MIT Sloan School of Management
15.761 Introduction to Operations Management — Spring 2011

Littlefield Technology Simulation Exercise

Second Assignment Description

The new setup

The setup of the second assignment is similar to the first one, but with few changes. This section describes the new setup, and highlights the changes.

1) Time and Administration

New: This simulation will run longer than the previous one. There will be 36 simulated days per real day, 200 simulated days in total.

The simulation will go live on **Sunday, April 10 at 5pm** and finish on **Friday, April 15 at 5pm.**

In order to familiarize yourself with the simulation game interface, analyze early demand data and plan your strategy for the game, you can access your factory as early as **April 1 at noon** using the following URL: http://quick.responsive.net/lt/mit/entry.html and the login that you used for the first simulation. We have already simulated the first 20, so you are in charge from day 20, until day 200.

2) Jobs and orders

Same structure as in assignment 1: 60 kits per order, lot-sizing can be 1, 2, 3, 5, or 10. Default value is 1.

New: You can now manage the maximum number of jobs that you accept. In the first assignment, this was fixed at 1000. If the number of jobs you are actively processing in your factory is equal to that maximum number of jobs, any new incoming job will not be accepted, and will be lost, until the number of jobs being actively processed drops. This max number can be changed from the Customer orders icon. (max WIP limit)

3) Process stations

The processing time for various stations will be the same as the first assignment:

Processing Time (hours):

Step	Station	Set-up time (per lot)	Operation time (per unit)
1	1	0	0.2
2	2	0	0.1
3	3	1	0.05
4	2	0	0.15

Steps 2 and 4 are still of deterministic duration, whereas durations in 1 and 3 are random.

New: The number of machines pre-installed is *10, 15 and 5*. Also, the cost of each machine (for any station) is *$1m*. There is no retire price for the machines, and no usage/service costs.

4) Inventory of kits

You are now responsible for handling the inventory of your factory. In assignment 1, you had tons of inventory on-hand, which is no longer the case.

New: The starting on-hand inventory (on day 0) is 20,000 kits (remember each order is for 60 kits). You need to decide on a *reorder point* and *reorder quantity*. Once your on-hand inventory drops below the reorder point, an order is immediately placed for new kits, equal in size to the reorder quantity.

Each kit costs $200, and there is a fixed ordering cost of $500,000 that you have to pay for any shipment, independent of its size. The total cost of the order is immediately deducted from your bank account, once the order is placed. In case you do not have enough money to cover the costs of the order, the order is cancelled. Materials arrive to your warehouse exactly 7 days after the order is placed successfully (i.e., paid for).

166 is most?

In case your inventory is depleted, any incoming jobs that require materials will be queued, until sufficient materials arrive.

The default policy is a reorder point of 10,000 and quantity of 10,000.

Inventory can be managed using the Materials buffer icon.

5) Demand

Same structure for the average, i.e., linear increase in the first 90-110 days, constant afterwards until day 180, and then linear decrease to 0 on day 200.

New: In the first simulation, the peak demand during days 90-110 and 180 was roughly 50 orders/day. This number might be *different*.

6) Financial

a) Contracts:

In the first part, there was a single contract with your customers, with a face value of $25,000, quoted lead time of 2 days, and maximum lead time of 3 days.

New: You now have a choice between two contracts:
C1: $35,000, quoted lead time of 48hrs, and maximum lead time of 72hrs.
C2: $50,000, quoted lead time of 32hrs, and maximum lead time of 36hrs.

C1 is the default contract. You can change the type of contract at any time (with immediate effect, for all future incoming jobs) from the Customer orders icon.

b) Debt

New: There is *no debt allowed*. Your initial capital is *$75m*.

Note that since there are no direct holding costs for your inventory, no usage costs for the machines, no service charges, this will reflect upon the interest rate. In particular, the interest rate for the cash balance will be *200%* (annually, compounded daily).

So what per day .54%/day

Dates

Access will be granted on **April 01 at noon** to help you familiarize yourself with the simulation game interface, analyze 20-day demand data and plan your game strategy.

