MSBA 7004
Operations Analytics

Class 1-2: Process Flow Analysis (I)
Capacity Rate, Flow Time, Bottleneck
2023

Process Analysis

- **Improving a process**
  - Capacity
    - Bottleneck Analysis
    - Levers for Improvement
  - Flow Time (Responsiveness)
    - Critical Path Analysis
    - Improvement Levers

Learning Objectives

- Understand the following concepts:

Flow Time | **Capacity Rate** | **Bottleneck**

- Tool: **Process Analysis**
  - **Objective: Improve the process**
  - Process mapping
  - Capacity analysis (also called bottleneck analysis)
- Applications
  - McDonald's make-to-order system
  - *Kristen's Cookie Company case* (Assignment 1)
  - *Shouldice Hospital case* (Assignment 2)

Processes are complex: Example

- What is the “capacity” of a restaurant?
- What does it depend on?
- Why is it important?

Understanding Process … and Making Them Visible

- ***Process Flow Diagram***: A good tool for understanding process and making them <u>visible</u>
- ***Process mapping***: The activity of constructing a process flow diagram
  - First identify the boundary of the process to analyze
    - Ex. Program (Module 1 – 5) or MSBA 7004 (Class 1 - 10)
  - Identify all activities in the process and how items flow through the process
    - Ex. Classes, exams….
  - Identify all resources in the process and which activities they are responsible for
    - Ex. Instructor, TAs…
  - Multiple products (flow units) and/or exceptions: Conditional routing depending on the product's characteristics
    - Ex. Different courses to take
  - Flow: Not only *materials*, but also *capital* and *information* to drive and control processes
    - We focus on material flows.

Understanding Process … and Making Them Visible

- ***Process Flow Diagram***: A good tool for understanding process and making them visible
- ***Process mapping***: The activity of constructing a process flow diagram
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  - Identify all activities in the process and how items flow through the process
  - Identify all resources in the process and which activities they are responsible for
  - Multiple products and/or exceptions: Conditional routing depending on the product's characteristics
  - Flow: Not only *materials*, but also *capital* and *information* to drive and control processes
- Generating a map and visualizing a processes makes it easier to analyze and can lead to new insights into how to better manage the process
- Types of process flow diagram: Standard, Linear, Swim-Lane, Gantt Chart, etc.

Process Entities

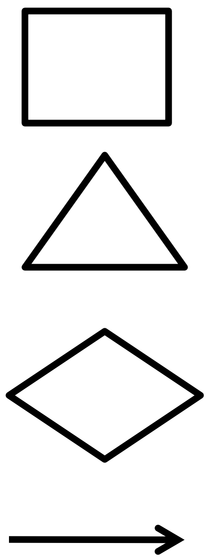
- ***Flow units***: The items that flow through the process
  - May be homogenous (identical) or heterogeneous (different)
  - Ex. Red marker, MSBA student, etc.

- ***Activities***: The transformation steps in the process where value is added to the flow units (and resources being used)
  - Each activity takes some time to complete
  - Ex. MSBA 7004, MSBA 7003, etc.

- ***Resources***: They perform the activities (*value-adding*)
  - Each resource has its own capacity
  - Ex. Instructor, TA, classroom, program staff, etc.

- ***Buffers***: Storage units for flow units (*non value-adding*)
  - May have finite size
  - Any non value-adding time spent corresponds to a buffer
  - Ex. Break between Module 1 and 2, etc.

Process Flow Diagram Elements



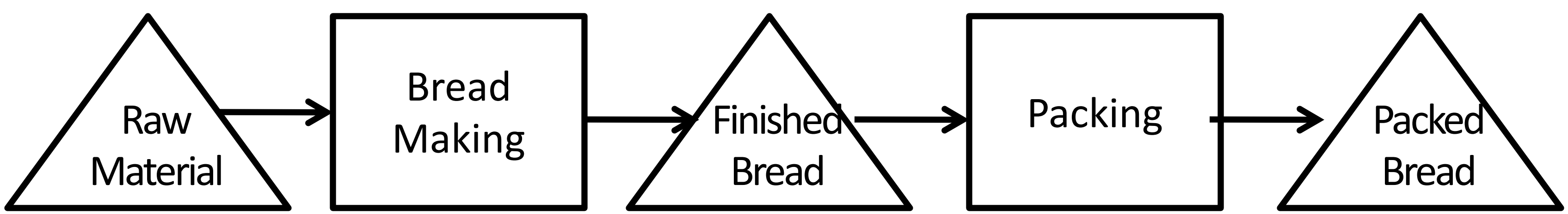
Activities, tasks or operations

Buffers: Queues or inventories

Decision points (multiple types of units)

Flow of materials

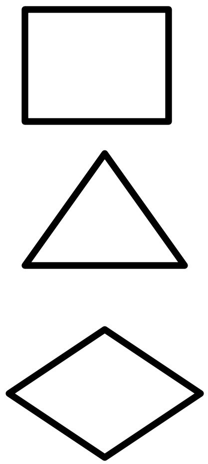
- Example: Bread making



Note: For different type of breads, the bread-making and packing activities may differ for each

Which resources are being used?

Process Flow Diagram Elements



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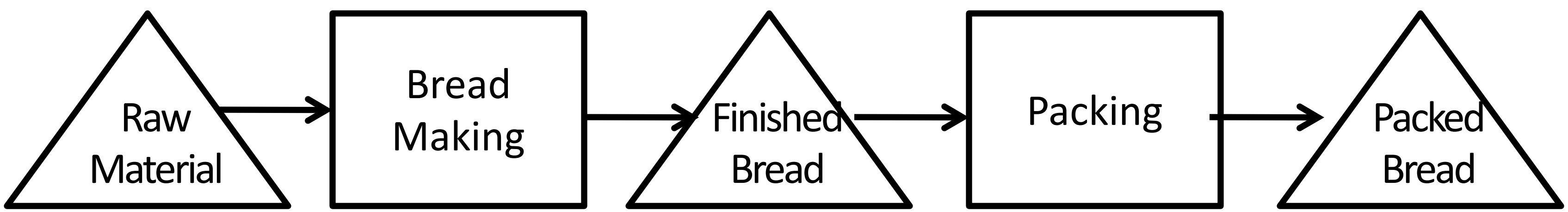


Note: For different type of breads, the bread-making and packing activities may differ for each

Employees, oven

Flow through a process

At any time in a process, A flow unit may be …	EXAMPLE Process: Security screening at HKG Flow unit: A passenger	EXAMPLE Process: Shipping an order of paper from a paper mill to a customer Flow unit: An order
Undergoing an activity, or …	The passenger may be actively involved in some portion of the screening process, or	The order may be in transit, or
Waiting in a buffer to undergo an activity	Waiting (in buffer) to undergo a screening activity	Waiting (in buffer) to be shipped on some leg of its route

