Capacity and Queuing-II

Recitation

Feb 17-18, 2011

Agenda

- AmEx Takeaway
- Build-up Diagrams
- Process Flow Analysis
- Any remaining Queuing Questions

Did not attend

AMEX Travel Lecture Wrap-Up

1. Queueing psychology - potentially cheap alternative to capacity expansion

   'Human' servers are not machines

2. Unpredictable Variability is expensive - require lower utilization

3. Prioritize Management Levers - Queueing Analysis!

4. Pool servers whenever you can!

AmEx Indiana BTC Wait Time vs. Staffing (utilization)

lambda	N	10	11	12	13	14	15	16	17	18	19
per 30 min											
20		0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25		0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30		0.08	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
35		0.16	0.08	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00
50		1.53	0.64	0.31	0.16	0.09	0.05	0.03	0.02	0.01	0.01
55		4.35	1.34	0.59	0.29	0.16	0.09	0.05	0.03	0.02	0.01
60		1.00E+06	3.45	1.18	0.54	0.28	0.15	0.09	0.05	0.03	0.02
65		1.00E+06	28.27	2.82	1.06	0.50	0.26	0.15	0.09	0.05	0.03
70		1.00E+06	1.00E+06	13.36	2.36	0.95	0.47	0.25	0.14	0.08	0.05
75		1.00E+06	1.00E+06	1.00E+06	8.45	2.01	0.86	0.43	0.24	0.14	0.08
80		1.00E+06	1.00E+06	1.00E+06	1.00E+06	6.03	1.73	0.78	0.40	0.23	0.13
85		1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06	4.60	1.51	0.71	0.38	0.22

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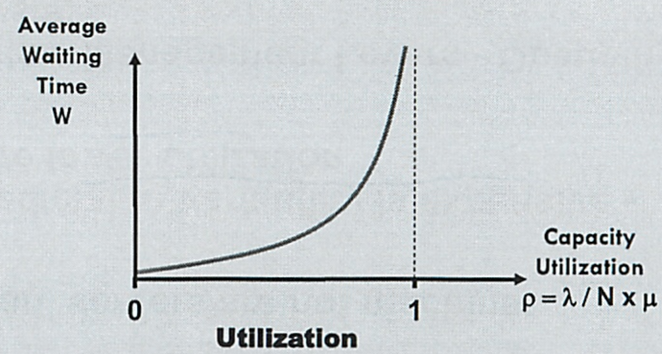
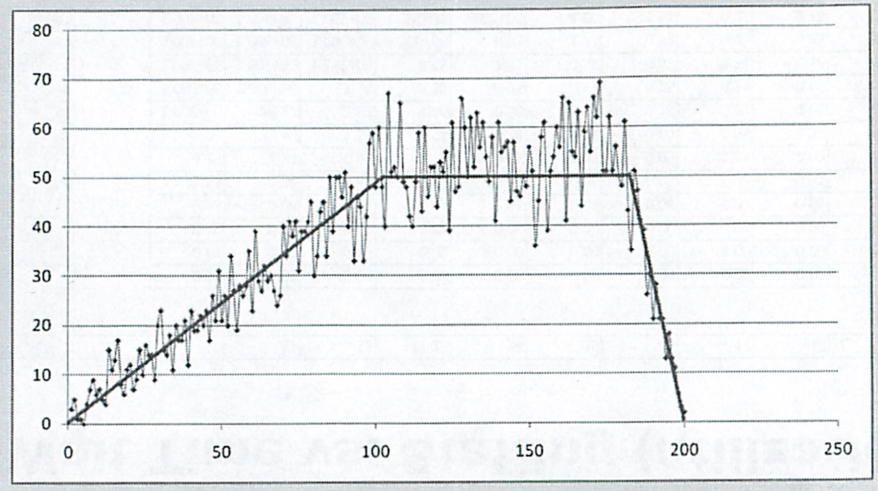
Main Queuing Insight

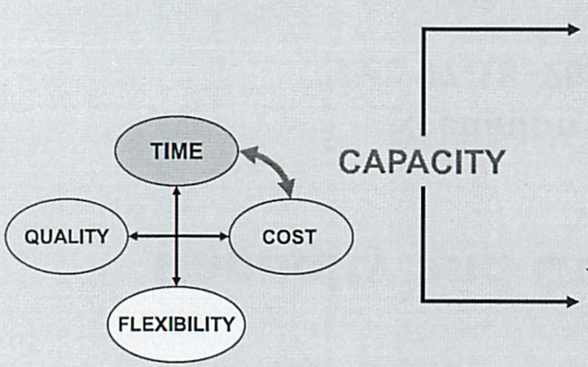


- The relationship between waiting time and capacity utilization is strongly non-linear!

Predictable vs. Unpredictable Variability



Capacity Tradeoff



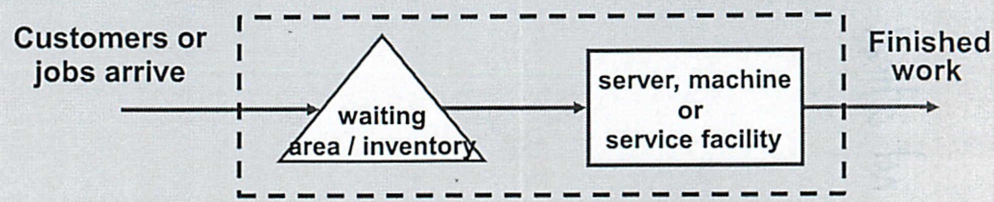
too high:

- Capital expenses
- Labor expenses
- Resource waste
- Environmental damage
- Cash flow issues

too low:

- Customer wait / death
- Brand damage
- Customer dissatisfaction
- Lost sales
- Low employee morale
- High turnover

Congestion Analysis



System Performance = F(System Parameters)

L	Inventory level/Queue size/Line length
W	Waiting time
C	Cycle time
P_{full}	Probability queue is full

λ	Arrival rate (1/E[A])
μ	Service rate per server (1/E[S])
A	Inter-arrival time distribution
S	Service time distribution
N	Number of servers
R	Queue/Buffer capacity

Congestion Analysis Tools

Build-Up Diagrams	*Queuing Theory*
• Predictable Variability • $\lambda(t) - \mu(t) > 0$ o.k. • Short Run Analysis • Variable rates o.k.	• Unpredictable Variability • $\lambda/\mu < 1$ only • Long Run Analysis • Fixed rates only
• assumes workflow is continuous and deterministic	• stochastic analysis with inter-arrival and service time distributions

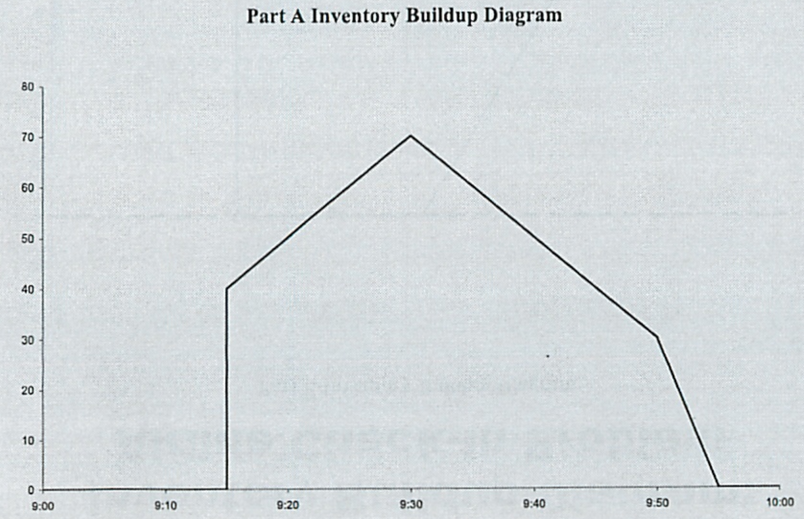
Today's Focus

Inventory Buildup Diagram: Airline Check-In Problem

The check-in counter of an airline can service 6 people/ minute.

Assume that 1 person arrived per minute between 9:00 and 9:15.
At 9:15, a bus with 40 people all arrived at once.
Then, from 9:15 until 9:30, 8 people arrived per minute.
From 9:30 until 9:50, 4 people arrived per minute.
No one arrived after 9:50 AM.
Please draw the queue buildup diagram for this scenario.

Inventory Buildup Diagram: Airline Check-In Problem



Inventory Buildup Diagram: Airline Check-In Problem

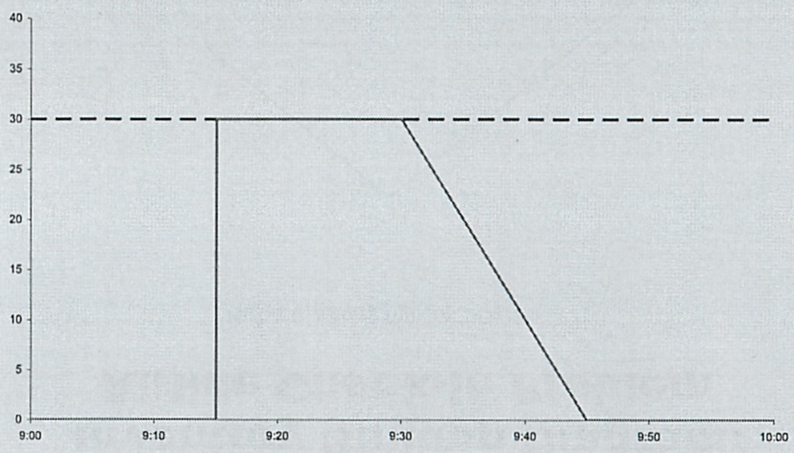
Part B:

The airline now caps the number of people who can wait in line at 30 (by offering a special check in process to all people beyond a certain point in line).

Draw the inventory buildup diagram for this scenario.

Inventory Buildup Diagram: Airline Check-In Problem

Part B Inventory Buildup Diagram



The E51 elevator

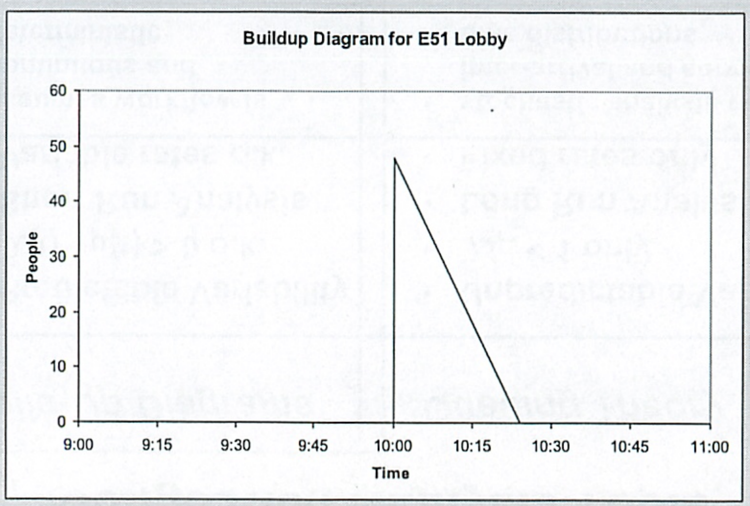
The lobby of E51 has an elevator that arrives every four minutes beginning at 9 a.m. The elevator can hold 10 people.

Throughout the day, again beginning at 9 a.m., a person arrives in the lobby every minute to ride the elevator.

At 10 a.m., a class of 60 students lets out into the lobby. 80% of them wish to take the elevator. However, every two minutes one of them gives up and takes the stairs.

Please draw the inventory buildup diagram for people in the lobby from 9 a.m. to 11 a.m.

The E51 Elevator



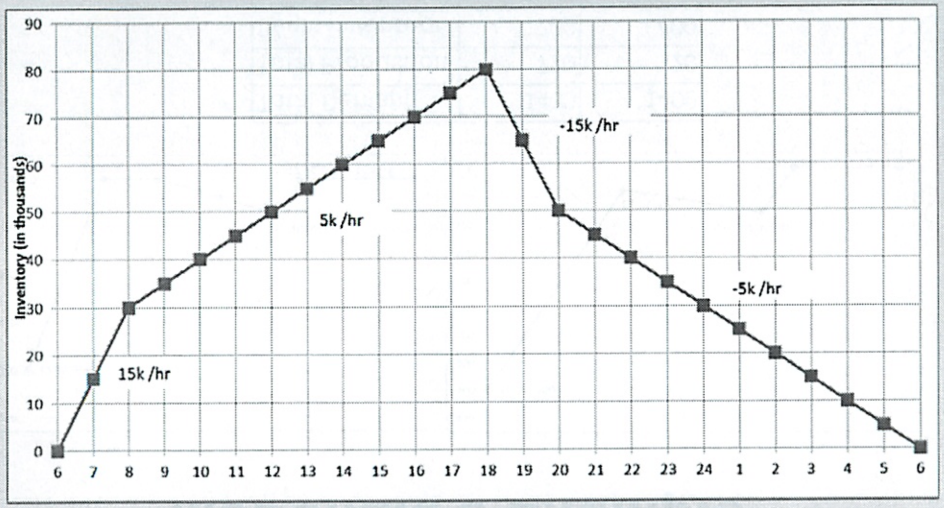
Overnight Package Service

The *Overnight Package Service (OPS)* provides express small package delivery overnight. Airplanes arrive 24/hrs a day at its national hub, where their contents are unloaded onto small 4-wheeler trucks, each capable of holding 1,000 packages. The trucks transport the packages to the sorting center. After being sorted, another fleet of trucks transports the packages to the outgoing planes.

