PRODUCTION AND OPERATIONS MANAGEMENT
2023/2024

Lisbon School of Economics & Management

UNIVERSIDADE DE LISBOA

Capacity and Constraint Management

Supplement 7

Capacity

- The throughput, or the number of units a facility can hold, receive, store, or produce in a period of time (e.g., seating capacity of a concert hall)
- Determines fixed costs
- Determines if demand will be satisfied
- Three time horizons

Planning Over a Time Horizon

Time Horizon

Options for Adjusting Capacity

Time Horizon	Modify capacity	Use capacity
Long-range planning	Add facilities Add long lead time equipment	*
Intermediate-range planning (aggregate planning)	Subcontract Add equipment Add shifts	Add personnel Build or use inventory
Short-range planning (scheduling)	*	Schedule jobs Schedule personnel Allocate machinery

* Difficult to adjust capacity as limited options exist

Big 5 Process Measures

- Capacity
- Capacity utilization
- Cycle time (CT)
- Throughput time (TPT)
- Lead Time (LT)

Design and Effective Capacity

- **Design capacity** is the maximum theoretical output of a system
  - Normally expressed as a rate
- **Effective capacity** is the capacity a firm expects to achieve given current operating constraints
  - Often lower than design capacity

Capacity Measurements

TABLE S7.1	Capacity Measurements	
MEASURE	**DEFINITION**	**EXAMPLE**
Design capacity	Ideal conditions exist during the time that the system is available	Machines at Frito-Lay are designed to produce 1,000 bags of chips/hr., and the plant operates 16 hrs./day. **Design Capacity = 1,000 bags/hr. × 16 hrs. = 16,000 bags/day**

Capacity Measurements

TABLE S7.1	Capacity Measurements	
MEASURE	**DEFINITION**	**EXAMPLE**
Effective capacity	Design capacity minus lost output because of *planned* resource unavailability (e.g., preventive maintenance, machine setups/changeovers, changes in product mix, scheduled breaks)	Frito-Lay loses 3 hours of output per day (= 0.5 hrs./day on preventive maintenance, 1 hr./day on employee breaks, and 1.5 hrs./day setting up machines for different products). **Effective Capacity = 16,000 bags/day – (1,000 bags/hr.)(3 hrs./day) = 16,000 bags/day – 3,000 bags/day = 13,000 bags/day**

Capacity Measurements

TABLE S7.1	Capacity Measurements	
MEASURE	**DEFINITION**	**EXAMPLE**
Actual output	Effective capacity minus lost output during *unplanned* resource idleness (e.g., absenteeism, machine breakdowns, unavailable parts, quality problems)	On average, if machines at Frito-Lay are not running 1 hr./day due to late parts and machine breakdowns. **Actual Output = 13,000 bags/day - (1,000 bags/hr.)(1 hr./day)** **= 13,000 bags/day - 1,000 bags/day** **= 12,000 bags/day**

Capacity Utilization and Efficiency

Utilization is the percent of design capacity actually achieved

- **Capacity Utilization** = Actual output/Design capacity

Efficiency is the percent of effective capacity actually achieved

- **Efficiency** = Actual output/Effective capacity

Capacity Utilization and Efficiency

Example: Plant processing *deluxe* breakfast rolls

- Operates 7 days a week, 3 x 8 hour shifts per day
- Design capacity – 1,200 per hour
- Effective capacity – 175,000 rolls per week
- Actual output – 148,000 rolls per week

Design capacity = 7 x 3 x 8hr x 1,200 rolls/hour = 201,600 week

Utilization = Actual output/Design capacity
148,000 / 201,600 = **73.4%**

Efficiency = Actual output/Effective capacity
148,000 / 175,000 = **84.6%**

Capacity and Strategy

- Capacity decisions impact all 10 decisions of operations management as well as other functional areas of the organization
- Capacity decisions must be integrated into the organization's mission and strategy

Capacity Considerations

1. Forecast demand accurately
2. Match technology increments and sales volume
3. Find the optimum operating size (volume) – see next slide
4. Build for change

