MSBA 7004
Operations Analytics

Class 3-1: Process Flow Analysis (II)
Kristen’s Cookie Company Case
2024

Process Analysis (I) Review

- Process mapping basics
  - Key steps in process analysis
  - Get feedback and validate maps
- Process analysis basics (3 keywords)

(Theoretical) Flow time (or **Throughput Time**):
(Min) Length of time a unit spends in the system

Capacity Rate of a **Resource** or **Process:**
Max rate at which units can flow through a resource or process

Bottleneck:
Resource with the slowest capacity rate in a process determines the capacity rate of a process

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

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: 36 sec**

Capacity rate of the whole process: 360 orders/hr

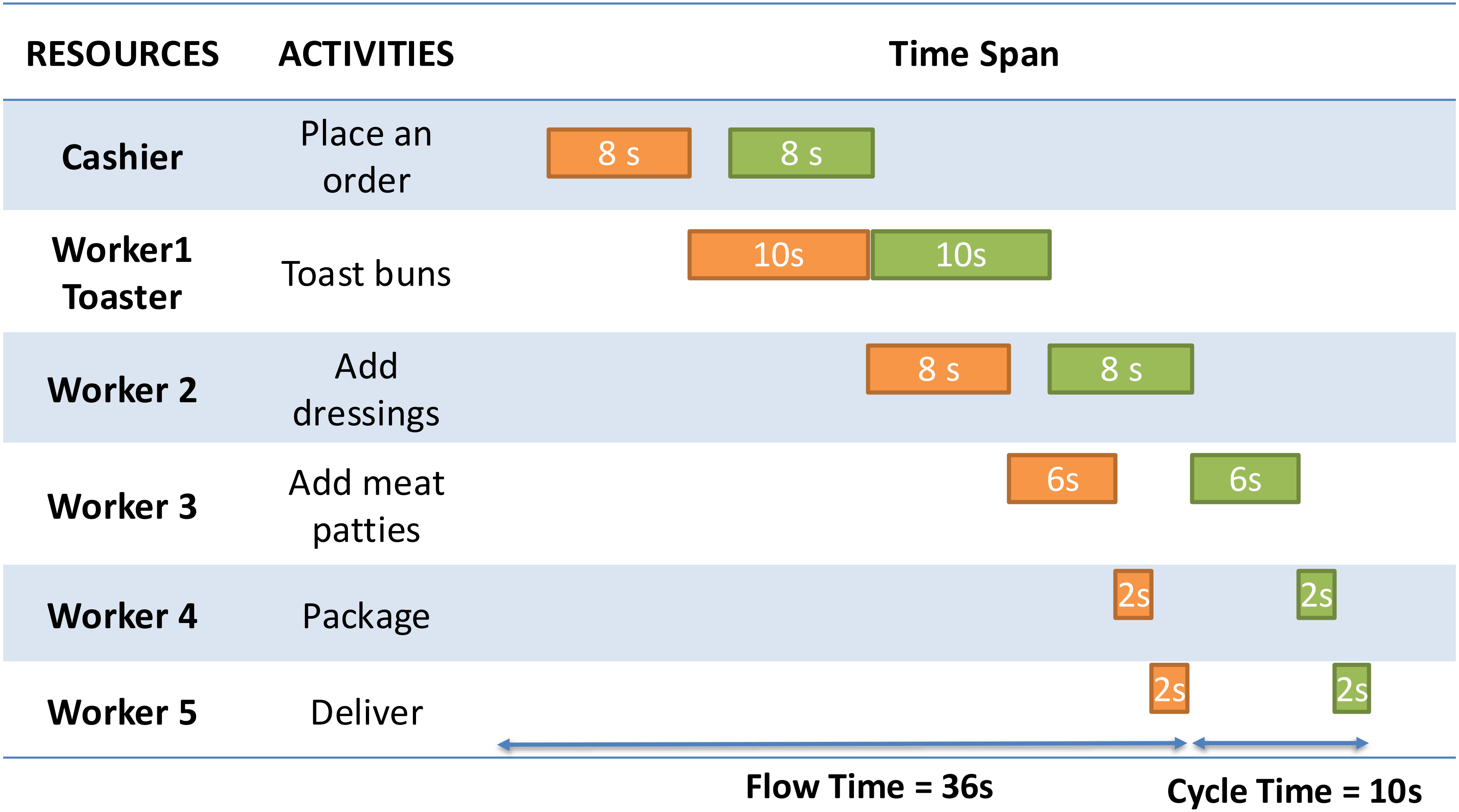
Note: The theoretical flow time ignores the possibility of waiting; so it is the lowest possible flow time

