Operations Management



Session 3: Kristen's Cookie Company

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Process Flow Measures

- **Flow time (Units of Time):**
  - Total time that a flow unit spends in an activity/process.
- **Inventory (#):**
  - Number of flow units in an activity/process at any point in time.
- **Throughput (#/Unit of Time):**
  - Number of flow units through an activity/process per unit of time.

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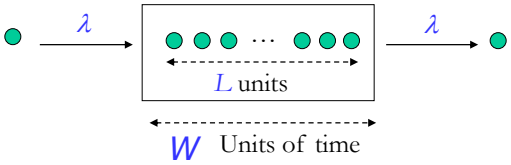
Little's Law

Inventory = Throughput x Flow time

L = Inventory
λ = Throughput
W = Flow time



$L = \lambda W$

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Process Flow Measures

- **Cycle time (UT):**
  - Average time between two consecutive flow units exiting an activity/process, which is working continuously.
- **Capacity (#/UT) :**
  - Throughput of an activity/process if it is working continuously.

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Relationship

Cycle time = 1/Capacity

Example: If a machine worked continuously, it would produce 5 units per hour. What is the cycle time of this machine?

Discussion: Flow time versus Cycle time.

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Example

Cycle time = 1/Capacity

Example: A restaurant has 100 seats and an average customer spends 15 minutes in the restaurant. What is the restaurant's capacity? In other words, what is the maximum rate at which the restaurant can serve customers?

Answer: The maximum inventory of the restaurant is L=100 customers and the customer's flow time is W=1/4 hr. Therefore, by using Little's Law, the capacity of the restaurant is:

$$\lambda = L/W = 100/(1/4) = \textbf{400 per hour}$$

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Measures of Process Performance

- How long does it take to produce a product? ⇒
  - **Flow time**: the time spent by a unit in the system.
- How many units can the process produce during a given time interval?
  - **Capacity**: the maximum rate at which output can be created given an infinite supply of inputs.
  - **Cycle time**: the time between two successive product completions when the process is operating at capacity.
- What is the level of work-in-process inventory? ⇒
  - **Inventory:** the number of units in the process at a given time.

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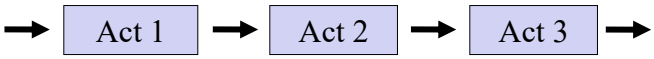
Bottleneck Analysis for Single Product Processes

Example: Consider the following process:



Capacities:	4 units/h	3 units/h	10 units/h
Cycle time:	15 mins	20 mins	6 mins

- What is the process capacity?
- **Capacity of the process = Capacity of the bottleneck**
- Important: Holds when different activities use different resources.
- If the throughput of the process is equal to its capacity, what percent of the time will each activity be working?

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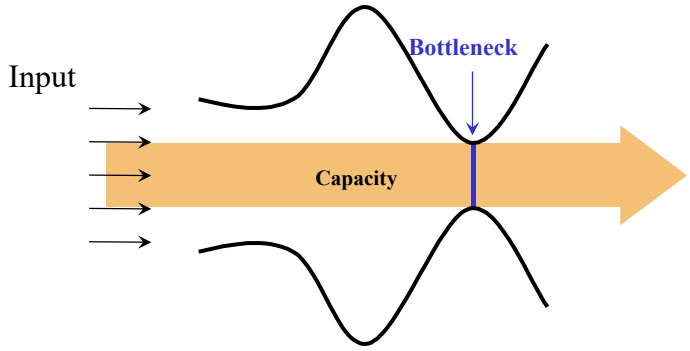
Law of the Minimum

How to determine the flow rate of the irregular pipeline?



It is sufficient to only focus on the point with the smallest gap!

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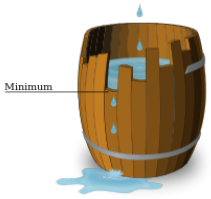
Law of the Minimum

The capacity of a barrel with staves of unequal length is limited by the shortest stave.



A chain is only as strong as its weakest link.

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Resources

A **resource** is any person, place or thing which is required in order for an **activity** to run.