Key Steps in Process Analysis

Step 1: **Determine the *Purpose* of the analysis**

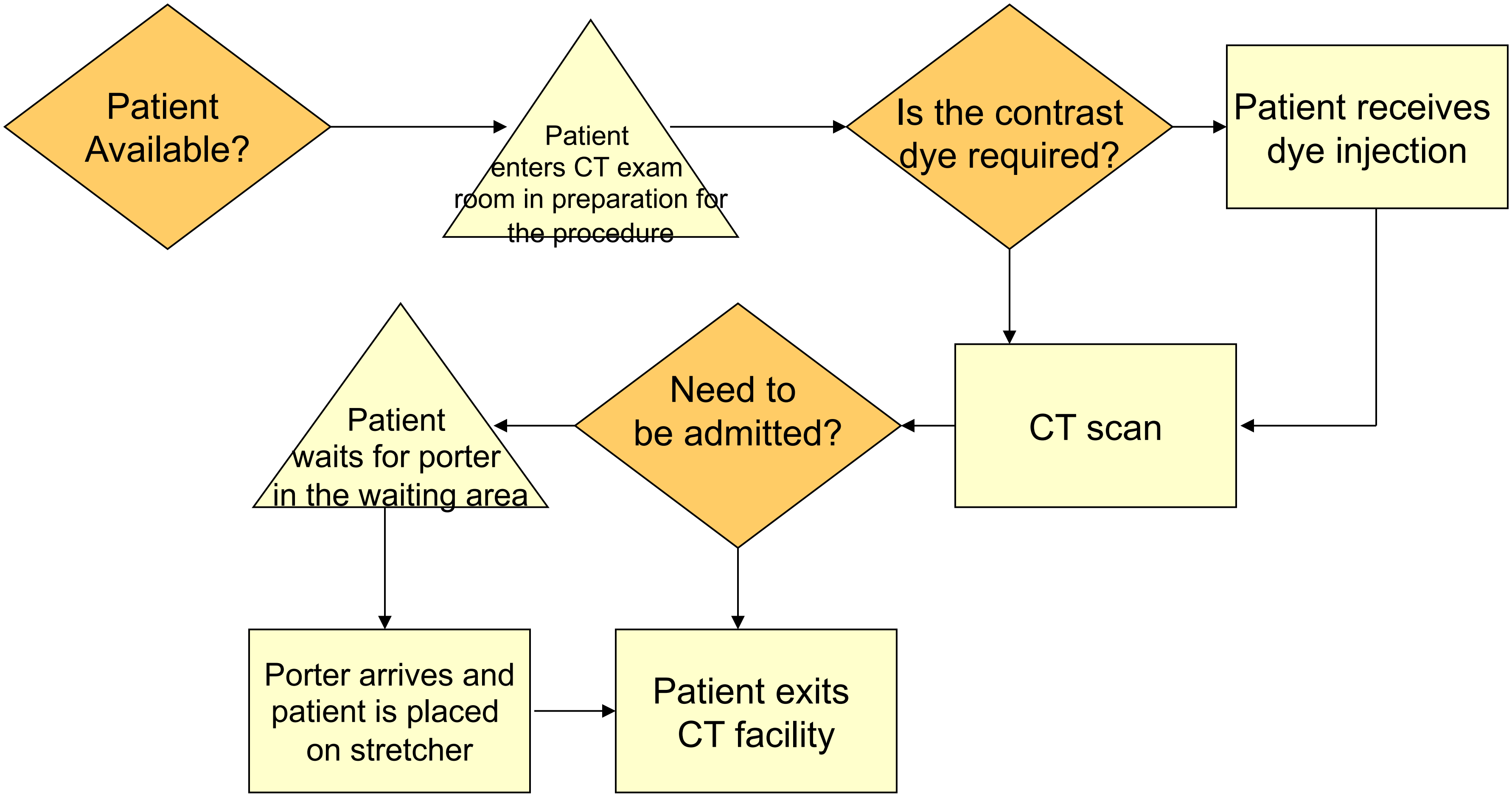
Step 2: **Process mapping (Define the process)**

- Determine the *process boundary*
- Determine the *flow units*
- Determine the *activities*, and the sequence of them
- Determine the time for each activity
- Determine which *resources* are used in each activity
- Determine where *inventory* is kept in the process (*buffer*)
- Record this through a process flow diagram

Step 3**: Capacity Analysis** (also called **Bottleneck Analysis**)

- Determine the capacity of each *resource*, and of the process

Process Map Example: CT Scan



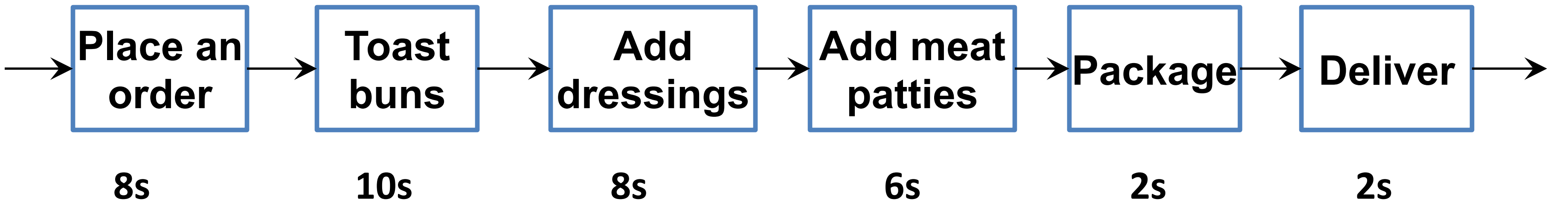
Example: McDonald’s Kitchen

- Purpose of the analysis: To determine the ***capacity rate*** of a McDonald’s restaurant

- Given this purpose, we draw the process boundary around the kitchen
  - We do not consider customers’ queue
  - We do not consider meat cooking processes (we assume cooked meat is always available when needed during the make-to-order process)

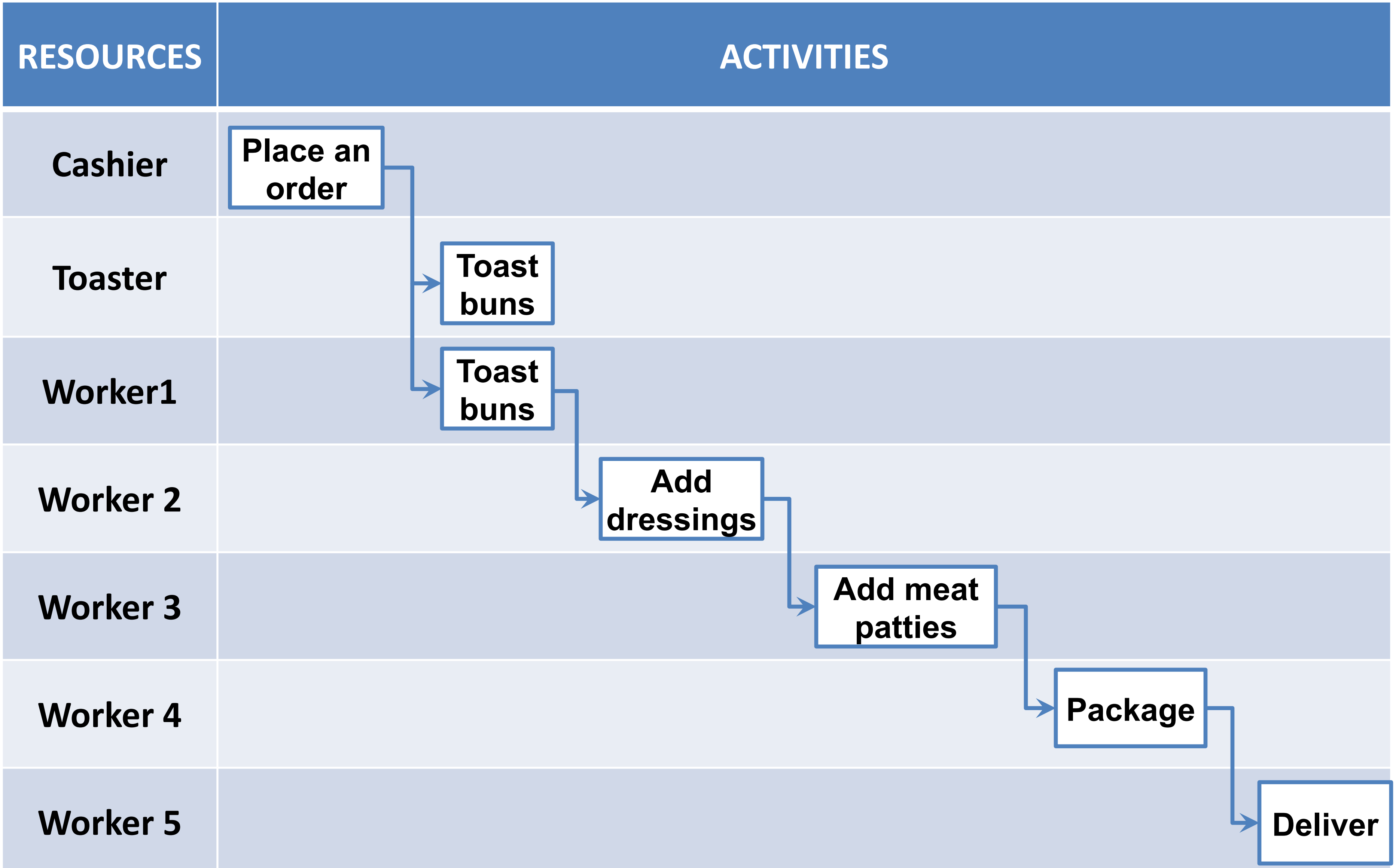
Linear Flow Chart

- Flow unit: An order (each order = one burger)
- Tasks (activities) and their sequences
- Flow time (activity time) of each task

