

MSBA 7004

Operations Analytics

Class 1-2: Process Flow Analysis (I)
Capacity Rate, Flow Time, Bottleneck
2024

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?
 - How many customers you can serve in a given period of time, X customers/day.
- What does it depend on?
 - Resources (number of staffs)
- Why is it important?
 - Affects revenue

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
 - 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 customer orders, Different courses to take...
 - Flow: Not only *materials*, but also *capital* and *information* to drive and control processes (production, service processes)
 - We focus on material flows. How the flow units flow through the process.

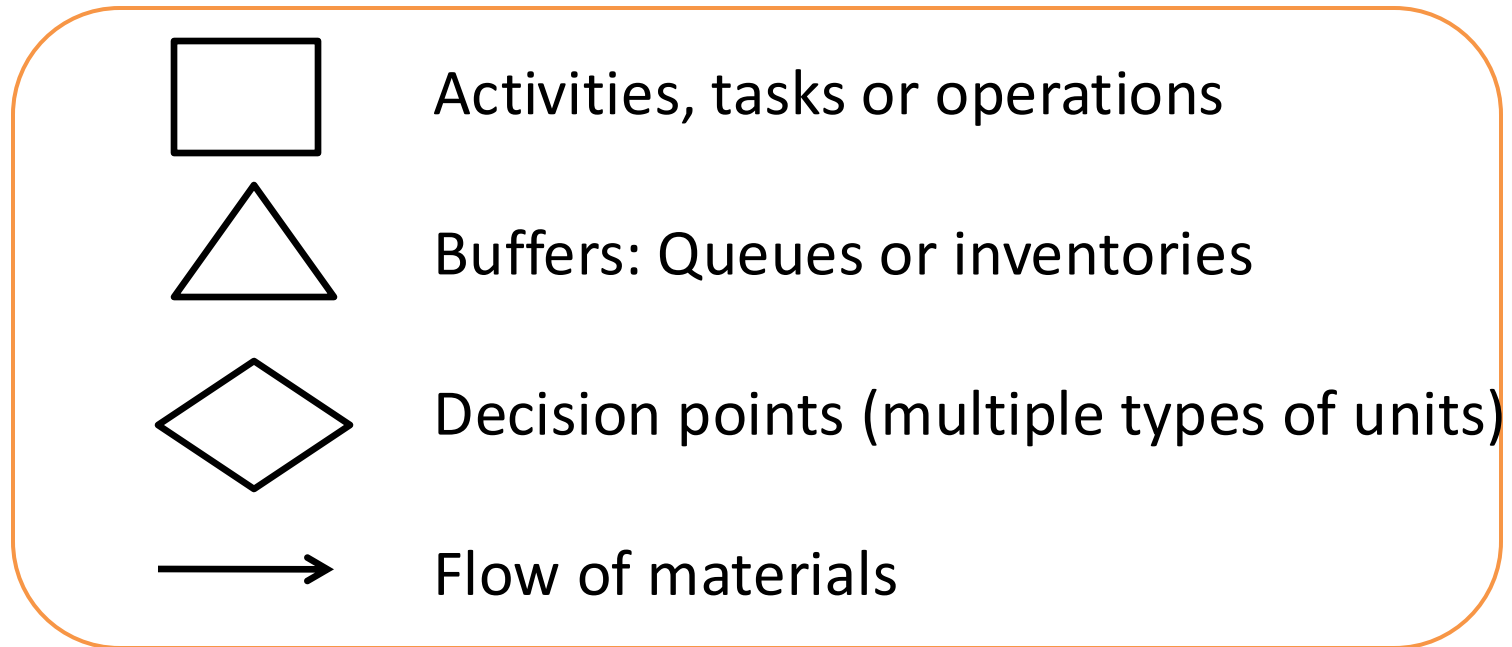
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 - Identify all activities in the process and how items flow through the process
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 - Multiple products and/or exceptions: Conditional routing depending on the product's characteristics
 - Flow: Not 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.

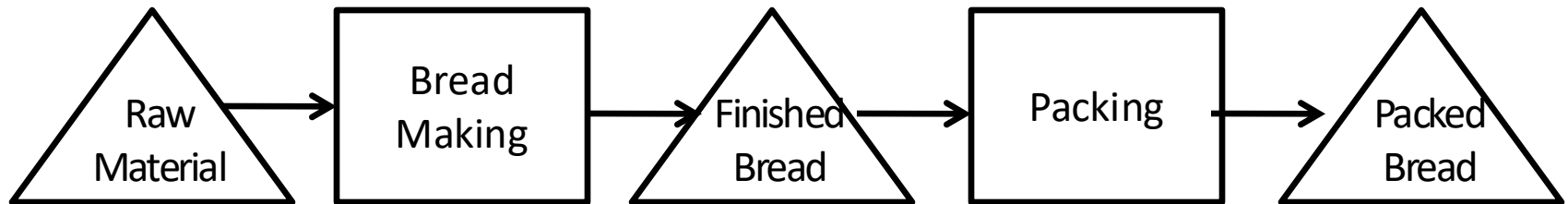
Process Entities

- **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



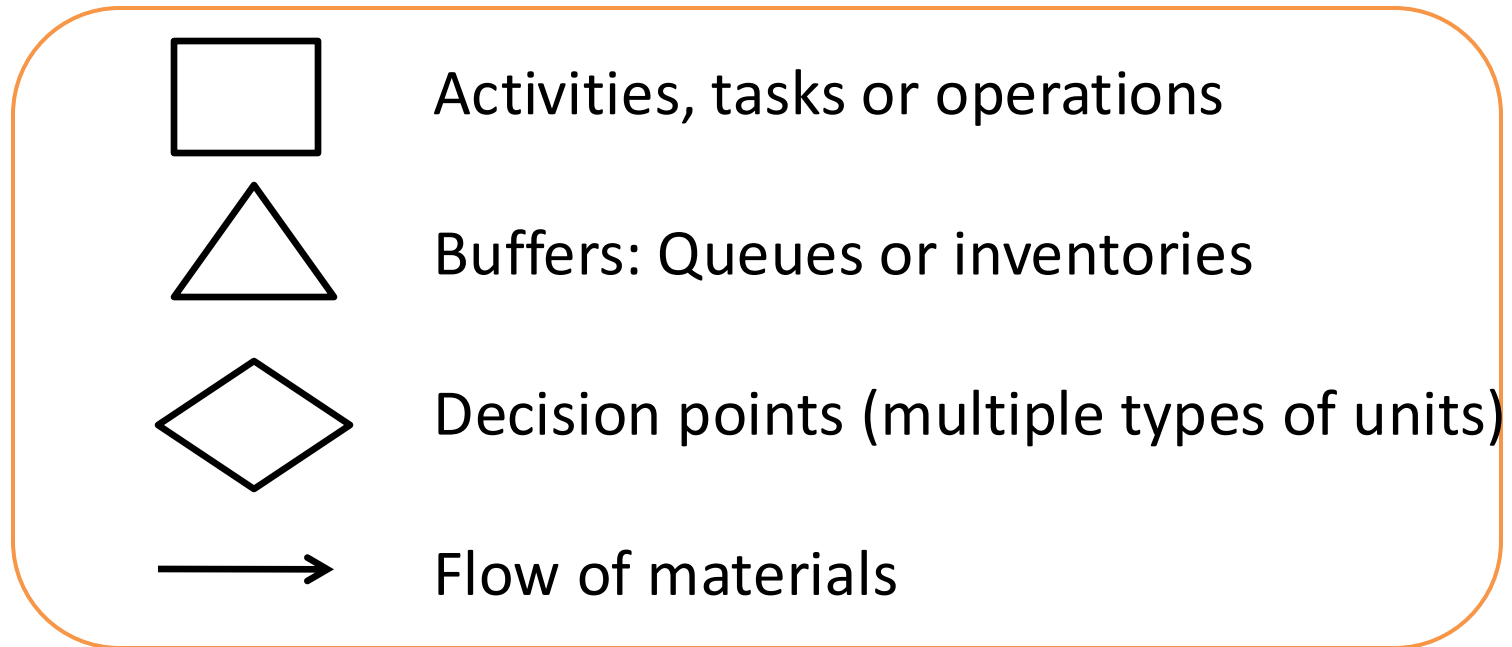
- Example: Bread making



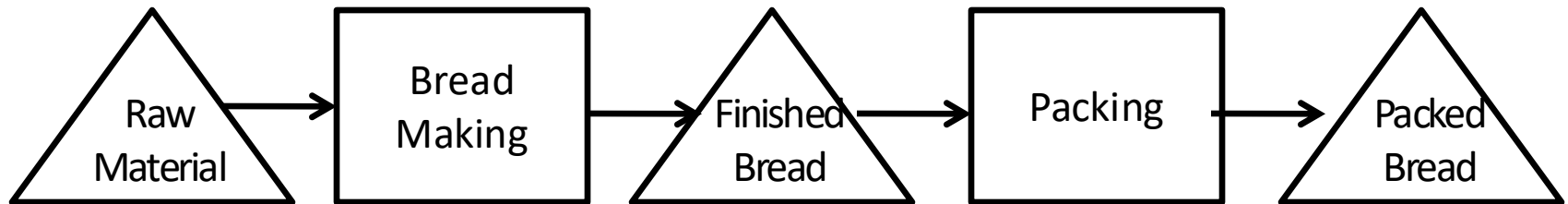
Note: For different type of breads, the bread-making and packing activities may differ for each

Which resources are being used?