- During the day (6am-6pm), airplanes arrive at a high rate providing an approximately continuous arrival flow of packages with an average rate of 25,000 parcels/hour.
- During the night (6pm-6am), however, air landings are slower, resulting in an average arrival rate of 5,000 parcels/hour.
- *OPS* runs two 12-hour shifts for its sorting center: the day shift starts at 8am has the largest amount of employees and can process up to 20,000 parcels/hour. The night shift is smaller and can process up to 10,000 parcels/hour from 8pm-8am.

Draw the inventory build-up diagram for this scenario.

Overnight Package Service

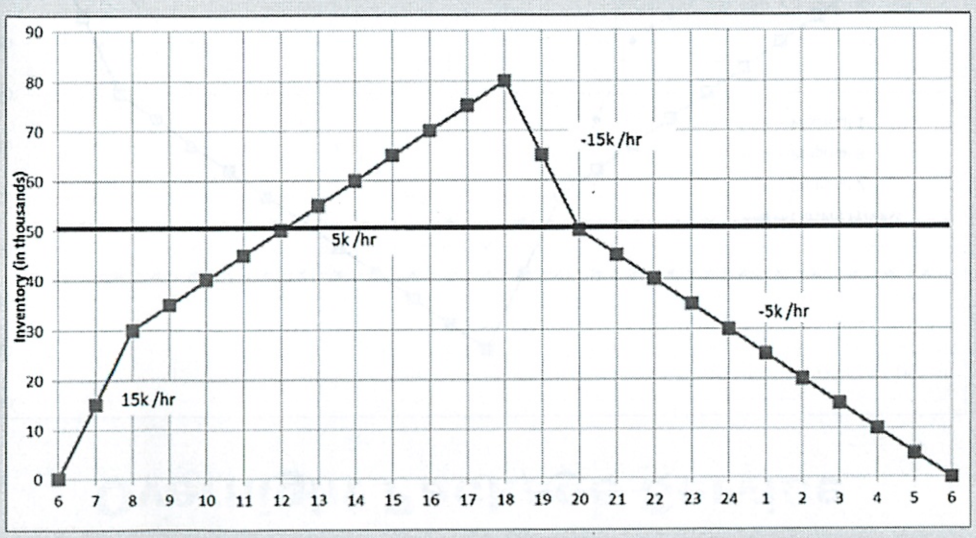


Overnight Package Service

The total storage area of the unloading zone at the sorting center is designed to store up to 50,000 parcels. Trucks had to wait when the unloading zone is full.

What are the effects?

Overnight Package Service



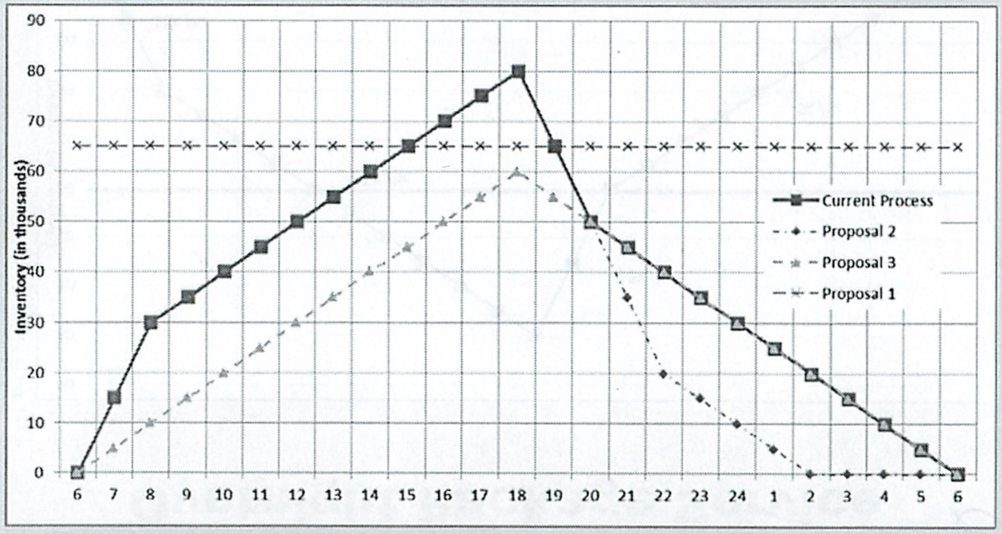
Overnight Package Service

Three solutions proposed.

1. Increase the unloading storage area to store an additional 15K
2. Run three shifts: 2 day shifts (8am-4pm and 4pm-10pm) processing 20K parcels/hour and 1 new night shift (10pm-8am) processing 10K parcels/hour
3. Move the first shift to 6am-6pm and second shift to 6pm-6am

Discuss the effects of these solutions using the inventory build-up diagram

Overnight Package Service



McDonald's Example

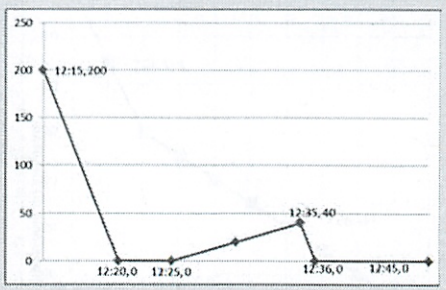
Demand for burger patties in McDonald on a holiday weekend during lunch hour:

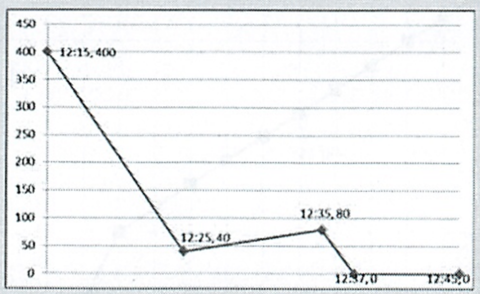
- **12:15-12:25: 60 patties per minute**
- **12:25-12:35: 20 patties per minute**
- **12:35-12:45: 60 patties per minute**

Maximum patty production is 24 patties per minute and assume that the production occurs continuously rather than in batches. Also assume that burgers must be thrown out if they are not sold within 10 minutes.

Draw the inventory build-up diagram when the starting inventory at 12:15 is (a) 200 and (b)400

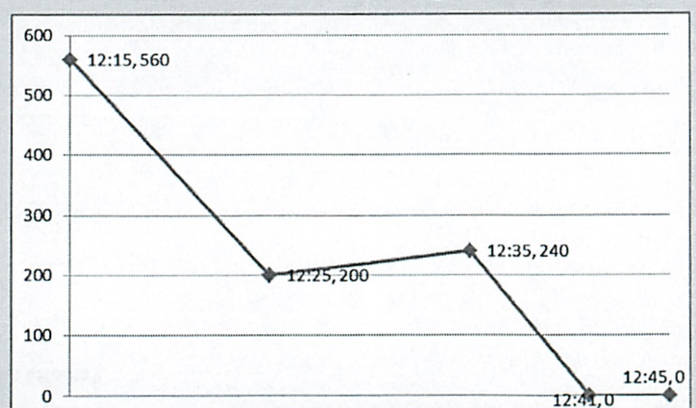
McDonald's Example





Total Demand	1400	1400
Total Production	720	720
Begin inventory	200	400
Unmet Demand	480	280
%	34.3%	20.0%

How Best can you get?

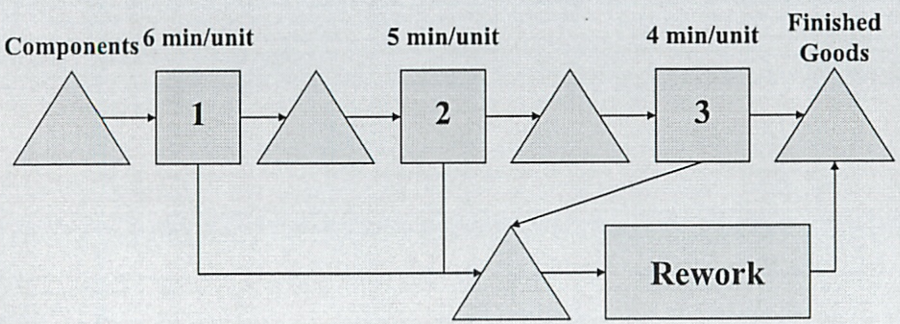


Total Demand	1400
Total Production	720
Begin inventory	560
Unmet Demand	120
%	8.6%

Or start at a high inventory level at 12:15 and vary production rate in the first 10 minutes

Process Flow Analysis: Ceramics Line

Consider the following three stage production process of glass ceramics, which is operated as a worker-paced line.



Process Flow Analysis: Ceramics Line

The process is experiencing severe quality problems related to insufficiently trained workers. Specifically, 20 percent of the parts going through Operation 1 are badly processed by the operator.

Rather than scrapping the unit, it is moved to a highly skilled rework operator, who can correct the mistake and finish up the unit completely within 10 minutes.

The same problem occurs at Operation 2, where 25 percent of the parts are badly processed. Operations 3 also has a 1/6 ratio of badly processed parts. All badly processed parts require 10 minutes to correct and finish up the unit completely.

A. What is the utilization of Operation 2 if work is released into the process at a rate of 5 units/hour?

B. Where in the process is the bottleneck? Why?

C. What is the process capacity?

Process Flow Analysis: Ceramics Line

General Analysis:

Operation 1: λ_1= 5 unit/hr, μ_1=10 unit/hr, $\rho_1 = \lambda_1/\mu_1$ = 5/10 = 1/2

Operation 2: $\lambda_2 = 0.8 * \lambda_1 = 0.8 *$ 5 unit/hr = 4 unit/hr, μ_2=12 unit/hr,
$\rho_2 = \lambda_2/\mu_2$ = 4/12 = 1/3

Operation 3: $\lambda_3 = 0.75 * \lambda_2 = 0.75 *$ 4 unit/hr = 3 unit/hr, μ_2=15 unit/hr,
$\rho_2 = \lambda_3/\mu_3$=3/15= 1/5

Rework: $\lambda_R = 0.2*\lambda_1 + 0.25*\lambda_2 + 1/6*\lambda_3$ = 0.2*5 unit/hr+ 0.25*4 unit/hr + 1/6* 3 unit/hr = 2.5 rework unit/hr, μ_R=6 rework units/hr
$\rho_R = \lambda_R/\mu_R$=2.5/6= 5/12

A. $\rho = \lambda / \mu$ = 1/3
B. Compare ρ's, Operation 1 is the Bottleneck!
C. 10 Unit/hour

MSD Chap 5 Op + Finance

Previous chap may have been too technical (Really???)

Objective: to create economic value

ROIC = return on investment capital

WACC = weighted avg cost of capital

Economic value created = Invested Capital · (ROIC − WACC)

Key question: how to improve ROIC

Furniture co. case study

5.2 ROIC case study

- need to break it down into its components

$$ROIC = \frac{Return}{Invested\ Capital}$$

$$= \frac{Return}{Revene} \cdot \frac{Revene}{Invested\ capital}$$

$$= Margin \cdot Capital\ Turn$$

↑ from Chap 2

(2)

$$\text{Return} = \underbrace{\text{Revenue}}_{\text{Flow rate} \cdot \text{price}} - \text{Fixed Costs} - \underbrace{\text{Production Volume}}_{\text{Flow Rate}} \cdot \text{Variable Costs}$$

$$\frac{\text{Return}}{\text{Revenue}} = \frac{\text{Revenue}}{\text{Revenue}} - \frac{\text{Fixed Costs}}{\text{Revenue}} - \frac{\text{Flow Rate} \cdot \text{Variable Costs}}{\text{Revenue}}$$

$$= 1 - \frac{\text{Fixed Costs}}{\text{Flow Rate} \cdot \text{price}} - \frac{\text{Flow Rate} \cdot \text{Variable Costs}}{\text{Flow Rate} \cdot \text{price}}$$

$$= 1 - \frac{\text{Fixed Costs}}{\text{Flow Rate} \cdot \text{Price}} - \frac{\text{Variable costs}}{\text{Price}}$$

$$\frac{\text{Revenue}}{\text{Invested Capital}} = \frac{\text{Flow Rate} \cdot \text{Price}}{\text{Invested Capital}}$$

$$\text{ROIC} = \left[1 - \frac{\text{Fixed Costs}}{\text{Flow Rate} \cdot \text{Price}} - \frac{\text{Variable Costs}}{\text{Price}}\right] \cdot \frac{\text{Flow Rate} \times \text{Price}}{\text{Invested Capital}}$$

- Going to lock down price (exogenous)
- Variable costs often locked down
  - supplies
  - labor contracts

So put this all in a tree

- Process Capacity
  - (÷)
  - Available Hrs
    - (×)
    - # workers
    - Hrs / year/worker
  - Hrs per table
    - (+)
    - Prod time
    - extra time
      - (+)
      - wait time
      - setup time

