of Items in the Process	▪ (also called the 'work-in-progress', or in-process inventory) as an average over a period of time.
Utilization	▪ Is the proportion of available time that the resources within the process are performing useful work.

Example 1: Car-wash



Cycle time : leaving every 10 minutes
Flow rate: 6 cars / hour

Example 1: Car-wash – multiple stations

¿What if we have multiple stations doing the same activity?

Suppose we decide to have two interior cleaning stations at Carwash so two cars can be worked on at the same time

- The processing time for interior cleaning still remains the same (10 minutes) but now there are two cars completed every 10 minutes.
- So the cycle time for the activity is: (10 mins / 2 persons) = 5 mins
- The flow rate = 1/CT = 1/5 = 0.2 cars/minutes

Cycle time of an activity = Processing Time / Number of Stations

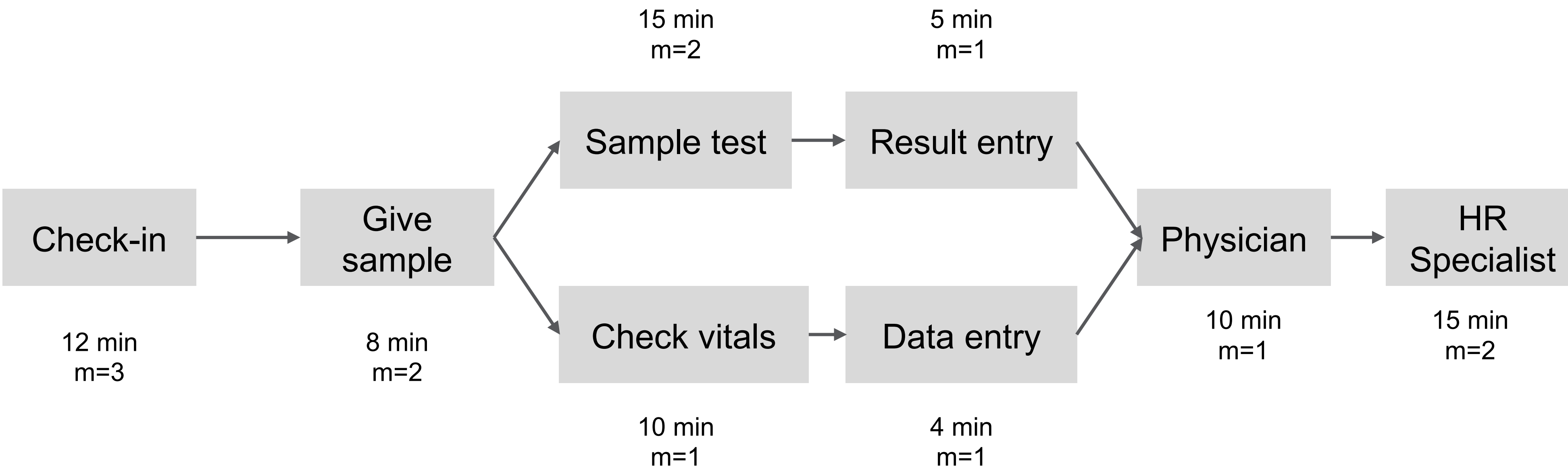
Example 2: Job application for a warehouse position

Job applicants for a warehouse position have to undergo a medical examination as shown below. Activity process times (PT) and number of parallel stations (m) are shown next to each activity. Job application process is shown as a flow chart which consists of 8 steps. These 8 steps with their processing times and parallel stations are as follows

1. Check in, 12 minutes, m = 3
2. Give sample, 8 minutes, m = 2
3. Sample test, 15 minutes, m = 2
4. Result entry, 5 minutes, m = 1
5. Check vitals, 10 minutes, m = 1
6. Data entry, 4 minutes, m = 1
7. Physician, 10 minutes, m = 1
8. HR Specialist, 15 minutes, m = 2

Activity 1 is followed by Activity 2 at which point there are two parallel sets of activities – activity 3 and 4 on one path, and activity 5 and 6 on the second path. The two paths merge at activity 7 which is followed by activity 8.