Process Flow Diagram Elements



- Example: Bread making



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

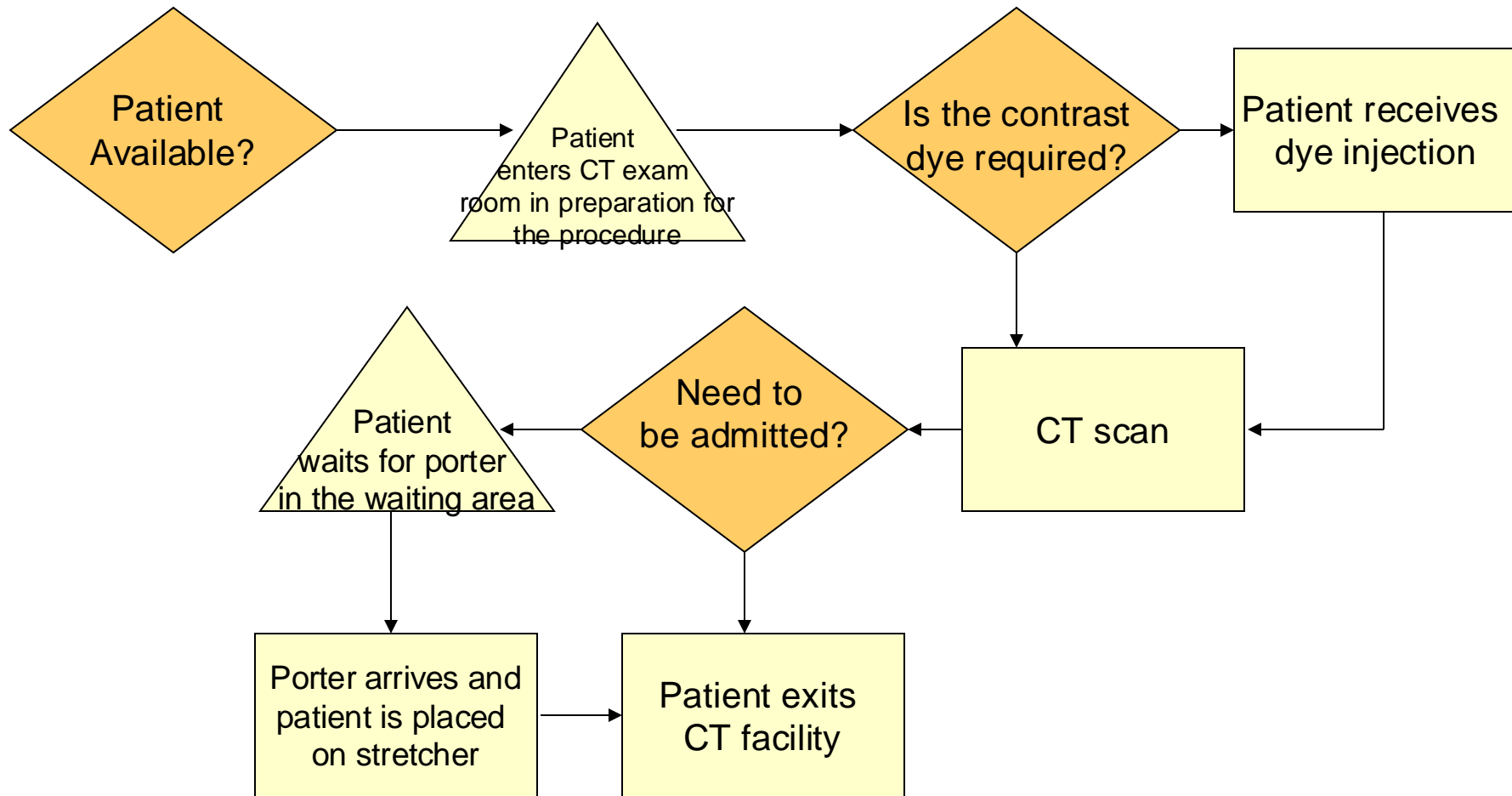
Step 2: Process mapping (Define the process)

- 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

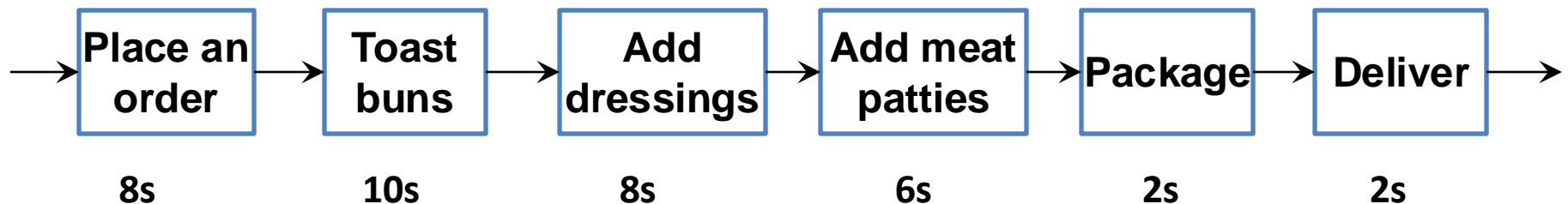


Example: McDonald's Kitchen

- 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)