The simulation will go live on **April 10 at 5pm.** It will end 5 days later, on **April 15 at 5pm.**

Report

The simulation report for your group must be submitted in at the beginning of the last class in the course on **Wednesday, May 11 (Thursday, May 12 for Section B and C).** See the class syllabus for details.

Littlefield

What to do?
Big thing is inventory
  EOQ model
Also stuff from The Goal
  - priortize out
Limit incoming jobs to capacity
Lot ~~size~~ sizes - somewhere in middle
Buy machines to keep capacity
Any formulas to use?
  Reorder big since ordering cost large
  Go back + reread our chat transcripts

EOQ

- constant deterministic demand
- instant replentishment
  - later model fix?

No want generize order up to policy
Continous: Order Q when Inventory reaches R
  - good at large fixed cost

(2)

Q = EOQ solution

R = newsvendor solution

- need desired service level α

DDLT = Demand during lead time

DDLTRP = Demand dring lead time + review paiod

So lets say 95% = α

$$P(D \le q^*) = \frac{U}{U+O}$$

(D = demand, q = q ordered)

U = lost order = 35,000 ← per item or per order?

O = lost cost = .54%/day

but how many days?

Say 5 days

= 2.7 · 200 = 5.4

U = 35,000 / 60 kits = 583 / per kit

$$P(D \le q) = \frac{583}{583+5.4} = 99.08\%$$

(3)

$q^* = \mu + k\sigma$

$k = \Phi(\,)^{-1} = \Phi(99.08)^{-1}$

$= 1.19174$

~~Q~~ What is mean ?

Mean demand per time period?

$E[DDLT] = 7$ days $=$ #orders/day $\cdot$ 7

$\sigma[DDLT]$ – calc this

$R = E[DDLT] + 1.19\,\sigma[DDLT]$

?

~~lead time~~

7 days demand

$Q =$ EOQ sol

Inventory costs $= 0 \cdot$ Cost $= 5.4$

Order cost $= 500{,}000$

? is this per item?

~~So~~ WP does everything per year

So notes say $\cdot$ ~~...~~ $\frac{D}{Q}$

(4)

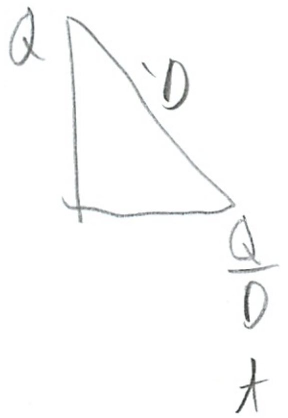
What is D?

Demand rate

What does that mean?

WP: annual demand

So Demand during an review



But how long is period
- depend on money?

It will tell us t ime

Say demand is DDLT for 7 days
- Same as before
- Say 400 for now

Well actually just look at

$$q^* = \sqrt{\frac{2FD}{CH}} = \sqrt{\frac{2 \cdot 500{,}000 \cdot 400}{5.4}}$$

↙ DDLT

↑ holding cost
- including everything

↖ purchasing cost

(5) = 8606

So time is

$$\frac{q}{D} = \frac{8606}{400} = 21.51 \text{ weeks}$$

But this is not realistic

My U is too low

- Little interest you get
- But the problem is you are ~~degree the~~ $ constrained
  - No debt
- So order as much as you can!

Still do middle lot sizes

- The Goal

Last time it was buying machines - how do we fix that?

Need to limit orders to our capacity

Try and go for C2

But how to figure out capacity?

- deterministic + uncertainty
  - but how to calc capacity

(6)

So 5 lot size

$.2 \cdot 5 + .1 \cdot 5 + 1 + .05 \cdot 5 + .15 \cdot 5 = 5$ hrs/lot
~5 items

But then items before/after - don't worry

Job is 60 items

So takes 12 ~~set of 2 machines~~ hrs on 1 set of machines

So roughly ~2 contracts per machine set

- But machine set is not linear

#1 $.2 \cdot 5$ → 1 ±

#2 $(1 + .15) \cdot 5$ 1.25

#3 $1 + .05 \cdot 5$ 1.25 ±

Actually is kinda balanced

Though 3 is random - but should even out

So

1	2	3
4	5	5

machines ~~is set set~~ is the multiple

Littlefield Starting

4/10

- ≈12 orders/day at start
- order 999
- change ~~All~~ 2 to pritorize completion
- fast contract now - for 2 days
- play w/ lot size
  - start 3 or 5
- Shut off new orders
- 1st few days hardest
- no debt
- rest of today is fine
- look at tmo
- better forecast after 1 day
- lead time 1.42
- does not close at night
- ~~we are too high~~
  we don't know # orders
  - so stick at standard contact