Example 2: Job application for a warehouse position



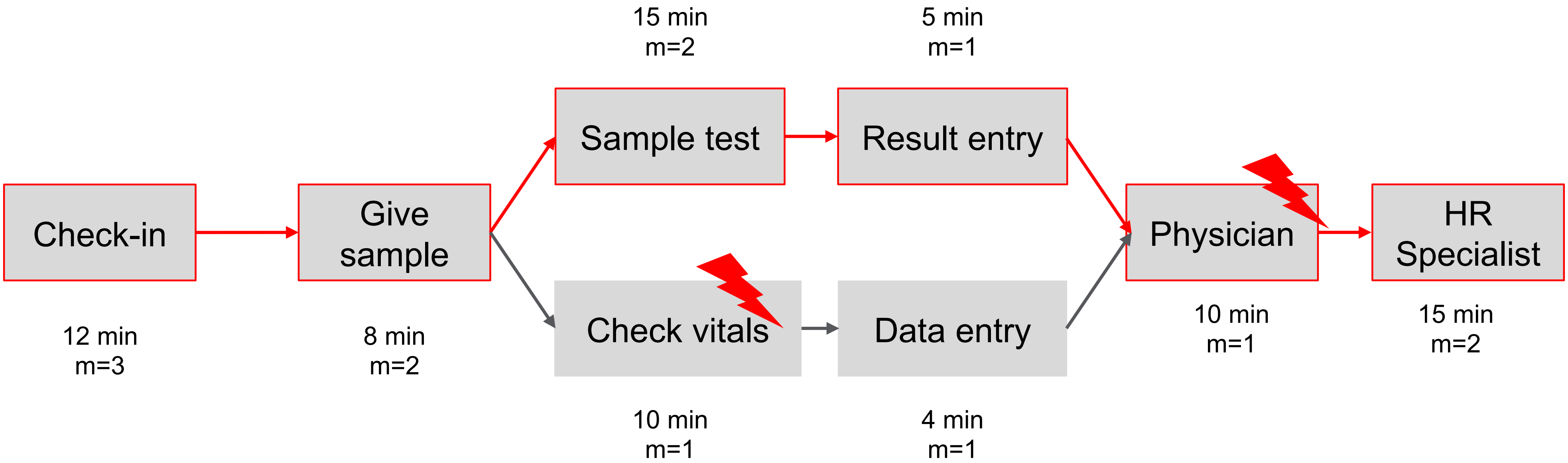
Example 2: Job application for a warehouse position

Activity	Activity Process Time (PT)	Stations (m)	Flow Rate = m/PT	Cycle Time
1	12	3		
2	8	2		
3	15	2		
4	5	1		
5	10	1		
6	4	1		
7	10	1		
8	15	2		

Example 2: Job application for a warehouse position

Activity	Activity Process Time (PT)	Stations (m)	Flow Rate = m/PT	Cycle Time
1	12	3	3/12 = 0.25	4
2	8	2	2/8 = 0.25	4
3	15	2	2/15 = 0.133	7.5
4	5	1	1/5 = 0.2	5
5	10	1	1/10 = 0.1	10
6	4	1	1/4 = 0.25	4
7	10	1	1/10 = 0.1	10
8	15	2	2/15 = 0.133	7.5

Example 2: Job application for a warehouse position



- Based on the activity cycle times, Activities 5 and 7 are bottleneck activities. The process cycle time is therefore 10 minutes.
- The longest path is indicated in red below. The sum of processing times on the longest path is the flow time
- Longest path is through activities, 1,2,3,4,7 and 8. After adding the processing times of activities of longest path, we get 65 minutes.

Capacity and Utilization

- Capacity determines the rate at which the operation can transform inputs into outputs and the *quantity* of a product or service that can be delivered within a *given time period.*
- **Capacity** → the “throughput,” or number of units a facility can hold, receive, store, or produce in a period of time.
- **Utilization** → Actual output as a percent of design capacity.
- **Efficiency** → Actual output as a percent of effective capacity.

Think about the consequences of capacity planning mistakes:

Capacity > Demand

- Inefficiency
- Low profitability

Demand > Capacity

- Missed opportunities
- Quality problems
- Supply delays

Capacity and Utilization: other definitions

- **Utilization -** the actual output shown as a percentage of the design capacity of the operation. This shows the percentage of time the facility is in actual use, and therefore demonstrates how well the resources are working.

- **Efficiency -** is the actual output shown as a percentage of the effective capacity of the operation. It demonstrates how well the operation is working to expectations.

- **Design Capacity -** is the expected output of an operation when there are no stoppages.

- **Effective Capacity -** is the expected output of an operation considering planned stoppages for maintenance, shift change over etc.

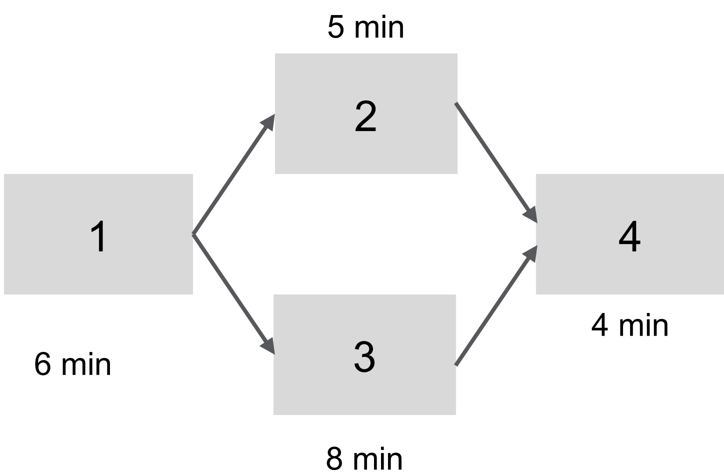
- **Actual Capacity -** is the expected output of an operation considering both planned stoppages and unplanned stoppages.