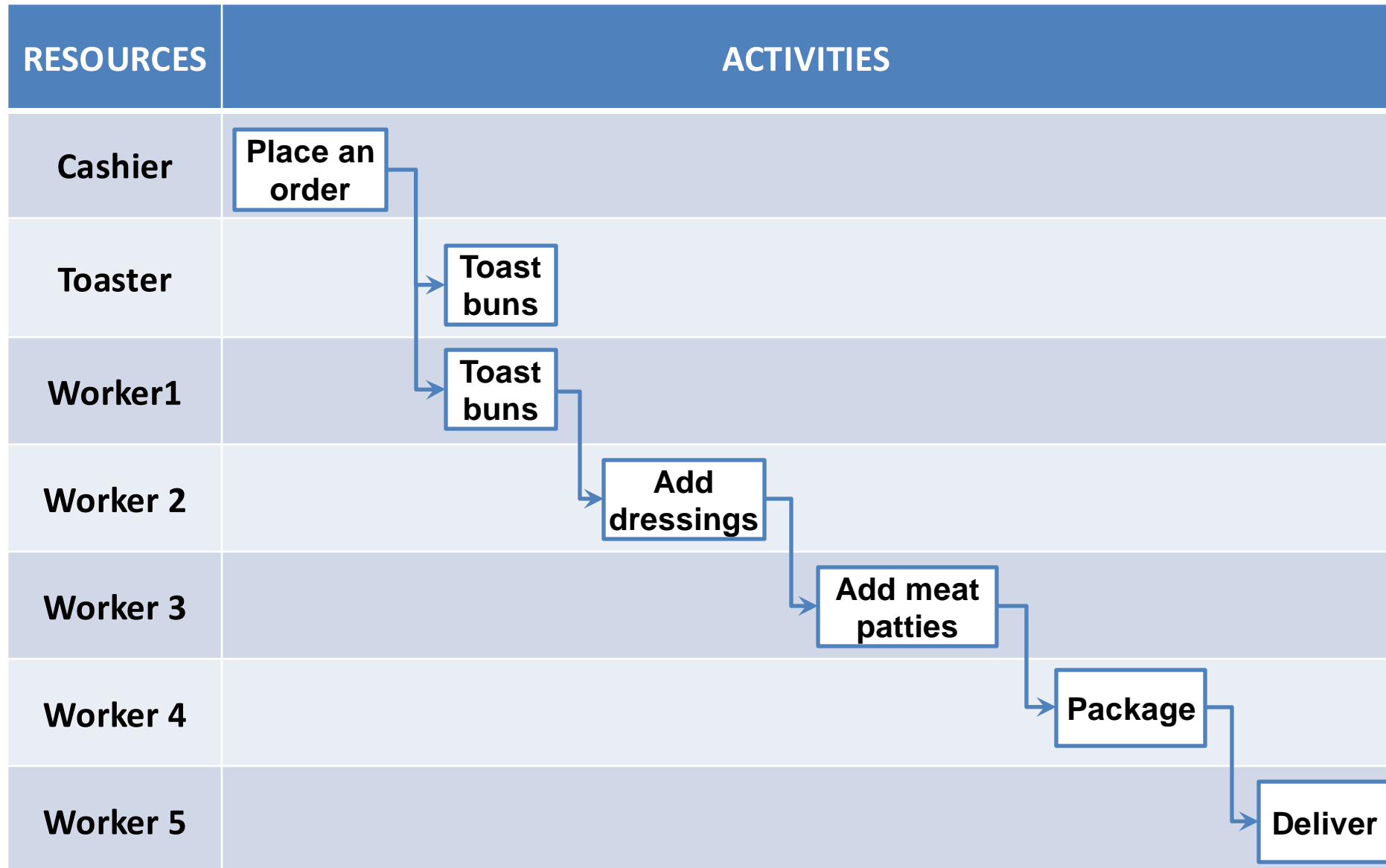
Linear Flow Chart

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

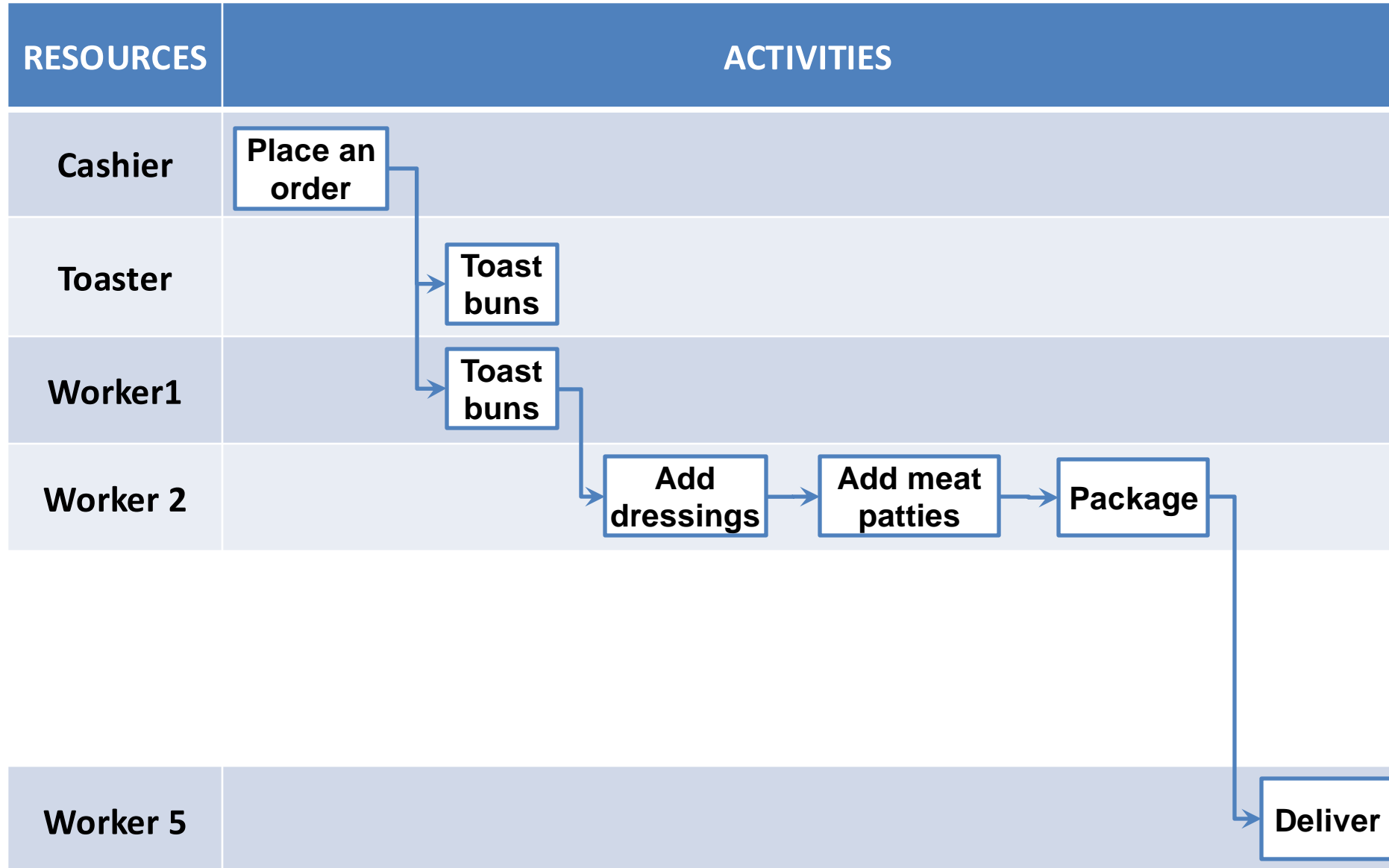


- Determine which resources are used in each task
 - Could indicate resources along each task
 - Swim-lane diagram or Gantt chart may be better