(3)

etc tree like for fixed costs

pre-tax

Using financial depreciation not tax

So this tree extends down to real values

Same for capital

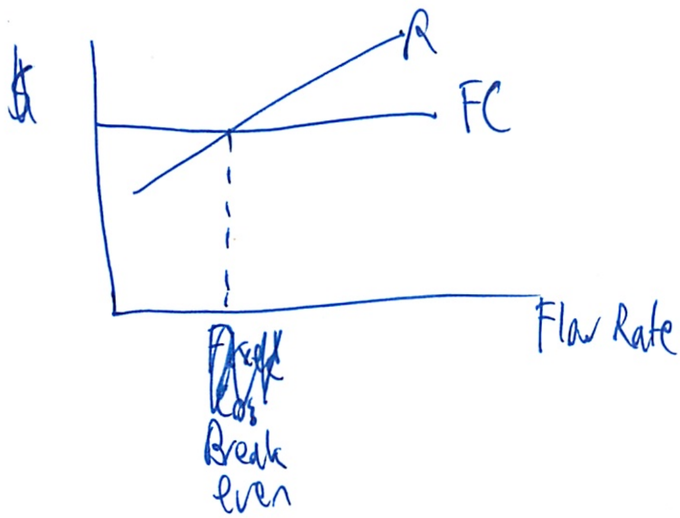
5.3 Valuing Operational Improvements

put a price tag on each lever

how much will each improvement be?

not always intuitive

may effect multiple things in tree



(4)

5.4 Analyzing Operations based on Financial Data

Can use data on public companies

$$\text{Productivity} = \frac{\text{Revenue}}{\text{Cost}}$$

$$\text{Labor Productivity} = \frac{\text{Revenue}}{\text{Labor Cost}}$$

$$\text{Productivity} = \frac{\text{Revenue}}{\text{Flow Rate}} \cdot \frac{\text{Flow Rate}}{\text{Resource}} \cdot \frac{\text{Resource}}{\text{Cost}}$$

$$\text{Labor Productivity (Airline)} = \frac{\text{Revenue}}{\text{RPM}} \cdot \frac{\text{RPM}}{\text{ASM}} \cdot \frac{\text{ASM}}{\text{Employees}} \cdot \frac{\text{Employees}}{\text{Labor Cost}}$$

$$= \text{Yield} \cdot \text{Efficiency} \cdot \text{Cost}$$

- Yield ↑ pricing power
- Efficiency ↑ utilization
- Cost ↑ resource cost

(use # to tell a story)

(use nice charts)

More data if inside company

MSD 6: Batching + Setup

So far had simple cycle time w/ smooth + constant flow
- does not work like that in real world

Esp if batch jobs using general purpose equipment

Some switching/set up time

6.1 Impact of Setups on Capacity

Must also count setup time

* "flow must go on"

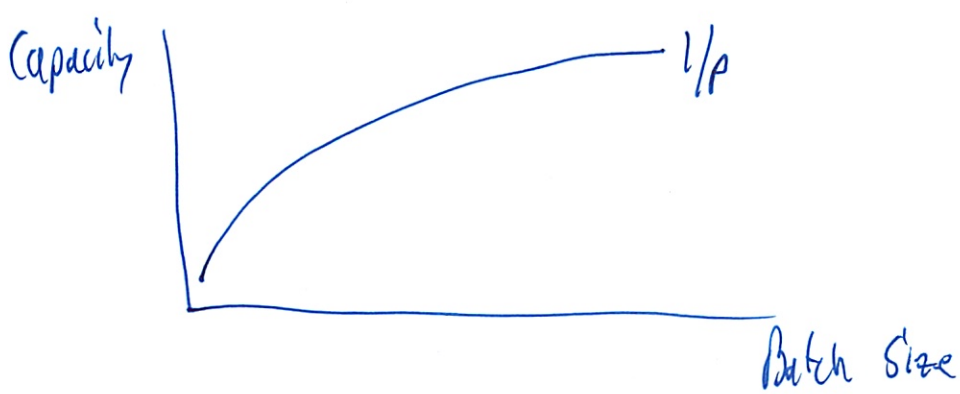
best: reduce or eliminate setup times

its a total waste

Need to pick right batch size

$$\underset{\text{given batch size}}{\text{Capacity}} = \frac{\text{Batch size}}{\text{Setup time} + \text{batch size} \times \text{time per unit}}$$

Spread unproductive setup time over larger batches



② 6.2 Batching + Inventory

- large batch sizes require large inventory
- which means long flow times
- then mismatch of supply + demand
- Toyota good at small batches
  - smaller inventory
- Since lots of waiting

- Capacity at bottleneck is very valuable
- Capacity elsewhere is free
  - so ↓ batch size

Fixing batch times may shift bottleneck

Want smallest batch size that does not affect capacity

$$\frac{B}{120 + B \cdot 2} = \frac{1}{3}$$

↑ solve for batch size

↑ bottleneck capacity of other steps

$$B = \frac{\text{Flow rate} \cdot \text{setup time}}{1 - \text{Flow rate} \cdot \text{time per unit}}$$

③

6.4 EOQ Model

If process capacity constrained - setup times have lost sale opp costs

Sometimes actual costs

- shipping costs
- time is money

Shows ~~oppor~~ econ of scale

Can either slowly build up inventory (internal) or all at once (delivery)

- purchase costs, delivery fees, holding costs
- assuming no quanity discount
  - Look at inventory cost - capital, space, obsolescence
  - get weekly costs

$$\text{Avg inventory} = \frac{\text{order quantity}}{2}$$

$$\text{Invetory cost / time} = \frac{1}{2}\text{ order quantity} \cdot h$$

$$\text{Setup costs / time} = \frac{\text{Setup cost}}{\text{lenght of order cycle}} = \frac{k}{Q/R} = \frac{k \cdot R}{Q}$$

$$C(Q) = \text{Setup} + \text{inventory costs} = \frac{k \cdot R}{Q} + \frac{1}{2} \cdot h \cdot Q$$

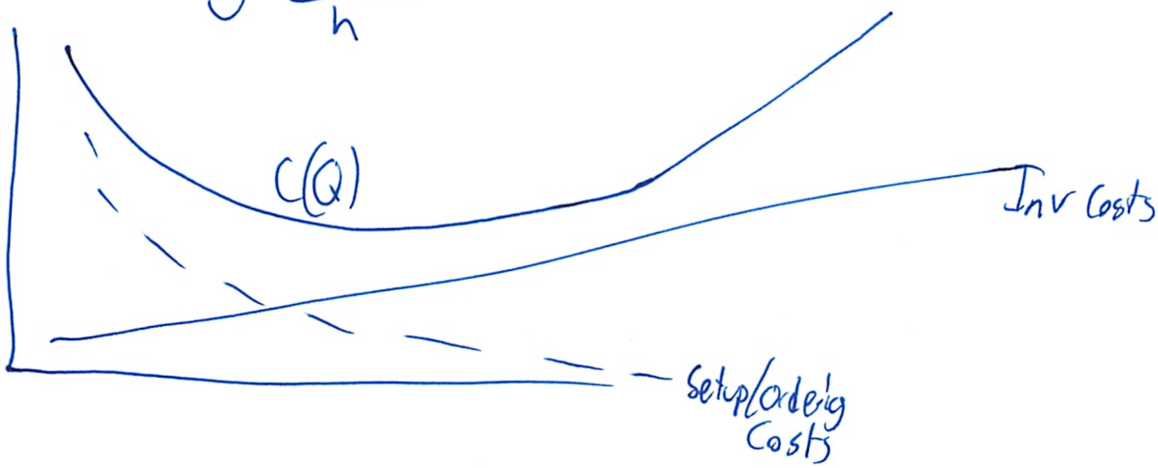
(4)

as Q ↑ ammortize delivery costs further
but ↑ inventory costs

find the minimum Q^* (EOQ)

$$Q^* = \sqrt{\frac{2 \cdot \text{Setup cost} \cdot \text{Flow rate}}{\text{Holding costs}}}$$

$$= \sqrt{\frac{2 \cdot k \cdot r}{h}}$$



6.5

Cost per unit of time $C(Q^*)$

$$C(Q^*) = \frac{k \cdot R}{Q^*} + \frac{1}{2} \cdot h \cdot Q^*$$

$$= \sqrt{2 \cdot k \cdot R \cdot h}$$

Cost per unit

$$\frac{C(Q^*)}{R} = \sqrt{\frac{2 \cdot k \cdot h}{R}}$$

becomes more efficent as demand ↑

(5)

Curve very flat around min

- So model is forgiving
- Can ~~build~~ add complexities
  - quantity discounts
  - shipping cost based on order size

Internal Production

Setup time ≠ setup cost

machine cost is sunk

choosing on cost does not consider capacity

- if it is the ~~bott~~ bottleneck

6.6 Transfer Batches

- from one process to another
- like forklift
- try to transfer in as small ~~...~~ sets as possible (book does not say why)

6.7 ~~Set time~~ Setup time reduction

- always good
- SMED - take 10 min tops

⑥

Also <u>external</u> – can be done while machine still operating

<u>internal</u> – must stop machine

Worthwhile at the bottleneck

6.8 Buffer or Suffer

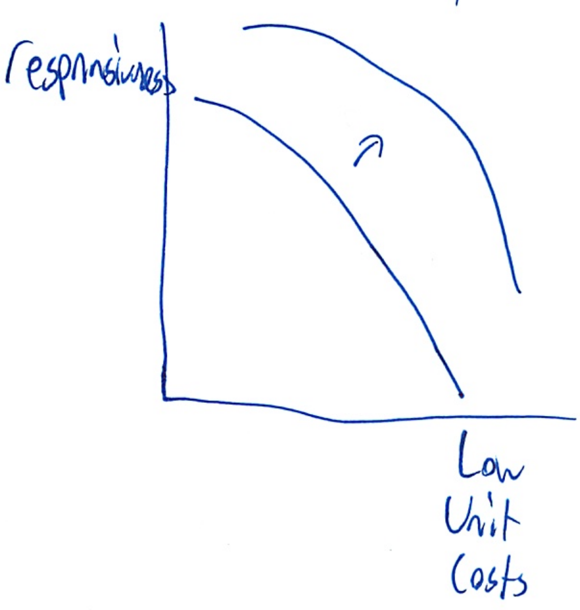
If you don't have a buffer when one step stops, all the other ones do too

And if bottleneck is before that step have opportunity to catch up if a step is stopped

So buffers to smooth out production

6.9 Conclusion

- ↑ Batch sizes
  - ↓ Costs
  - ↓ Flexibility



Can move frontier out by ↓ set up times

Case: MGH-Pre-Admission Testing Area (PATA)

Case Analysis – Team Assignment

Note to Students:

Hand in one paper copy of the write-up for each student group at the beginning of the class on **23 Feb** (24 Feb for Sections B & C). Your paper should provide answers to the specific case questions listed below. The answers must be less than 4 pages in length (excluding appendices) with font size of 12. Every graph or table/spreadsheet showing the results of computations must be accompanied by both a clear description of what all numbers shown represent qualitatively, and an exhaustive explanation of how they are computed, including relevant mathematical formulas or algorithms.

Our general policy for this class is that when preparing cases and assignments you should not receive any related input from anyone who has already participated in a faculty-led discussion of the same material, be it at Sloan or another school. When preparing any graded assignment you may not consult or use material not already included in the course packet or posted on the course webpage, unless this has been explicitly authorized by the instructor.

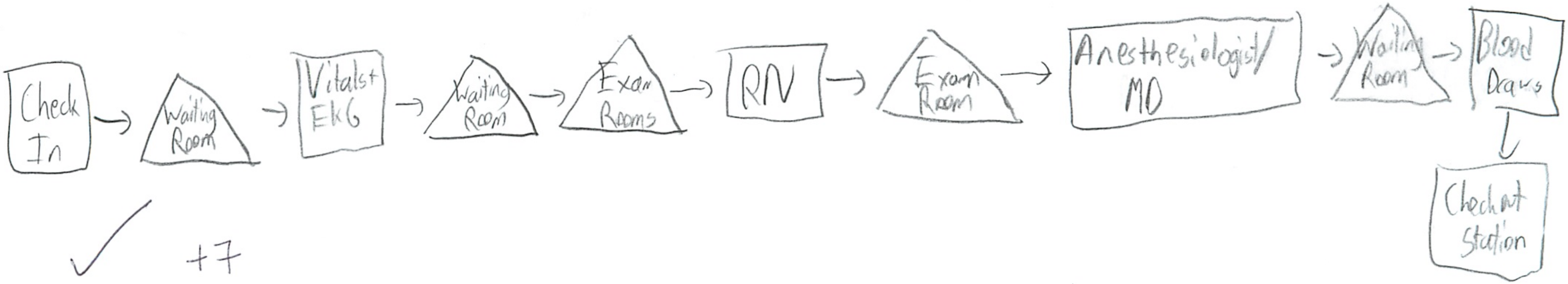
PATA Case Questions:

1. Construct a process flow diagram of the PATA visit from a patient's perspective. Calculate the capacity and utilization rate at each step in the process.
2. Use capacity analysis tools (build-up diagrams or/and queuing) to decide if and where there is a bottleneck in the clinic. If a bottleneck does indeed exist, how long do patients wait as a result of the bottleneck? (As an approximation, assume that all appointment slots were filled and patients arrived on time)
3. Evaluate the three Task Force diagnoses - not enough time between appointments, not enough rooms, not enough physicians. Are these diagnoses valid? If so, are they primary contributors to long patient wait times? Why or why not?
4. What factors contribute to variability in PATA process flow and what control, if any, does the clinic have to eliminate it?
5. What changes would you recommend to improve PATA?

Michael Plasmeier
Michael Nackoul

PATA

2/22



✓ +7

−4 − exclusion of process steps not seen by patient.