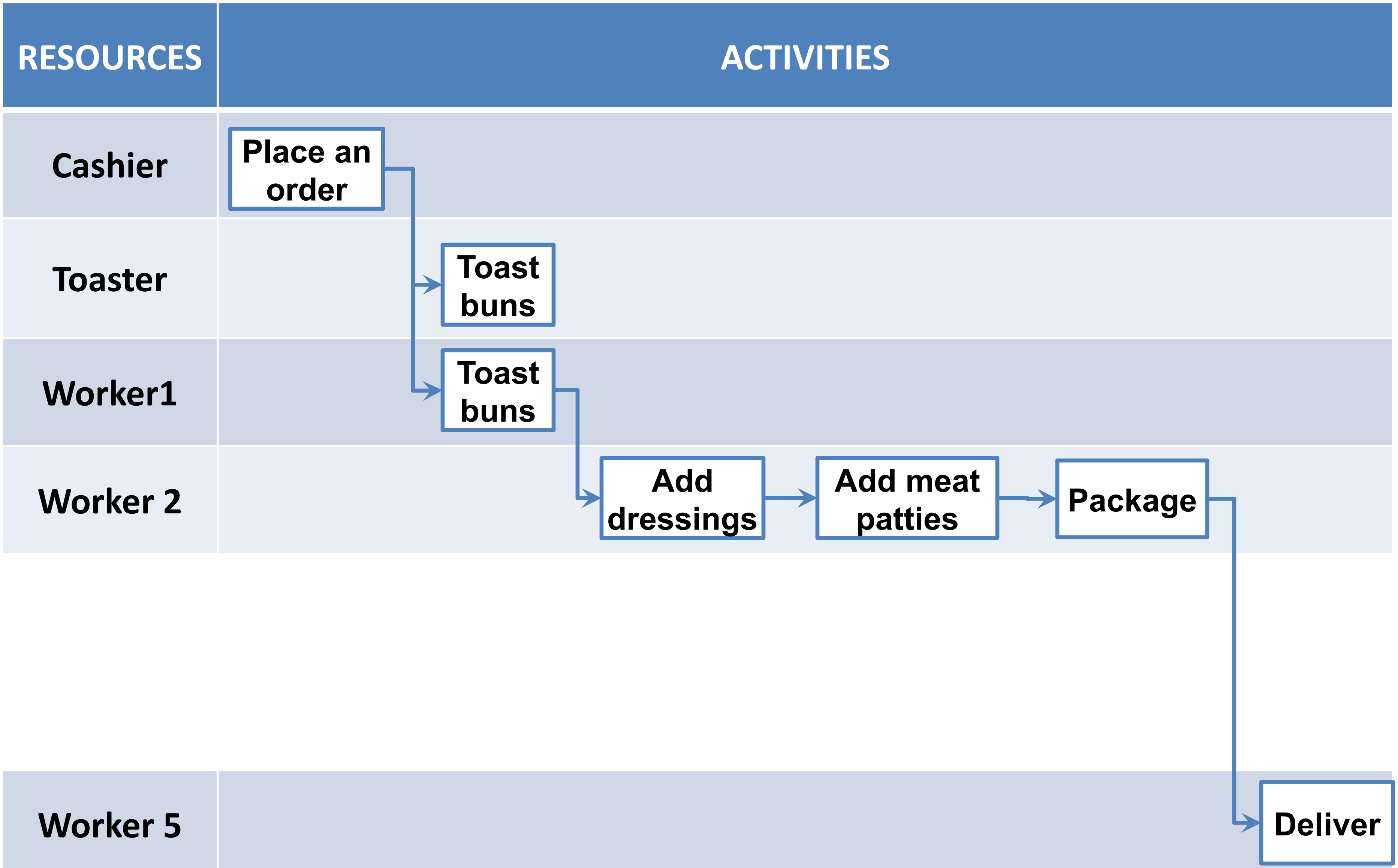


- Determine which resources are used in each task
  - Could indicate resources along each task
  - Swim-lane diagram or Gantt chart may be better

Swim-Lane (Deployment) Flowchart



Swim-Lane (Deployment) Flowchart



Gantt Chart

RESOURCES	ACTIVITIES	Time Span
Cashier	Place an order	8 s
Worker1 Toaster	Toast buns	10s
Worker 2	Add dressings	8 s
Worker 3	Add meat patties	6s
Worker 4	Package	2s
Worker 5	Deliver	2s

Time

Process Mapping: Some Notes

- There is no *one way* to draw a process map
- Get feedback from all the people involved in the process to *validate* the process map
  - Do not map the process as you think it works
  - Map it as it *actually* works
- Process map itself is informative
  - Visualization *always* work
- Starting point for process analysis
  - Great tool for brainstorming process improvements

Capacity of a Resource

- **Unit Load of a Resource (Ti)**
  - The average time it takes for a resource to perform all activities (task) it is in charge on one flow unit
  - Ex) An ATM machine takes 60 seconds per customer on average
- **Capacity of a resource (1/ Ti)**
  - The maximum number of flow units that a resource can complete in a certain period of time
  - Ex) 1 customer / 60 seconds= 1/60 customer per second = 1 customer per min
- **A Pool of Resources**
  - Effective capacity of a pool of Resource (ci/Ti)
  - ci=number of servers in the resource pool
    - Ex) 3 ATM machines

Basic Process Analysis
Single Stage Process

Toaster
Worker 1

Flow Time

(Time that buns spend in the toaster = worker 1's time required for each bun)

10 sec

Capacity Rate (of toaster and worker 1)

6 orders/min, or 360 orders/hr

Process Performance Characteristics: Capacity Rate and Flow Time VS. Cycle Time

- *Capacity rate*: Maximum rate at which (flow) units can flow through the process
- *(Theoretical) Flow time* (or *Throughput time*): Total length of time a unit spends in the process
  - Shortest time (hence without waiting at all) for a flow unit to go through the entire process
  - In practice, flow time is often referred to as cycle time, but we should distinguish
- *Cycle time*: ***In theory***, the inverse of the capacity rate
  - Equivalent to the average time between completion of successive flow units
  - Think as interval between consecutive finishes
  - McDonald’s Example
    - You may wait 5 minutes for one order. Every minute, there could be multiple orders finished.

Basic Process Analysis
Multiple Stage Process

→ **Place an order** → **Toast buns** → **Add dressings** → **Add meat patties** → **Package** → **Deliver** →

Cashier	Worker 1 Toaster	Worker 2	Worker 3	Worker 4	Worker 5
8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
?	?	?	?	?	?

Basic Process Analysis
Multiple Stage Process

→ Place an order → Toast buns → Add dressings → Add meat patties → Package → Deliver →

Cashier	Worker 1 Toaster	Worker 2	Worker 3	Worker 4	Worker 5
8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
450/hr	360/hr	450/hr	600/hr	1800/hr	1800/hr

Theoretical <u>Flow Time</u> of the whole process: ???

<u>Capacity rate</u> of the whole process: ???