Littlefield

4/11
10pm

- Meeting w/ Michael
- Day 63
- We're 5th!
  - Dmmy 1 above
- We are on express contract
  - doing good
- Queve time is expenential
  - ~~[illegible]~~ GGN
- Look at util axis!
- 3 is bottleneck
  - buy some machines
  - Look at jobs
  - How much time w/ 1 machine
    - So 1 1.25 1.25

    One job every 12 hrs
    ^ 60 kits

(2)

Jobs are linear upward

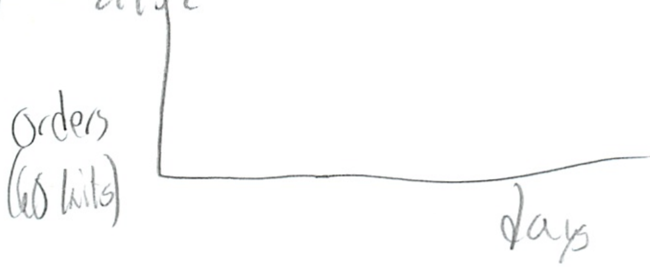
24 real hrs ≈ 40 days

; Meet everyday to predict demand

Just monitor + buy what need

Slope = 0.261

y int = 2.152



Day ~~60~~ 63

= 18.53 Jobs

Day 100

= ~~[illegible]~~ 28.25

$\sigma = 5.696$

So what to do?

1 st dev

or newsvendor to know # of st devs
w/ α

(3)

Before $k = 1.19$ # of st dev for $\alpha = 95\%$

$S_0 = \mu + k\sigma$

$= 28.25 + 1.19 \cdot 5.69$

$= 35.02$ jobs

So how many machines is that

- Maxed out now
- We do a job in 12 hrs
- 36 hrs
- Could use GGN
  - but mostly w/ few processors

$L =$

Do for now

What happens when add 1 more

Do for 3 - biggest bottleneck

(4)

N = 5

P = util = 1 ↓ above 1

C_A = Assume 1

C_S = " normal

$$L = \frac{1^{\sqrt{12}}}{0}$$

P = .99

L = 96 avg # waiting

Real life

186 - way over capacity

What do we want this to be ?

Looking at dates

- around date 26 - capacity = .7
- so # orders on day 26 ≈ 20

(5)

So 20 is max

- exponential ?
- trails off ?

5 machines · 12 hrs ~~[illegible]~~

5 jobs = 12 hrs
10 " = 24 hrs

Much lower than 20 jobs in 24 hrs
Mike got ↗

Actually he has ~15

We are expecting 35 so

5 mach → 15 jobs
if linear

$$\frac{5}{15} = \frac{?}{35}$$

mach → 5
job → 15

11.66

So 12 machines

(6)

Should add others?

- are not bottlenecks
- don't want others to <u>become</u> bottlenecks

.88 on station 2 w/ ~25 ~~mo~~ jobs w/ 15 machines
? target

$$\frac{15}{25} = \frac{?}{35}$$

? = 21 - buy 6 more

Prior 4 never was set

1.0 on station 1 w/ ~25 jobs w/ 10 machines

$$\frac{10}{25} = \frac{?}{35}$$

? = 14 machines - buy 4

Machines Cheaper now

Now #21 in rankings

15,761

4/12
~~10pm~~
10:15PM

Back to 4th

All today: adjust machines

Day 99
- almost peak of demand
  - maybe 10 more days
- Forgot to adjust parts ordering!!!
  - Fuck - did not fix before
- Never changed reorder pt
- Actually inv just came in just in time
- We are at Util = 1 on station 1
- 2 queue spiked up
  - went away when ran out of inventory
- Will jobs in for a day
  - we just did
- 24 hrs to go through inventory
  ↑ real
- Slightly higher
  - demand won't be much higher

(2)

166 → 200

So # stations

Mean of jobs

$y = .2755x + 1.698$

$\sigma = 8.877$

↑ larger

But when going steady

Middle of flat

Also fluctiations

So go to 110

$\mu = 32 / day$

So not σ since assuming max day

~~So ~ day 99~~

~~15 machine 1s is 7 1~~

~~Went 1 on day 85~~

↳ 38 orders that day

(3)

We did 1.19 st dev above

So 1 st dev

40 jobs/day

Say 38?