- **Overall Equipment Effectiveness (OEE) -** is the *actual capacity* when applied to individual machines tells the operation how well the equipment is being used

- **Overall Professional Effectiveness (OPE) -** is the *actual capacity* when applied to the workers tells the operation how well the employee is performing

Example 3: Process capacity

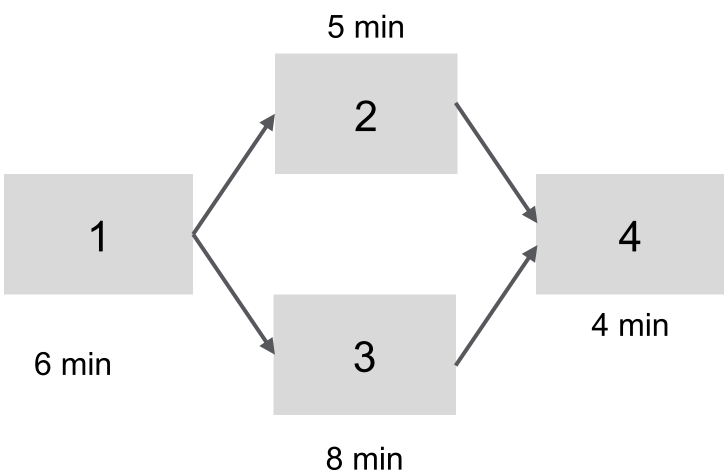
Consider the following four operations



Activity	1	2	3	4
Flow rate				

Example 3: Process capacity

Consider the following four operations



Activity	1	2	3	4
Flow rate	10/h	12/h	7.5/h	15/h

Activity 3 is the bottleneck
Process capacity is 7.5/hr

Capacity utilization

- The presence of a bottleneck activity means that other activities will be idle for some of the time
- How much of an activity's capacity is being utilized?

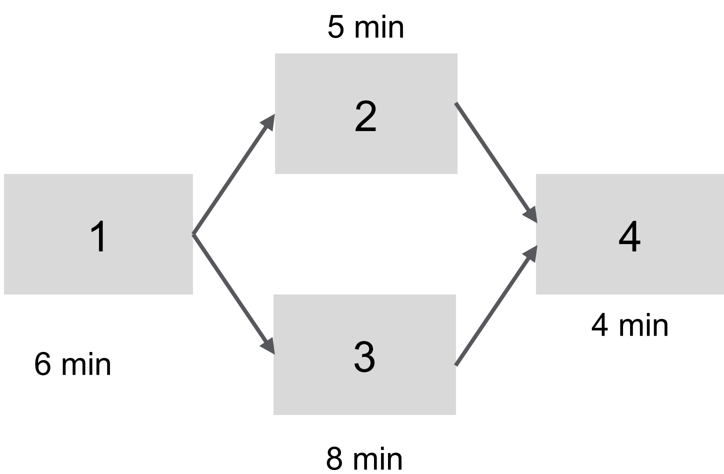
$$Utilization = \frac{Actual\ Production\ Rate}{Available\ Capacity}$$