Managing Demand

- Demand exceeds capacity
  - Curtail demand by raising prices, scheduling longer lead times
  - Long-term solution is to increase capacity
- Capacity exceeds demand
  - Stimulate market
  - Product changes
- Adjusting to seasonal demands
  - Produce products with complementary demand patterns

Complementary Demand Patterns

Figure S7.3 By Combining Products That Have Complementary Seasonal Patterns, Capacity Can Be Better Utilized

Tactics for Matching Capacity to Demand

1. Making staffing changes
2. Adjusting equipment
   - Purchasing additional machinery
   - Selling or leasing out existing equipment
3. Improving processes to increase throughput
4. Redesigning products to facilitate more throughput
5. Adding process flexibility to meet changing product preferences
6. Closing facilities (e.g., production lines, factories)

Service Sector Demand and Capacity Management

- **Demand management**
  - Appointment (doctors' office), reservations (hotels), First Come First Served (FCFS) rule (post office)
- **Capacity management** (when managing demand is not feasible)
  - Changes in full time, temporary, or part-time staff

Process Measures

- **Task time:** Time required at a particular task to complete the activities (sum of set up and run time)
- **Throughput time:** is the time it takes a unit to go through production from start to end ***with no waiting***
- **Cycle time:** The average interval between two successive units of output
- **Lead Time:** Time spent from the point of order to the point of delivery
- **Yield:** Percentage of units without defects

Capacity is the Inverse of Cycle Time

$$\text{Capacity} = \frac{1}{\text{Cycle Time}}$$

$$\text{Cycle Time} = \frac{1}{\text{Capacity}}$$

Units?

Capacity is the Inverse of Cycle Time

$$\text{Capacity} = \frac{1}{\text{Cycle Time}};\quad \boxed{\text{Capacity}} \rightarrow \text{e.g., } \mathbf{15\ units/hour}$$

$$\text{Cycle Time} = \frac{1}{\text{Capacity}};\quad \boxed{\text{Cycle Time}} \rightarrow \text{e.g., } \mathbf{15\ seconds}$$

Bottleneck Analysis and the Theory of Constraints

- Each work area can have its own unique capacity
- **Capacity analysis** determines the throughput capacity of workstations in a system
- The time to produce a unit or a specified batch size is the **process time**
- A **bottleneck** is a limiting factor or constraint
  - A bottleneck has the lowest effective capacity in a system
  - The **bottleneck time** is the time of the **slowest workstation** (**the one that takes the longest**) in a production system
  - The capacity of the bottleneck **defines the capacity of the entire process**!
  - Complex systems with multiple products may have different bottlenecks for different products.

Theory of Constraints (TOC)

TOC is a body of knowledge that deals with anything that limits or constrains an organization's ability to achieve its goals.

Constraints can be **physical** (e.g., process or personnel availability, raw materials, or supplies) or **nonphysical** (e.g., procedures, morale, and training).

Recognizing and managing these limitations through a **five-step process** is the basis of TOC.

Theory of Constraints (TOC)

- **Five-step process** for recognizing and managing limitations

Step 1: Identify the constraints

Step 2: Develop a plan for overcoming the constraints

Step 3: Focus resources on accomplishing Step 2

Step 4: Reduce the effects of constraints by **offloading work** or **expanding capability**