In future, please include λ, μ and ρ as part of the process flow diagram

~~80~~ 75/100

Michael & Michael :) I think you understand the material well but need to work on presenting your thoughts better. Please see me before/after class/ during office hours

— Kanaka

(2) λ = input units/time
μ = service rate units/time

1b. $\rho = \frac{\lambda}{\mu \cdot N}$ = capacity utilization = ratio

L = avg # waiting

C_A = Var inter-arrival

C_S = var service time

N = # of servers

Data dump

55 people scheduled/day
low variation

Checkin 2 min
stocastic

26 chairs in wait room

5 lab techs/day - cross trained
EKG + vitals 10 min avg
St dev 3.5 min

5 RNs/day
Review 5 min avg
20 min max

$\sigma_{RN\ 3\ steps}$ = 21 min

27 min in room
11 min extra doc

8 MDs/day
10 min review
visit 37 min avg
15 - 70 min range

$\sigma_{MD\ 3\ steps}$ = 29 min

17 min post

(2b)

Blood work 6 min avg

st dev = 2

inter-arrival var = .4

<u>Capacities</u> (per hour)

<u>Check In</u>

$\lambda = 8 \frac{people}{hr}$ ✓

$\mu = 30 \frac{people}{hr}$ ✓

Must include checkout in utilization

Wait room size not addressed here

<u>Vitals + EKG</u>

$\lambda = 8 \frac{people}{hr}$

$\mu = \frac{60}{10} = 6 \frac{people}{hr}$ ✓

N = 1-5 cross trained w/ blood draw

so capacity later → can make an assumption for N

(3)

RN in room

27 min / patient

(need to add out of room time! Time spent doing other things could affect ρ)

N = 12 exam rooms - shared w/ MDs

(OK I see you do this later)

$\lambda = 8 \frac{people}{hr}$

5 RNs

$\mu = \frac{60}{27} = 2.22 \frac{people}{hr}$

ultimatley not very useful

MD in room

8 MDs

37 min

$\lambda = \frac{8 \text{ people}}{hr}$

$\mu = \frac{60}{37} = 1.62 \frac{people}{hr}$

Blood Draw

$\lambda = \frac{8 \text{ people}}{hr}$

$\mu = \frac{60}{6} = \frac{10 \text{ people}}{hr}$ ✓

Checkout

$\lambda = 8 \frac{people}{hr}$

$\mu = \frac{60}{1} = 60 \frac{people}{hr}$? 6 min/patient ≤ 10 people/hr

(4)

Joint Capacities

- Use averages

Check in/out

$\lambda = 8 + 8 = 16$

$\mu = \frac{1+2}{2} = 1.5 \rightarrow \frac{60}{1.5} = 40 \ \frac{\text{people}}{\text{hr}}$

$N = 1$

$\rho = \frac{\lambda}{\mu N} = \frac{16}{1 \cdot 40} = .4$

Lab Work

$\lambda = 8 + 8 = 16$

$\mu = \frac{10+6}{2} = 8 \rightarrow \frac{60}{8} = 7.5 \ \frac{\text{people}}{\text{hr}}$

$N = 5$

$\rho = \frac{\lambda}{\mu \cdot N} = \frac{16}{5 \cdot 7.5} = .426$

(5).

Rooms Just Productive times

$\lambda = 8 + 8 = 16$

$\mu = \frac{27+37}{2} \rightarrow \frac{60}{32} = 1.875 \frac{\text{people}}{\text{hr}}$

$\rho = \frac{16}{12 \cdot 1.875} = .71$

RN whole time

$\lambda = 8$

$\mu = \frac{60}{5+27+11} = 1.395 \frac{\text{people}}{\text{hr}}$

$\rho = \frac{8}{5 \cdot 1.395} = 1.14$ /

MDs whole time

$\lambda = 8$

$\mu = \frac{60}{10+37+17} = .937 \frac{\text{people}}{\text{hr}}$

$\rho = \frac{8}{8 \cdot .937} = 1.06$ /

22/25

(6)

2. RNs are bottleneck, ✓ +5
MDs over subscribed ✓

Do we want to use queuing formula?
- random when actually arrive for RN

Patient waiting time each step

Like how much time waiting to check in if someone already at checking desk

So need to do Build-Up diagram? yes ✓

Is it predictable variability
- appointments yes
- inter service time no

So is queuing theory?
- But will ↑ ∞ since over capacity

Lets just try in RN

$$L = \frac{1.14^{\sqrt{2(5+1)}}}{1-1.14} \cdot \frac{1^2 + \left(\frac{21}{43}\right)^2}{2}$$

$= -6.9641$

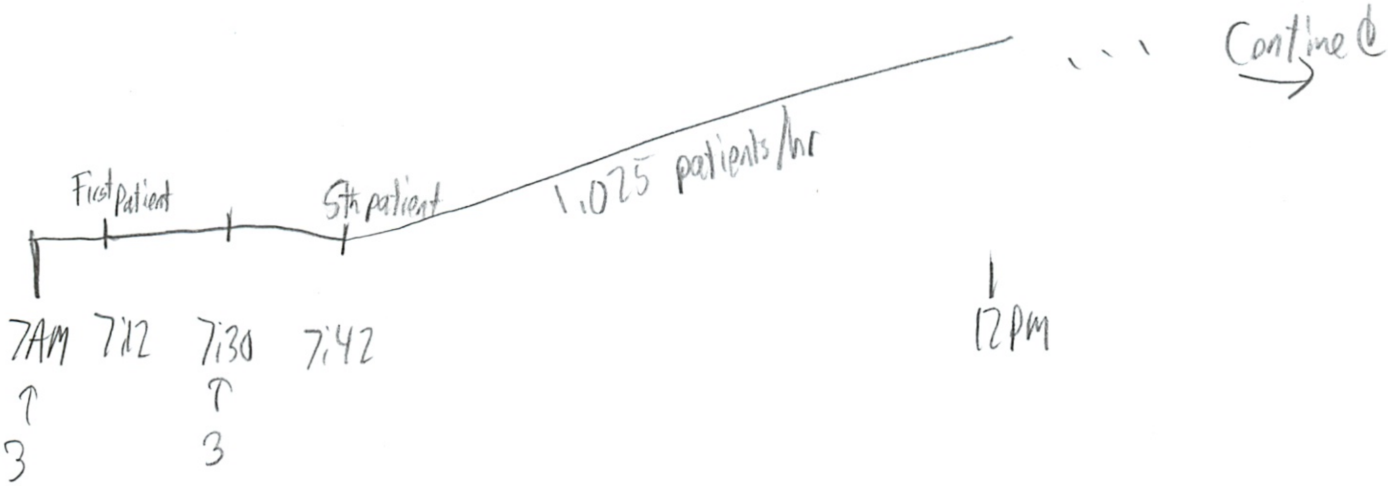
Not accurate, so don't use ✓

(7)

How many patients can RN serve per hr?

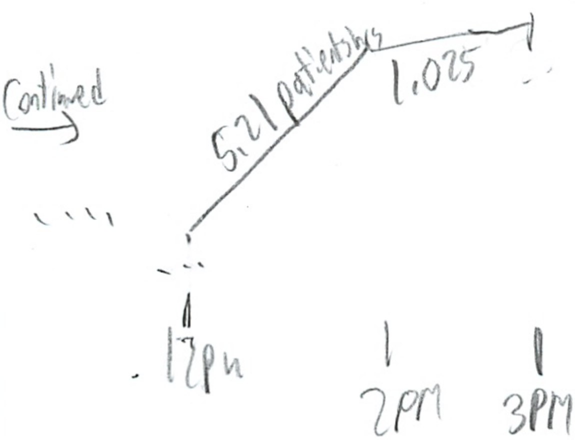
$1.395 \cdot 5 = 6.975$ patients

$8 - 6.975 = 1.025$ patients extra



$1.395 \cdot 2 = 2.79$

$8 - 2.79 = 5.21$

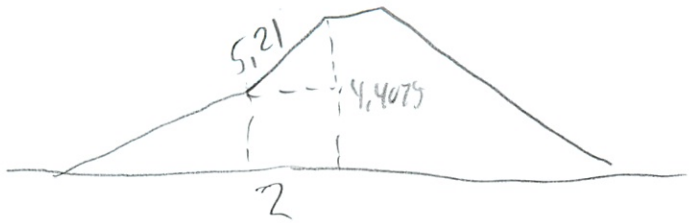


Open-12PM

$$\int_{7:42\,AM}^{12\,PM} 1.025 = \int_{0}^{4.3} 1.025x = 4.4075$$

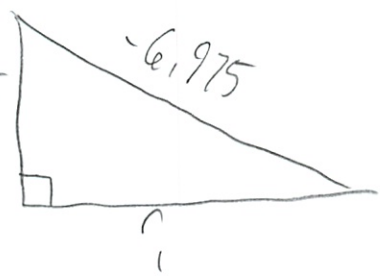
7 $\frac{42}{60}$

(8)



[12-2PM] $\frac{1}{2} \cdot 5{,}21 \cdot 2 + 4{,}4075 \cdot 2 = 14{,}025$

[2-3PM] $14{,}025 + \frac{1}{2} \cdot 1{,}025 = 14.5375$



[3-Close] ~~$? = \sqrt{(6{,}975)^2 - (14{,}5375)^2} =$~~

$$\frac{14{,}5375}{6{,}975} = 2{,}08423 \text{ hrs after close}$$

How long do patients wait?
- depends on time of day at arrival

$L = \lambda \cdot W$

$14{,}5375 = 8 \; W$

$W = 1{,}75$ hrs at 3 PM
Peak hr ✓

+20/20

(9)

3. Nursing Director

- She does not mean last patients start at 6
- She means pay staff extra hr

- 45min window is a 50% ↓ in volume
  - no wait times
  - even less patients -50% patients

Medical Director

- add nurses - the bottle neck, correct ✓ +3
- add a MD too once that bottleneck ✓

OR MD

- good suggestions
  - thats always the best thing
  - Can you do it? is the problem

The recommendations you needed to evaluate

- not enough rooms
- not enough time between appts

~~[illegible]~~

~~8~~/15

(19)

4. Essentially where are variations not 0

Patient arrival - fine patients showing up late
- may not work so well

Lab work - Not a significant source of variability

Charge nurse not checking stuff off
- automate that system (EMR, Lights)

Chart reviews - Lots of variation
Politically bad to force lower chart times
Have all forms ready

Patient RN interview - shorten forms
make sure have right info
pre fill out form

MD - Phone calls
disorganized charts - have forms ready
Consult w/ colleagues - not much can do

RN - long medical histories
many medications
translator
) not much can do
missing diagnostics - have forms ready
"talker" patients

✓ 15/15

(1.1.)

5. EMR for doctors
   - tablet PC
   - or assistent enters forms into PC

Light indicator - who is where, empty rooms, et

Shorter Forms

Pre fill form w/ pertinent info

Make sure have pre-recs before appointment

? Can you do fewer steps

More RNs + MDs

Gets vitals + EKG from refering physican, if avaliable

Fix missing charts, etc problem

PATA should charge sepeatly for services so economic value is realized

14/20

clarity and presentation (1/5)

PATA Case ~~Review~~ Feedback from TA

3/10

Understanding fine

More effort

presentation

3 recs laid out

- answered diff things
- did not directly answer qu

More numerical

Why is that the best think

Write stuff out more

- no b/w line

Pull the data back again

Make sure ans qu asked

Announcements

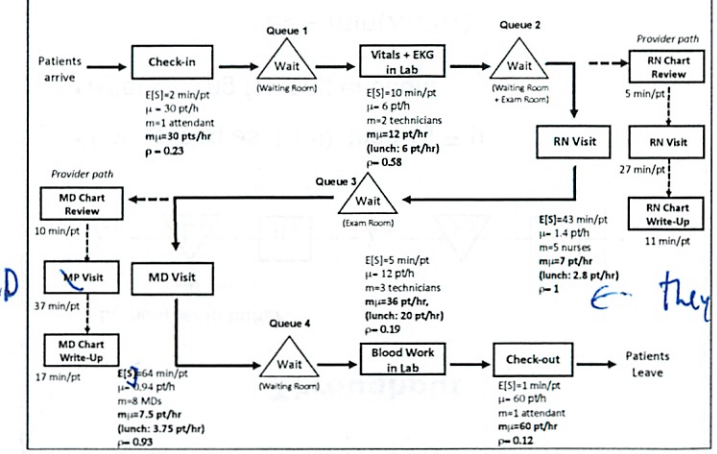
1. PATA case report is due now
2. No recitations this week
3. Next week: Process improvement and innovation
4. Reminder: The Goal report is due April 7; start reading!

MGH Pre-Admission Testing Area

1. PATA – Stakeholders views
2. Capacity analysis
3. Evaluation of task force recommendations
4. What would you do to improve PATA?