Note: The theoretical flow time ignores the possibility of waiting; so it is the lowest possible flow time

Basic Process Analysis
Multiple Stage Process

→ Place an order → Toast buns → Add dressings → Add meat patties → Package → Deliver →

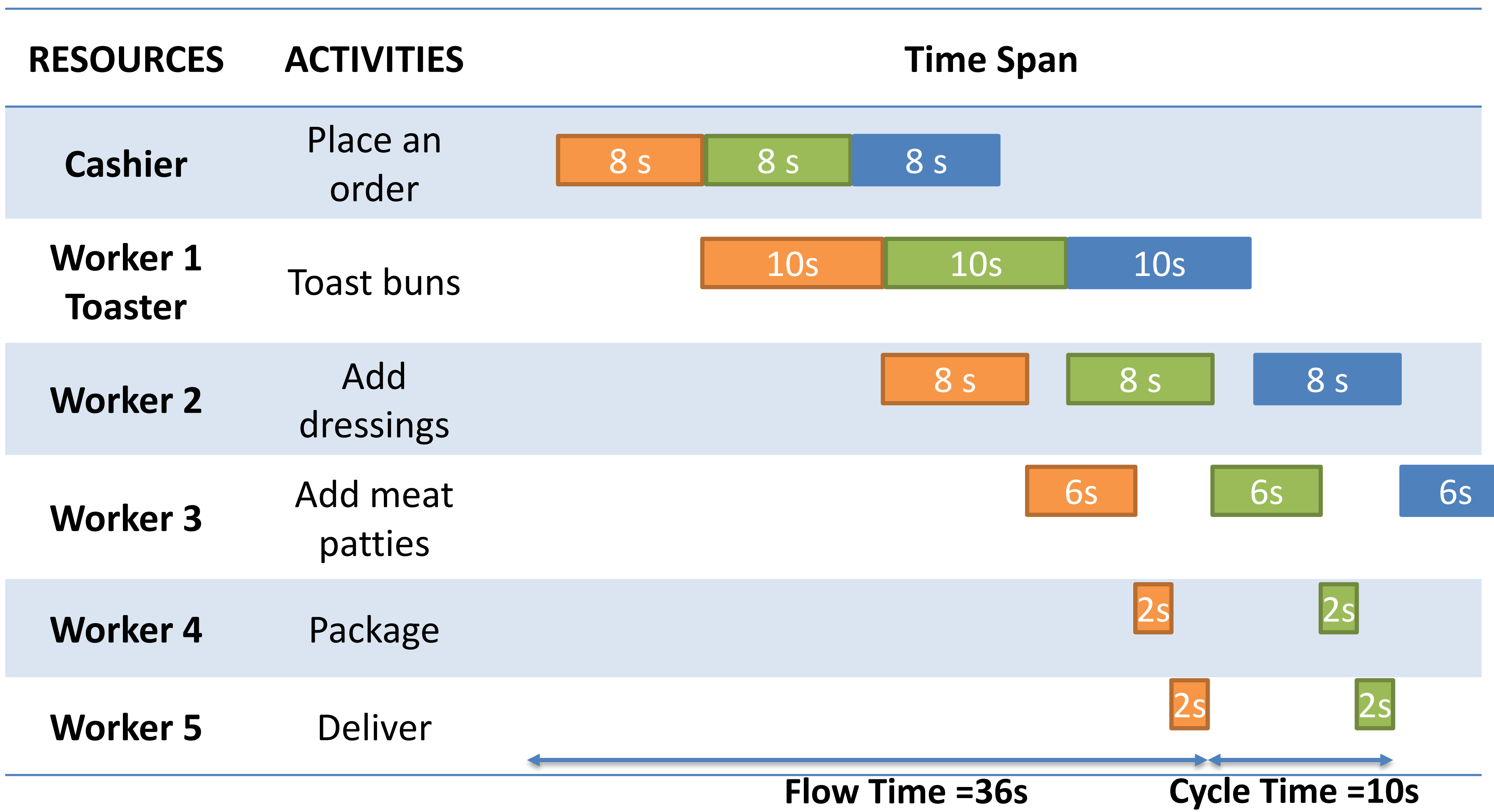
Cashier	Worker 1 Toaster	Worker 2	Worker 3	Worker 4	Worker 5
8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
450/hr	360/hr	450/hr	600/hr	1800/hr	1800/hr

Theoretical Flow Time of the whole process: 36 sec

Capacity rate of the whole process: 360 orders/hr

Note: The theoretical flow time ignores the possibility of waiting; so it is the lowest possible flow time