Step 5: Once overcome, go back to Step 1 and find new constraints

Bottleneck Management

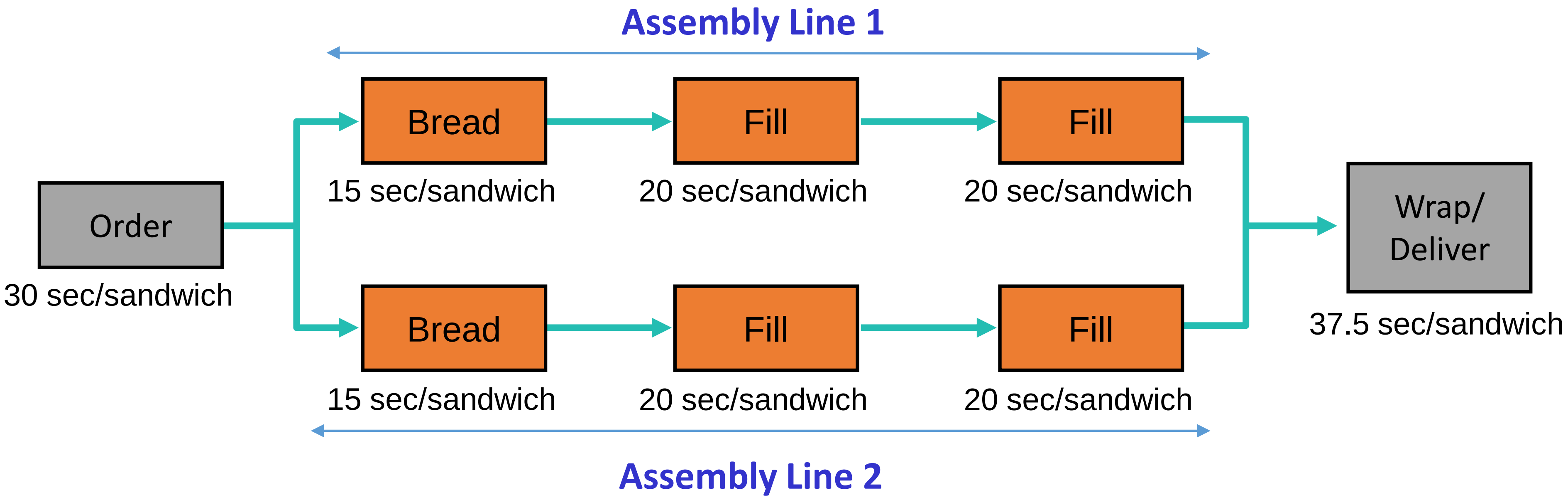
1. Release work orders to the system at the pace set by the bottleneck's capacity.
   - Concepts of:
   - **Drum** – is the pace of production
   - **Buffer** – is the resource, usually inventory, which may be helpful to keep the bottleneck operating at the pace of the drum
   - **Rope** – provides the synchronization or communication necessary to pull units through the system
2. Lost time at the bottleneck represents lost time for the whole system - *this principle implies that the bottleneck should always be kept busy with work*

Bottleneck Management

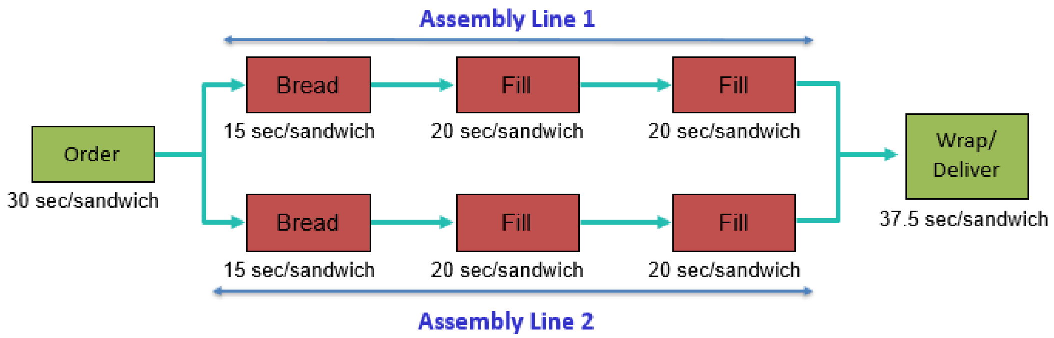
3. Increasing the capacity of a non-bottleneck station is a mirage - *increasing the capacity of non-bottleneck stations has no impact on the system's overall capacity, therefore working faster on a nonbottleneck station may just create extra inventory*
4. Increasing the capacity of a bottleneck increases the capacity of the whole system - *bottleneck capacity may be improved by various means, including offloading some of the bottleneck operations to another, increasing capacity of the bottleneck, subcontracting, developing alternative routings, and reducing setup times*