$$Utilization = \frac{Time\ Used\ for\ Production}{Available\ Time}$$

Example 3: Capacity utilization

Consider the following four operations

$$Utilization = \frac{Actual\ Production\ Rate}{Available\ Capacity}$$

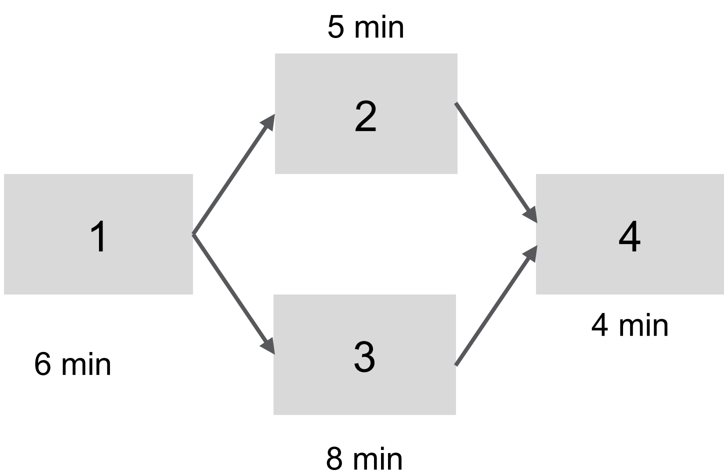


Activity	1	2	3	4
Flow rate	10/h	12/h	7.5/h	15/h
% Utilization				

Example 3: Capacity utilization

Consider the following four operations

$$Utilization = \frac{Actual\ Production\ Rate}{Available\ Capacity}$$



$$Utilization = \frac{7.5}{10} = 75\%$$

$$Utilization = \frac{7.5}{12} = 62.5\%$$

$$Utilization = \frac{7.5}{7.5} = 100\%$$

$$Utilization = \frac{7.5}{15} = 50\%$$

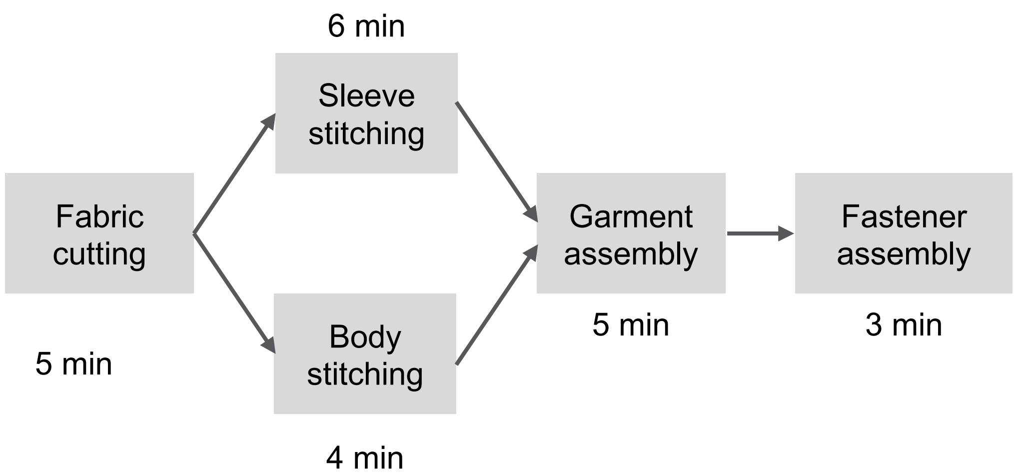
Activity	1	2	3	4
Flow rate	10/h	12/h	7.5/h	15/h
% Utilization	75	62.5	100	50

Activity 3 is the bottleneck
Process capacity is 7.5/hr

Example 4: Garment manufacturing

Garment manufacturing is a multistep process as shown in the process flow diagram below. The table indicates the batch size and batch processing time for each step

1:fabric cutting, 2:sleeve stitching, 3:body stitching, 4:garment assembly, 5:fastener assembly



Activity	Process time	Batch size	Flow rate	% Utilization
1	5 min	24		
2	6 min	1		
3	4 min	1		
4	5 min	1		
5	3 min	1		

Example 4: Garment manufacturing

Garment manufacturing is a multistep process as shown in the process flow diagram below. The table indicates the batch size and batch processing time for each step

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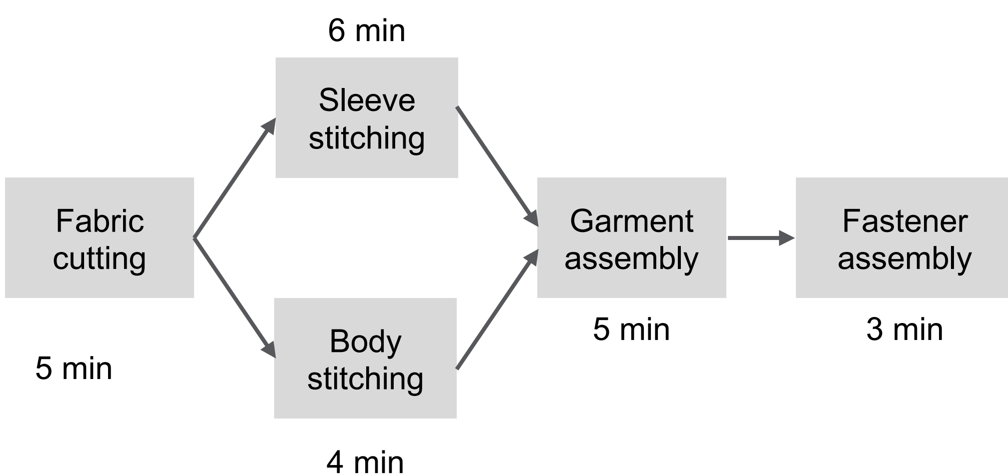


Activity	Process time	Batch size	Flow rate	% Utilization
1	5 min	24	4.8	3.47
2	6 min	1	1/6	100
3	4 min	1	1/4	66.67
4	5 min	1	1/5	83.33
5	3 min	1	1/3	50

Implied Utilization

What if the demand is less or more than the process flow rate?