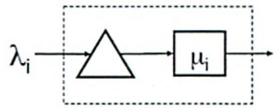
Stakeholder Issues with PATA

PATA Process Flow Diagram



His capacity is weighted for lunch

Step 2: Demand/Capacity Analysis



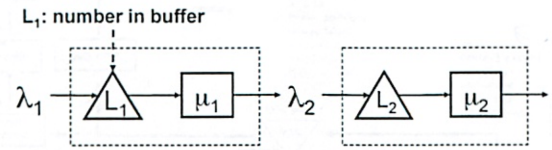
For each process step i, determine:

- λ_i : demand or input rate (in units of work per unit of time)
- μ_i : realistic maximum service rate, assuming no idle time (in units of work per unit of time)

⇩ $\rho_i = \lambda_i / \mu_i$: capacity utilization

⇩ $\lambda_i - \mu_i$: build-up rate

Throughput



- For as long as L1>0, then $\lambda_2 = \mu_1$
- After waiting for long enough:

$$\lambda_2 = \min(\lambda_1, \mu_1)$$

Congestion Analysis Queue 2

G/G/N Queuing Formula

<u>Approximation with an infinite buffer size:</u>

$$L = \frac{\rho^{\sqrt{2(N+1)}}}{1-\rho} \times \frac{C_A^2 + C_S^2}{2}$$

L	average number waiting
ρ	capacity utilization ($= \lambda / N\mu$)
C_A	coefficient of variation: inter-arrival times
C_S	coefficient of variation: service times
N	number of servers

Congestion Analysis Queue 1,3,4

Vitals+EKG:	wait 6.1	min, activity 10 min
RN:	wait 40 + 5	min, activity 27 min
MD:	wait 8.6 + 10	min, activity 37 min
Blood work:	wait 0	min, activity 5 min
Total:	wait 70	min, activity 79 min

(Total visit length 149 min= 2.5 h)

Recommendation 1: Spreading Patient Arrivals

λ=4 pt/0.5hr=8 pt/hr	7-12 and 2-3	⇨	λ=4 pt/0.75hr=6 pt/hr	7-12 and 2-5
λ=2 pt/0.5hr=4 pt/hr	12-2 (lunch)		λ=2 pt/0.75hr=3 pt/hr	12-2 (lunch)

Pros:

Cons:

Recommendation 2: More Rooms

Recommendation 3: More Physicians

PATA Improvement Recommendations

MGH PATA Wrap-Up

1. Capacity problems require systemic and quantitative analysis: remember the extra room and extra physician requests

2. PFD → utilization analysis → congestion analysis → financial/impact analysis

3. Process analysis and reengineering opportunities in health care

4. Management of change is a major challenge

15.761

2/24

PATA case due

HW 1 4.1/5 avg

In folders

The Goal reading due April 7

No recitation due today

PATA / MGH

- Video
- First anisteasdogist
- PATA

Stake holders

- Patients
  - multiple qu
  - wait time
- Nurses
  - long hrs
  - uncertain hrs
  - duplicate info
- Charge Nurse
  - lots of info
  - more control of info

(2)

Hospital

- satisfaction
- so don't lose referrals
- cost-center
- want more patients
- only 65%
- face of hospital

- avoiding mal-practice
  - assume doing work properly
  - just not efficently

Surgeons

- want stuff done in PATA
- or delays their time

MDs

- time

How to fix

1. Gather data
   - to see where bottleneck is
   - ~~to see~~

   Look at other hospitals

Analize

i. Should have looked at 55 people/day
Not 8 hr

(3)

Plus he assigned more resources ~~th~~ (lab techs)
~~than~~ to shorter process

And he did not pool resources

From a patient point of view
- So don't consider rooms
- so are we missing stuff
- Prof: consider later

Oh and less patients arrive during lunch
- Opps we missed

One student thinks this is the bottleneck
So our diagram

And hospitals can't add rooms easily
- ~~d~~ so don't look at it this way

Nurses are the bottleneck
- (Is his ρ too low?)
- You cap at 1
  ↳ (So ~~ma~~ I'm guessing ~~show~~ oh to show bigger than 1)
  (But in queueing formula use 1 as max)

(4)

How define bottleneck
- the highest utilization
^ unless have info about utilization

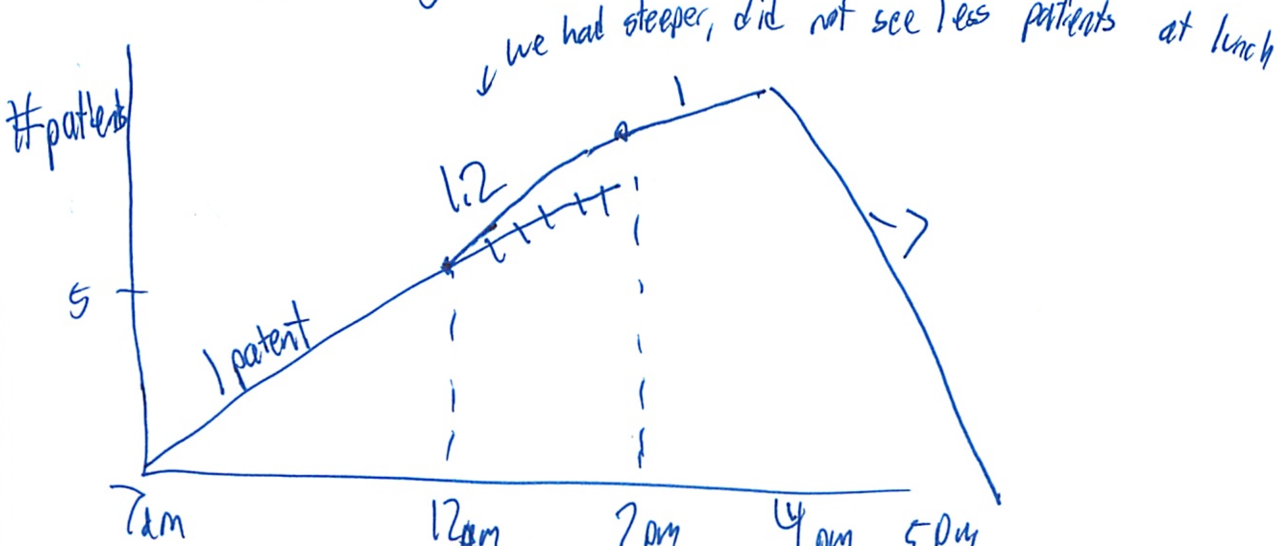
Zoom into nurse process
(Why do the HW before being taught)

Buildup rate $\lambda - \mu$

- don't think we used

Throughput from one to other
- So input on other later steps not 8
- but I think he used

With GGN ρ must be < 1 and its not, so can't use
So buildup diagram



? Can start at ~7:45 am - just shifts ans - same qualatative

(5)

Assumed $\lambda = 8$

- Third process
- but no bottleneck before this
- (we messed this up too) for bottlenecks after this

Now calc wait time

-

~~area~~ height of triangle = # of patents in queue

area = patients' cumulative wait time

avg ~~wait time~~ height = $\frac{area}{9.2}$ = L = avg # in queue

$W = \frac{L}{\lambda}$ = avg wait time = $\frac{\text{cumulative wait time}}{\text{\# patients}}$

(Nice way to think about)

area = $\frac{5.5}{2} + \frac{5+7.4}{2} + \frac{7.4+8.4}{2} + \frac{8.4 \cdot 1.2}{2} = 37.8$

$L = \frac{37.8}{9.2}$

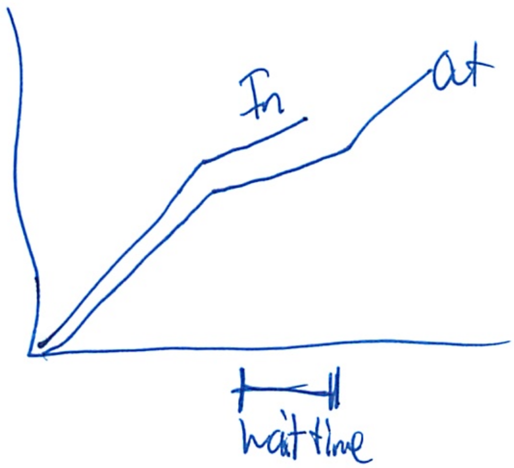
$\lambda = \frac{6.8+4.2}{9.2}$

$W = \frac{L}{\lambda} = 40$ min

(we did not do this)

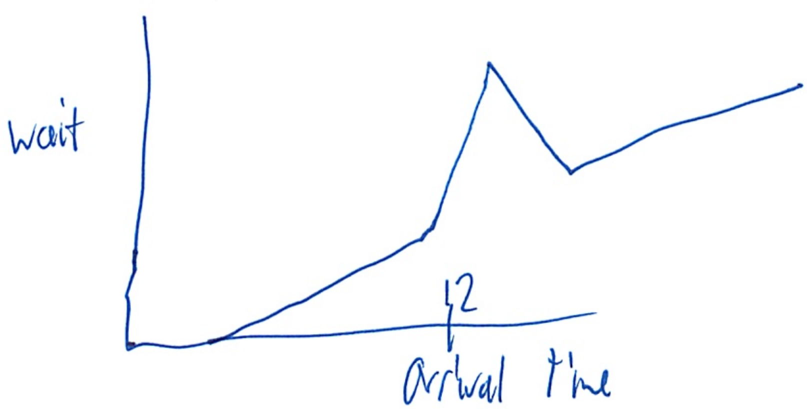
(e)

Can plot cumulative
- do time step
- Plot inflow + outflow



(Learn, study, use this graph!)

So plot wait time as fn arrival time



Under or over estimating?
- Under since no variability
(also) - over: since less than 8 people hr
- and people may not show up

(7)

Now look at bigger process

Can use GCN formula to calc wait times b/w steps
└ long-run

(we should have done this!)

	Wait		Process
Vitals	6.1 ← GCN		10
RN	40 + 5 ← pre chart	← Build-up	27
MD	8.6 + 10	← GCN	37
Blood	0		5
	70 wait		79

Total visit length 149 min = 2.5 hrs

(Nice chart - should have done better job realizing had to do this calculation

---

What they suggest

45 min

4 pt / .75 hrs = 6 pt / hr

2 pt / .75 = 3 pt/hr lunch

Could drop queue

But less hrs

(8)

Cut processing capacity in half:

8 → 6 : pt/hr ← correct

or 8 → 4

(I think I miscounted)

Staff works to 6 anyway

Would certainty to 6 be better than 6 variability

But can show costs in surgery

Not best solution

More Rooms

Before not had to have patient switch rooms

- Improved psychology

Or not enough rooms to providers

- really don't want providers to wait for rooms

(we did not look at current rooms scenarios

- just idea - that patients only in room when matters

Not the change they made

(4)

Assume that RNs are not the bottleneck

Activity time for rooms 27 + 15 + 37 + 10 = 79

μ Processing rate $\frac{60}{79} = .76$

Capacity 12 · .76 = 9.1

Util .76 - .87 depends on which λ

- ~~depends on~~
- high
- but not bottleneck

<u>Rec 3 More providers</u>

<u>MD</u>

If ↑ nurses, then, bottleneck at MDs
93% will have issue
- GCN queuing
(It seems so straightforward when have ans!)

<u>Nurse</u>

Of course add

Trade a technician for a nurse

Charge Nurse - make her job eaiser
- IT, automation

(10)

Will help cut variability
But not eliminate

Provider variability chart
- Look at their avg, variability, min, max
(But lots of political danger in this)

Best practices, standarization

One student tried changing σ in GCN model
- did not make much of a difference

IT
Paperless
Monitoring
Incentives

Some charge nurses better

Recs
- Paperless
- Switch RN → NP/MD
- Team/coordination
- Standrdize
- Continuous monitoring

(11)

Need to manage changes

Scanning system

Simulation results

- (How do you run these?)
- (Just write program to generate RVs I guess)

(Tweak parameters)

Sensitivity analysis on parameters

He just assumed paperless will take stuff at

- not add
- (Risky I think)

I liked this case - learned stuff

Just wish was not graded till after learned

TA Review

Email was ~~before~~ after I did for CS

Did not look at peak arrivals

after I did

- was it because deterministic

Quite off in terms of # of servers

85 calls/~~hr~~ half hr = 17 servers needed

170 calls/hr ← did not show up to 170 peak

- only up to 110

Limitation of linear staffing rule

- no variability b/c CS problem

But must assume some variability

Benefits of centralizing

- add calls
- call patterns different - smoothing demand

Clear that understand

<u>Case Reading</u> Reingereering Work 2/28

Very interesting how Ford blew all assumptions out of the water when reengineering its processes

Did not realize such shocking change was possible

Think about ~~ll~~ buying a Sprint phone
- Complete + utter mess

Based on old tech + assumptions that no longer hold

Quality & innovation more important than control

More about ~~high~~ high quality people
- than adaquate clerks

But ford lost some stuff
- Pushing back AP
- But personell savings made up for it?