That was peak - day 96

So 40

want 1.0 util

Station 1

Went 1.0 on day 81 w/ 15 machines

~25 orders

$$\frac{25}{15} = \frac{40}{?}$$

15 → 24 maches need

Station 2

Went 1.0 ~ day 91 w/ 21 maches

~25 orders

orders → $\frac{30}{21} = \frac{40}{28}$

mach →

21 → 28 machines

(3)

Station 3

12 machines

peaked day 91

~30

$$\frac{12}{30} = \frac{x}{40}$$

12 → 16 machines

Shutting down jobs

19 jobs queued

- stop orders 1 game day

- 1hr

or till when jobs are gone

10:40 now

- Check back

Littlefield

4/13
9:15

#29 now
- was it all since screwup
- day 134

We are in flat demand now

#1 .8
#2 .6-.7
#3 .7

For end - dial down inventory

Are queued again

Ran out for 1 day again
↑ reorder pt
200 -> 215

No machines purchase
- Just did huge inv purchase

Turn off for 1 day
- 1 hr real life
- well till chart = 0

Extra Notes for Littlefield

These notes are only for completion of the exposition. You are not required BY ANY MEANS to follow these notes in planning your strategy, since they involve a more sophisticated way of thinking than the one required. You might find those notes useful later, when you may happen to manage your own money (rather than virtual simulation money).

The question that we deal with is, how does a prediction in delay time through the Littlefield factory translate to expected revenue per job?

For example, suppose we use 1 lot. Then, the total processing time will be 1hr set-up time in station 3,and 0.25*60=15hrs operation time from stations 2 and 4. The operation time in stations 1 and 3 will be random, with mean 0.25*60=15hrs. Suppose that the waiting time in queues is almost zero (as is almost the case in the first 20 days of simulation)

Then, a natural question is, how much do we generate per job on average?

One might think that, since the average delay is 15+15+1=31hrs, which is below 48hrs, we will be making 35,000 on average (assuming C1). This is wrong. To get an estimate, we need to generate random samples for the delay, find the corresponding payoff, and then average out the payoffs.

All service operation waiting/processing times are modeled as exponential random variables. In this case, the random part of the processing time is then exponential, and its mean is 15 hrs. To generate random samples of an exponentially distributed R.V. with mean M, once needs to use the formula in excel

-LN(RAND())*M

Hence, for our example to generate samples of total processing time, we use the formula

16 + (-LN(RAND()))*15

The first term is the deterministic part we calculated above, and the second term is the random sample of the random variable. If we do that 10,000 times or so, we get samples of the delay. Then, we need to translate each delay to a payoff (if less than 48 for instance, payoff is 35,000, etc.) By averaging out the payoffs, we find the average payoff we should be expecting!!

NOTE: In case there is also delay in the queues, this needs to be added. In particular, suppose that using the formula we used in class, you are able to estimate the average waiting time to be 5hrs. Then, you need to add this to the mean of the random part; hence, the samples will look like

16 + (-LN(RAND()))*(15+5)

Littlefield

4/14
10:15pm

Day 171

In 30th place we just bought inventory - so should be back up

Day 180 it crashes

- so no more inventory?

219,000,000

We just reordered

~35 days was inventory

So too much or just not enough

Turn off reordering now

We may want to order few at end

Have WIP been turned away

- things were turned away when 100 = WIP limit

- would not accept larger # - 999 or 101

Revenue solid since last meeting

~~XX~~ We are not spending a single $ from now on

Down at 5PM

TNG RM?