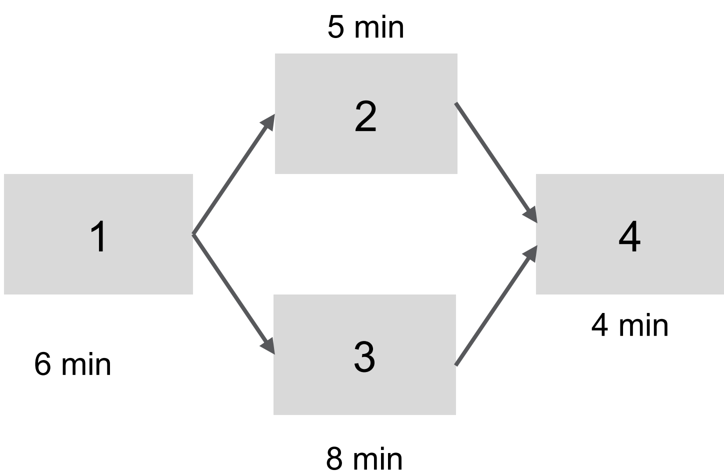
If the demand rate is higher than the available capacity then Implied Utilization will be greater than 100%

$$Implied\ Utilization = \frac{Demand\ Rate}{Available\ Capacity}$$

Example 5: Implied Utilization

Suppose the customer demand is 8 unites per hour

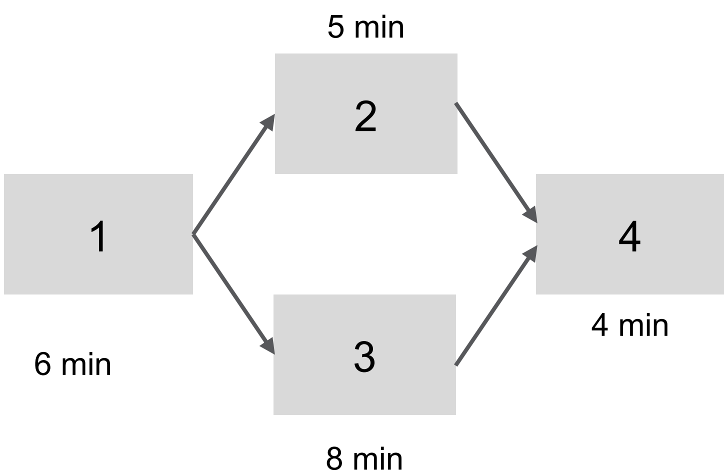
$$Utilización\ implícita = \frac{Demand\ Rate}{Available\ Capacity}$$



Activity	1	2	3	4
Capacity	10/h	12/h	7.5/h	15/h
% implied utilization				

Example 5: Implied Utilization

Suppose the customer demand is 8 unites per hour



$$Implied\ Utilization = \frac{Demand\ Rate}{Available\ Capacity}$$

$$Implied\ Utilization = \frac{8}{10} = 80\%$$

$$Implied\ Utilization = \frac{8}{12} = 66.67\%$$

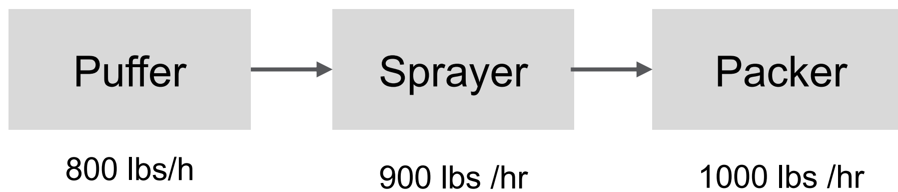
$$Implied\ Utilization = \frac{8}{7.5} = 100\%$$

$$Implied\ Utilization = \frac{8}{15} = 53.33\%$$

Activity	1	2	3	4
Capacity	10/h	12/h	7.5/h	15/h
% implied utilization	80	66.67	106.67	53.33

Example 6 : Capacity in a continous flow process

A cereal manufacturing plant which has three activities. There's a puffer, a sprayer, and a packer. The puffer takes grain and pass it up into puffed rice like rice crispies, for example, which then gets transferred to the sprayer, and the sprayer spray some honey syrup on them. There are nozzles in the sprayer which are doing this. The grain is then taken to the packer, where it is packed. This entire process is occurring as a continuous stream so that the product doesn't wait anywhere in between. The puffer is capable of producing at 800 pounds per hour, the sprayer is capable of producing at 900 pounds per hour, and the packer is capable of producing at 1,000 pounds per hour. Unfortunately, the sprayer has a problem. After running for a little while, the spray nozzle start getting clogged. The process has to be run for three hours, the screening process, and then for 30 minutes, it has to be stopped so the nozzles can be cleaned before you start the process again.



