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 <u>visible</u>
- ***Process mapping***: The activity of constructing a process flow diagram
  - First identify the boundary of the process to analyze
  - 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

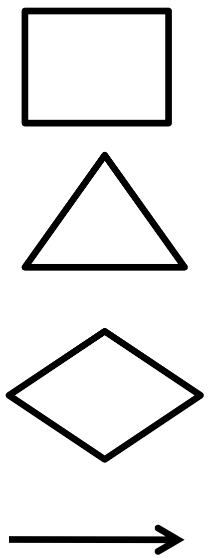
- ***Flow units***: The items that flow through the process
  - May be homogenous (identical) or heterogeneous (different)
  - Ex. Red marker, MSBA student, etc.

- ***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 (sorry for no break this year!), etc.

Process Flow Diagram Elements



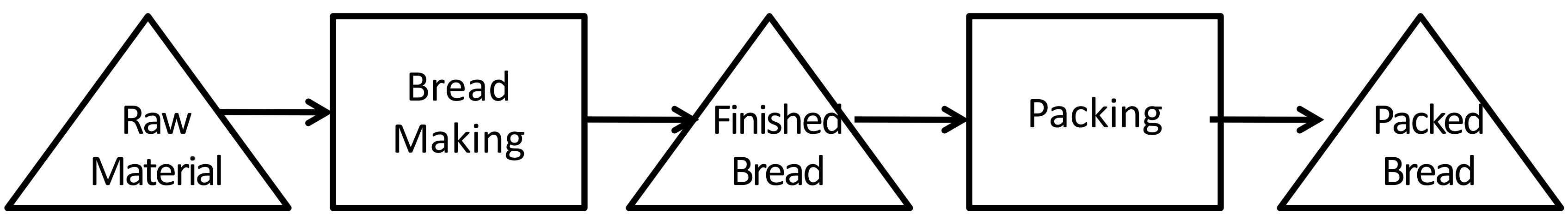
Activities, tasks or operations

Buffers: Queues or inventories

Decision points (multiple types of units)

Flow of materials

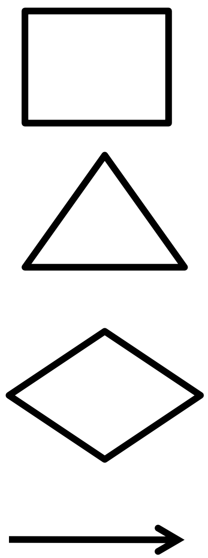
- Example: Bread making



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



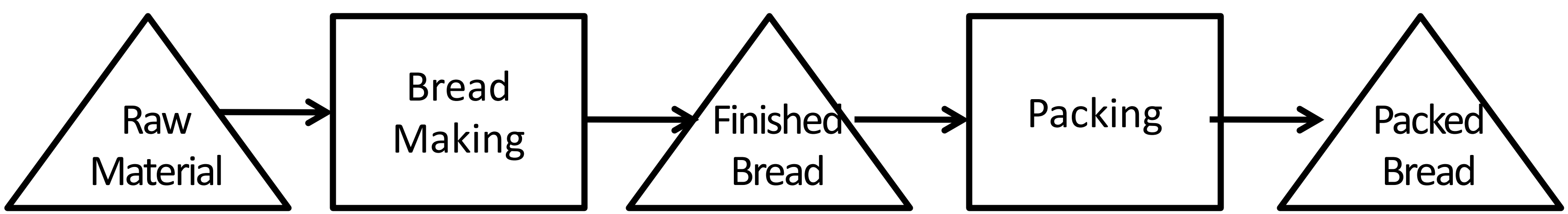
Activities, tasks or operations

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

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**

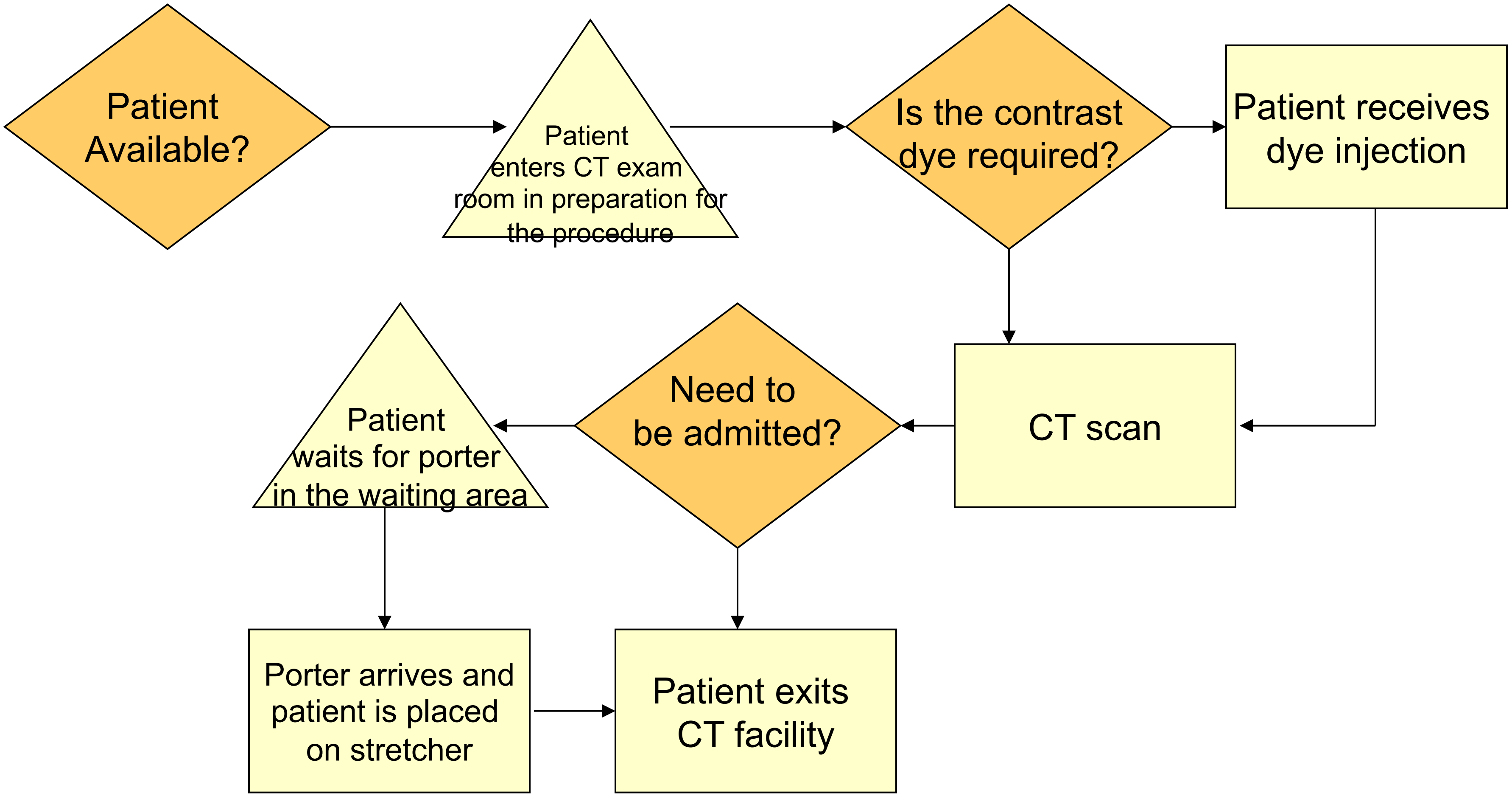
Step 2: **Process mapping (Define the process)**