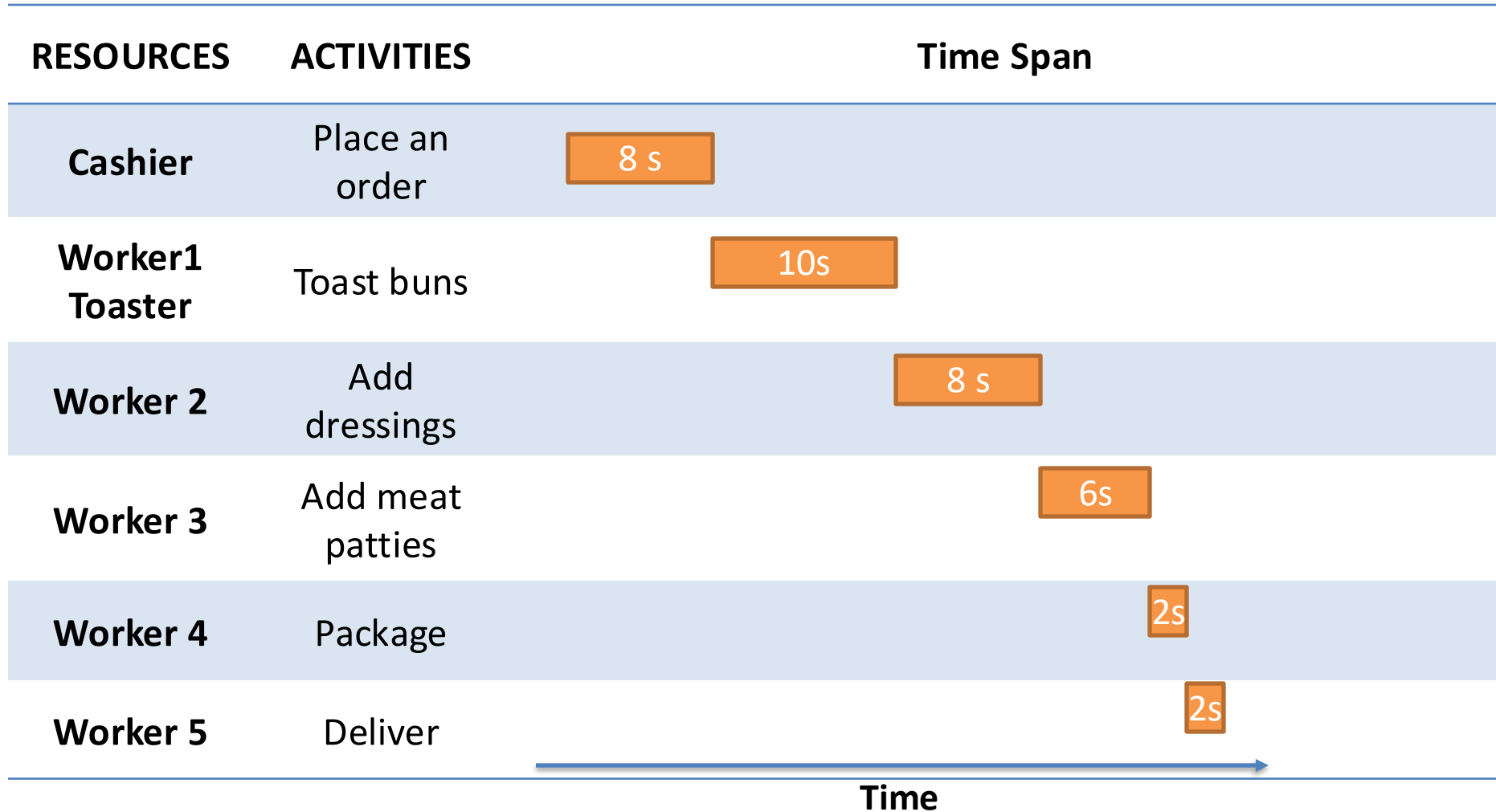
Swim-Lane (Deployment) Flowchart



Swim-Lane (Deployment) Flowchart



Gantt Chart



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 (T_i)**

- 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 ($1/T_i$)**

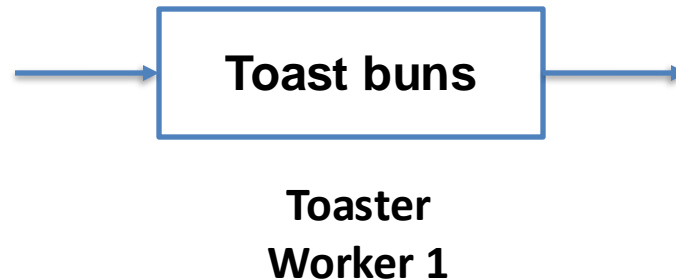
- The maximum number of flow units that a resource can complete in a certain period of time
- Ex) 1 customer / 60 seconds = $1/60$ customer per second = 1 customer per min

- **A Pool of Resources**

- Effective capacity of a pool of Resource (c_i/T_i)
- c_i =number of servers in the resource pool
 - Ex) 3 ATM machines

Basic Process Analysis

Single Stage Process



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)

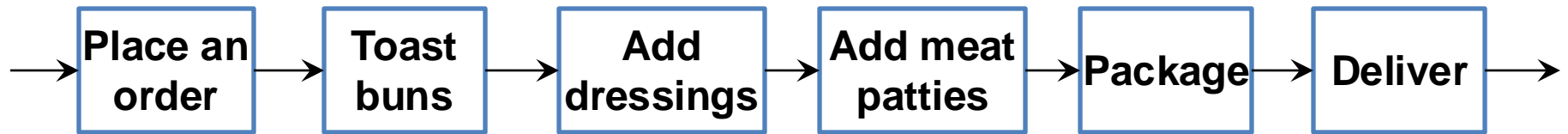
6 orders/min, or 360 orders/hr

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

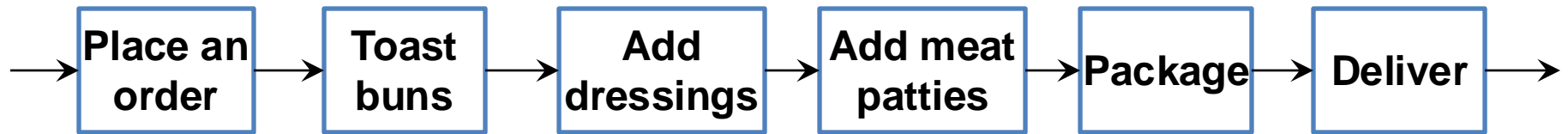
Multiple Stage Process



| 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



| 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 |

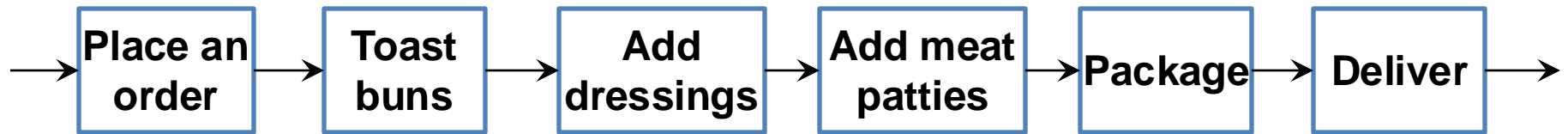
Theoretical Flow Time of the whole process: ???

Capacity rate 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



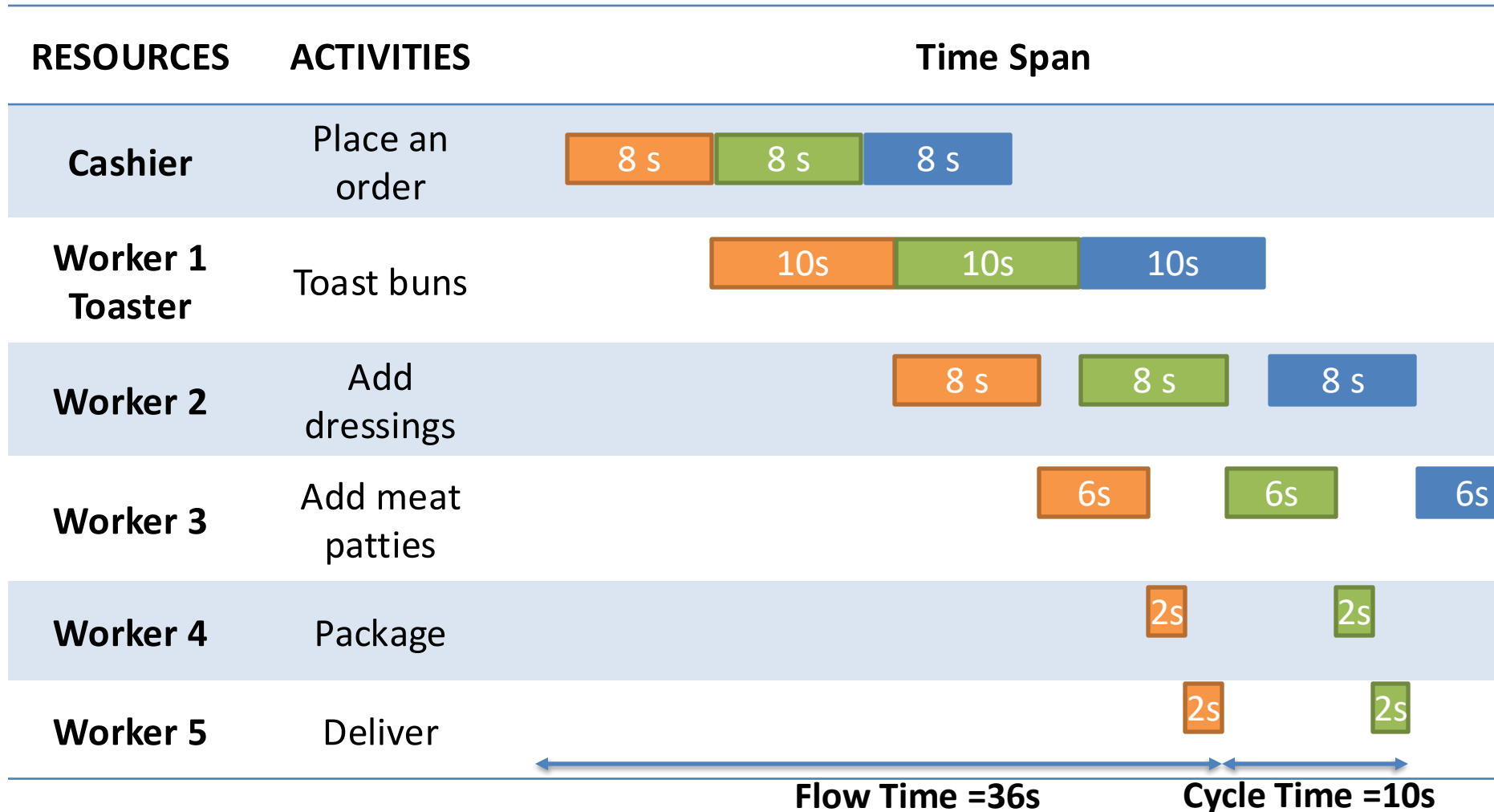
| Cashier | Worker 1 Toaster | Worker 2 | Worker 3 | Worker 4 | Worker 5 |
|---------|---------------------|----------|----------|----------|----------|
| 8 sec | 10 sec | 8 sec | 6 sec | 2 sec | 2 sec |
| 450/hr | 360/hr | 450/hr | 600/hr | 1800/hr | 1800/hr |