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

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



Q1: Item, Resource, and Tasks

KRISTEN'S COOKIE COMPANY

- Flow-units: (items)

  Orders of cookies (1 dozen)

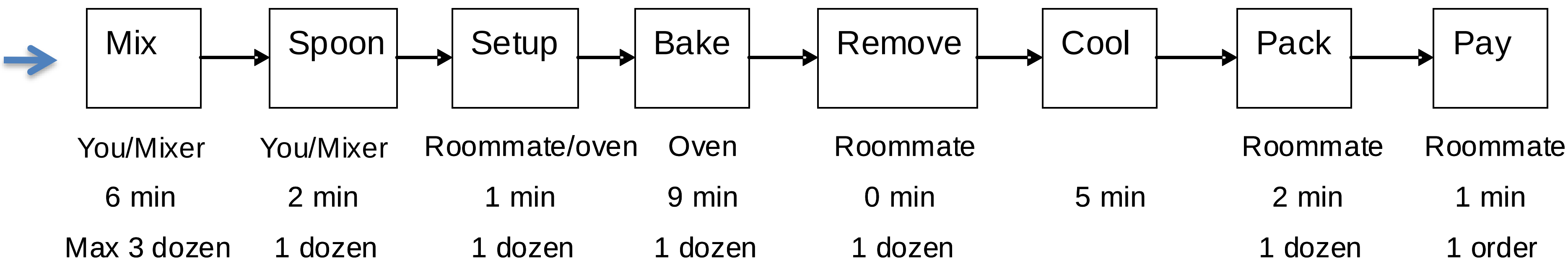
- Steps or tasks or actions:

  Mix, spoon, oven setup, bake, remove, cool, pack, and receive payment

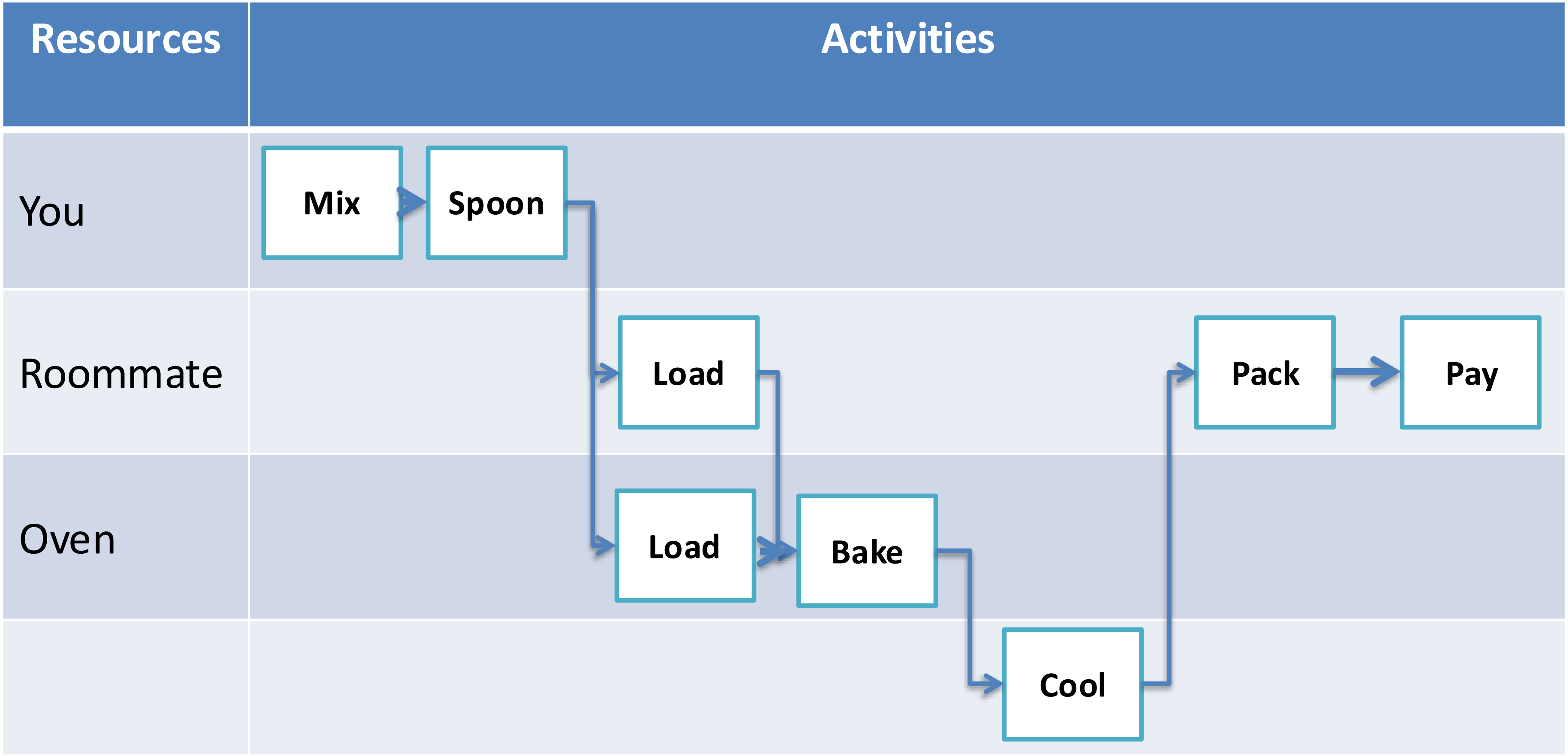
- Resources:

  You (Kristen) and roommate (RM), mixer, spoons (plenty), tray, oven

Q1: Linear Process Flow Chart



Q1: Swim-Lane (Deployment) Flow Chart



Q2: Processing Time and Resource

Activity	Wash, Mix	Spoon	Setup Oven	Bake	Cool	Pack	Pay	Total time
Processing time	6 min	2 min	1 min	9 min	5 min	2 min	1 min	26 min
K's time	6 min	2 min						8 min
RM's time			1 min			2 min	1 min	4 min
Tray time		2 min	1 min	9 min	5 min	2 min		19 min
Oven time			1 min	9 min				10 min
Mixer time	6 min	2 min						8 min

Applies to today's discussion

Q2: Resource Capacity

Resource	Unit load (mins per dozen)	Capacity (dozen per hr)
K	8 min	60/8=7.5/hr
RM	4 min	60/4=15/hr
Oven	10 min	60/10=6/hr
Mixer	8 min	60/8=7.5/hr

Which resource is the bottleneck?

Oven!

Once it is "up and running", what is the process's **hourly capacity**?

6 dozens (at best)

Q3: Rush Order (1 dozen)

What operational measure is the question asking for?
- *Theoretical Flow Time (TFT)*

	Wash, Mix	Spoon	Setup Oven	Bake	Cool	Pack	Pay	Total time
Processing time	6 min	2 min	1 min	9 min	5 min	2 min	1 min	26 min

The time required to fill the "rush order" is:

Theoretical Flow Time = 26 minutes

NOTE: The answer of 26 minutes assumes that there aren't any cookies in the oven, or, if there are cookies in the oven, the remaining oven setup + baking time is at most 8 minutes. If cookies are in the oven and have a setup + baking time in excess of 8 minutes when the rush order is placed, then, if the cookies are not removed from the oven during baking, the time required to fill the "rush order" increases by the remaining time less 8 minutes.