Consider each cycle of spraying and nozzle cleaning. Each cycle is 3.5 hrs (3 hrs spraying and 0.5 hr for cleaning).

Example 6 : Capacity in a continous flow process

	Puffer	Sprayer	Packer
Amount produced (lbs)	3 x 800 = 2400	3 x 900 = 2700	3 x 1000 = 3000
Effective flowrate	2400/3.5 = 685.71	2700/3.5 = 771.43	3000/3.5 = 857.14

The puffer is the bottleneck activity and controls the flow rate, so the line can only produce 685.71 lbs/hr

Little's Law

Little's Law shows that the average number of items in a system (I) is the product of the average arrival rate to the system (R) and the average time an item stays in the system (T). This average time in the system is throughput time, the time from when the processing begins until the product or service is completely finished.

It includes both active processing time and any waiting time that occurs during processing. In mathematical terms Little's Law is stated as follows:

$$\boldsymbol{I = T \times R}$$

$I = average\ number\ of\ things\ in\ the\ system\ (or\ \text{“}inventory\text{”})$

$T = average\ throughput\ time\ (processing\ time + waiting\ time)$

$R = average\ flow\ rate\ in\ the\ process$

La ley de Little relaciona el inventario o el número de unidades de flujo en el sistema, con la tasa de producción y el tiempo de flujo.

Example 2: Job application for a warehouse position (Little's Law)

Consider the examination process example

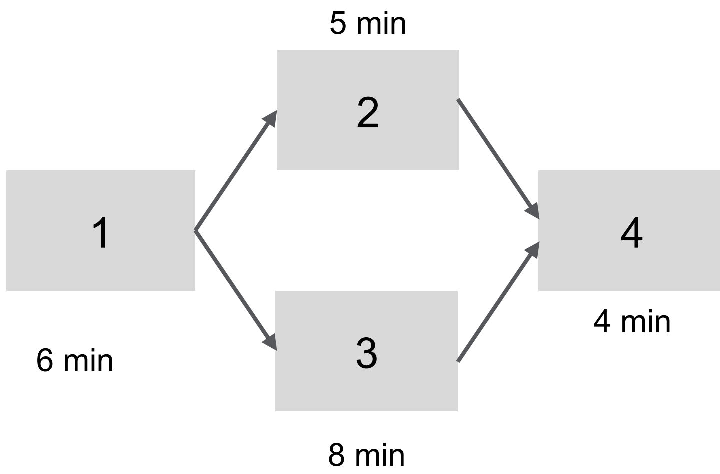
We calculated the flow time for the process as 65 mins and the flow rate as 1/10 applicants/minutes

From Little's Law the average number of applicants in the system

$$I = R * T = 65 * 0.1 = 6.5\, applicants$$

Example 3: Little's Law

Based on the previous example 3



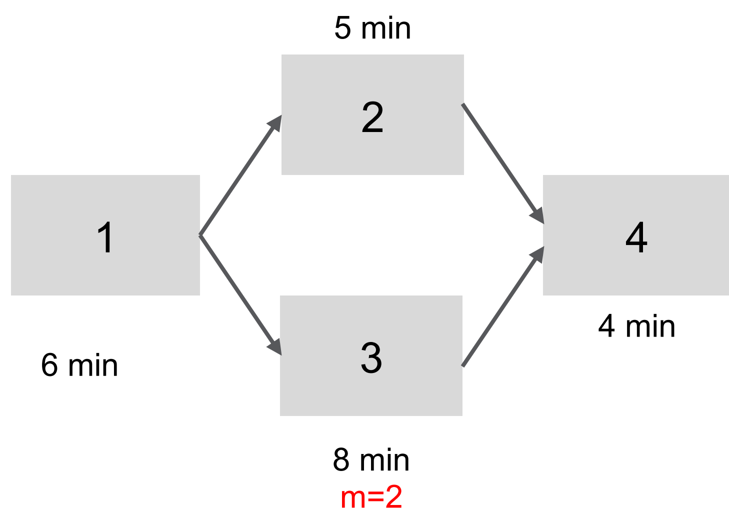
Based on the given data, the process has an **average flow rate of 7.5 units/hr** and has a **flow time** (6 + 8 + 4) = **18 minutes** = 18/60 horas = **0.3 horas**

Then from Little's Law, the inventory, (i.e., the average number of units in the system)

$$I = R * T = 7.5 * 0.3 = 2.25\, units$$

Example 3: Little’s Law (adding one more station)

Considere agregar una estación más en la acitividad 3



Consider adding an extra resource to Activity 3 as shown. This will change the flowrate for Activity 3 and so the new bottleneck will be Activity 1. The flow rate for the process will be 10/hr

The flowtime will continue to be 18 minutes or 0.3 hours.