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

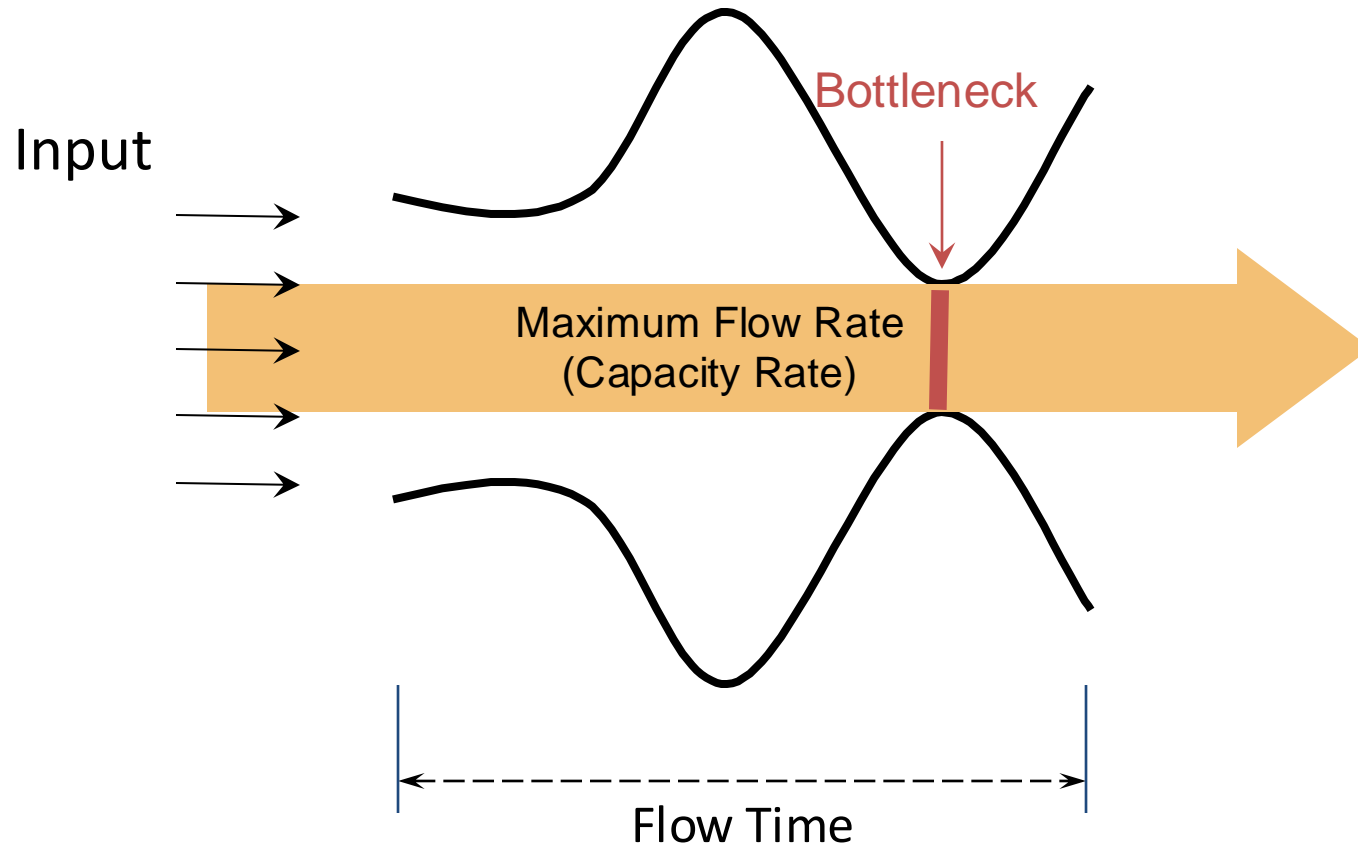
Gantt Chart: Multiple Stage Process



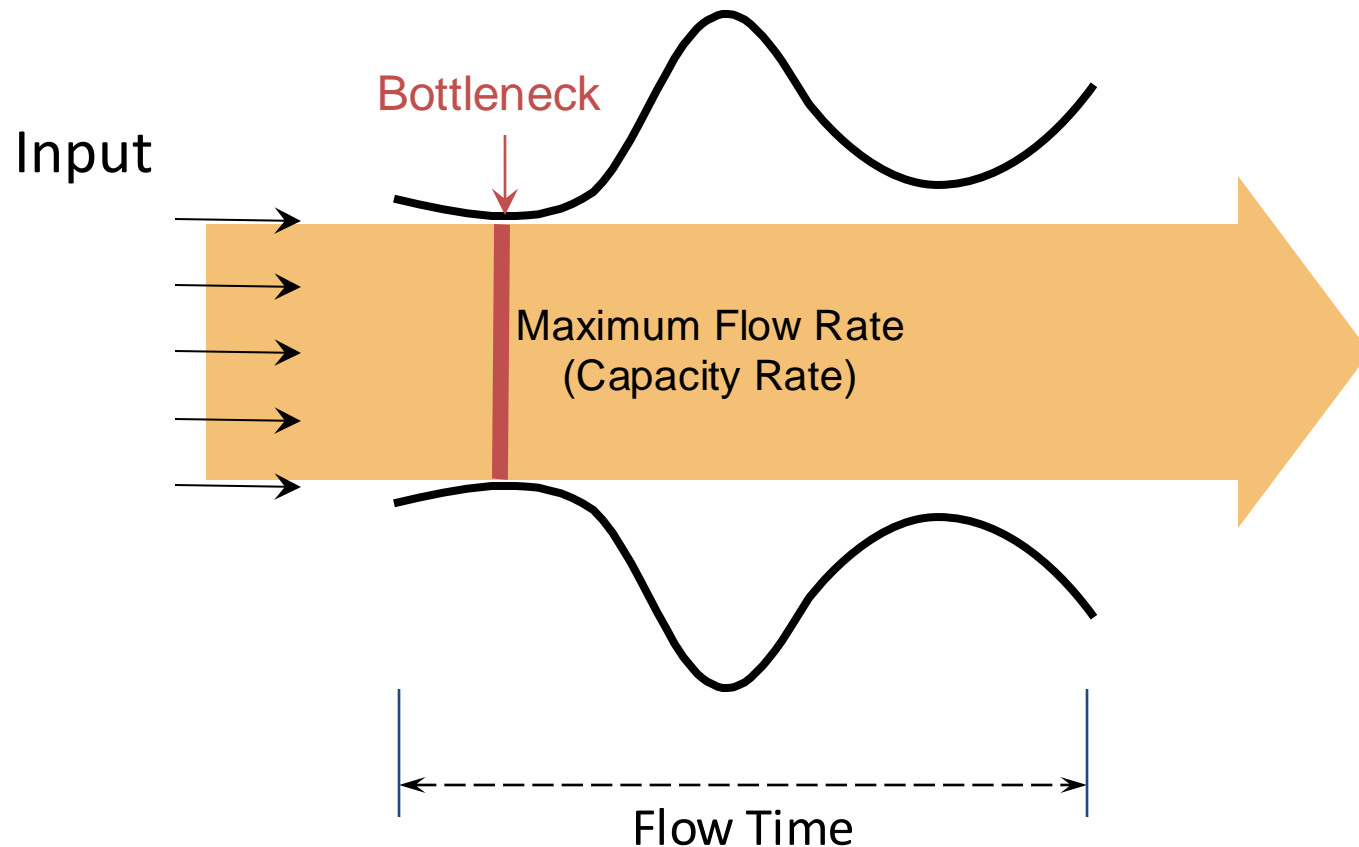
The Bottleneck

- The **resource(s)** with the lowest capacity rate
 - The “slowest” resource(s)
 - *Unit load (T_i)*: 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??