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List of Activities and Resources

Activity	Flow Time	Resources
Take order	0 mins	Telephone or Computer
Wash & Mix	6 mins (up to 3 dozens)	Kristen, Mixing bowl, Mixer
Dish up cookies	2 mins per dozen	Kristen, Trays
Load & Set timer	1 mins per dozen	Roommate and Oven
Bake	9 mins per dozen	Oven
Unload	0 mins	Roommate
Cool down	5 mins (no matter how many)	Trays
Pack	2 mins per dozen	Roommate, Boxes
Accept payment	1 min per order	Roommate

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Bottleneck Analysis for Single Product Processes

- The **bottleneck resource** for a single product process is the resource with the lowest capacity or highest cycle time.

Capacity of single product process = Capacity of bottleneck resource

- The **utilization** of a resource is the percentage of the capacity (of this resource) that is utilized.

Utilization = Throughput / Capacity

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Questions for Kristen's Cookies

1. How long will it take Kristen and her roommate to fill a rush order?
2. How many orders can Kristen and her roommate fill in one night (4 hours)?
3. How much of Kristen's and her roommate's valuable time are utilized?
4. What happens if Kristen's roommate is absent?

Assumptions:

- Each order is mixed separately.
- All orders are of the same size (1 or 2 dozens).
- There is infinite space for cooling down in the apartment.
- Infinite number of cookie trays and boxes.
- All the activities are one-at-a time activities.

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Process Flow Chart

Activities	Resources	Processing times
Wash & Mix	Kristen (& Bowl)	6 mins/**order**
Dish up to trays	Kristen (& Trays)	2 mins/dozen
Load & Set timer	Roommate & Oven	1 min/dozen
Baking	Oven	9 mins/dozen
Cooling	Empty space	5 mins/dozen
Packing	Roommate	2 mins/dozen
Payment	Roommate	1 min/**order**

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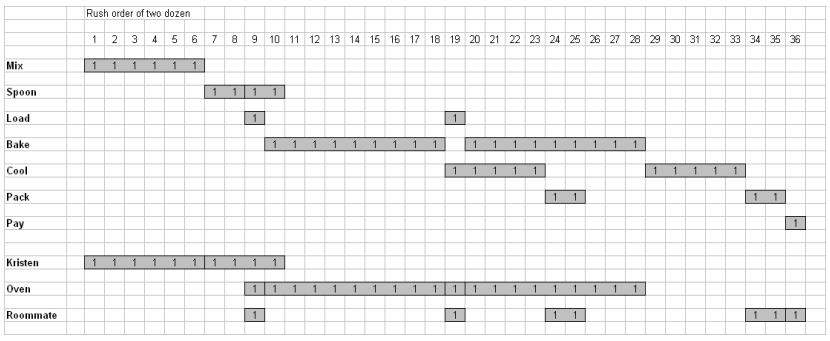
1. How Long to Fill a Rush Order?

- How long will it take Kristen and her roommate to fill a rush order?
  - For orders of size 1 dozen, we can just sum up the processing times:
  - For orders of size 2 dozen, we must use a **Gantt chart** and we find:



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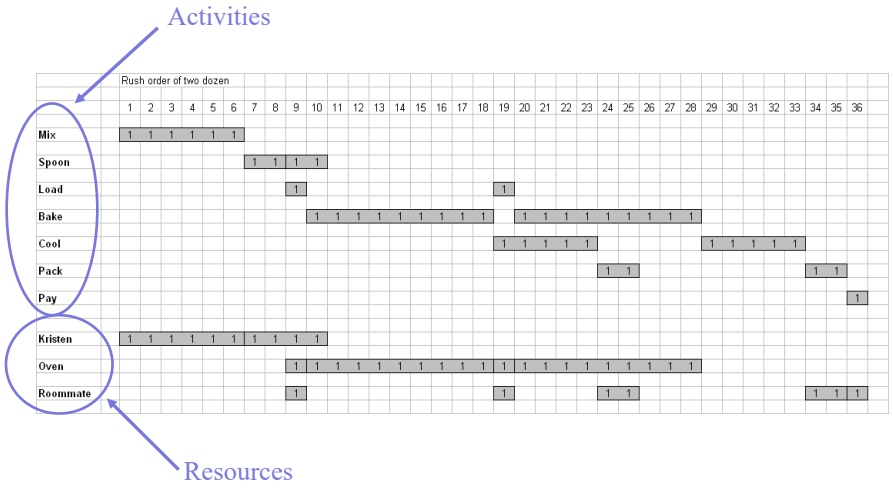
1. How Long to Fill a Rush Order?



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2. How many orders can Kristen and her roommate fill in one night (4 hours)?