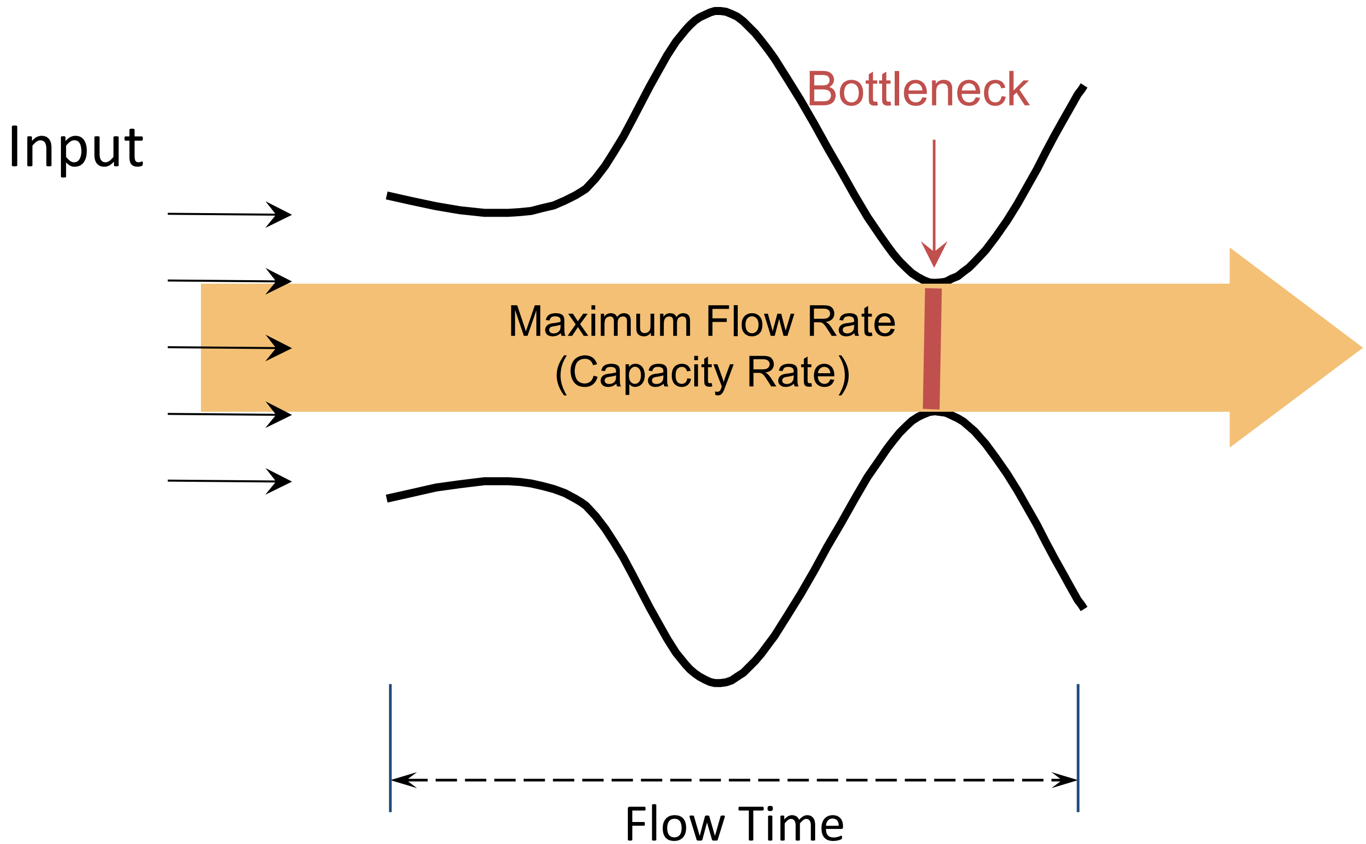
Gantt Chart: Multiple Stage Process



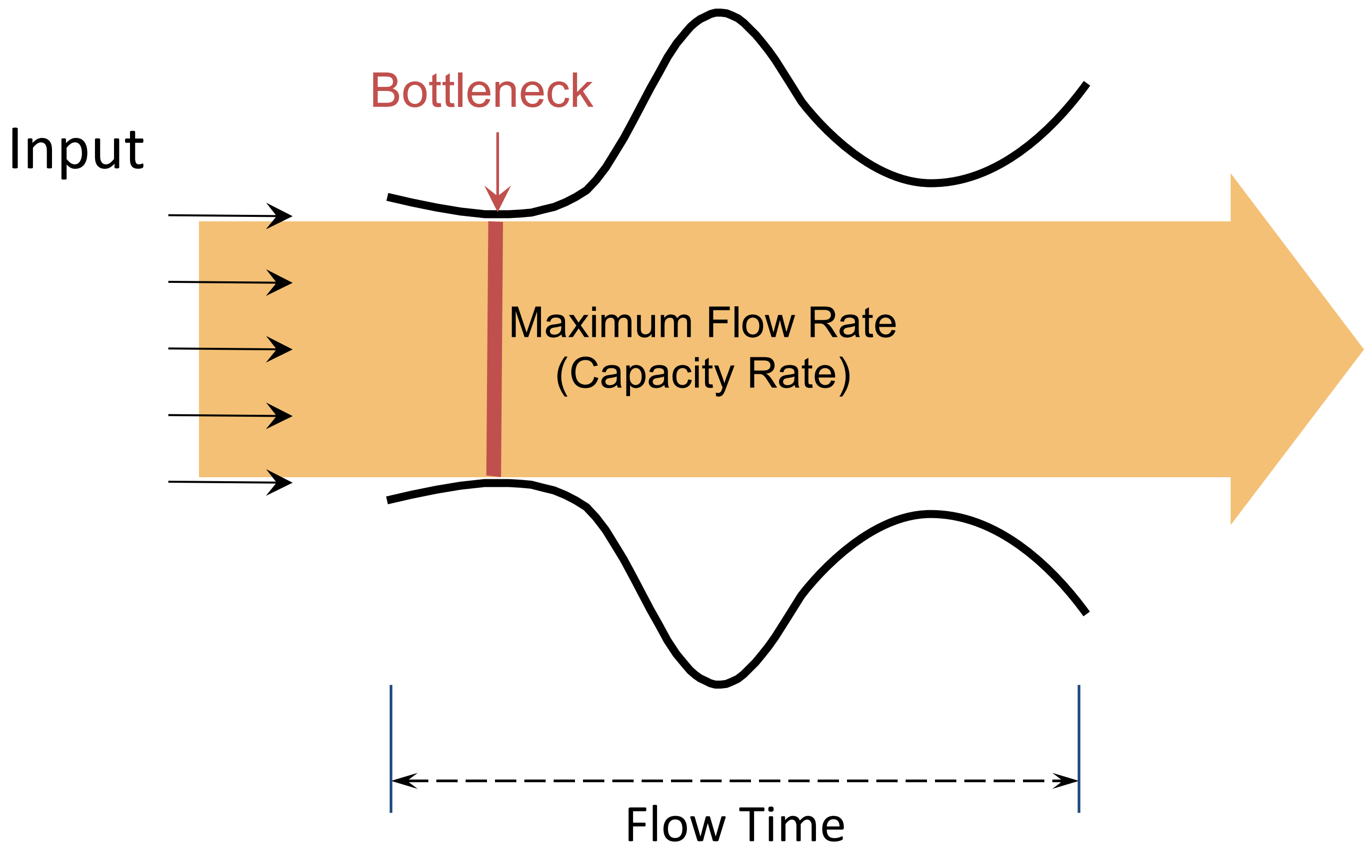
The Bottleneck

- The ***resource(s)*** with the lowest capacity rate
  - The “slowest” resource(s)
  - *Unit load (Ti):* Total amount of time the resource works to process each flow unit
  - **A process can have multiple bottlenecks**
- Determines the capacity rate of the entire process
- Will the increase of the capacity of non-bottleneck resources increase the capacity rate of the process??

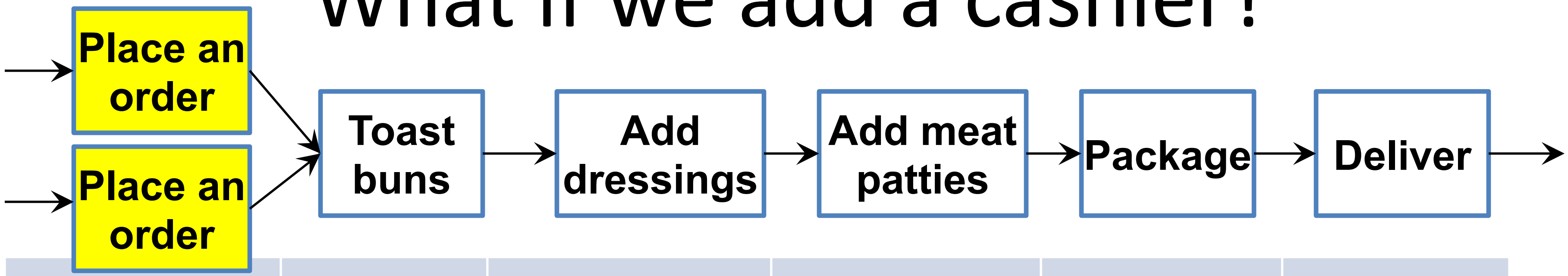
Capacity and Bottleneck



Capacity and Bottleneck



Increasing the capacity rate of a process: What if we add a cashier?



Cashiers	Worker 1 Toaster	Worker 2	Worker 3	Worker 4	Worker 5
8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
450/hr ???	360/hr	450/hr	600/hr	1800/hr	1800/hr

Theoretical Flow Time of the whole process: 36 sec

Capacity rate of the whole process: 360 orders/hr

Increasing the capacity rate of a process: What if we add a *toaster (and another worker)*?

→ Place an order → (Toast buns / Toast buns) → Add dressings → Add meat patties → Package → Deliver →

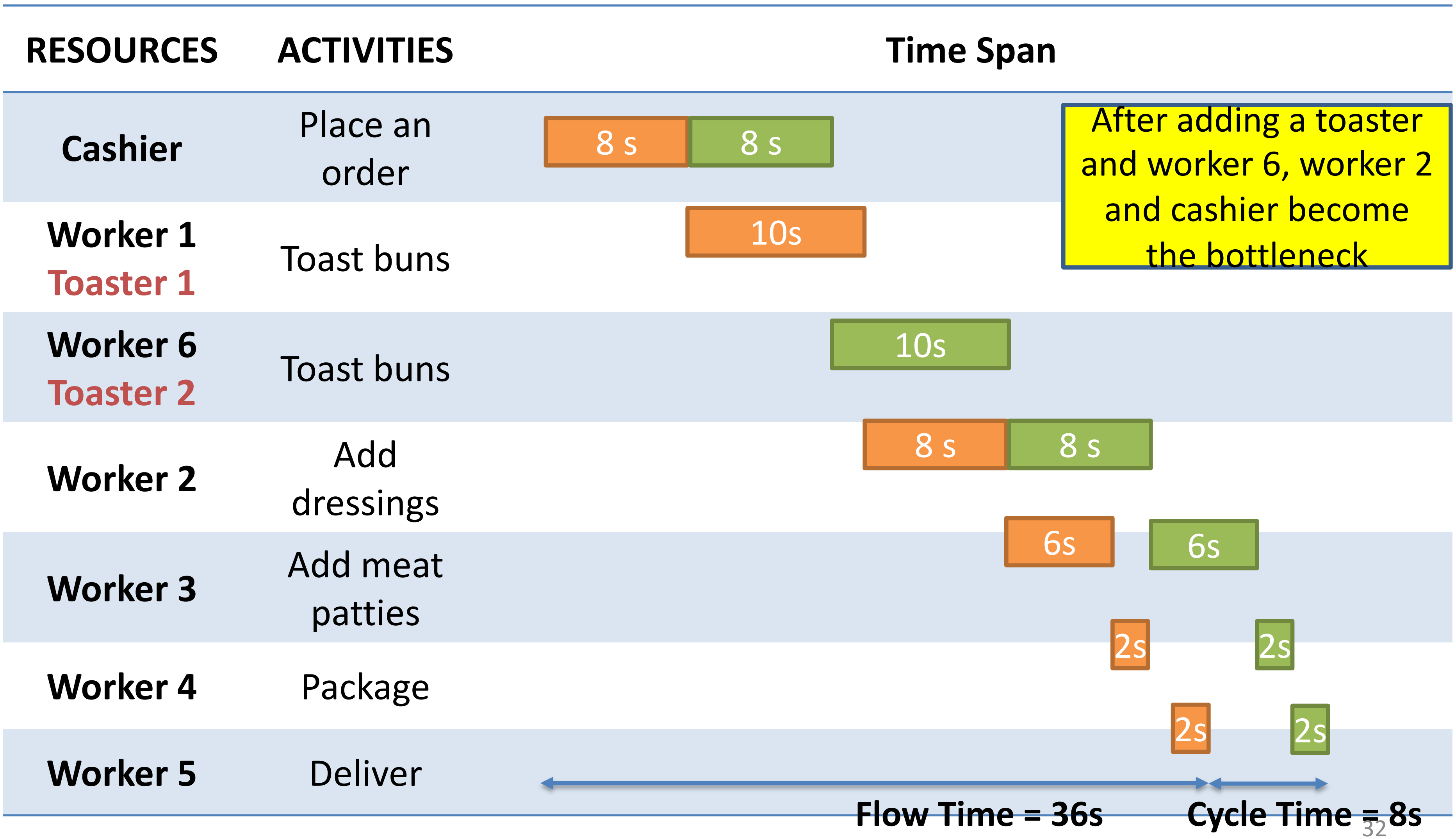
Cashier	Worker 1 Toasters	Worker 2	Worker 3	Worker 4	Worker 5
8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
450/hr	720/hr (2 * 360/hr)	450/hr	600/hr	1800/hr	1800/hr