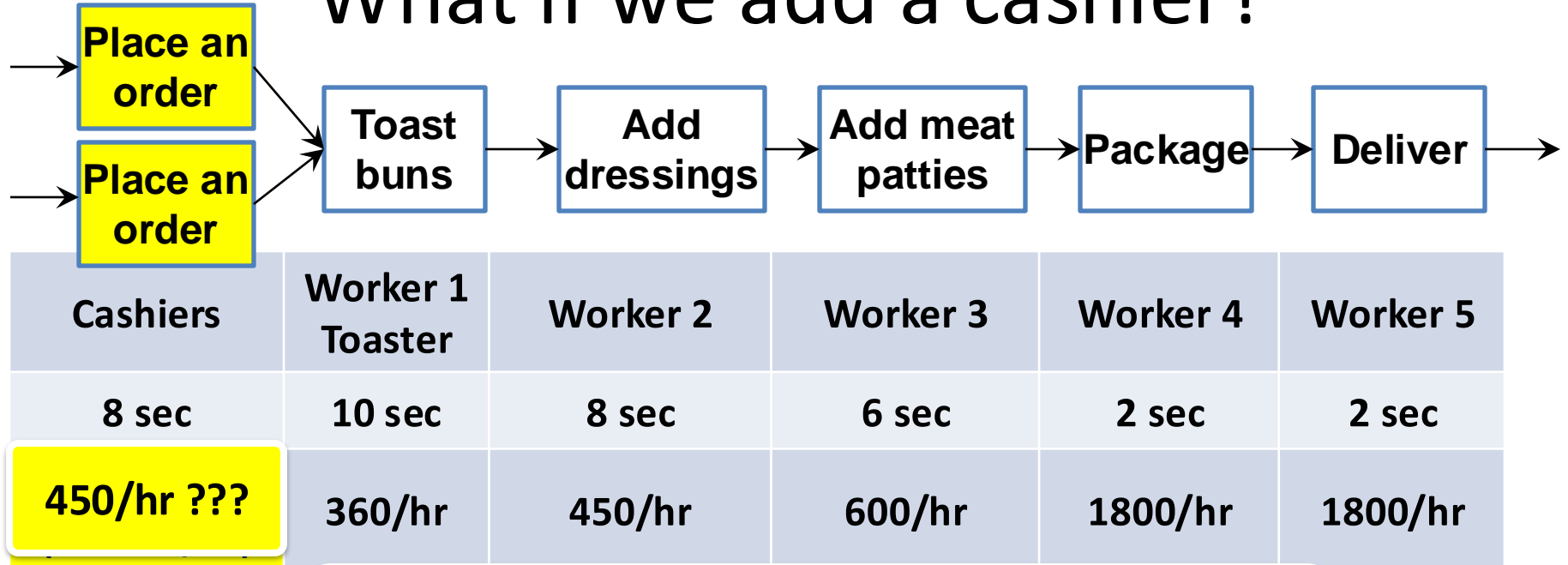
Capacity and Bottleneck



Capacity and Bottleneck



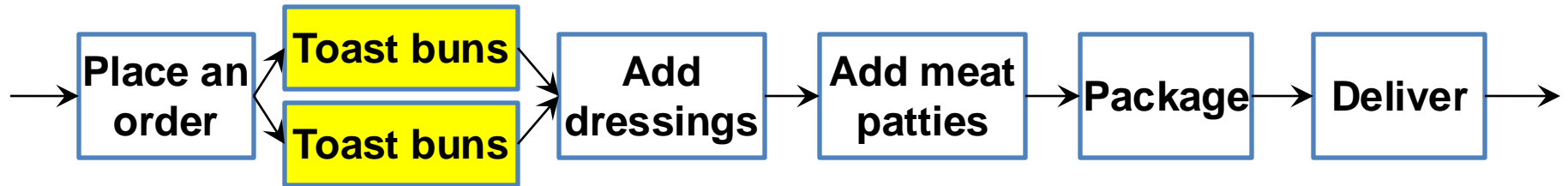
Increasing the capacity rate of a process: What if we add a cashier?



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)?



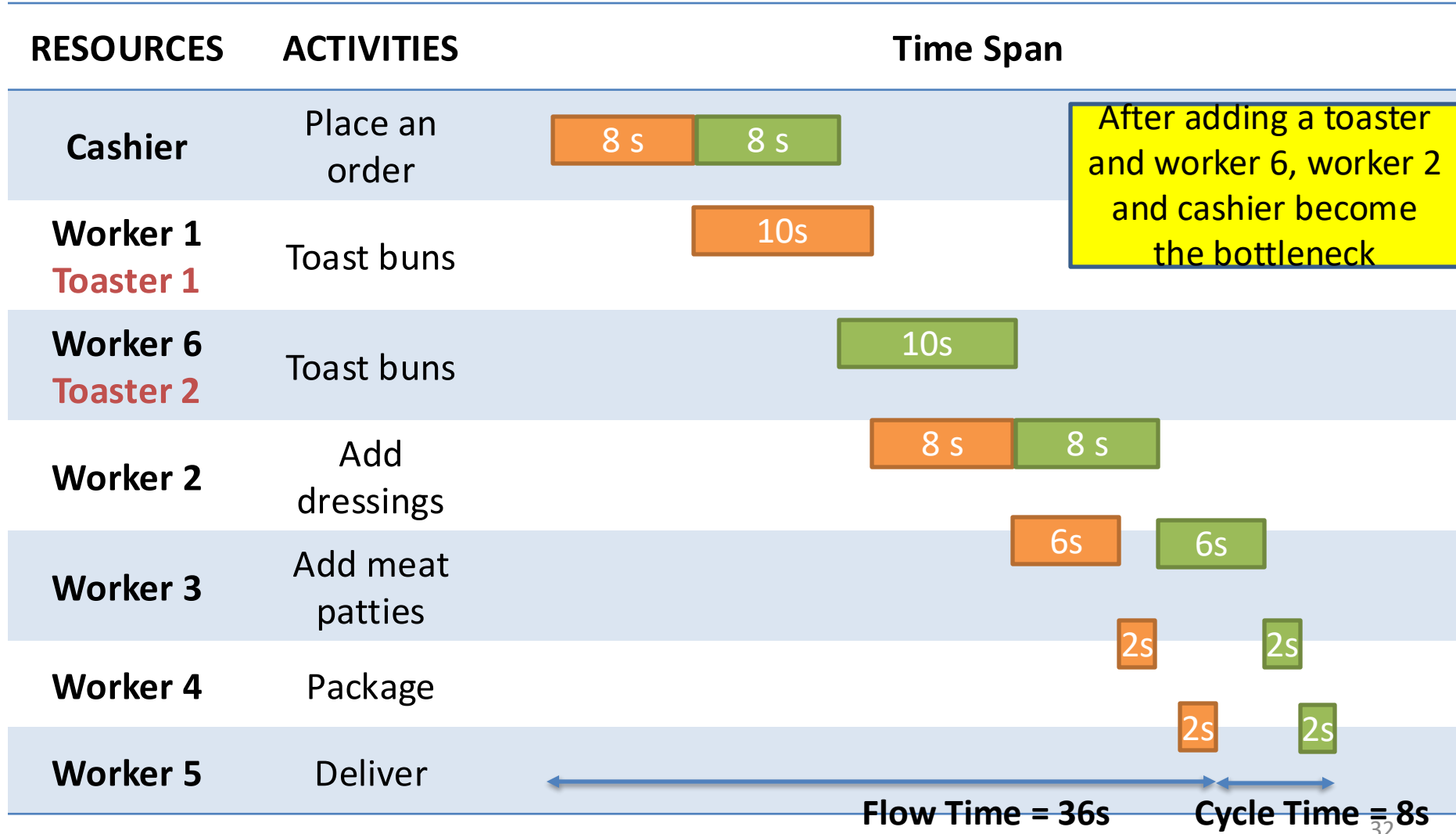
| Cashier | Worker 1 Toasters | Worker 2 | Worker 3 | Worker 4 | Worker 5 |
|---------|------------------------|----------|----------|----------|----------|
| 8 sec | 10 sec | 8 sec | 6 sec | 2 sec | 2 sec |
| 450/hr | 720/hr (2 * 360/hr) | 450/hr | 600/hr | 1800/hr | 1800/hr |

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

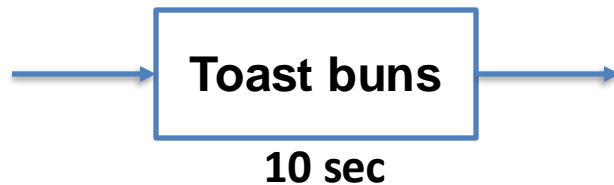
- Increase the capacity rate of the bottleneck
 - Expand the resource pool (add resource)
 - Other way?
 - Reduce Unit Load
- Some other resources may become a bottleneck when capacity is increased
 - Shifting the bottleneck
 - Increase in bottleneck capacity does not always result in commensurate increase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

Increasing Capacity (1)

Increase the Size of the “Resource Pool”

- One Toaster

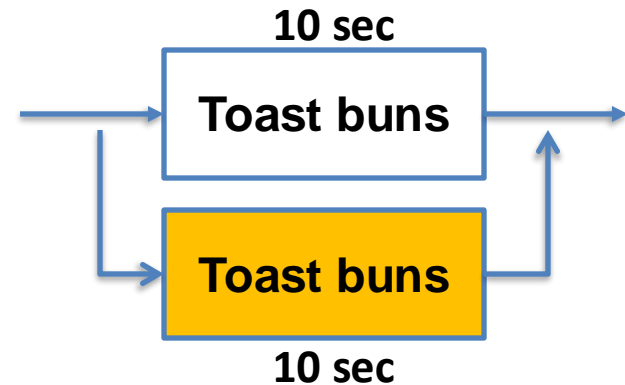
Capacity rate: 360/hr



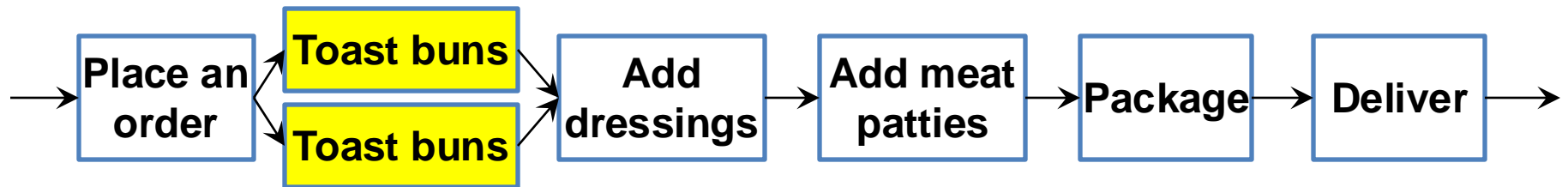
- Two Toasters

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 |

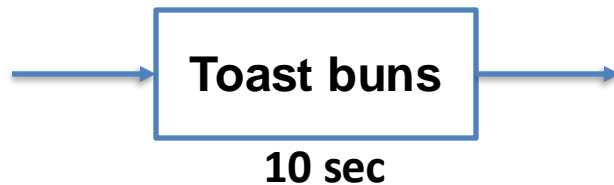
Theoretical Flow Time of the whole process: 36 sec