5/6

Announcements

1. Simulation Report is due May 12 (last class)

2. Next (last) class agenda:

   - Game debrief + winners acknowledgement
   - Course summary + takeaways
   - Follow-up courses

Transportation National Group

1. What are the key management challenges?

2. Critique lease performance measures

3. Is RM viable at TNG?

4. Quantify the maximum upshot to RM at TNG

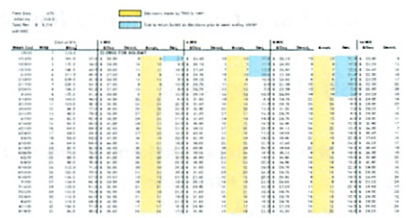
5. What are your immediate recommendations?

Management Challenges

Performance Measures

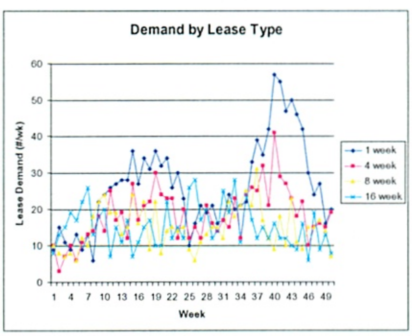
RM at TNG - Possible?

Yakima Branch



Total Revenue = $4.71m
Operating Expenses = 0.4M
Gross Profit = $4.3m
ROI = $4.3m/(470 x $80k) = 11.4%

Demand



Yakima Branch RM

- Resources: Trailer availability during given week.
- Products: Trailer lease over 1,4,8, or 16 week intervals.
- Problem: Allocate capacity to each product
  - Cant lease more trailers than available
  - Cant sell more products than demand

- MAXIMIZE REVENUE

Example Resource Constraint

Say we have two leases, 1week and 4 week ...

Week 6		#(4-week 6)
Week 7		+ #(4-week 7)
Week 8		+ #(4-week 8)
Week 9	#(1-week 9)	+ #(4-week 9) ≤ # Trailers

Trailer Consumption @ Week 9 — Trailers Avail.

Example Demand Constraint

#(4-week 6) ≤ E[Demand for 4wk lease in week 6]

(No. of 4 wk. leases sold in week 6)

Maximize Revenue

\$26 x #(1-week 1) + \$94 x #(4-week 1) + \$29 x #(1-week 2) + \$104 x #(4-week 2) + ...

Prices Assumed Given

Can be solved as an LP....

Upshot of RM (Optimistic)

4.92 mil revenue for 12% ROI

Total Revenue = \$4.71m
Operating Expenses = 0.4M
Gross Profit = \$4.3m
ROI = \$4.3m/(470 x \$80k) = 11.4%

Next Steps?

TNG Wrap-Up

1. **Revenue Management = Limited inventory sold to the right customers**

2. **Yield management = Hedging against high paying demand**

3. **Need to appropriately segment (differentiate) between products/services**

4. **RM requires appropriate data and is 'hard' to implement (centralized vs. local management)**

15.761 TNG RM:

5/16

Sim report due next class
- handed in today

Next class game debreif

TNG RM:

- Will RM work at TNG?

Key Challenges

- highly seasonal
- every branch for itself
- compete on price
  - they think they compete on brand
- Cust well edu about market, negiotiate a lot
- Subsidary of larger fin firm
- need to choose short vs long term contracts
  1 way vs round trip
- Small/no op cost here
- ? low startup costs vs airlines
  - but all assets

(2)

Network effects ~~etc~~

(Thought about as talking in class - did not think of before class)

Airlines can do some branding/perks

((Confusion from prof + MBAs

- Prof bad at redirecting responses)

(You need to be very good at that)

Airlines differentiate products

- but yield management - differentiate <u>within</u> class
- but lots of trying to differentiate

TNG could start an advanced reservation system

How do managers decide now?

- Want ROI over 10%

$$\frac{\text{annual return}}{\text{investment}}$$

? Build relationship

Diff contract levels - Think about how affects ROI

- it depends how you calculate it

Are you considering 4% vs 0% ROI

- no ROI if sitting on the lot
- ~~does meaning~~ 4% - only if "protecting"

How consider seasonality?