- 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

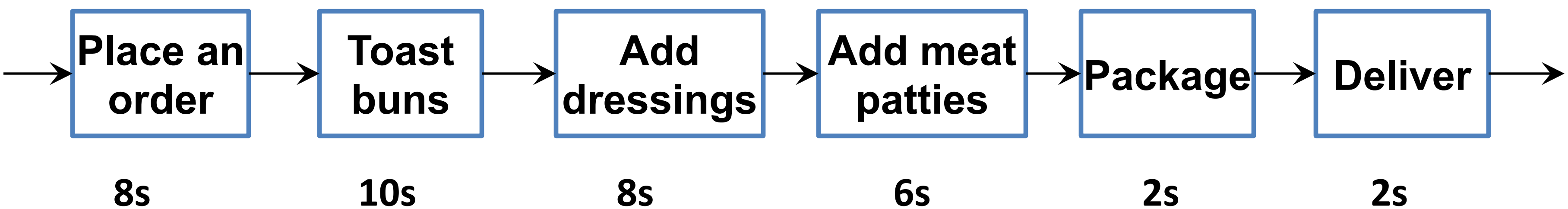


Example: McDonald's Kitchen

- 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)

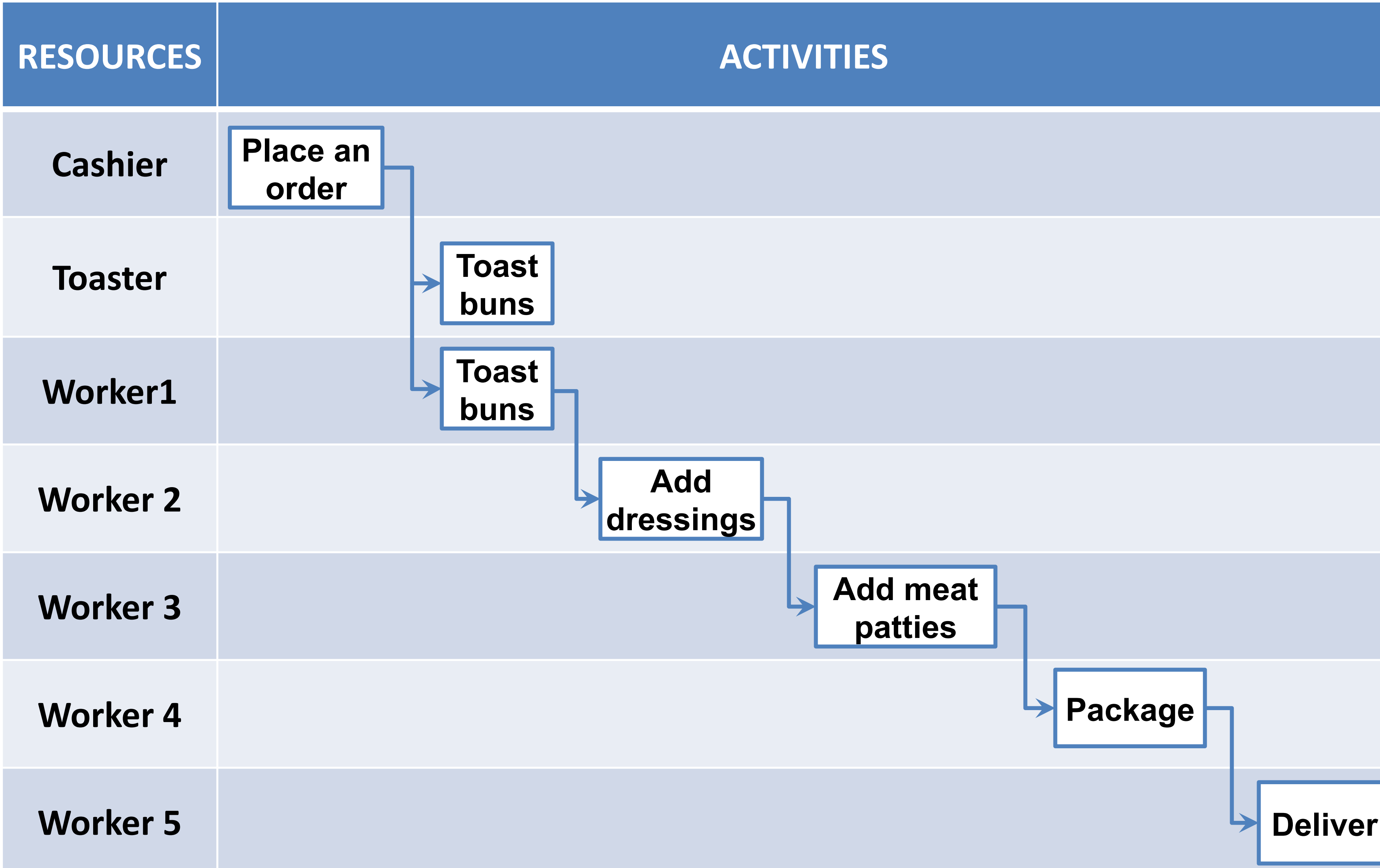
Linear Flow Chart

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

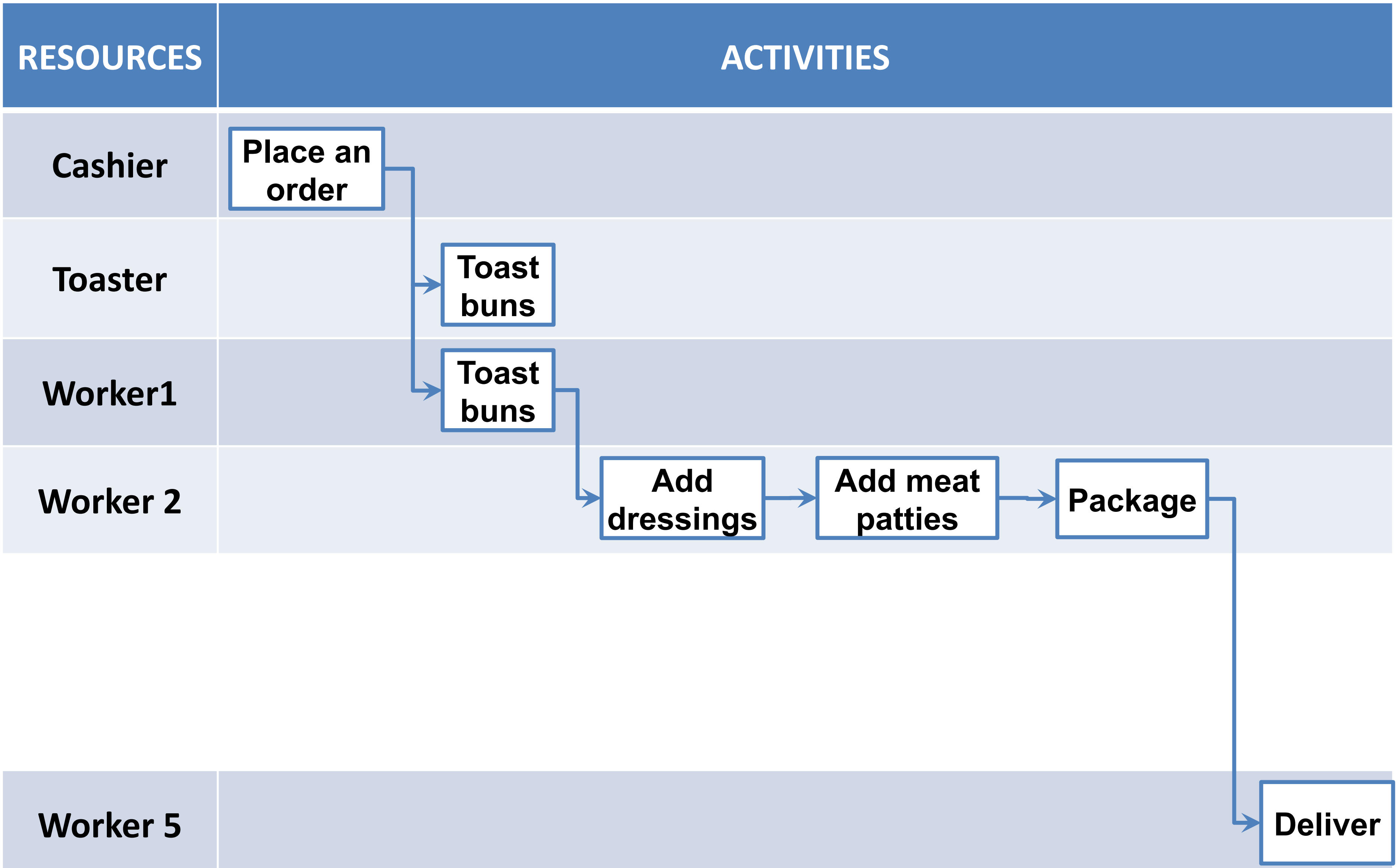


- Determine which resources are used in each task
  - Could indicate resources along each task
  - Swim-lane diagram or Gantt chart may be better

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

<u>Flow Time</u>
(Time that buns spend in the toaster = worker 1's time required for each bun)
10 sec

<u>Capacity Rate (of toaster and worker 1)</u>
???