Capacity rate of the whole process: 450 orders/hr

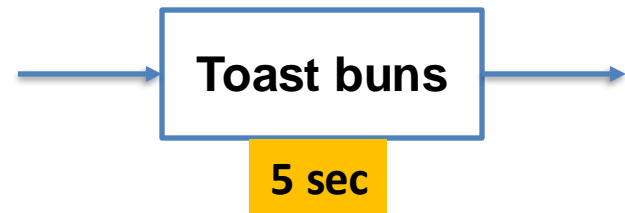
Increasing Capacity (2)

Reducing the Unit Load

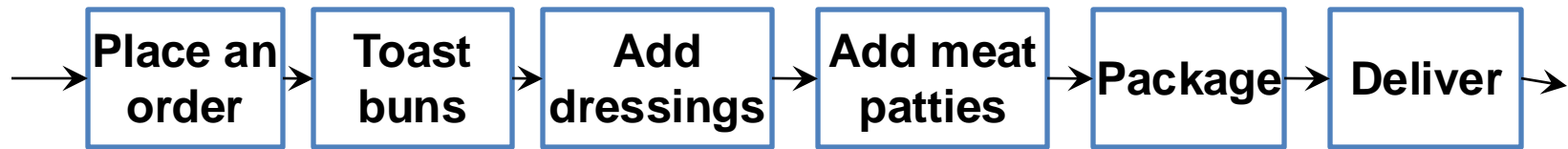
- Current Toaster
Capacity rate: 360/hr



- Faster Toaster
Works twice as fast
Capacity rate: 720/hr



Reduce Unit Load at the Bottleneck

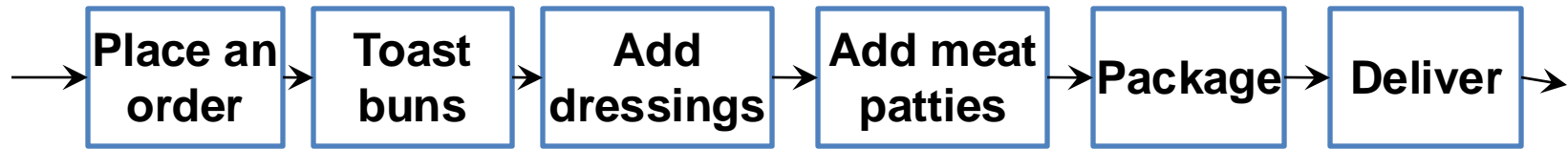


| | Cashier | Worker 1 Toaster | Worker 2 | Worker 3 | Worker 4 | Worker 5 |
|-------------------|---------|---------------------|----------|----------|----------|----------|
| Old Flow Time | 8 sec | 10 sec | 8 sec | 6 sec | 2 sec | 2 sec |
| Old Capacity Rate | 450/hr | 360/hr | 450/hr | 600/hr | 1800/hr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



| | 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

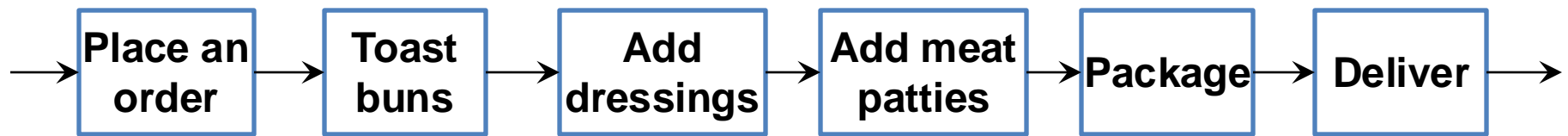
Beyond Basics:

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”



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

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

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

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

- Capacity Rate (by default, of a process)
= maximum output (or throughput) rate of a process
= capacity rate of bottleneck resource

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

By formula for capacity rate of a single resource

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

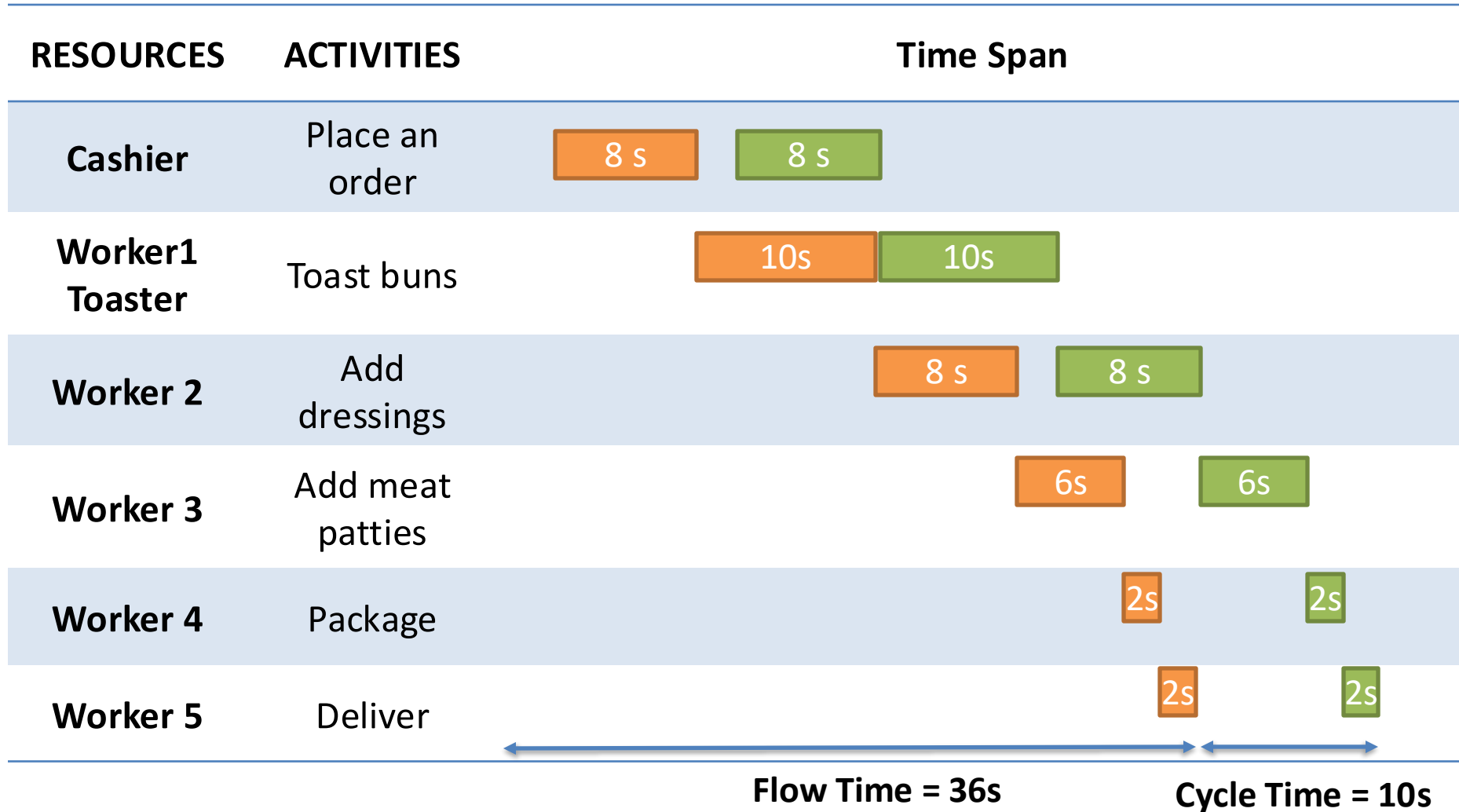
By definition of cycle time (see next slide)