Organize around outcomes, not tasks

Put decision point where work is performed

Basically trust your workers to do more than 1 task

Manager supports + facilitates not controls + supervises

Gives new responsabilities to people

Treat vendors more as partners

Might have to change HR policies like promotion

②

(It does not say anything about potential downsides)

Culture: doing work more important than supervising

(Military does not do this at all)

Hard to do b/c lots of cynics

Front line does not want to see change

Announcements

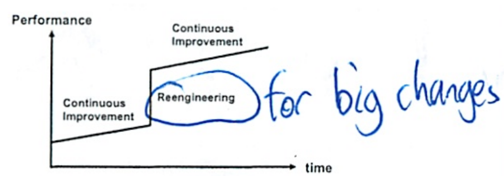
1. Recitation this week on the PATA case
2. Guest lecture Gavin DeNyse from HP on April 13, 11.30-1, E51- 345

CVS Pharmacy Service Improvement

1. What is the existing fulfillment process and what are the problems?
2. Proposed process and IT changes?

Process Design (Reengineering)

- Focus on the organization of work, not its substance
- Reengineering can yield dramatic performance improvement

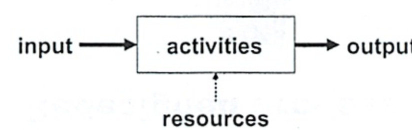


	Reengineering	TQM / 6σ
Impulse	top → down	bottom → up
Scope	global	local

Note: Many slides and examples in this lecture are derived from material initially developed by Dr. Michael Hammer

OM Definition: The Process View

- *Operations Management* is the activity of designing and managing processes in order to achieve results of value to the various stakeholders of an enterprise
- A *Process* is a set of coordinated activities relying on various resources to transform inputs into outputs

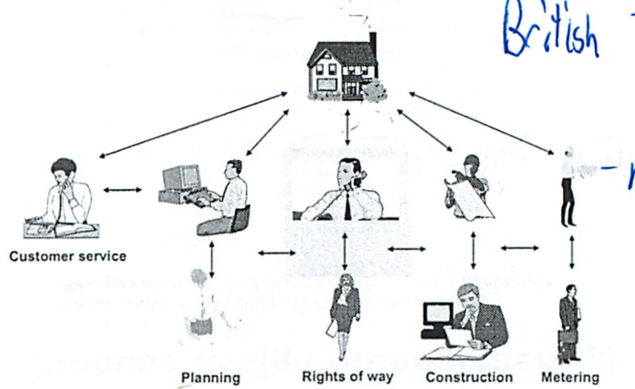


3/11

Called "assembly line"

Old Phone Connection Process

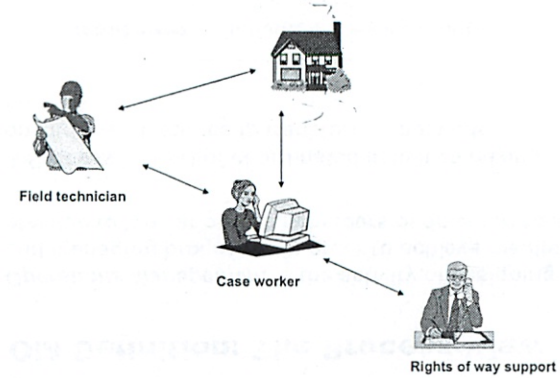
British Telecom



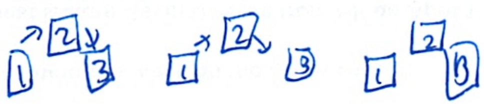
– not built for service

each person does a specialized narrow task

Redesigned Process



End-to-End Principle



Rationale?

End-to-End Principle Cont'd

Limitations?

key

The Reengineering Revolution

	Industrial Revolution	Reengineering Revolution
Labor market	Unskilled labor Tight class barriers	Skilled labor Permeable class barriers
Market goals	Standardized Volume	Customized Response Time
Organization	Scalable	Integrated
Management	Control Reports / Audits	Support Customer Feedback
Design principles	Division of Labor Simple Tasks Complex processes	End-to-end work Complex Tasks Simple processes
Symbol	Line worker	Case worker

Process Design Levers / Variables

Process design is not about what (input) you do, but how you do it:

Design Lever	Example
Who	
When	
Where	
Whether	do we even have to do this?
What order	
What frequency (how often)	

G/G/N Queuing Formula

Approximation with an infinite buffer size:

L changing N does not change process

$$L = \frac{\rho^{\sqrt{2(N+1)}}}{1-\rho} \times \frac{C_A^2 + C_S^2}{2}$$

L	average number waiting
ρ	capacity utilization (= λ / Nμ) changing process time
C_A	coefficient of variation: inter-arrival times
C_S	coefficient of variation: service times
N	number of servers

Process Design Principles 1990

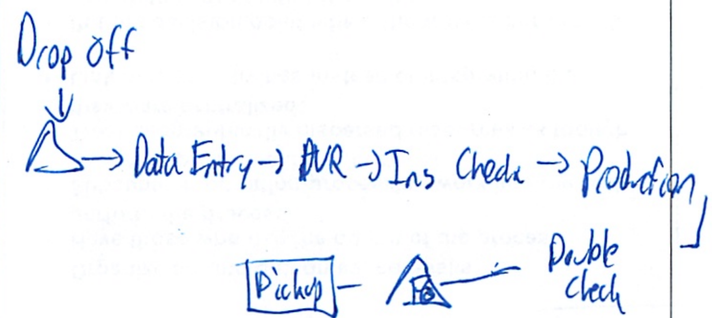
from the reading

- Organize around outcomes, not tasks
- Have those who use the output of the process perform the process
- Subsume information-processing work into the real work that produces the information
- Treat geographically dispersed resources as though they were centralized
- Link parallel activities instead of integrating their results
- Put the decision point where the work is performed, and build control into the process
- Capture information once and at the source

Process Design Principles 2000

- Work should be done by whoever is in the best position to do it
- A process should be performed by as few people as possible
- Do work at the best time for it to be done
- Location is a variable, not a given
- Strive for simplicity
- Structure in terms of alternatives rather than exceptions
- Consider the context when performing work
- Control must be subjected to cost-benefit analysis, just like everything else

CVS– Flow Diagram



CVS– New Process

Work Assignment Principle

⇨ *Have those who use the output of the process perform the process*

Examples:	HP Procurement, ABP, Customer repair, Shouldice hospital
Rationale?	
Limitations?	
2000:	*Work should be done by whoever is in the best position to do it*

Re Captcha

ESP game for labling pictures

Information Principles

1990: *Subsume information-processing work into the real work that produces the information*
Capture information once and at the source

Examples: Ford A/P, Hospital vitals

Rationale: Simplify, reduce interface, reduce NVA

Limitations: Incentives, Constraint management

process info when you got it

Control Principles

1990: *Put decision point where work is performed, build control into process*

2000: *Control must be subjected to cost-benefit analysis, just like everything else*

Examples: Progressive Insurance, Ford A/P, Newspaper vending machines, Toyota Poka-Yoke, Hertz Gold Club

Rationale?

Limitations?

Is control cost effective?

Don't over control

not always control

Time & Location Principles

2000: *Do work at the best time for it to be done*
Location is a variable, not a given

Examples: Building Inspector, Insurance Processing

Rationale: reduce NVA, increase motivation, hierarchy inertia

Limitations: Capacity requirements

Parallel Tasks Principle

1990: *Link parallel activities instead of integrating their results*

Examples: Multiple bank divisions, Product Development

Rationale?

Limitations?

Successful Reengineering Guidelines

- Clean sheet thinking
- Nothing off-limit
- Surface and challenge all underlying assumptions
- Creative use of IT
- Start with customer and see what happens (no organizational restrictions)

Reengineering Project Steps

Top Ways to Fail at Reengineering

1. Don't focus on processes
2. Spend a lot of time analyzing the current situation
3. Proceed without strong executive leadership
4. Be timid in redesign
5. Go directly from conceptual design to implementation
6. Reengineer slowly
7. Place some aspects of the business off-limits
8. Ignore the concerns of your people

Process Design Wrap-Up

1. Industrial revolution Vs. Reengineering
2. Design principles: examples, rationale, limitations
3. Reengineering execution: steps and pitfalls

<u>Recommended follow-up readings:</u>

Reengineering the Corporation by M. Hammer and J. Champy

The Reengineering Revolution Handbook by M. Hammer and S. Stanton

15.761 Reengineering + CVS

~~2/29~~ 3/1

Sometimes can dramatically change process
¿Looking for volume
Drop up employment ?

Redesigned
- no re learn
- field info much more upfront
- cust knows where is in process
- single point of contact
- fewer workers
- less specialized
- IT

Called end-to end principle
- around outcomes not tasks
- what cust needs

Disadvantages - scale
- need better trained employees
- sharing best practices
- lost of consistency
- unless controls

(2)

CVS

- cust service
- high error rate
  - bad for customers
  - bad ~~for~~ for employees
- lots of reasons why
  - drug to drug interaction
  - insurance
  - over ~~paying~~ charging b/c insurance
  - out of stock
  - out of refills

Problems

- bad service

Suggestions

- Enter data immedidtly
- Lab tech as case manager?
  (I don't know - shifts
  - may not be right
  - but topic of day)
- Collect info at drop off
- Pharmists at drop off

(3)

~~Cust as~~

We tell cust when pesciption is ready

Could do both checks at once

Don't fill presciptions if Qx fail

Do checks when cust are there w/ data entry

- when cust are in place

Can we ~~sepeat~~ have people wait for drop off?

- Look at arrival rates

Do FIFO - not one hr before

Solution	Dropoff, Data entry Ins check in one

Online + Phone entry

- Saves errors

Inventory check

- now done in production

Have doctors send pesciptions online

~~DUR~~ Solution; DUR + QA same

- after production

very low IT investment

Also do production right after drop-off

(4)

Also have to convince people to use new process

Not easy to convince workers

Get them involved

Principles

- get ~~people~~ Customer to do process for you
  - quick service restaurants
  - ikea build yourself furniture
  - ~~che~~ self check out
  - online banking
  - eticket
  - or kiosk to check in
- you do this for free
- but psychology for queueing
- Some people did not like it
- them having to do more work
- quality may suffer
- fraud!
- elderly don't want to do it

(5)

- ~~Somet~~
Onlide ~~do~~ less errors

Don't over control

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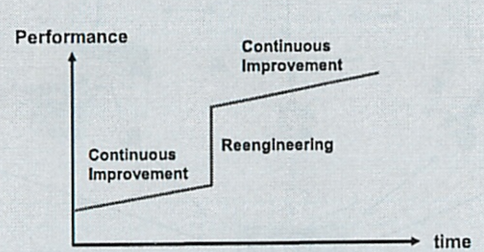
CVS Pharmacy Service Improvement

1. What is the existing fulfillment process and what are the problems?
2. Proposed process and IT changes?

Solutions

Process Design (Reengineering)

- Focus on the organization of work, not its substance
- Reengineering can yield dramatic performance improvement

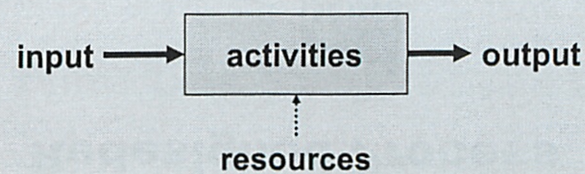


	Reengineering	TQM / 6σ
Impulse	top → down	bottom → up
Scope	global	local

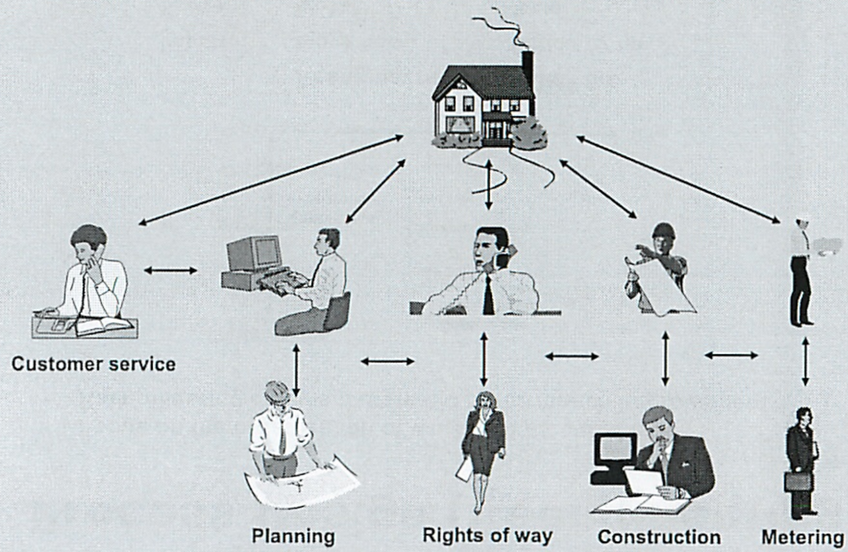
Note: Many slides and examples in this lecture are derived from material initially developed by Dr. Michael Hammer

OM Definition: The Process View

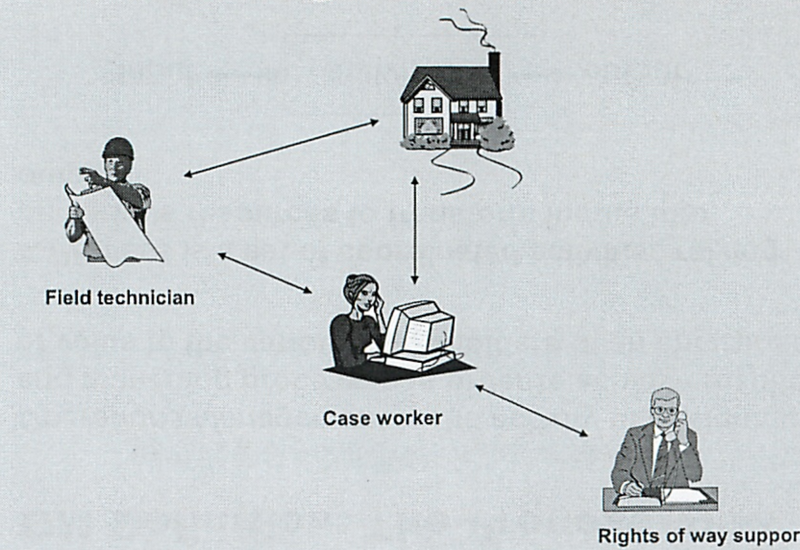
- *Operations Management* is the activity of designing and managing processes in order to achieve results of value to the various stakeholders of an enterprise
- A *Process* is a set of coordinated activities relying on various resources to transform inputs into outputs



Old Phone Connection Process

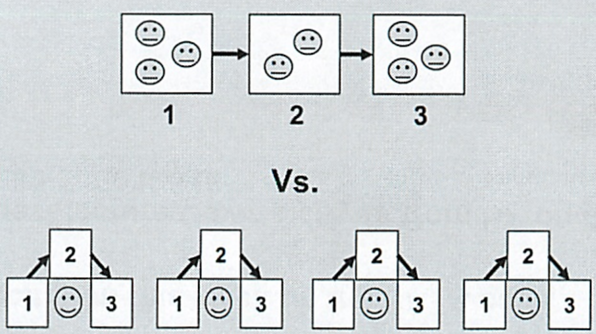


Redesigned Process



End-to-End Principle

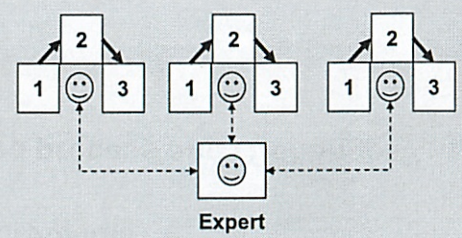
Organize around outcomes, not tasks



Rationale?