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 →

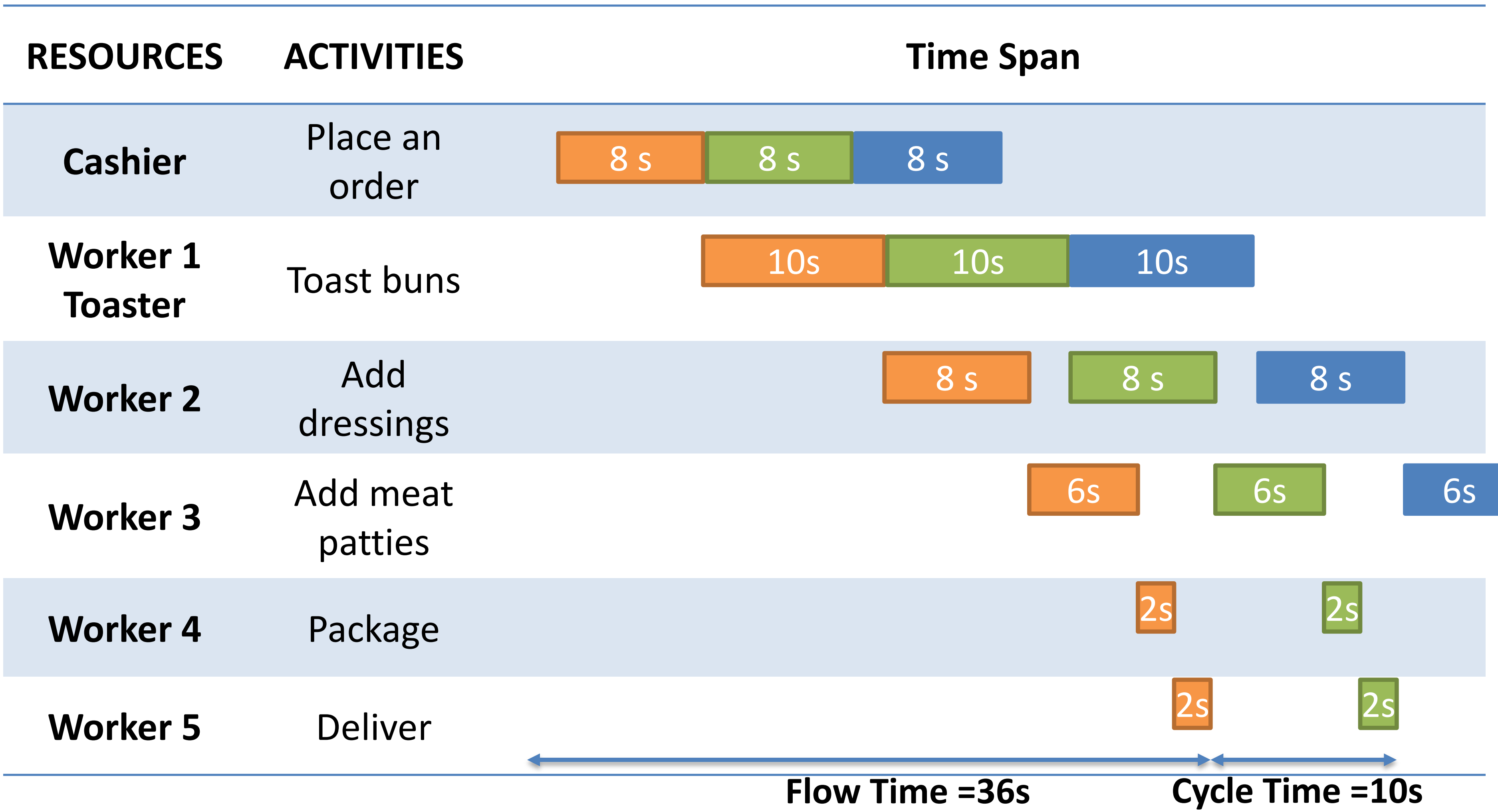
Cashier	Worker 1 Toaster	Worker 2	Worker 3	Worker 4	Worker 5
8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
450/hr	360/hr	450/hr	600/hr	1800/hr	1800/hr