Theoretical Flow Time of the whole process: 36 sec

Which resource is the bottleneck?

Capacity rate of the whole process: 450 orders/hr

Adding a Toaster: Gantt Chart



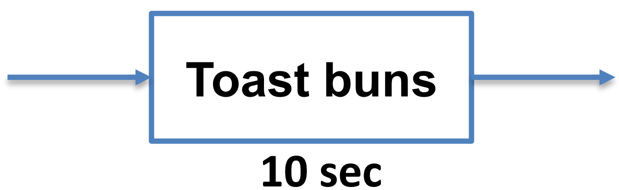
Increasing the Capacity Rate of a Process

- Increase the capacity rate of the *bottleneck*
  - Expand the resource pool (add resource)
  - Reduce Unit Load
- Some other resources may become a bottleneck when capacity is increased
  - *Shifting the bottleneck*
  - Increase in bottleneck capacity does not always result in commensurate increase in process capacity
  - Important when we justify additional capacity

Increasing Capacity (1)
Increase the Size of the "Resource Pool"

- One Toaster

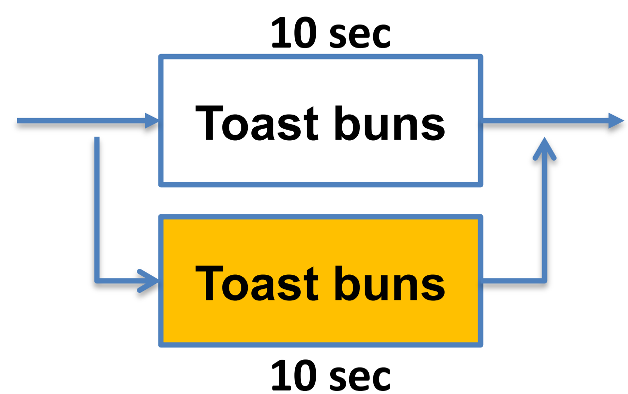
  Capacity rate: 360/hr



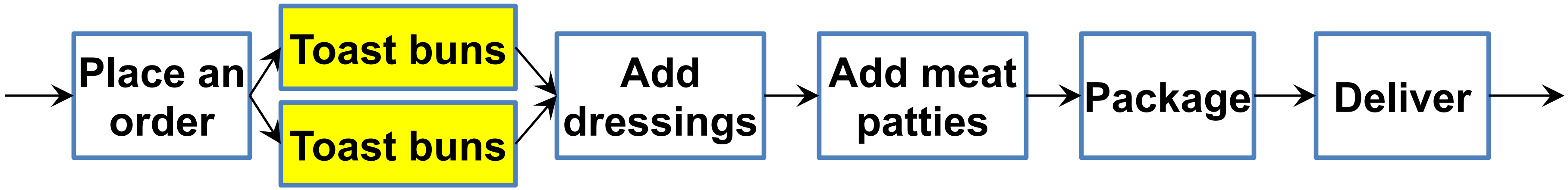
- Two Toasters

  Working in Parallel

  Capacity rate: 720/hr



Expand the resource pool at the bottleneck



Cashier	Worker 1 Toasters	Worker 2	Worker 3	Worker 4	Worker 5
8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
450/hr	720/hr (2 * 360/hr)	450/hr	600/hr	1800/hr	1800/hr

***Theoretical* Flow Time** of the whole process: 36 sec

Capacity rate of the whole process: 450 orders/hr

Increasing Capacity (2)
Reducing the Unit Load

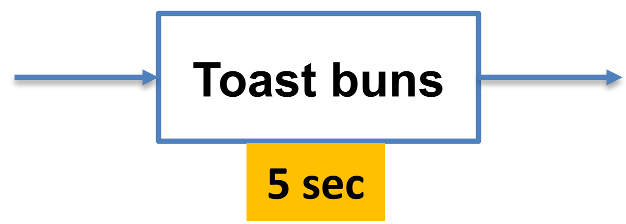
- Current Toaster

  Capacity rate: 360/hr

- Faster Toaster

  Works twice as fast

  Capacity rate: 720/hr



Reduce Unit Load at the Bottleneck

→ Place an order → Toast buns → Add dressings → Add meat patties → Package → Deliver →

	Cashier	Worker 1 Toaster	Worker 2	Worker 3	Worker 4	Worker 5
Old Flow Time	8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
Old Capacity Rate	450/hr	360/hr	450/hr	600/hr	1800/hr	1800/hr
New Flow Time	8 sec	5 sec	8 sec	6 sec	2 sec	2 sec
New Capacity Rate	450/hr	720/hr	450/hr	600/hr	1800/hr	1800/hr

Theoretical Flow Time : 31 sec

Capacity rate of the process: 450 /hr

Any operational benefit of reducing unit load at non-bottlenecks?

→ Place an order → Toast buns → Add dressings → Add meat patties → Package → Deliver →

	Cashier	Worker 1 Toaster	Worker 2	Worker 3	Worker 4	Worker 5
Old Flow Time	8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
Old Capacity Rate	450/hr	360/hr	450/hr	600/hr	1800/hr	1800/hr
New Flow Time	4 sec	10 sec	6 sec	4 sec	1 sec	1 sec
New Capacity Rate	900/hr	360/hr	600/hr	900/hr	3600/hr	3600/hr

Theoretical Flow Time : 26 sec

Capacity rate of the process: 360 /hr

Beyond Basics: Unit Load & Buffer Effects

Resource	Unit Load (sec/unit)	Capacity Rate (unit/min)	Capacity rate (unit/hr)
Cashier	8	7.5	450
Toaster	10	6	360
Worker 1	10	6	360
Worker 2	8	7.5	450
Worker 3	6	10	600
Worker 4	2	30	1800
Worker 5	2	30	1800

Unit Load: Total amount of time the resource works to process each flow unit

Thinking in terms of “Unit Loads”

→ Place an order → Toast buns → Add dressings → Add meat patties → Package → Deliver →

Cashier	Worker 1 Toaster	Worker 2	Worker 3	Worker 3	Worker 3
8 sec	10 sec	8 sec	6 sec	2 sec	2 sec