Q3: Rush Order (k dozen)

- Would the TFT for k dozen order be k*(TFT of 1 dozen order)?
  - Besides the bottleneck resource, resources are not always utilized. Resources can work on the next dozen while the oven is busy.

  - Answer: 26+10*(k-1) = 16 + 10*k

Is this still true if one order contains different tastes?

Night Capacity (Q4)

How many orders can you fill in a night, assuming you are open four hours each night and all orders are one dozen cookies each?

Night Capacity (Q4)

Process capacity = Bottleneck capacity = 6 dozers per hour

For 4 hours, you would HOPE for 4 x 6 = 24 dozens. This is achievable when you are up and ready before opening.

But, **if you start the process as you open**, there are setup times; the first batch will come out after 26 minutes since opening.

The best Kristen can do is 22 dozens.

Night Capacity (Q4)

How many orders can you fill in a night, assuming you are open four and a half hours each night and all orders are one dozen cookies each?

Night Capacity (Q4)

Process capacity = Bottleneck capacity = 6 dozers per hour

For 4.5 hours, you would HOPE for 4.5 x 6 = 27 dozens. This is achievable when you are up and ready before opening.

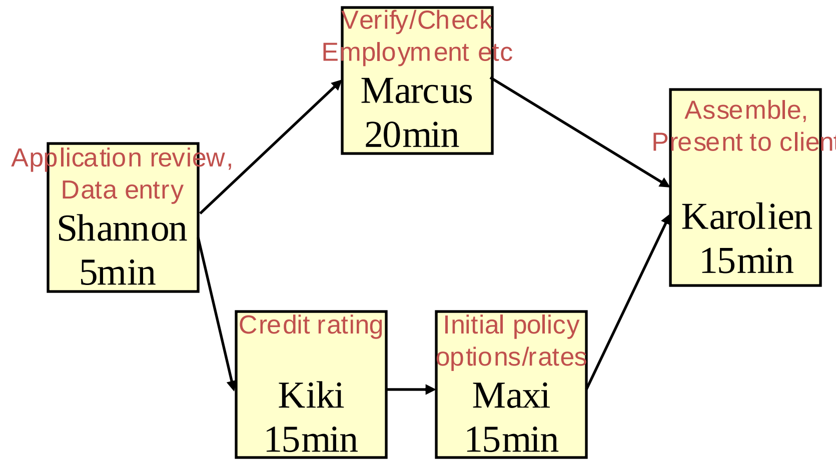
But, **if you start the process as you open**, there are setup times; the first batch will come out after 26 minutes since opening.

The best Kristen can do is 25 dozens.

What if you open for x hours?

Capacity Rate?

Mortgage Application



Resource	Unit Load (time/job)	Resource Capacity			Process Capacity
		Unit Capacity	# of units	Total Capacity	
Shannon	5min	12/hr	1	12/hr	3/hr
Marcus	20min	3/hr	1	3/hr	3/hr
Kiki	15min	4/hr	1	4/hr	3/hr
Maxi	15min	4/hr	1	4/hr	3/hr
Karolien	15min	4/hr	1	4/hr	3/hr

$\textbf{\textit{Total Time for Producing k units}}$

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

$$= 36 + 10(k-1)\ s$$

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

Flow Time = 36s **Cycle Time = 10s**

Discussion Question: Labor Time (Q6)

How much of your own and your roommate's time will it take to fill each order? (Hint: Will all orders be the same size?)

Q6: Labor Time (one dozen)

	Wash, Mix	Spoon	Setup Oven	Bake	Cool	Pack	Pay	Total time
K's time	6 min	2 min						8 min
RM's time			1 min			2 min	1 min	4 min

Each order (one dozen) takes **10** min. Why?

- *Processing time (unit load) of the bottleneck resource (oven) is 10min.*

Kristen works 8 min during baking/oven setup time (20% idle)

RM works 4 min during baking/oven setup time (60% idle)

What can they do?