Theoretical 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

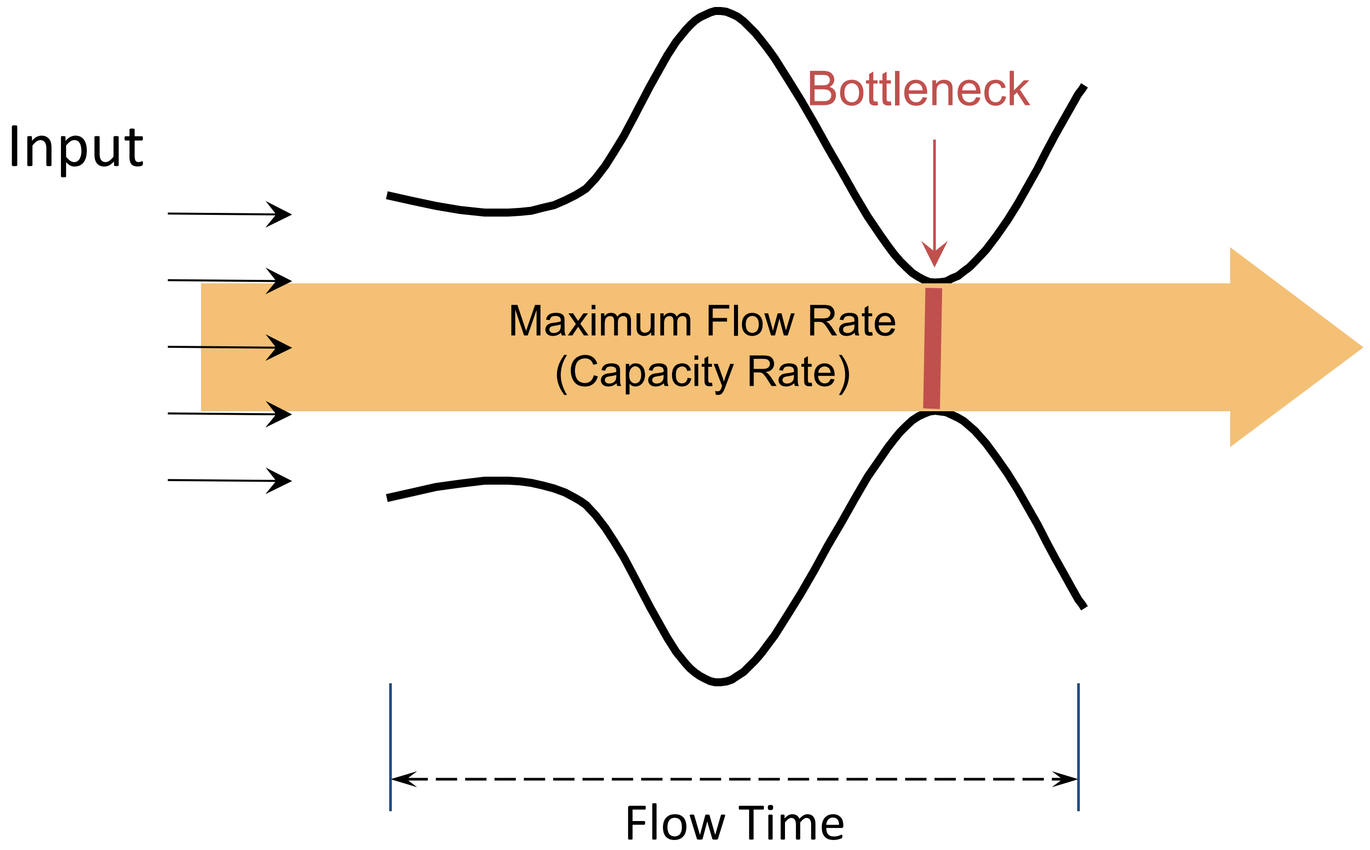
Gantt Chart: Multiple Stage Process



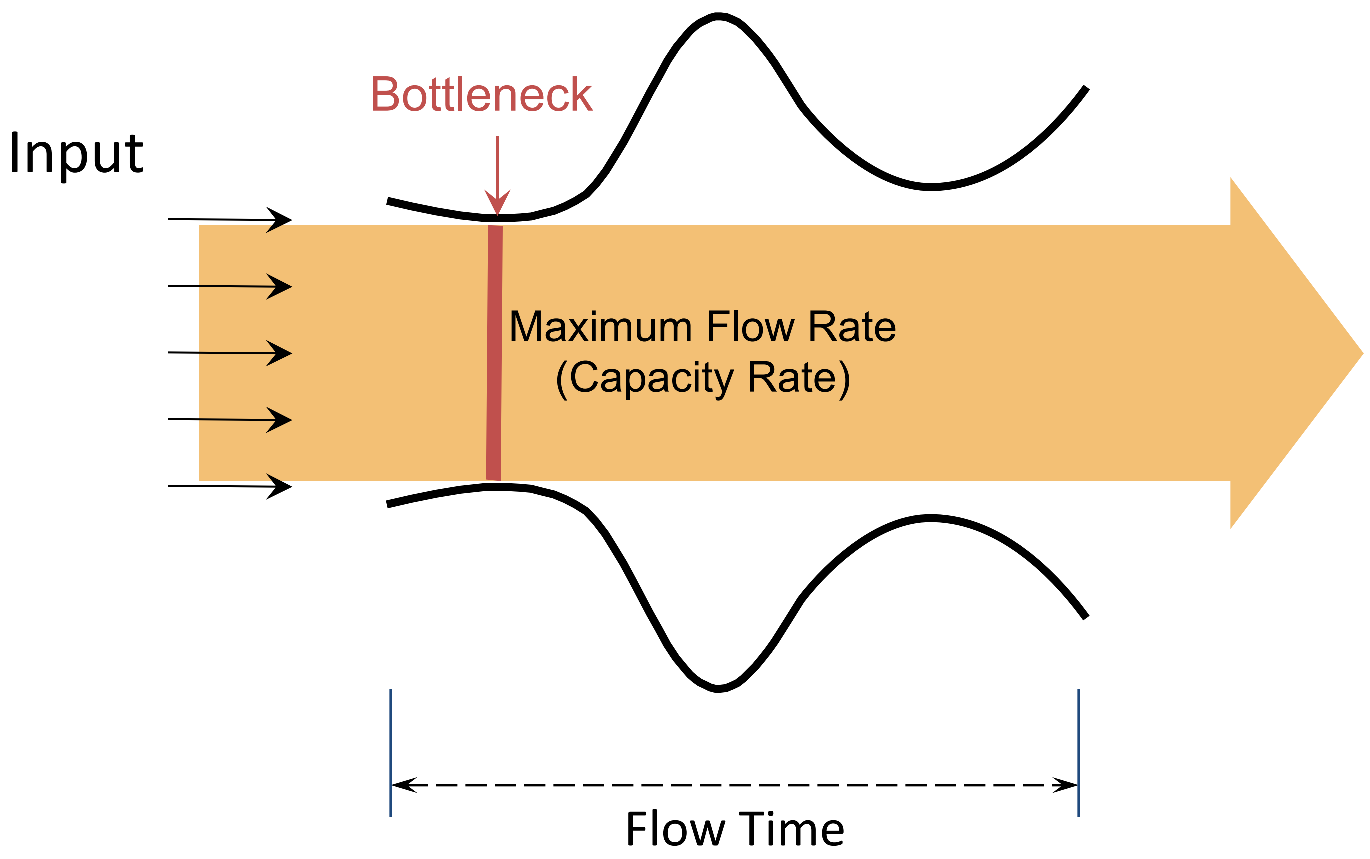
The Bottleneck

- The ***<u>resource(s)</u>*** 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??