Capacity Analysis: Example 1 – Parallel Processes

- Two identical sandwich lines
- Each Line has two workers and three operations
- All completed sandwiches are wrapped



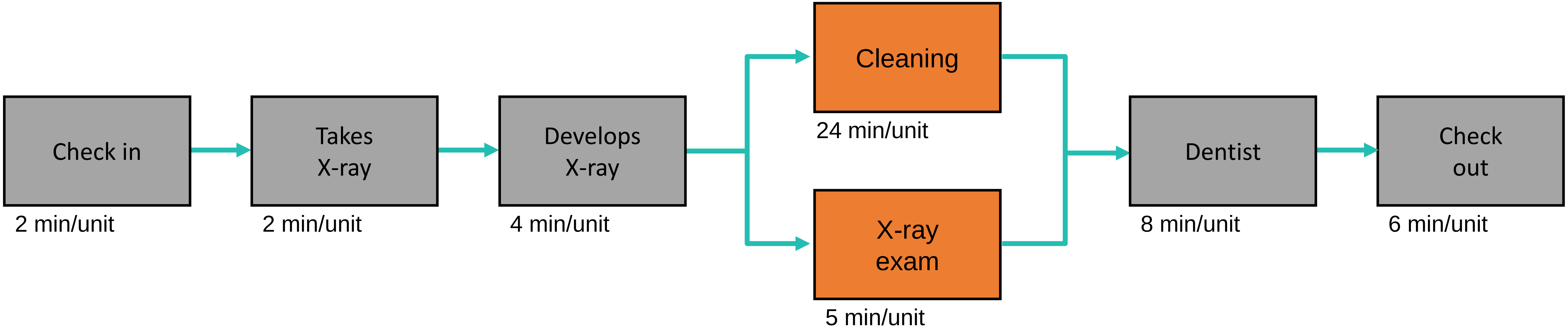
Capacity Analysis: Example 1 – Parallel Processes



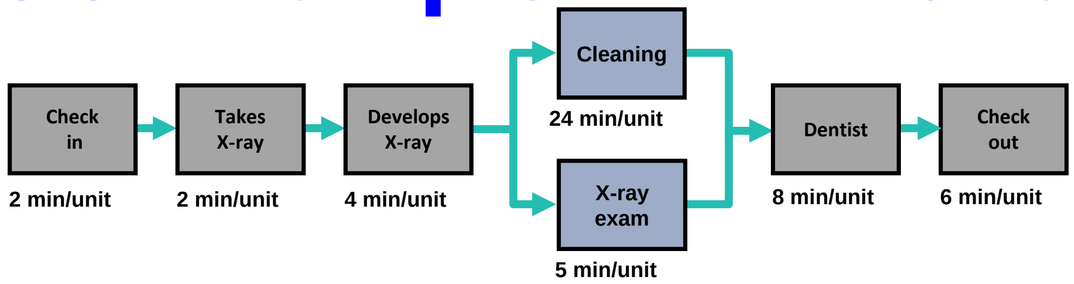
- The two lines each deliver a sandwich every 20 seconds
- At 37.5 seconds, **wrapping and delivery** has the longest processing time and **is the bottleneck**
- Capacity per hour is 3600 seconds/37.5 seconds/sandwich = 96 sandwiches per hour
- Throughput time is 30 + 15 + 20 + 20 + 37.5 = 122.5 seconds
- Cycle time = 37.5 seconds

Capacity Analysis: Example 1 – Parallel Processes

- Standard process for cleaning teeth
- Cleaning and examining X-rays can happen simultaneously