Study? Or synchronize the process that all resources do not have any idle time?

Q6: Labor Time (multiple dozens, same ingredients)

When order size $k < 3$

Your time: $6 + 2k$ mins

Your roommate's time: $1 + 3k$ mins

If order size $k >= 3$, then you process every 3-dozen, and then process the rest.

$k = 3p + q$ (p is the quotient, q is the remainder)

You take 12mins (= 6mins (mixing) + 3*2mins(spoon) for each 3-dozen.

Your time: $12p + (6 + 2q)$ mins if $q > 0$, $12p$ mins if $q = 0$.

Your roommate takes 9min (= 3*(1+2; setup and pack) mins) for each 3-dozen and 1 min for accepting payment regardless of order size (even orders larger than 3 dozens)

Your roommate's time: $9p+3q+1=3k+1$ mins

Discussion Question: Number of Mixers and Trays (Q7)

How many electric mixers and baking trays will you need?

Q7: Number of Mixers and Trays

One electric mixer is enough since oven is the bottleneck.

Two trays are required: One in the oven while the other one is cooling. Why is two enough?

Processing Time and Resource (Q7)

Activity	Wash, Mix	Spoon	Setup Oven	Bake	Cool	Pack	Pay	Total time
Processing time	6 min	2 min	1 min	9 min	5 min	2 min	1 min	26 min
K's time	6 min	2 min						8 min
RM's time			1 min			2 min	1 min	4 min
Tray time		2 min	1 min	9 min	5 min	2 min		19 min
Oven time			1 min	9 min				10 min
Mixer time	6 min	2 min						8 min

Discussion: Discount? What if…. (Q8)

Because your baking trays can hold exactly one dozen cookies, you will produce and sell cookies by the dozen. Should you give any discount for people who order two dozen cookies, three dozen cookies, or more? If so, how much? Will it take you any longer to fill a two-dozen cookie order than a one-dozen cookie order? (Ignore the initial setup time)

Discussion: Discount? What if…. (Q8)

What if everyone order TWO dozen cookies? (same Ingredients)

	Wash, Mix	Spoon	Setup Oven	Bake	Cool	Pack	Pay	Total time	Capacity
Processing time	6 min	4 min	2 min	18 min	10 min	4 min	1 min		
K's time	6 min	4 min						10 min	6/hr
RM's time			2 min			4 min	1 min	7 min	8.57/hr
Oven time			2 min	18 min				20 min	3/hr
Mixer time	6 min	4 min						10 min	6/hr

It takes 10 (=36-26) more minutes more to fill a two-dozens order than a one-dozen order. Why? (TFT for two-dozens is 36mins=6+2+1+9+1+9+5+2+1)

The bottleneck is still the oven.

Process capacity = BN capacity = 3 orders/hr X 2 dozens/order = 6 dozens/hr

Process capacity is the same because the bottleneck doesn't change.

Q8: Production Cost

Suppose that Kristen and her roommate have outside offers for $12/hour.

If they are paid only when they work. (Unrealistic, but for the sake of analysis let's assume for once)

For a **ONE**-dozen order, Kristen and her roommate work a total of

8 + 4 =**12 minutes**

Labor cost = 12 x $12 /60 = $2.4 / dozen

Materials cost (ingredient and box) = $0.6 + $0.1 =$0.7 / dozen

Kristen should charge $3.1/dozen to break even.

Q8: Production Cost

Suppose that Kristen and her roommate have outside offers for $12/hour.

If they are paid for **even when they are idle.**

For a ONE-dozen order, Kristen and her roommate spend a total of

10 + 10 = **20 minutes**

Labor cost = 20 x $12 /60 = $4/dozen or 2*$12/hour / 6 dozens/hour= $4/dozen

Materials cost = $0.6 + $0.1 =$0.7 / dozen

Kristen should charge $4.7/dozen to break even.

Q8: Production Cost

Suppose that Kristen and her roommate have outside offers for \$12/hour.