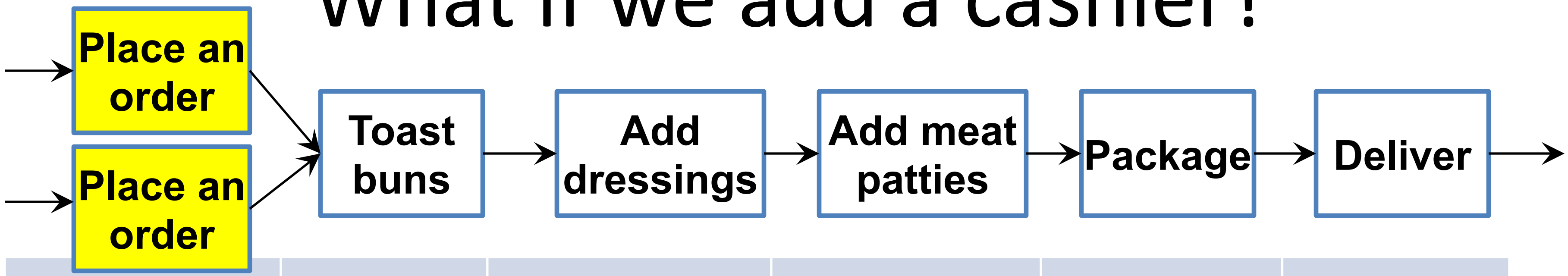
Capacity and Bottleneck



Capacity and Bottleneck



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

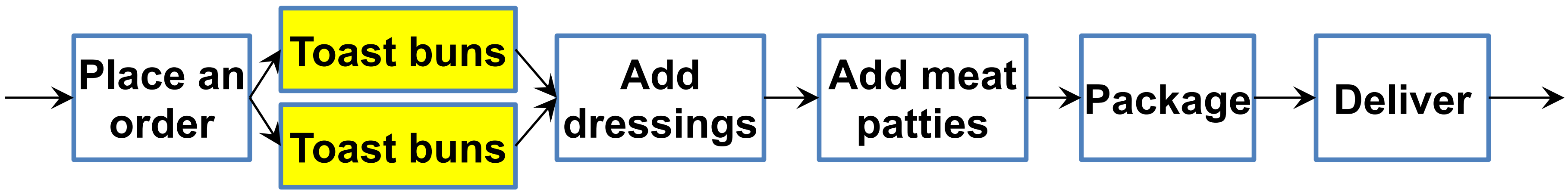


Cashiers	Worker 1 Toaster	Worker 2	Worker 3	Worker 4	Worker 5
8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
450/hr ???	360/hr	450/hr	600/hr	1800/hr	1800/hr

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

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

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



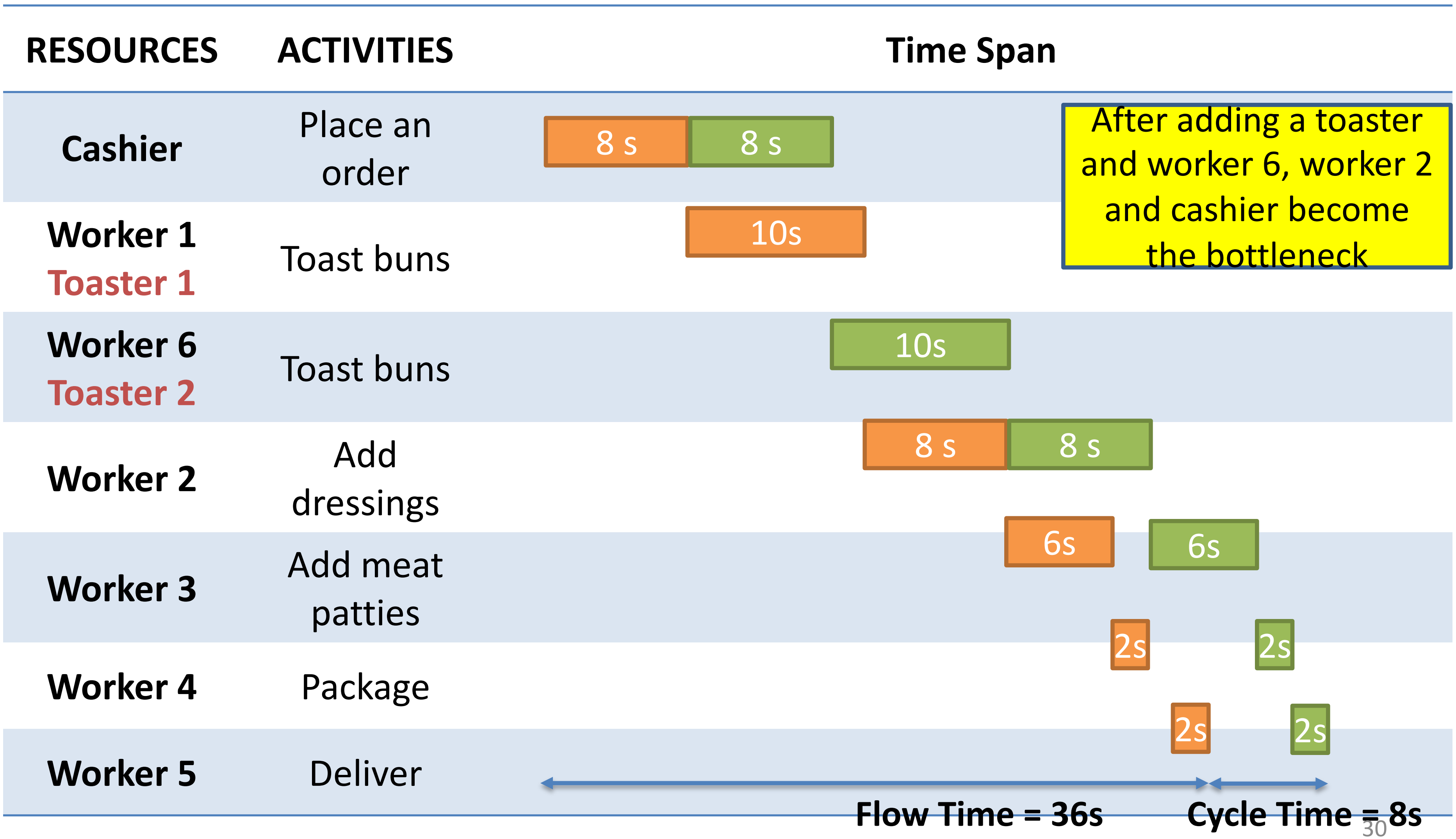
Cashier	Worker 1 Toasters	Worker 2	Worker 3	Worker 4	Worker 5
8 sec	10 sec	8 sec	6 sec	2 sec	2 sec
450/hr	720/hr (2 * 360/hr)	450/hr	600/hr	1800/hr	1800/hr

Theoretical Flow Time of the whole process: ???