<u>*Theoretical* Flow Time</u> of the whole process: 36 sec

<u>Capacity rate</u> of the whole process: 360 orders/hr

Note: The theoretical flow time ignores the possibility of waiting; so it is the lowest possible flow time

Thinking in terms of "Unit Loads"

Resource	Unit Load (sec/unit)	Capacity Rate (unit/min)	Capacity rate (unit/hr)
Cashier	8	7.5	450
Toaster	10	6	360
Worker 1	10	6	360
Worker 2	8	7.5	450
Worker 3	10	6	360

Unit Load: Total amount of time the resource works to process each flow unit

Whiteboard I (Formula for Capacity Rate)

- Capacity Rate of a single resource

  = maximum output (or throughput) rate of a single resource

  $$= \frac{Number\ of\ Resource}{Unit\ Load}$$

- Capacity Rate (by default, of a process)

  = maximum output (or throughput) rate of a process

  = capacity rate of bottleneck resource

  $$= \frac{Number\ of\ Bottleneck\ Resource}{Unit\ Load\ of\ Bottleneck\ Resource}$$

  By formula for capacity rate of a single resource

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

  By definition of cycle time (see next slide)

Whiteboard II (Formula for Flow Time)

- (Theoretical) Flow Time of a single activity
  = Unit Load of the Resource for that activity
- (Theoretical) Flow Time (by default, of the Process)
  = Sum of Flow Time of all activities
- Cycle Time, defined as Additional Time Required for Producing One More Unit

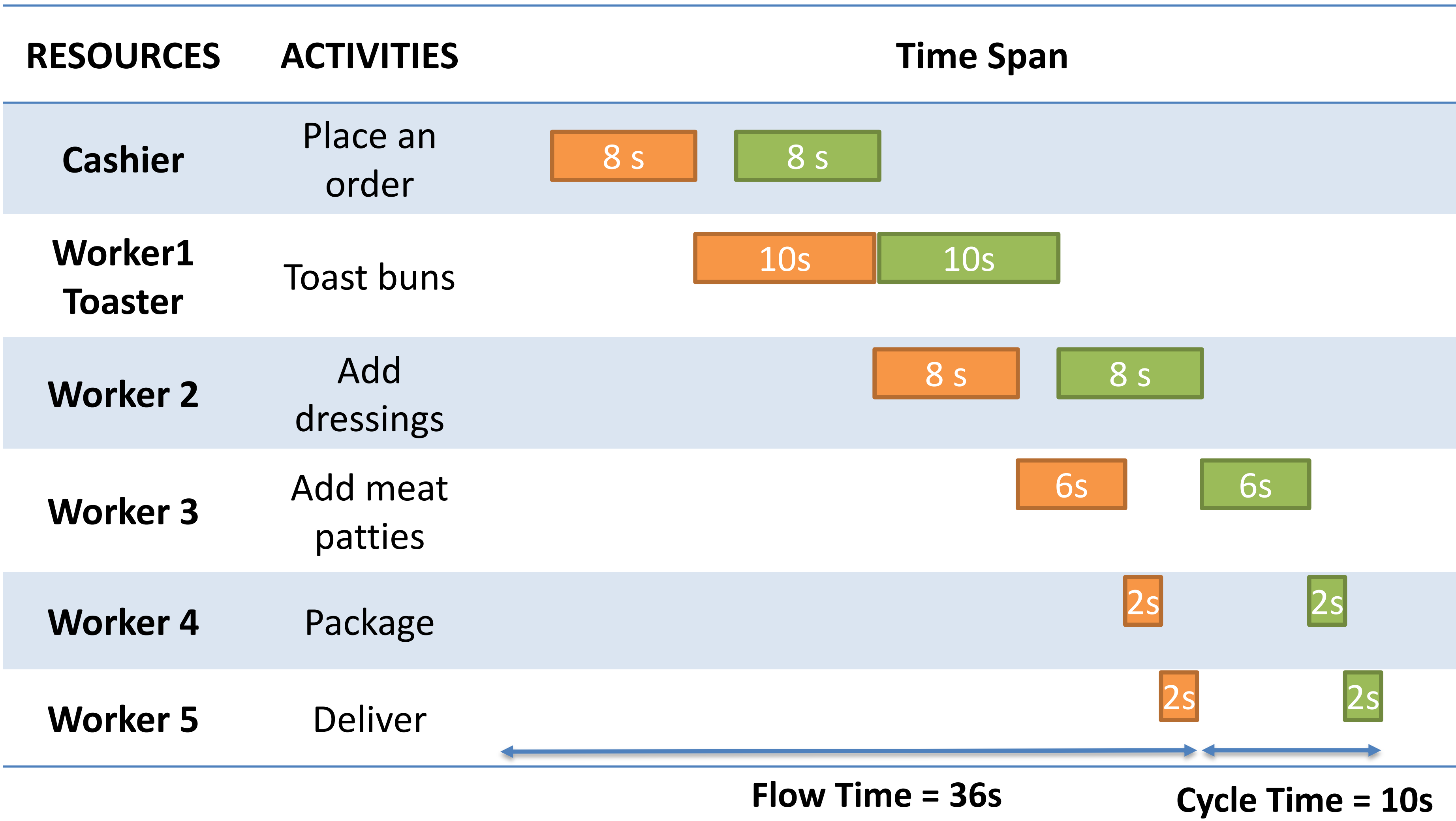
$$= \frac{Unit\ Load\ For\ Bottleneck\ Resource}{Number\ of\ Bottleneck\ Resource}$$

$$= \frac{1}{Capacity\ Rate}$$

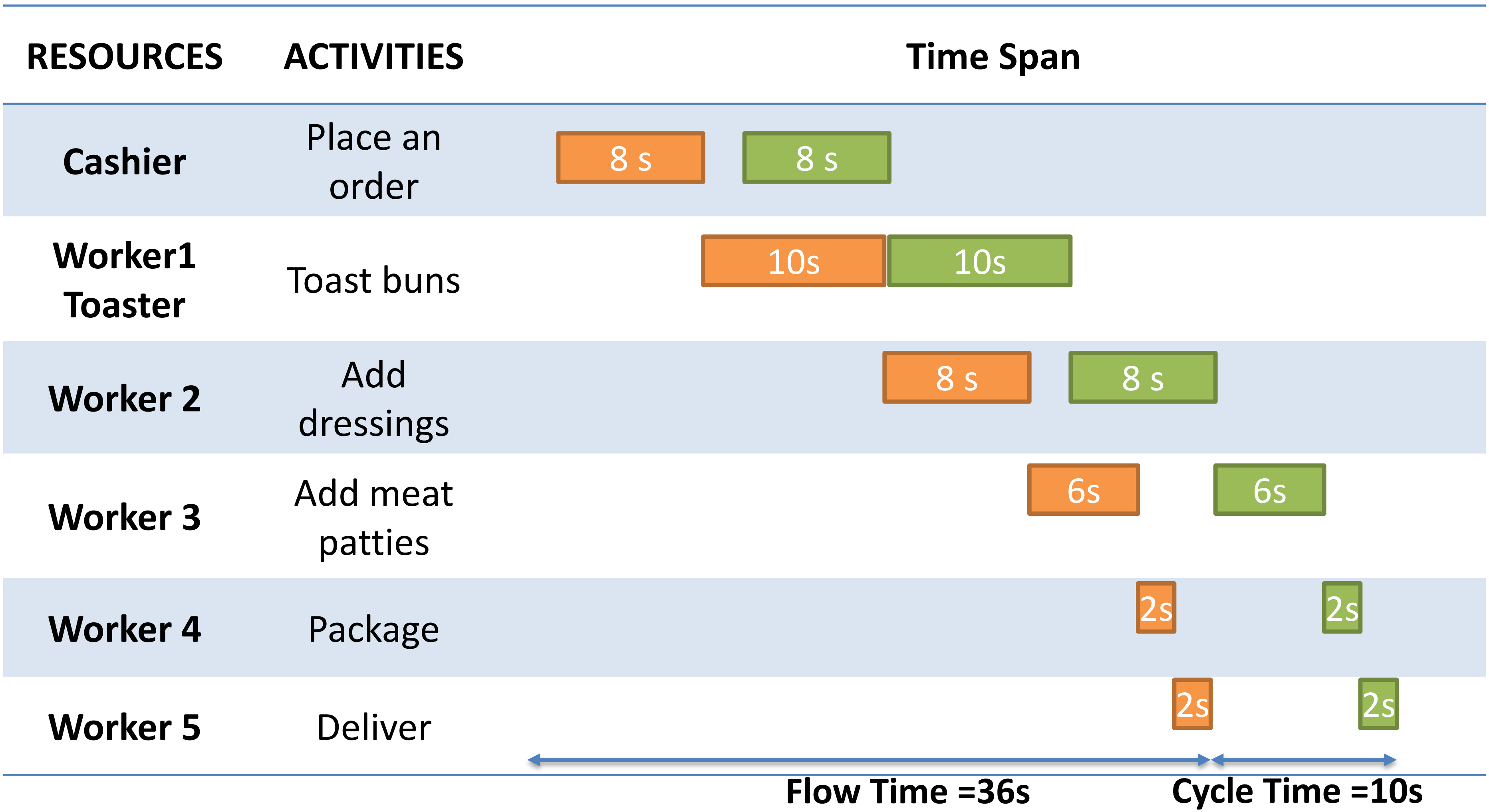
- Flow Time for producing k flow units
  = Flow Time + (k-1)*cycle time
  = Flow time +(k-1) *1/capacity rate