End-to-End Principle Cont'd

Limitations?



The Reengineering Revolution

	Industrial Revolution	Reengineering Revolution
Labor market	Unskilled labor Tight class barriers	Skilled labor Permeable class barriers
Market goals	Standardized Volume	Customized Response Time
Organization	Scalable	Integrated
Management	Control Reports / Audits	Support Customer Feedback
Design principles	Division of Labor Simple Tasks Complex processes	End-to-end work Complex Tasks Simple processes
Symbol	Line worker	Case worker

Process Design Levers / Variables

Process design is not about what (input) you do, but how you do it:

Design Lever	Example
Who	
When	
Where	
Whether	
What order	
What frequency (how often)	

G/G/N Queuing Formula

<u>Approximation with an infinite buffer size:</u>

$$L = \frac{\rho^{\sqrt{2(N+1)}}}{1-\rho} \times \frac{C_A^2 + C_S^2}{2}$$

L	average number waiting
ρ	capacity utilization ($= \lambda / N\mu$)
C_A	coefficient of variation: inter-arrival times
C_S	coefficient of variation: service times
N	number of servers

Process Design Principles 1990

- Organize around outcomes, not tasks
- Have those who use the output of the process perform the process
- Subsume information-processing work into the real work that produces the information
- Treat geographically dispersed resources as though they were centralized
- Link parallel activities instead of integrating their results
- Put the decision point where the work is performed, and build control into the process
- Capture information once and at the source

Process Design Principles 2000

- Work should be done by whoever is in the best position to do it
- A process should be performed by as few people as possible
- Do work at the best time for it to be done
- Location is a variable, not a given
- Strive for simplicity
- Structure in terms of alternatives rather than exceptions
- Consider the context when performing work
- Control must be subjected to cost-benefit analysis, just like everything else

Work Assignment Principle

→ *Have those who use the output of the process perform the process*

Examples: HP Procurement, ABP, Customer repair, Shouldice hospital

Rationale?

Limitations?

2000: *Work should be done by whoever is in the best position to do it*

Information Principles

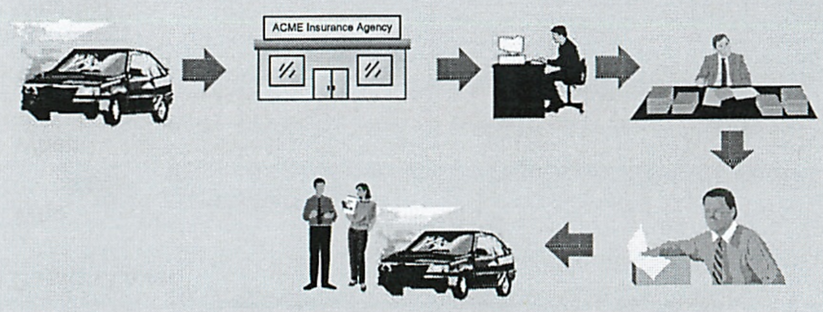
1990: *Subsume information-processing work into the real work that produces the information*
Capture information once and at the source

Examples: Ford A/P, Hospital vitals

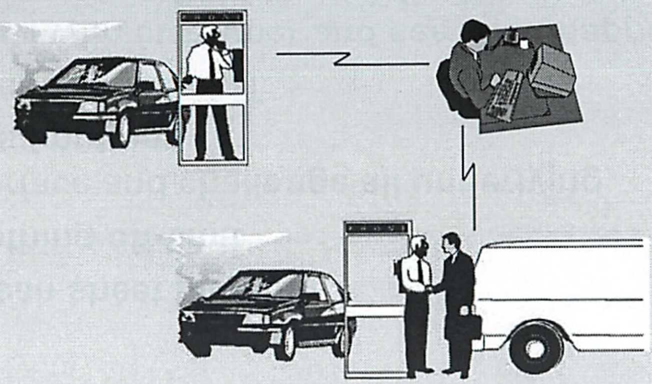
Rationale: Simplify, reduce interface, reduce NVA

Limitations: Incentives, Constraint management

Insurance Claims Processing



Insurance Claims Processing



Control Principles

1990: *Put decision point where work is performed, build control into process*

2000: *Control must be subjected to cost-benefit analysis, just like everything else*

Examples: Progressive Insurance, Ford A/P, Newspaper vending machines, Toyota Poka-Yoke, Hertz Gold Club

Rationale?

Limitations?

Time & Location Principles

2000: *Do work at the best time for it to be done*
Location is a variable, not a given

Examples: Building Inspector, Insurance Processing

Rationale: reduce NVA, increase motivation, hierarchy inertia

Limitations: Capacity requirements

Parallel Tasks Principle

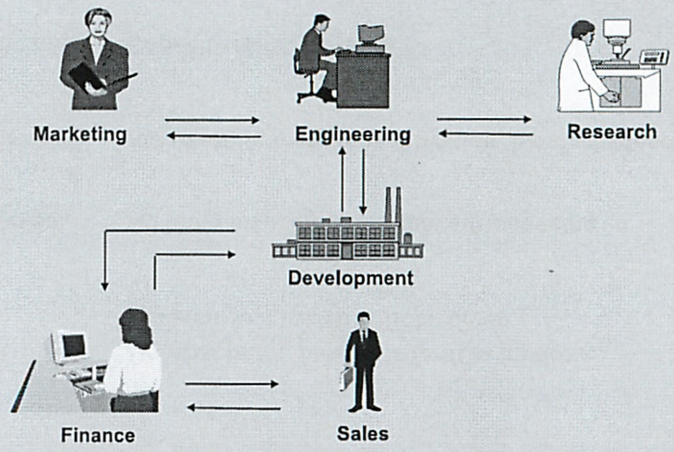
1990: *Link parallel activities instead of integrating their results*

Examples: Multiple bank divisions, Product Development

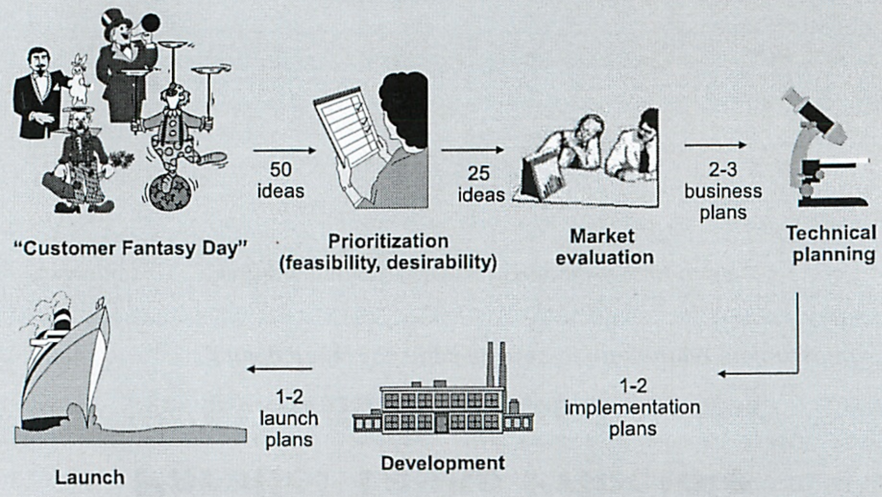
Rationale?

Limitations?

Traditional Product Development



3M Product Development



Successful Reengineering Guidelines

- Clean sheet thinking
- Nothing off-limit
- Surface and challenge all underlying assumptions
- Creative use of IT
- Start with customer and see what happens (no organizational restrictions)

Reengineering Project Steps

Top Ways to Fail at Reengineering

1. Don't focus on processes
2. Spend a lot of time analyzing the current situation
3. Proceed without strong executive leadership
4. Be timid in redesign
5. Go directly from conceptual design to implementation
6. Reengineer slowly
7. Place some aspects of the business off-limits
8. Ignore the concerns of your people

Process Design Wrap-Up

1. Industrial revolution Vs. Reengineering
2. Design principles: examples, rationale, limitations
3. Reengineering execution: steps and pitfalls

<u>Recommended follow-up readings:</u>

Reengineering the Corporation by M. Hammer and J. Champy
The Reengineering Revolution Handbook by M. Hammer and S. Stanton

Reading

3/2

6 Sigma - nice persuasive article about why
- good use of #s

Big campeign

Aimed at line workers

Toyota

Lots of slogans + sayings

lots of training

How can this complex ops be in a case?

Largly about people

Make defects stand-out

lots of sales forcasting

switch over b/w modes seamslessly

¿physical order sheets for parts? kanbans

Small repair clinic

* focus on low cost suppliers, not low-price
  - find their ~~pr~~ cost data

Just in time seats
- 30 min drive
- ~~one~~ 1 truck load staging area

Multiple-vendor policy

(2)

Seat variation too large
build rest of car in meanwhile
but why seat errors?
- lots of possibilities
  KFS big part of responsibility
  Missing part or material flaw

Toyota DNA

- many failed to recreate
- not cultural ; honda has not copied
- ~~da~~ looks strict
  - but actually very flexible
  - rigerous problem solving method
  - scientific method
  - learning org
  - ~~measure~~ very detailed instruction steps
  - help measure to the second
  - Socratic: ask emp what they are doing
  (Is strictly specifing everything worth it?)
  - more direct connection w/ supplier

③

Employees incentived to ask for help

↳ Others encarage employees to solve problem on own

Get to root of problem + solve it

No forks or loops in supply chain

↳ (other case said opposet)

Parts flow to a specific point

Designated people to assist

And designated backups

Training for suppliers

Andon cords are "counter measures" not "solutions"

↳ if something better comes up, they switch

keep inventory seperate for diff reasons

Saftey stock - machine downtimes

batch - changeover takes time

voltiity of cust demand - buffer stock

and try to reduce need for each

Org styles not standardized

↳ What meets need best

target batches of 1

(4)

Does bend rules if warented

Their rules allow flexibility

15.761 Toyota

Happy customers
Green + sustainable image

Video
don't lift heavy stuff
everyone has their task
- not rushing, but steady pace
manifest w/ options

Principles

Continuous improvement
waste reduction
identify problems rapidly
rapid problem solving + escalation - jidoka
everything is specified

4 rules

project displine

1. standarization of Tasks
2. " Communication
3. " Process
4. " Continuous improvement

(2)

Also in process
- standard
- like fulfilment at Amazon

Processes are contisously designed

Toyota chose to be highly process-centered
- other companies hero-centered, aka firefighting

Process-centered - no heros,
    people never written up
    process + team centered

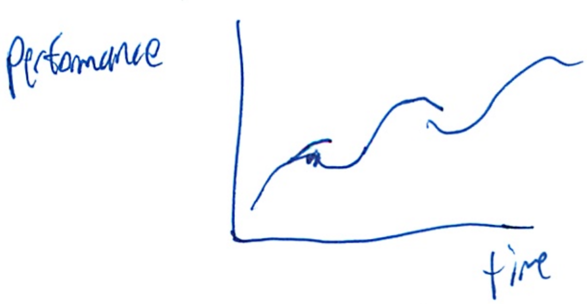
Culture of problem solving + improvement
- high level of employee involvement

Go + see problem
- not solved sitting behind your computer

~~Just in Time~~

Scientific model

Creativity + innovation through the process
- ; so innovation is incremental



Cell phones — radical innovations
reg Phones — incremental

③

Have not seen next 5

- Zipcare
- Better Place
- Nano

Just in Time

3 principles of forcasting
1. The forcast is always wrong

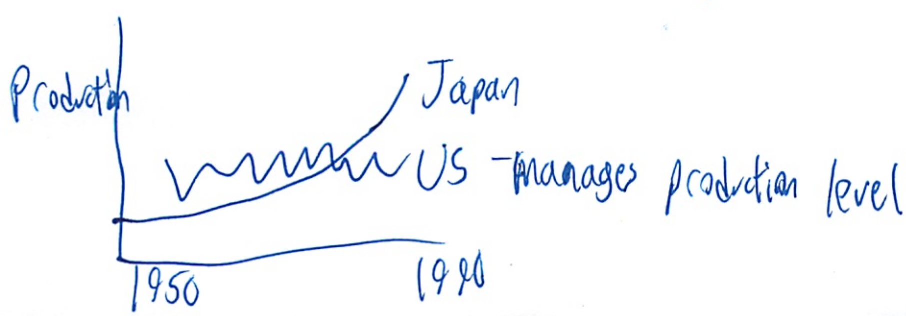
Toyota is the strong Maestro in this supply chain
- Some don't have any Maestros

Toyota shares supply chain plans w/ all suppliers

Forcasting is always wrong - but constantly upgraded

A pull system
- only produce when they get an order

Toyota tries to manage demand
"Machine That Will Change the World"



(4)

Most cars are bought off the lot
  80-90%

BMW in Germany mostly made to order

Several weeks for made to order
  L 2 months

Demand management
  - restrict supply so some excess demand
  - long term sustainable growth
    - to build trust w/ employers + suppliers

Respect for people is also part of TPS

Heijunka - smoothing

Dell - price you paid was based on what was in stock

Five Whys - finding root cause → solution

Need trust so people don't hide things
  - blame system not people

Toyota careful for selection + training
  - attitude
  - train skills

Had to engineer low changeover time

Or all options in - just disabled
  - ~~lb~~ production costs lower than putting unused stuff in

(5)

Other companies do this

McD

Q How can a small company do this?