Which resource is the bottleneck?

Capacity rate of the whole process: ???

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"

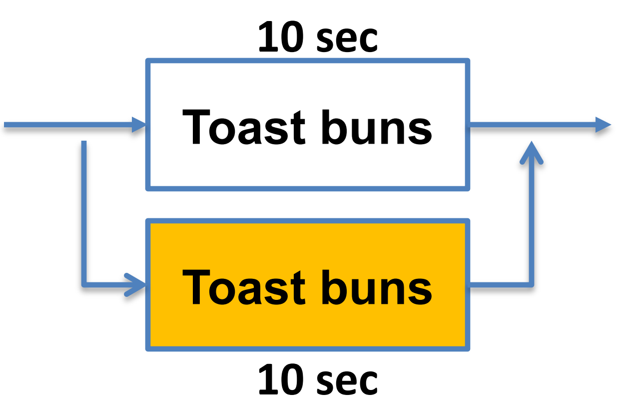
- One Toaster

  Capacity rate: 360/hr

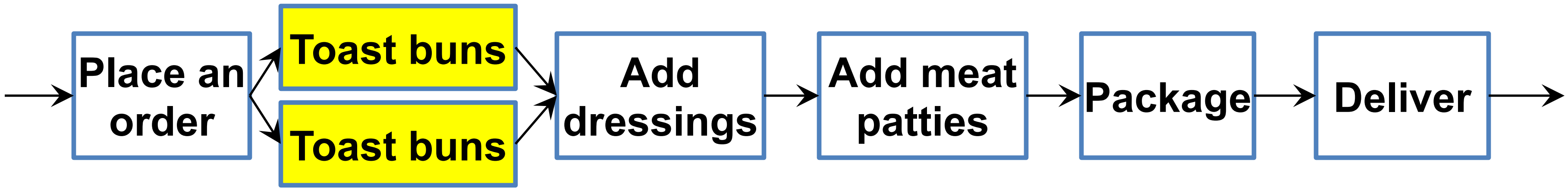
- Two Toasters

  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

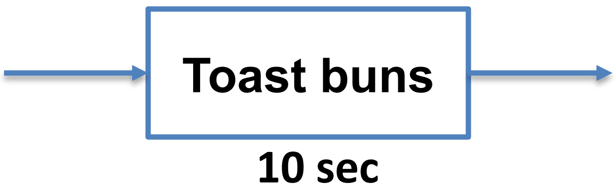
***Theoretical* Flow Time of the whole process: 36 sec**

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 : ???

Capacity rate of the process: ???

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

<u>Theoretical Flow Time</u> : ???

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

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

***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

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

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

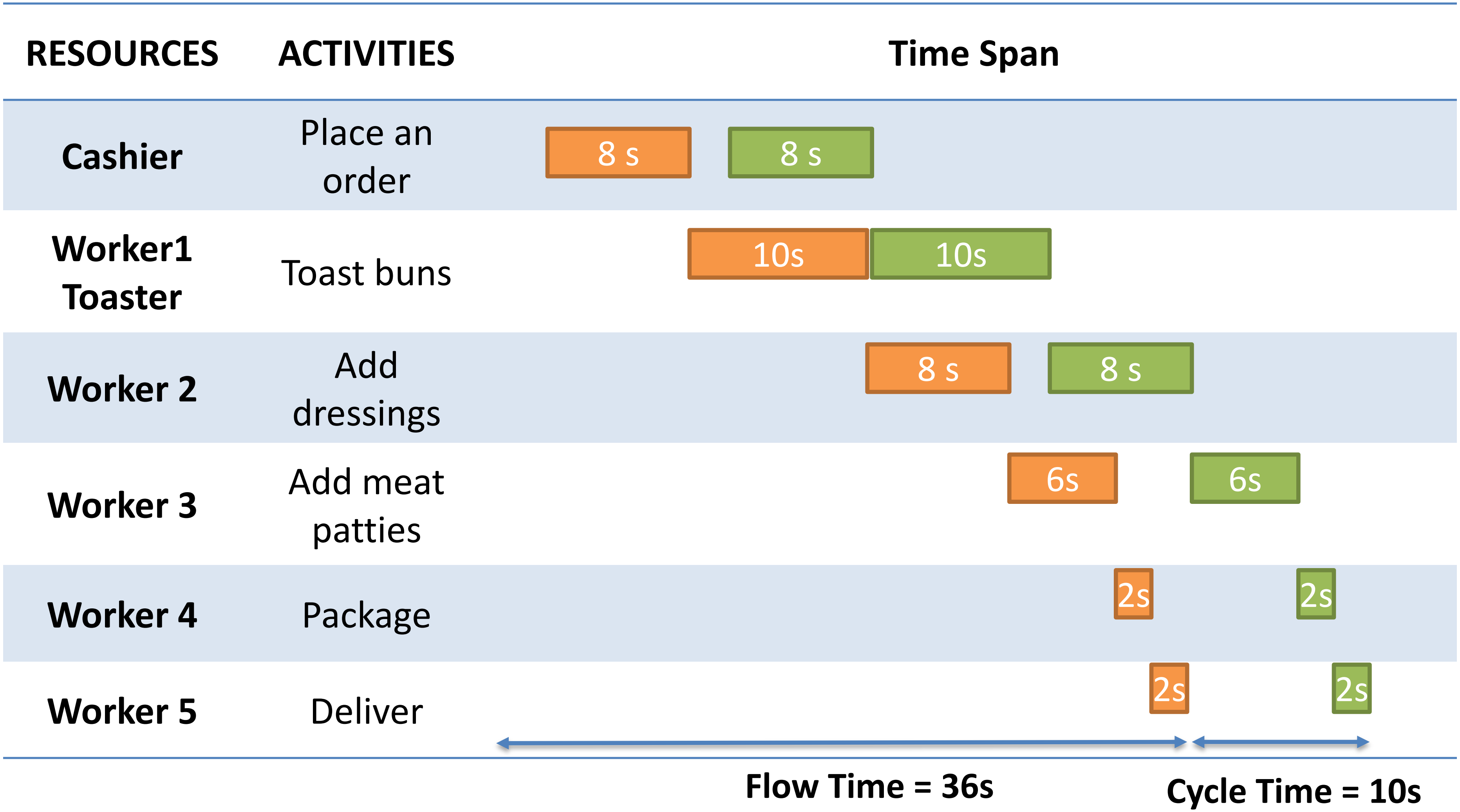
  By definition of cycle time (see next slide)