Whiteboard II (Formula for Flow Time)

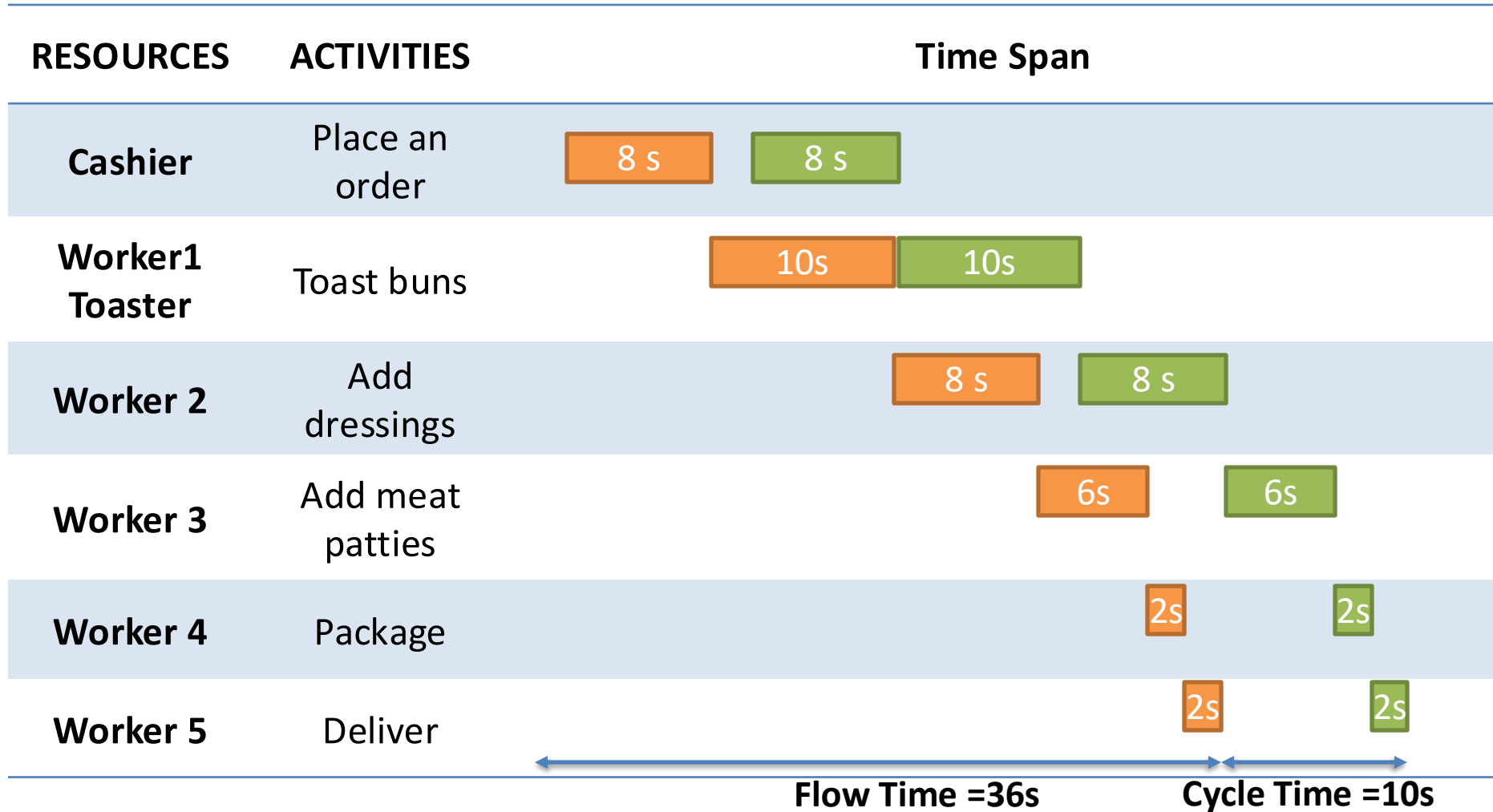
- (Theoretical) Flow Time of a single activity
= Unit Load of the Resource for that activity
- (Theoretical) Flow Time (by default, of the Process)
= Sum of Flow Time of all activities
- Cycle Time, defined as **Additional Time Required for Producing One More Unit**
= $\frac{\text{Unit Load For Bottleneck Resource}}{\text{Number of Bottleneck Resource}}$
= $\frac{1}{\text{Capacity Rate}}$
- 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)

$$\begin{aligned}
 & \text{Total Time for Producing } k \text{ units} \\
 &= \text{Flow Time (36s)} + (k - 1) * \text{Cycle Time (10s)} \\
 &= 36 + 10(k - 1) \text{ s}
 \end{aligned}$$






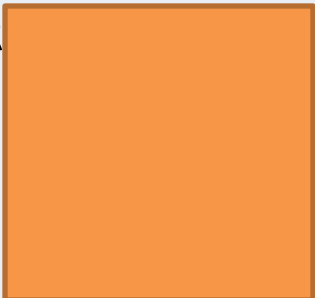

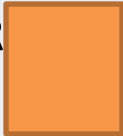
$$\text{Capacity Rate} = \frac{1}{\text{Cycle Time}} \neq \frac{1}{\text{Flow Time}}, \text{ Why?}$$



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

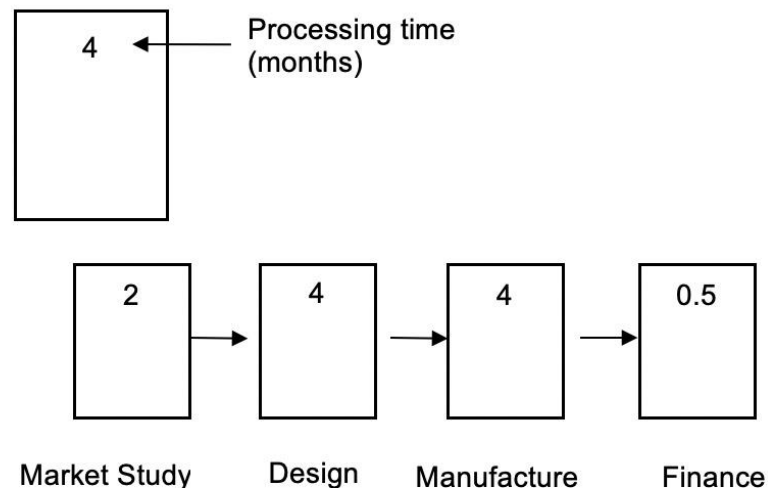
CR: Capacity Rate (of the Process)

FL: Flow Time (of the Process)

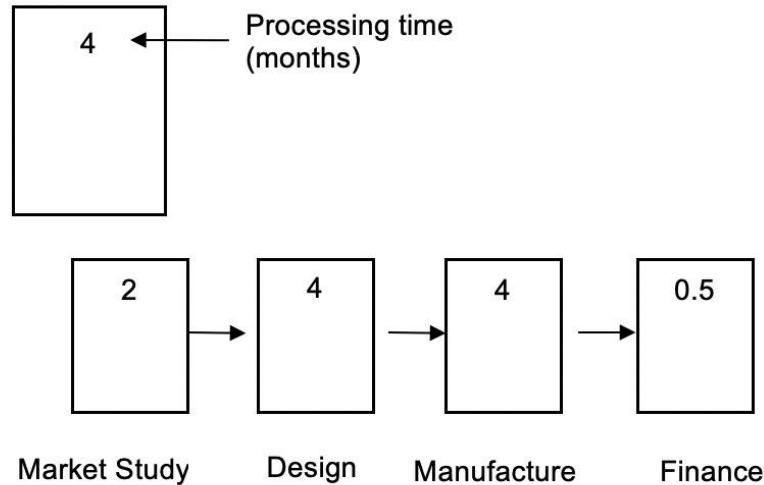
| | Reduce Unit Load | Increase Number of Resources | Increase Unit Load |
|-------------------------|--|--|---|
| Non-Bottleneck Resource | CR = FL ↓ | CR = FL = | CR ↓ if it becomes the new bottleneck; = otherwise FL ↑ |
| Bottleneck Resource | CR = if not unique; ↑ if unique FL ↓ | CR = if not unique; ↑ 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 capacity rate of the firm in developing new products?
- *Bottleneck is the resource(s) with lowest capacity. Design and manufacturing departments are both bottleneck. Capacity rate is $0.25 \text{ projects/month} = 3 \text{ projects/year}$.*
- How long the development of a new product takes in this company? (What is the theoretical flow time?)
 $2+4+4+0.5=10.5 \text{ months}$

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: $\frac{1}{4}$ customers/minutes = 15 customers/hour.