If they are paid only when they work.

For a **TWO**-dozen order, Kristen and her roommate work a total of

8+2 (K:spoon)+ 4+1 (RM:setup oven) + 2 (RM:pack)= **17 minutes**

Labor cost = 17 x \$12 /60 = \$3.4 / two-dozen

Materials cost = \$0.6 x 2 + \$0.1 x 2=\$1.4 / two-dozen

Kristen should charge \$4.8/two-dozen (or \$2.4/dozen) to break even.

Kristen can offer a discount of \$0.7/dozen (=\$3.1/dozen-\$2.4/dozen) for people who order two dozens at a time.

Q8: Production Cost

Suppose that Kristen and her roommate have outside offers for \$12/hour.

If they are paid even when they are idle.

For a **TWO**-dozen order, Kristen and her roommate work a total of

(10+10)+(10+10)= **40 minutes**

Labor cost = 40 x \$12 /60 = \$8 / two-dozen

Materials cost = \$0.6 x 2 + \$0.1 x 2=\$1.4 / two-dozen

Kristen should charge \$9.4/two-dozen (or \$4.7/dozen) to break even.

From a purely financial perspective, Kristen cannot offer a discount for people who order two dozens at a time.

Process Improvement (Q5)

What is the effect of adding another oven? How much would you be willing to pay to rent an additional oven? (Here, we assume every order is one dozen cookie. In class, we discuss the case when one order contains multiple dozens) (Ignore the initial setup time)

Q5: Process Improvement

What if Kristen has TWO ovens? (All orders are 1 dozen)

Resource	Total time (unit load) per resource	Unit capacity (per resource)	# of resources	Resource capacity
K	8 min	7.5 dozen/hr	1	7.5 do/hr*1=7.5 do/hr
RM	4 min	15 dozen/hr	1	15 do/hr*1=15 do/hr
Oven	10 min	6 dozen/hr	2	6 do/hr*2=12 do/hr
Mixer	8 min	7.5 dozen/hr	1	7.5 do/hr*1=7.5 do/hr

The bottleneck becomes Kristine and the mixer. If we ignore the initial setup (warm up), cooling, packing, and payment processing, the capacity is

7.5 x 4 =30 dozens per day

Capacity increase of 6 (=30-24) dozens per day

Q5: Improvement Outcome

- Doubling the bottleneck capacity does **NOT** double the process capacity.
- The new bottleneck controls the process's hourly capacity, which increases by only 25% in Kristen's case.
- Value of the second oven (per day) =

(additional order fulfilled per day) X (profit per additionally fulfilled order) =

(6) x [(Selling Price per Dozen)-(Material Cost per Dozen)]

- Break-even analysis for purchasing a second oven?

Q5: Process Improvement

What if Kristen has TWO ovens? (All orders are 2 dozen, same flavor)

Resource	Total time (unit load) per resource	Unit capacity (per resource)	# of resources	Resource capacity
K	10 min?	6 or/hr	1	6 or/hr*1=6 or/hr =12 do/hr
RM	7 min?	8.57 or/hr	1	8.57 or/hr*1=8.57 or/hr = 17.14 do/hr
Oven	20 min	3 or/hr	2	3 or/hr*2= 6 or/hr =12 do/hr
Mixer	10 min	6 or/hr	1	6 or/hr*1=6 or/hr = 12 do/hr

The bottleneck becomes Kristine, oven, and the mixer. If we ignore the initial setup time, the capacity is

12 x 4 = 48 dozens per day.

Q5: Process Improvement

What if Kristen has TWO ovens? (All orders are 3 dozen, same flavor)

Resource	Total time (unit load) per resource	Unit capacity (per resource)	# of resources	Resource capacity
K	12 min	5 or/hr	1	5 or/hr*1=5 or/hr =15 do/hr
RM	10 min	6 or/hr	1	6 or/hr*1=6 or/hr = 18 do/hr
Oven	30 min	2 or/hr	2	2 or/hr*2= 4 or/hr =12 do/hr
Mixer	12 min	5 or/hr	1	5 or/hr*1=5 or/hr = 15 do/hr

The bottleneck is the oven only. If we ignore the initial setup time, the capacity is

12 x 4 =48 dozens per day.