Capacity Analysis: Example 2 – Simultaneous Processes



- All possible paths must be compared
- **Bottleneck** is the hygienist at 24 minutes
- Hourly capacity is 60/24 = 2.5 patients
- X-ray exam path is 2 + 2 + 4 + 5 + 8 + 6 = 27 minutes
- Cleaning path is 2 + 2 + 4 + 24 + 8 + 6 = 46 minutes
- Longest path involves the hygienist cleaning the teeth, patient should complete in 46 minutes

Process Flow Charting or Mapping

Conventions we use	
Operations: Tasks/Processes	Rectangles Ovals
Inventory/Buffers	Triangles
Decision Points	Diamonds
Product Service Flows	Solid Lines
Information Flows	Dotted Lines

Capacity Analysis: Example 3 – Pizza Nostra

Task times for each step in the process:

- Knead and shape the dough: 8 minutes (1 person)
- Put on the toppings: 5 minutes (1 person)
- Cook the pizza: 20 minutes (1 oven)
- Slice and box the pizza: 2 minutes (1 person)

Draw the Process Flow Diagram

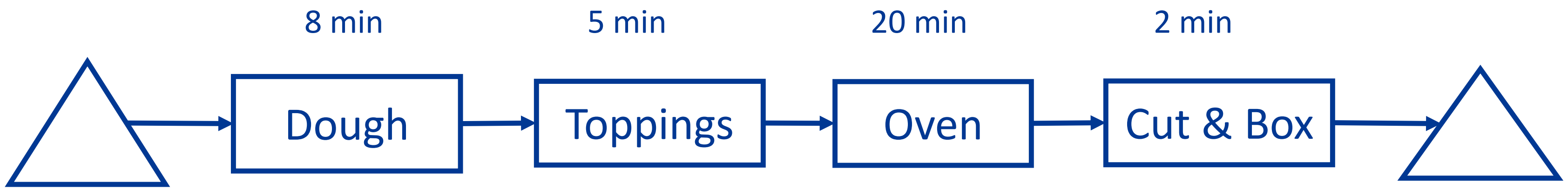
Capacity Analysis: Example 3 – Pizza Nostra

Steps in the Process:

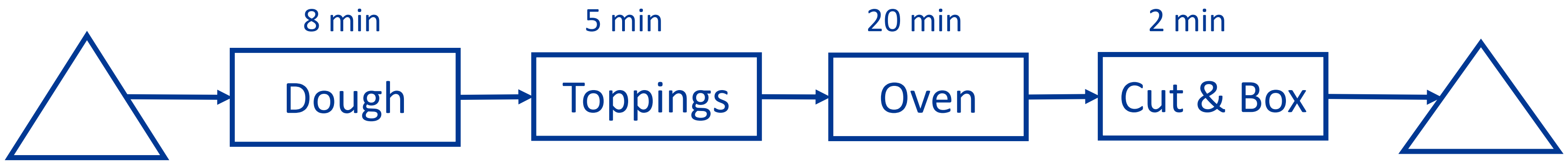
- Knead & Shape dough (1 person)
- Put on the toppings (1 person)
- Cook the pizza (1 person and 1 oven)
- Slice and box the pizza (1 person)

Assumptions:

- no WIP buffers
  (i.e. bottleneck pacing)
- one pizza / one oven



Capacity Analysis: Example 3 – Pizza Nostra



Which operation is the **Bottleneck?** – **Oven**

What is the Cycle Time of the bottleneck? – **20 min**

What is the Cycle Time for the entire process? – **20 min**

What is the Capacity of the process? – 1 pizza/20 min = **3 pizzas/hour**

Capacity Analysis: Example 3 – Pizza Nostra

A Question for the Manager

Since your capacity is only 3 pizzas/hour, you are asked to invest wisely in the expanding the resources

You have the choice of:

1. Getting another person to knead and shape dough
2. Hire another person to add toppings
3. Buy another oven
4. Hire a second person to cut and box pizzas

What would you consider doing first and why?