- It depends on the order size. Orders of size 1 dozen? Orders of size 2 dozen?
- First list resources and group the activities performed by each resource.

Resource	Activities
Kristen	Wash & Mix, Dish up
Roommate	Load, Pack, Payment
Oven	Load, Bake

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Bottleneck Analysis

Recipe of bottleneck analysis

- List activities, times, and resources.
- Group the activities performed by each resource.
- Capacity analysis for each resource.
- Capacity of process = Capacity of the resource with the smallest capacity.

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Capacity Analysis for each Resource

Resource	Number Available	Activities where needed	Time required per order (**1 dozen**)	Capacity (number/processing time)
Kristen	1	Wash & Mix Dish up		
Roommate	1	Load Pack Payment		
Oven	1	Load Bake		

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Bottleneck Analysis

Two dozens per order (and one oven)

Resource	Number Available	Process steps where needed	Time required per order (**2 dozen**)	Capacity (number/processing time)
Kristen	1	Wash & Mix Dish up		
Roommate	1	Load Pack Payment		
Oven	1	Load Bake		

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2. How many orders can Kristen and her roommate fill in one night (4 hours)?

- Orders of size 1 dozen:
  - => Bottleneck:
  - => Capacity:

- Orders of size 2 dozen:
  - => Bottleneck:
  - => Capacity:

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3. How much of Kristen's and her roommate's valuable time are utilized?

- Orders of size 1 dozen:
  - Kristen: 8 mins per order.
  - Roommate: 4 mins per order.

  If work continuously: capacity 6 orders/hour
  - Kristen: 48 mins per hour or **80%**.
  - Roommate: 24 mins per hour or **40%**.
- Orders of size 2 dozen:
  - Kristen: 10 mins per order.
  - Roommate: 7 mins per order.

  If work continuously: capacity 3 orders/hour
  - Kristen: 30 mins per hour or **50%**.
  - Roommate: 21 mins per hour or **35%**.
- Capacity utilization decreases with the size of orders. Why?

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4. What happens if Kristen's roommate is absent?

- Now there are only two resources.
- Kristen must complete her roommate's activities.

Resource	Activities
Kristen	Wash & Mix, Dish up, Load, Pack, Payment
Oven	Load, Bake

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4. What happens if Kristen's roommate is absent?

The amount of time per order for each resource:

Resource	1 Dozen	2 Dozen
Kristen		
Oven		

Time per order for each resource (in minutes)

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4. What happens if Kristen's roommate is absent?

Capacity of each resource:

Resource	1 Dozen	2 Dozen
Kristen		
Oven		

Capacity of each resource (orders per hour)

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4. What happens if Kristen's roommate is absent?

- For orders of size 1 dozen:
  - Bottleneck:
  - Capacity:
- For orders of size 2 dozen:
  - Bottleneck:
  - Capacity:

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Recommendation 1: Adding an Oven

- What is the capacity when we add an extra oven? (Asssume orders of 1 dozen)

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Recommendation 2: Pool Kristen and Roommate

Resource	Number Available	Process steps where needed	Time required per unit (1 dozen)	Capacity (number/processing time)
Kristen & Roommate	2	Wash & Mix Dish up Load Pack Payment		
Oven	2	Load Bake		

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Home Reading: Recommendation 3: Increase the Batch Size to Two

Resource	Number Available	Process steps where needed	Time required per batch (**2 dozen**)	Capacity (number/processing time)
Kristen	1	Wash & Mix Dish up	6 mins 2+2 mins	60/(6+4)= **6** batches/hr
Roommate	1	Load Pack Payment	1+1 min 2+2 mins 1 min	60/(2+4+1)= **8.57** batches/hr
Oven	2	Load Bake	1+1 min 9+9mins	**2***60/(2+18)= **6** batches/hr

Process capacity increases to 6 batches/hr or 12 dozen/hr!

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Summary

- Process concepts
  - Performance measures: Capacity, Cycle time, Flow time, Bottleneck
  - Gantt Chart
  - Effect of order size on capacity and cost
- How to analyze a process?
  - Little's Law
  - Bottleneck resource determines process capacity – bottlenecks can shift
- How to improve a process?
  - Increase the bottleneck resource (e.g., add an oven)
  - Pool the bottleneck resource with some non-bottleneck resources
  - Change the batch size
  - Eliminate some non-bottleneck resources