From Little's Law: $I = R * T = 10 * 0.3 = 3\,units$

Notice that increasing the resources at Activity 3 increased the flow rate so the number of units in the system also increased.

Example 7: Little's Law – Sandwish assembly

In a new in a new sandwich assembly and sales process, the average number of customers in the process should be limited to around 10 and the maximum time a customer is in the process should be on average four minutes. If the time to assemble and sell a sandwich (from customer request to the customer leaving the process) in the new process has been reduced to 1.2 minutes, how many staff should be serving?

$Putting\ this\ into\ Little's\ Law$:

$$Throughput\ time = 4\ minutos$$

and:

$$Work - in - progress\ (WIP) = 10$$

$so, since$:

$$Throughput\ time = WIP \times cycle\ time$$

$$Cycle\ time = \frac{Throughput\ time}{WIP} = \frac{4}{10} = 0.4\ minutes$$

$That\ is, a\ customer\ should\ emerge\ from\ the\ process\ every\ 0.4\ minutes, on\ average.$
$Given\ that\ an\ individual\ can\ be\ served\ in\ 1.2\ minutes$:

$$The\ number\ of\ servers\ required = \frac{1.2}{0.4} = 3$$

$In\ other\ words, three\ servers\ would\ serve\ three\ customers\ in\ 1.2\ minutes,$
$that\ is\ one\ customer\ in\ 0.4\ minutes$

Example 8: Measuring process flows at PIZZA PTY

Suppose that one of the pizza stores produces fresh pizza with seven different topping choices, including the most popular "everything dump" pizza. The store is staffed by two employees: a pizza chef and an assistant. It has an oven that can bake up to four pizzas at a time. The transformation process (sequence of steps) followed at the store is as follows:

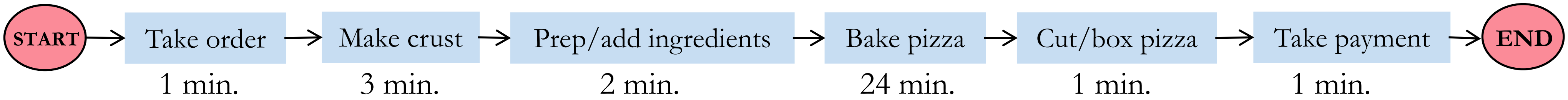
	Minutes	Who
Take the order	1	Assistant
Make the crust	3	Chef
Prepare and add ingredients	2	Chef
Bake the pizza	24	Oven
Cut pizza and box the order	1	Assistant
Take payment	1	Assistant

Details: Assume all toppings added to every pizza.
Two employees working at a time.
Oven can bake up to 4 pizzas at a time.

Assume the chef gets paid $15 per hour, the assistant gets paid $11 per hour, and overhead cost is 50 % of direct labor cost. Assume the cost of ingredients is $2.00 per pizza.

a. What is the capacity of this process?
b. What is the bottleneck in this process?
c. What is the throughput time?
d. What is the flow rate?
e. What does it cost to make a pizza if the average demand is 60% of capacity?
f. How can the unit cost of pizzas be reduced?

Example 8: Measuring process flows at PIZZA PTY



a. What is the capacity of this process?

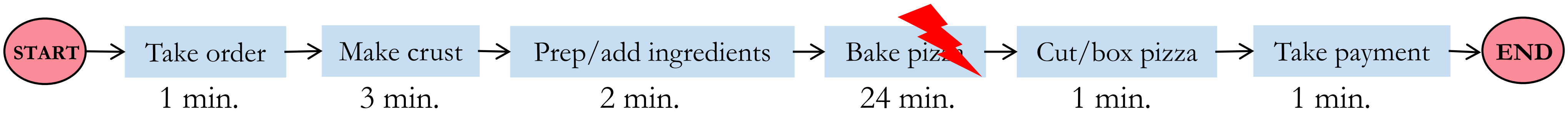
Looking at the three resources, we have:

- The **assistant** takes 3 minutes per order (1 + 1 + 1) and thus can process **20 orders per hour.**
- The **chef** takes 5 minutes per order (3 + 2) and can process **12 orders per hour.**
- The **oven** takes an average of 6 minutes per order (24 ÷ 4, because the oven holds 4 pizzas at a time), or **10 orders per hour.**

Therefore…

Process capacity (flow rate) = 10 pizzas/hour

Example 8: Measuring process flows at PIZZA PTY



b. What is the bottleneck in this process?