Because each additional Unit takes another cycle to produce, see example in the next slide (after the process being stable)

$$Total\ Time\ for\ Producing\ k\ units$$
$$= Flow\ Time\ (36s) + (k-1) * Cycle\ Time\ (10s)$$
$$= 36 + 10(k-1)\ s$$



$$Capacity\ Rate = \frac{1}{Cycle\ Time} \neq \frac{1}{Flow\ Time}\text{, Why?}$$



Whiteboard III

CR: Capacity Rate (of the Process)
FL: Flow Time (of the Process)

	Reduce Unit Load	Increase Number of Resources	Increase Unit Load
Non-Bottleneck Resource	CR FL	CR FL	CR the bot FL
Bottleneck Resource	CR un FL	CR FL	CR FL

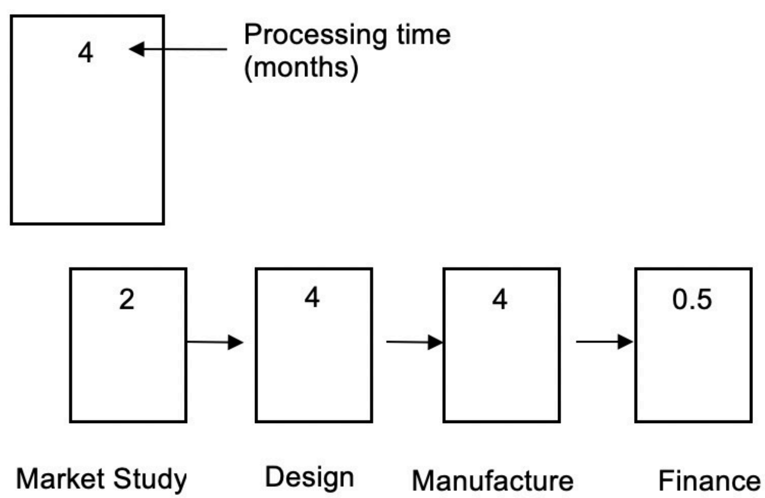
Whiteboard III

CR: Capacity Rate (of the Process)
FL: Flow Time (of the Process)

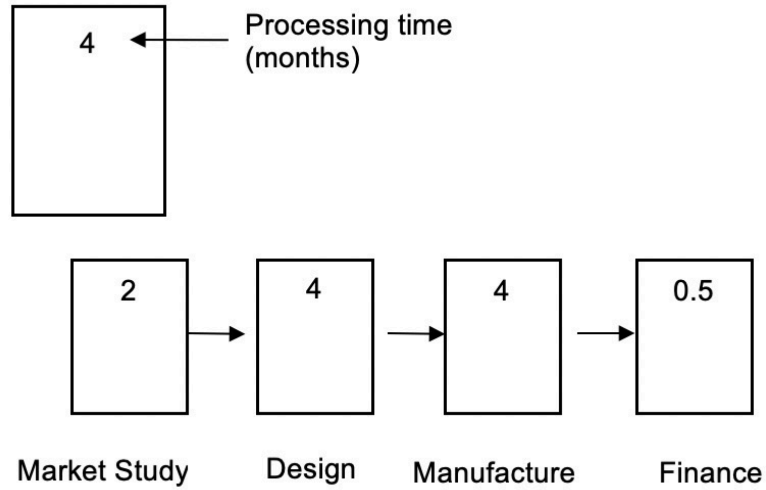
	Reduce Unit Load	**Increase Number of Resources**	**Increase Unit Load**
Non-Bottleneck Resource	CR = FL ↓	CR = FL =	CR ↓ if it becomes the new bottleneck; = otherwise FL ↑
Bottleneck Resource	CR = if not unique; ↑ if unique FL ↓	CR = if not unique; ↑ if unique FL =	CR ↓ FL ↑

In Class Practice Problems

- Assume that you have been hired to improve a new product development process in an electronics manufacturer. Currently, the new product development process consists of a market study done by the marketing department (stage 1), a design study done by the design department (stage 2), a manufacturing study done by the manufacturing department (stage 3), and a final financial study done by the finance department (stage 4) that leads to a pricing decision for the product. For each stage, we characterize the processing time (in months) that department takes to complete its study for one new product. Since the firm has a severe labor shortage, staff at each stage can only work on only one new product development project at a time.



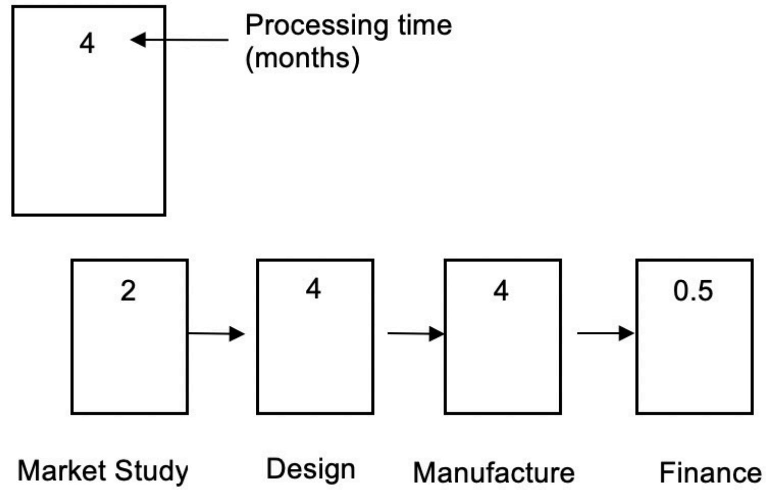
In Class Practice Problems



- Which resource(s) (corresponds to the process stage(s)) is the bottleneck? What is the maximum number of new products that this firm can develop per year with the process it is using? (what is the maximum capacity the firm can obtain?)

- How long the development of a new product takes in this company? (What is the theoretical flow time?)

In Class Practice Problems



- Which resource(s) (corresponds to the process stage(s)) is the bottleneck? What is the maximum number of new products that this firm can develop per year with the process it is using? (what is the maximum capacity the firm can obtain?)

Bottleneck is the resource(s) with lowest capacity. Design and manufacturing departments are both bottleneck. Capacity rate is 0.25 projects/month = 3 projects/year.

- How long the development of a new product takes in this company? (What is the theoretical flow time?)

2+4+4+0.5=10.5 months

You observe a long line at a Bakery with customers leaving every 4 minutes. What is the capacity (in customers per hour) of the bakery?

Cycle time: 4 minutes.

Capacity: ¼ customers/minutes = 15 customers/hour.