Q5: Improvement Outcome

- The improvement in sales is in the range of [6 dozens/day, 24 dozens/day].
- You will rent an oven
  - for sure if the rent < 6 X (profit per additional dozen)
  - not rent for sure if rent > 24 X (profit per additional dozen)
  - not sure if it is in between due to variability in order sizes.
- Need more information on demand forecast.

Discussion Question: Process Improvement (Q9)

Are there any changes you can make in your production plans that will allow you to make more cookies in less time or at lower cost? For example, is there a bottleneck operation in your production process that you can expand cheaply?

- What improvements would you suggest?

Q9: Continuous Process Improvement

Back to two ovens where all orders are 1 dozen (Q5).

Resource	Total time (unit load) per resource	Unit capacity (per resource)	# of resources	Resource capacity
K	8 min	7.5 dozen/hr	1	7.5 do/hr*1=7.5 do/hr
RM	4 min	15 dozen/hr	1	15 do/hr*1=15 do/hr
Oven	10 min	6 dozen/hr	2	6 do/hr*2=12 do/hr
Mixer	8 min	7.5 dozen/hr	1	7.5 do/hr*1=7.5 do/hr

By adding an oven we increased the capacity by 1.5 dozen/hr. This is a result of shifting the bottleneck to other resources: Kristine and the mixer.

Q9: Continuous Process Improvement

Back to two ovens where all orders are 1 dozen.

Resource	Total time (unit load) per resource	Unit capacity (per resource)	# of resources	Resource capacity
K	8 min	7.5 dozen/hr	2	7.5 do/hr*2=15 do/hr
RM	4 min	15 dozen/hr	1	15 do/hr*1=15 do/hr
Oven	10 min	6 dozen/hr	2	6 do/hr*2=12 do/hr
Mixer	8 min	7.5 dozen/hr	2	7.5 do/hr*1=15 do/hr

Q9: Continuous Process Improvement

Back to two ovens where all orders are 1 dozen.

Resource	Total time (unit load) per resource	Unit capacity (per resource)	# of resources	Resource capacity
K	~~8~~ 6 min	10 dozen/hr	1	10 do/hr*1=10 do/hr
RM	~~4~~ 6 min	10 dozen/hr	1	10 do/hr*1=10 do/hr
Oven	10 min	6 dozen/hr	2	6 do/hr*2=12 do/hr
Mixer	8 min	7.5 dozen/hr	2	7.5 do/hr*2= 15 do/hr

Q9: What More Can We Do?

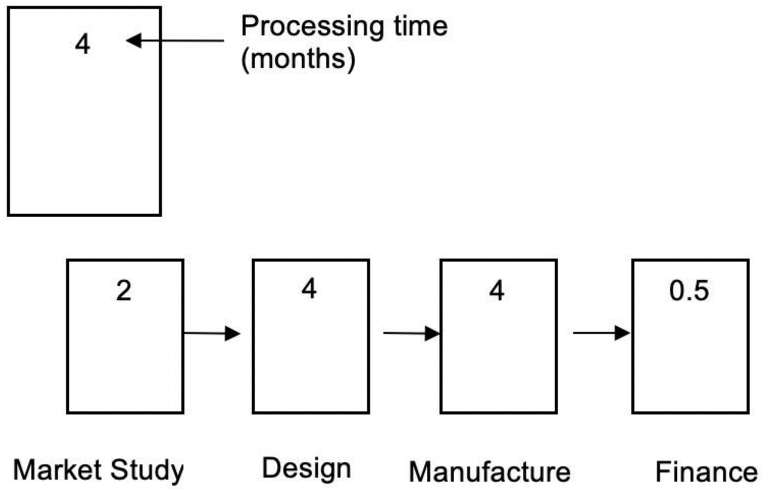
- Improving on bottleneck again:
  - Reduce processing time for Kristine and mixer so that the oven is again the bottleneck
    - Better measurement tools/mixer to speed up the mixing time
    - More convenient spoons? Or streamlined spooning process?
    - Premixing ingredients