At an average process time of 6 min. per pizza…
the **OVEN** is the **slowest activity**…..
and that determines process capacity….
and is, therefore, the bottleneck.

The process cannot produce more than the slowest activity. (flow rate = 10 pizzas/hr)

c. What is the throughput time?

Throughput time = time to **complete one** product or service

Pizza Throughput time = 1 + 3 + 2 + 24 + 1 + 1 = 32 min

Example 8: Measuring process flows at PIZZA PTY

START → Take order (1 min.) → Make crust (3 min.) → Prep/add ingredients (2 min.) → Bake pizza (24 min.) → Cut/box pizza (1 min.) → Take payment (1 min.) → END

d. What is the flow rate?

Assuming that demand and supply exceed capacity, the flow rate is determined by the bottleneck capacity of **10 orders per hour.**
However, this is the maximum flow rate; the actual flow rate could be much less.
If either demand or supply is less than capacity, then the smaller of the two will determine the flow rate.

e. What does it cost to make a pizza if the average demand is 60% of capacity?

At 60 % of capacity, **the average flow rate is six pizzas per hour.**
The **cost per hour of operations** is \$15 + \$11 = \$26 for labor plus 50 % added for overhead = **\$39 per hour, or \$39 ÷ 6 = \$6.50 per pizza.**
Therefore, the **total cost** is \$6.50 + \$2.00 = **\$8.50 per pizza**

f. How can the unit cost of pizzas be reduced?

- Increase demand through pricing, advertising, or other means.
- If demand increases to exceed capacity, increase the flow rate of the entire transformation process by means of automation or process improvements.
- Reduce the unit cost of labor, materials, or overhead.

Example 9: Throughput efficiency of the process

A vehicle licensing centre receives application documents, keys in details, checks the information provided on the application, classifies the application according to the type of licence required, confirms payment and then issues and mails the licence. It is currently processing an average of 5,000 licences for eight hours every day. A recent spot check found 15,000 applications that were ‘in progress’ or waiting to be processed. The sum of all activities that are required to process an application is 25 minutes.

What is the throughput efficiency of the process?

Example 9: Throughput efficiency of the process

$$Work\ in\ Progress = 15000\ applications$$

$$Cycle\ Time = Time\ producing$$

$$\frac{Time\ producing}{Number\ produced} = \frac{8\ hours}{5000} = \frac{480\ minutes}{5000} = 0.96\ minutes$$

$$From\ Little's\ Law:$$

$$\begin{aligned} Throughput\ Time &= WIP \times Cycle\ Time \\ &= 15000 \times 0.096 \\ &= 1440\ minutes = 24\ hours = 3\ days\ of\ working \end{aligned}$$

Although the process is achieving a throughput time of 3 days (which seems reasonable for this kind of process) the applications are only being worked on for 1.7 per cent of the time they are in the process.

Example 10: Little’s Law

Every year it was the same. All the workstations in the building had to be renovated (tested, new software installed, etc.) and there was only one week in which to do it. The one week fell in the middle of the August vacation period when the renovation process would cause minimum disruption to normal working. Last year the company's 500 workstations had all been renovated within one working week (40 hours). Each renovation last year took on average 2 hours and 25 technicians had completed the process within the week. This year there would be 530 workstations to renovate but the company's IT support unit had devised a faster testing and renovation routine that would take on average only 1 ½ hours instead of 2 hours.

How many technicians will be needed this year to complete the renovation processes within the week?

Example 10: Little's Law

Last year:

$$Work - in - progress\ (WIP)\ =\ 500\ workstations$$

$$Time\ available\ (T_t)\ =\ 40\ hours$$

$$Average\ time\ to\ renovate\ =\ 2\ hours$$

$Therefore$

$$\text{Throughput rate}\ (T_r) = \frac{1}{2} hour\ per\ technician\ =\ 0.5N$$

$where\ N\ =\ Number\ of\ technicians$

From Litte's Law

$$WIP\ = T_t \times T_r$$

$$500\ = 40 \times 0.5N$$

$$= 25\ technicians$$

Example 10: Little’s Law

This year:

$$Work - in - progress\ (WIP)\ =\ 530\ workstations$$

$$Time\ available\ (T_t)\ =\ 40\ hours$$

$$Average\ time\ to\ renovate\ = 1.5\ hours$$

$$Throughput\ rate\ (T_r) = \frac{1}{1.5} hour\ per\ technician\ =\ 0.67N$$

$where\ N\ =\ Number\ of\ technicians$

From Litte’s Law

$$WIP\ = T_t \times T_r$$

$$530\ = 40 \times 0.67N$$

$$= 19.88\ \rightarrow 20\ technicians$$

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