Walmart squeezes suppliers

Perhaps go in and make a deal, be nice

2 ways to low cost

- Squeeze
- Collaberate

Seat Problem

What is the seat problem or problems?

increased complexity → more defects?

transition

~~a~~ learning - can't find pattern

learning cost

more places to go wrong

hook damaged

big backlog of cars to be fixed

replacements not coming in right

~~[illegible]~~ order form hard to read

⑥

Usually stop the line
- cognitive dissonance

---

diff ways to solve each

TPS - can we afford to stop line?
- financial analysis has not been talked about at all

Process
- hard design engineering request lost in shuffle
- global manufacturing is harder
- same problem in last year

Prof: you can't pick + choose feature
- its an integrated system
- other companies fit ~~these~~ parts together in a diff system
- not Toyota Production Attributes

Want to fix things ASAP
Send a runner back + forth
Sent an engineer

Littlefield Debreif

Littlefield

GCQN to make decision

Was in recitation

No bottleneck

Priortizing step 2 vs 4 - only when constrained

- 4 to get stuff out by lead time

- ~~$$~~

Can dump jobs in 2nd situations

MSD Chap 7 Variability ~~Reading~~

3/6

- Waiting is visible + annoying

① Occurs when demand temporarily > supply
  - Utilization > 100

② or if variability
  - On average utilization < 100
  - but the variability causes lines sometimes

(This seems to be the key focus of the lecture part of the class)

- variability is secondary effect from capacity problem for ①
- " is main effect in ②

7.1 Unrealistic Call Center

Say calls take 4 min

~~A~~ And call every 5 min

So should be no wait time!

Flow rate = 12 calls per hr

Capacity = 15 calls per hr

~~Professor I messing up symbols~~

$$U = \frac{\text{flow rate}}{\text{Capacity}} = \frac{12}{15} = 80\%$$

No one ever has to wait!

②

But of course it's not that simple!

Arrival patterns random

Calls take different lengths of time

So many custs do have to wait

↳ while many ~~secs~~ minutes CSR is idle

Plus calls build up on hold

- takes a while to go back down
- and meanwhile people have had to hold for some time

Saw in chap 6 → buffer or suffer

↳ but here custs get buffered

↳ and thus suffer

7.2 Variability: Sources + Measurement

(oh no, not this again!)

- variability from inflow of customers
- variability in activity times
  - ↳ guests who check in may have problems
- resources not always available
- random routing
  - ↳ (I guess when looking at overall, "total" process
- Coefficient of variation = $CV = \frac{\sigma}{\mu}$ – so know how important variation is

(3)

7.3 Analyzing an Arrival Process

Arrival times $= AT_i$

Interarrival times $= IA_i = AT_{i+1} - AT_i$

Do data analysis to make sure # are of high quality

Is the process stationary - or will it change?

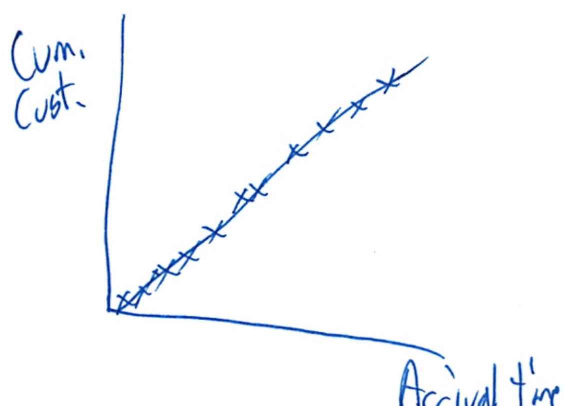
Are arrivals exponentially (Poisson) distributed?

For a call center - arrival rate is "seasonal" by hour

Know diff. due to seasonality - reflects a pattern

variability - simple random

Plot the arrival times



If follows straight line - is stationary

If curved, is seasonal

Break into smaller pieces till line is straight

└ stationary at the micro-level

(4)

Inter arrival times often follow an exponential dist.

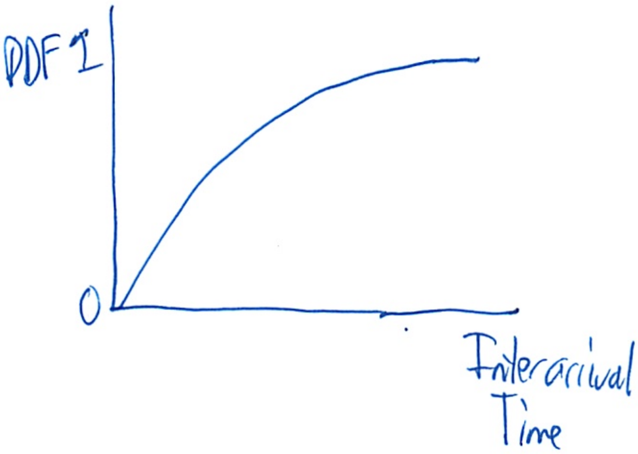
$$\text{Prob}\ (IA \le t) = 1 - e^{-\frac{t}{a}}$$

a = avg inter-arrival time

"Poisson"

fits emperically

memory less - does not matter what happend in past



$CV = \frac{\sigma}{\mu} = 1$

<u>Sometimes not exponential</u>

- like if schedled every hour

$$CV_a = \frac{\sigma_{IA}}{\mu_{IA}}$$

(5)

7.4 Service Time Variability

Actual duration of call is random as well

mean + std. dev capture the variation

~~..~~ Calc CV_p

7.5 Predicting Waiting Time | Resource

- Inputs: inventory, flow rate, flow time
- one resource
- unlimited buffer space

$$\text{Utilization} = \frac{\text{flow rate}}{\text{Capacity}} = \frac{1/a}{1/p} = \frac{p}{a} < 100$$

a = avg arrival rate

p = avg service time

Overall:

Flow time = Time in Queue + Activity time

$$T_q + p$$

Inventory = Inventory in Queue + Inventory in Process

$$I_q + I_p$$

With only 1 server I_p is 1 if in service

Prob that server is ~~...~~ busy = utilization here

(6)

$$\text{Avg Time in queue} = \text{Activity time} \cdot \frac{\text{Utilization}}{1-\text{Utilization}} \cdot \frac{CV_a^2 + CV_p^2}{2}$$

If dist are not exponential, then this is approx.

Waiting time is a multiple of activity time

Utilization must be < 100%

Waiting time grows w/ variability

This is avg time in queue!

This is for steady-state systems

First few patients when system opens would have lower ~~weight~~ wait times

Use Little's Law to compute inventory from this

$I_q = 1/a \cdot T_q$ ← only for wait line as mini-process

I_p = prob of ~~caller being~~ server being used (since only 1)

7.6 Predicting Wait Time - Multiple Resources

Now have identical, parallel servers

$$\text{Utilization} = \frac{\text{Flow Rate}}{\text{Capacity}} = \frac{1/\text{Interarrival Time}}{(\#\text{resources}/\text{Activity Time})}$$

$$= \frac{1/a}{m/p} = \frac{p}{a \cdot m}$$

7

$$\text{Avg Time in Queue} = \frac{\text{Activity time}}{m} \cdot \frac{\text{Utilization}^{\sqrt{2(m+1)}-1}}{1-\text{Utilization}} \cdot \frac{CV_a^2 + CV_p^2}{2}$$

m = # of servers

here ~~wa~~ wait time is an approximation

Works best if u/m is high

$$I_p = m \cdot U$$

$$U = \frac{p}{a \cdot m}$$

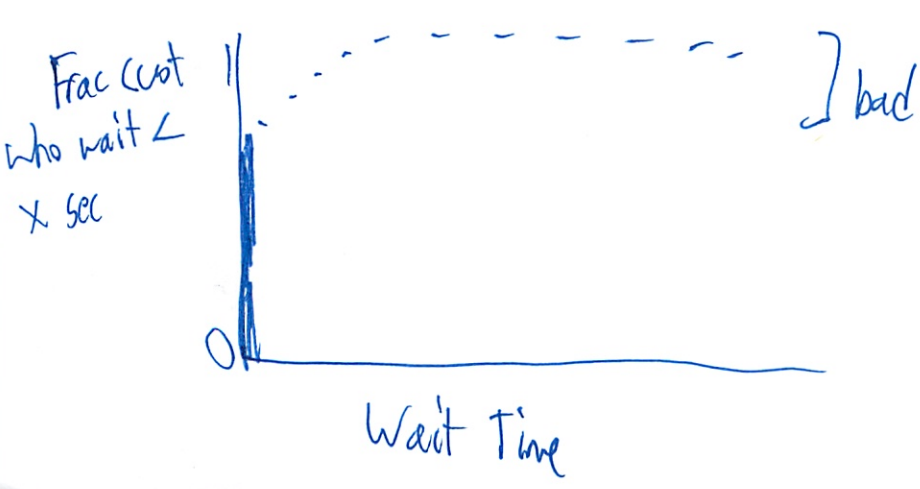
~~There~~

7.7 Service Level Problems

But custs don't care about avg service time - only them

Want # calls > target wait time (TWT)

Service level = P(wait time ≤ TWT)



8)

7.8 Economic Implications + Staffing Plan

Trade off service level + costs

800 # hold time cost ~~A~~ 2.05 cents/min

Service cost from CSR

Cost of direct labor = $\frac{\text{total wages } \text{~~\$~~}/\text{time}}{\text{flow rate } \text{~~cu~~}/\text{time}}$

If seasonal arrival rate – do for each "season"

More complex since breaks + length of work periods

7.9 Pooling: Econ of Scale

Avg utilization does not change

but waiting time ↓

Since at about ~85% util. wait time can go through the roof as queue builds

But with ~~less~~ more servers – at same avg utilization ~~85~~ 90%

is much lower wait times

But if lines not independent as custs auto go to shortest line in supermarket → little if any effect

– operators need a higher rate of skill since do multiple things

– ~~oper~~ for complex cases, lot of time getting up to speed

Could make things worse if some clerks assigned for complex processes

7.10 Priority Rules in Waiting Lines

assign priorities in a triage

Service Time / Shortest Processing Time

If you know tasks & customers that will go fast, doing them first will ↓ avg wait time

← (I do that for hw!)

Service-Time Independent

hard to know how long service time will be

So First-Come First Serve

Or priority based on urgancy (emergency room)

Or how good a cust you are

Avg wait time does not change

↳ even Last-In First Out avg still the same
— but unfair

7.11 Reducing Variability

Variability is enemy of ops

reduce arrival variability w/ appoitments

↳ but many people late/skip

best custs often arrive late

but may still have to wait for appointment

↳ does not change underlying demand

(10)

So incentives based on time

- early bird specials

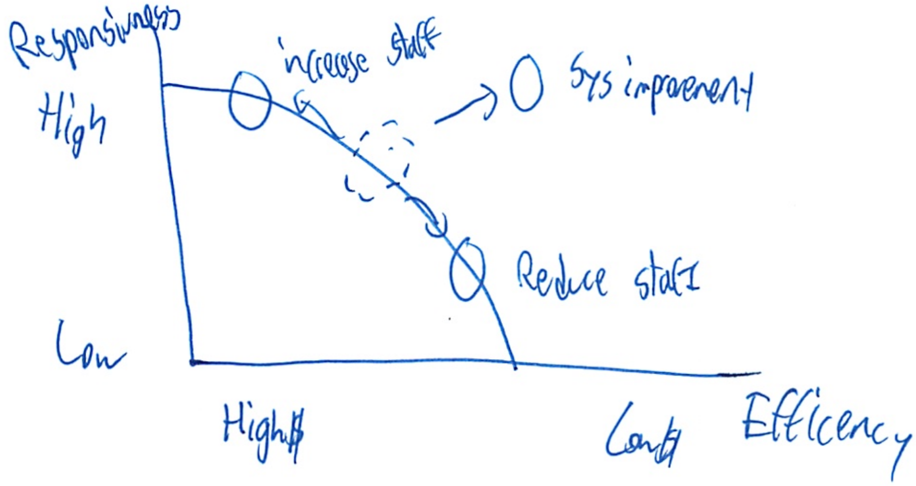
also internal operators not on avg

- training + technology
- know what to say when

reducing involvement of cust

¿Underlying quality problems?

7.12 Summary



Can do less-time critical work

- like outbound calls
- reports

(pooling is like bundling from 15.567!)