- We can continue the loop of process improvement by tackling the new bottleneck and the next new bottleneck,…

Take-Away Points

- Key action = *optimize only bottleneck management*
  - *one bottleneck at a time*
  - *Never let bottlenecks (slowest resources) wait (or be idle): Inventory will pile up*
  - Move work content from bottlenecks to non-bottlenecks : Cross-training?
  - Increase Net Availability of Process: more operating hours?

In Class Practice Problems



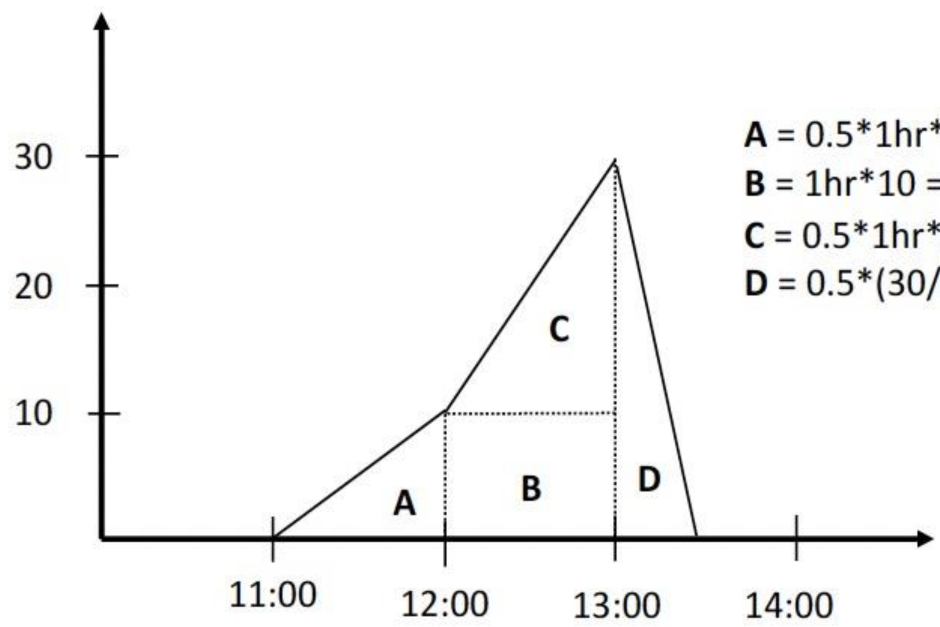
- Assuming this firm introduces new products at the rate of 2.4 projects per year, what is the utilization of each department in the company? (i.e., what percent of time are they busy?)
- *2.4 projects/year= 0.2 projects/month， Market Study: 0.2/0.5=0.4 i.e., 40%， Design: 0.2/0.25=0.8, i.e., 80%, Manufacturing 0.2/0.25=80%， Pricing 0.2/2=0.1 i.e., 10%*
- *Note: keep the same unit.*

A Taco truck is serving customers during lunch time (11:00 am – 2 pm). People arrive at the truck from 11:00 am to 1:00 pm (see table below).

Time	Demand rate
11:00 – 12:00	60 customers/hour
12:00 – 1:00	90 customers/hour

The capacity of the Taco truck is 50 customers/hr during the off-peak hour of 11:00-12:00, then afterwards becomes 70 customers/hr until all the customers have been served. Inventory is assumed to change continuously. What is the average number of customers waiting in line **during lunch time?**

The inventory buildup diagram of customers waiting in line is.



A = 0.5*1hr*10 = 5

B = 1hr*10 = 10

C = 0.5*1hr*20=10

D = 0.5*(30/70 hr)*30=6.429

Area/# of hours =

(A+B+C+D)/3

= 10.48.