Whiteboard II (Formula for Flow Time)

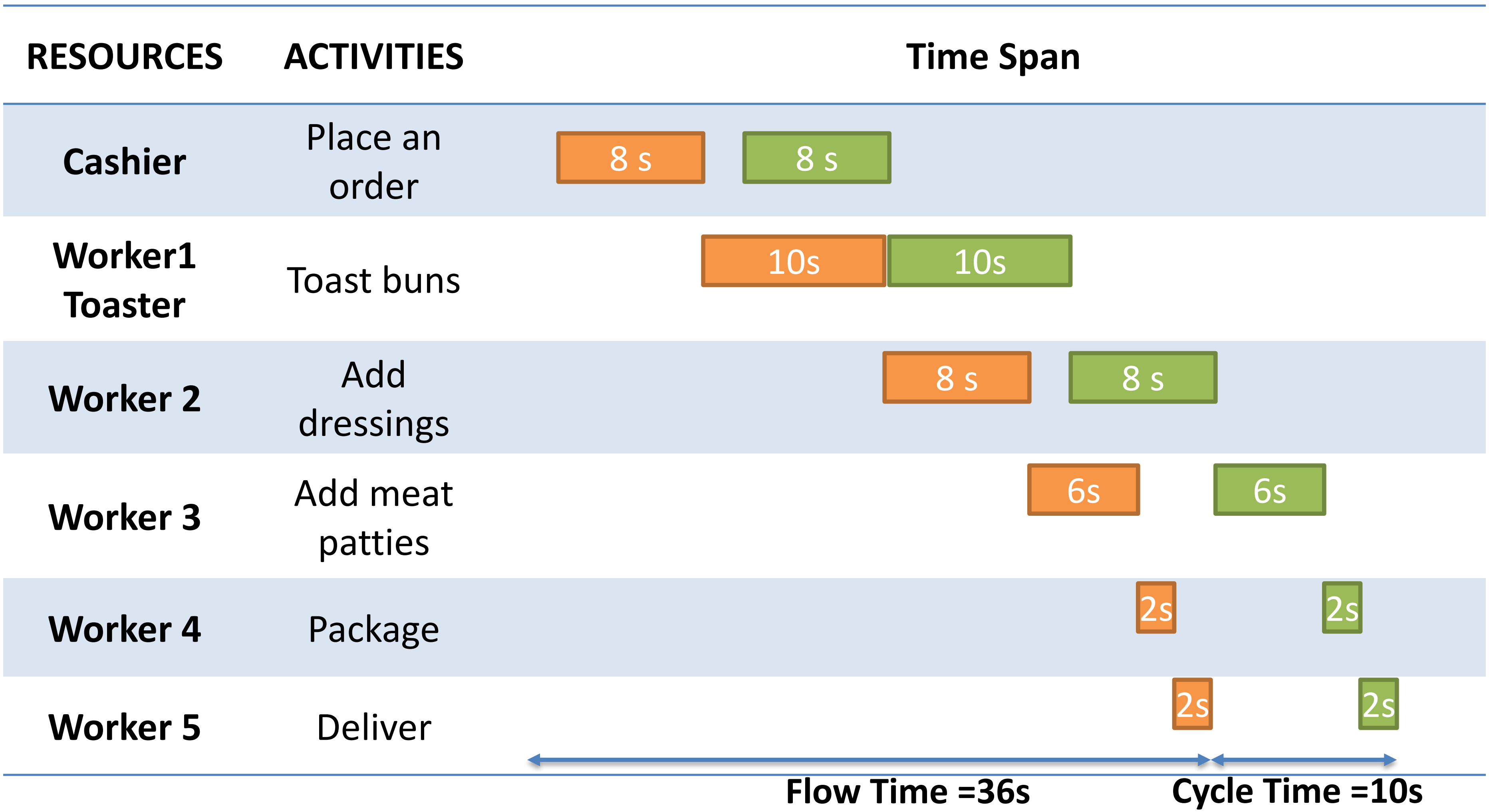
- (Theoretical) Flow Time of a single activity
  = Unit Load of the Resource for that activity
- (Theoretical) Flow Time (by default, of the Process)
  = Sum of Flow Time of all activities
- Cycle Time, defined as Additional Time Required for Producing One More Unit
  $$= \frac{Unit\ Load\ For\ Bottleneck\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

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



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



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 FL
Bottleneck Resource	CR FL	CR FL	CR FL