Capacity Analysis: Example 3 – Pizza Nostra

A Question for the Manager

ANSWER:

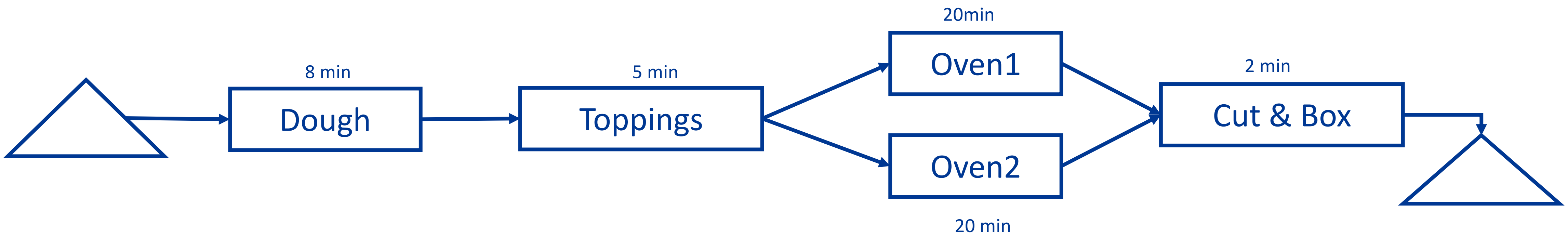
Buy another oven.

The oven is the bottleneck!

You cannot improve the process by making any other change!

Capacity Analysis: Example 3 – Pizza Nostra

Process Improvement: 2 Ovens



Which operation is the Bottleneck? – **Ovens**

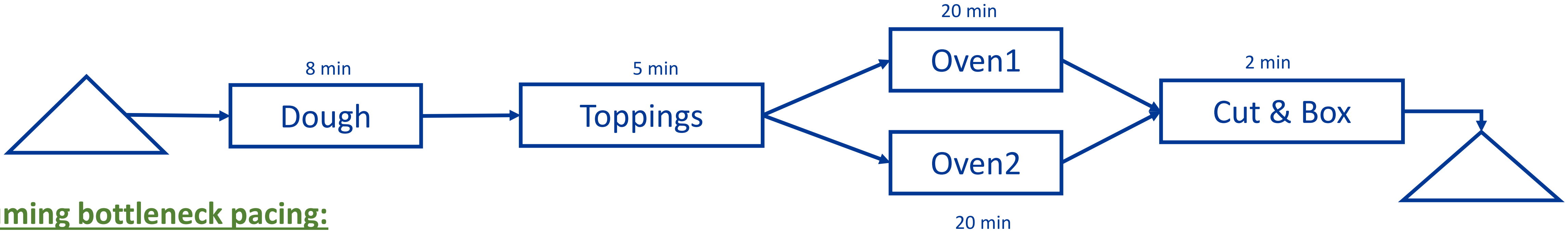
What is the Cycle Time of the bottleneck? – **10 min**

What is the Cycle Time for the entire process? – **10 min**

What is the Capacity of the process? – 1 pizza/10 min = **6 pizzas/hour**

Capacity Analysis: Example 3 – Pizza Nostra

Process Improvement: 2 Ovens



Assuming bottleneck pacing:

What is the Utilization of the cut & box operation? ➔
➔ (6 pizzas/hour)/(30 pizzas/hour) = **20%**

What is the Utilization of the toppings operation? ➔
➔ (6 pizzas/hour)/(12 pizzas/hour) = **50%**

What is the Utilization of the ovens? ➔ (6 pizzas/hour)/(6 pizzas/hour) = **100%**

Capacity Analysis: Example 3 – Pizza Nostra

More generally, how do we address the Bottleneck?

- Increase the number of resource units at the bottleneck.
  - Buy another oven.
- Increase load batch of the bottleneck.
  - Fit two pizzas into the oven.
- Increase scheduled availability of the bottleneck (overtime work).
  - Have the oven operate for longer hours.
- Decrease unit load into the bottleneck.
  - Different pizza design (e.g. thin crust) that could cook faster.

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MINDS.
GRAB
THE FUTURE.