③

Is goal to max ROI or max revenue?

Look at revenue not ROI?

Mei Industry can't constrain capacity
Can they forecast demand?
    They throw away data!
"Really try to collect data!
- Past sales
- When ~~a~~ ~~contra~~ cust establish interest
- Type of products
- Elasticity of product
- Competitor's price + sales

- What people use it for
    - what triggers can be used?
        - like Sat Night Stay
Auction model?
    - (I actually really like this
        - Nice thought by someone!
        - Its what Google does
        - But will it work)

(4)

- Start from behavior of customers
  - Talk to the sales people
- Differentiate on <u>when</u>, <u>duration</u>, <u>where</u>
- Play w/ durations as projects
- Trips
  - i how to charge less for less popular
  (I think that was exactly what airlines didn't do)
  (Cheaper "trucks" sold out faster)
- Tiers of geo location
- Use
  - is it possible
- Markdowns/price differentation
- Deny service from some custs so others willing to pay more
(I think you can only do this <u>if</u> you have a shortage)
- Size of cust
- New/returning cust

(5)

We have several ~~week~~ months of data

- What model can we build so we know this is a good or bad idea?

- Can differentiate b/w times
  - how much inventory to allocate to each
- Not enough data for complex
- Only have enough data for simple approach

1, 4, 8, 16 weeks

Allocate capacity to each product

Can't lease more trailers than available

Can't sell more products than deman[d]

Investment cost sunk

Resource constraint

Say 1, 4 week contracts - look at week 9

Week 6: #(4 week lease in week 6)

7: + #(4 week lease in week 7)

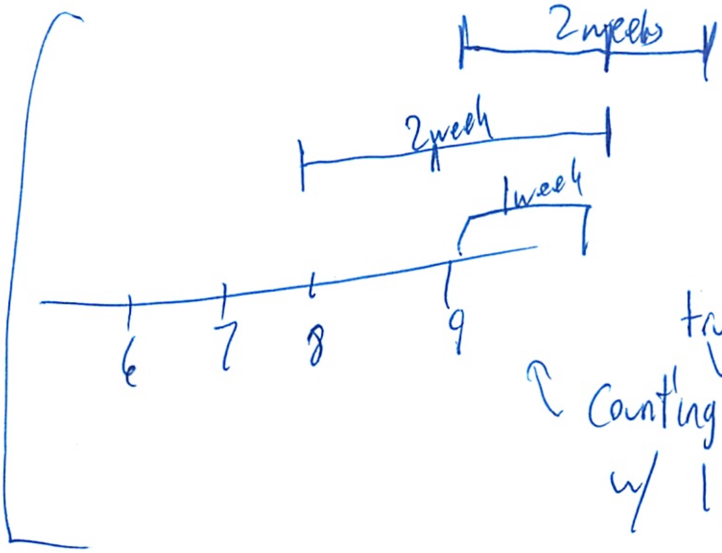
8: + #(4 week lease in week 8)

9: #(1 week lease in week 9) + #(4 week lease in week 9)

≤ # Trailers available

(sum above = trailer consumption week 9)

(6)



trucks not available
↑ Counting at week 9
w/ 1, 2 week contracts possible

Need to repeat table for each week

Also can't sell more than the demand: <u>Demand Constraint</u>

#(4-week 6) $\leq$ E[Demand for 4 week lease in week 6]

↑ # of 4 week leases sold in week 6

Maximize Revenue

Revenue = 26 · #(1 week lease in week 1) + 94(# 4 week lease in week 1) + (... etc)

↑ prices assumed given

Solve as LP

Just round up to int - not really losing

Show 9.92 mill revenue - 12% ROI

(1)

Future steps:

- National System
  - ton of data
  - office resistance
  - each office have diff data

This was on simple data

Need to start forecasting

Do trial in seperate braches

Add in costs of different ~~data~~ types of trailers

Resistance of cost not factored in

What are all the risks of the system

(Need to always asks this)

Need diff incentives for employees

Is it solvable?

Can we have a threshhold policy

- ~~Have~~ it vary through year
- ~~Also~~ keeps autonomy for sales rep

Could do sensitivity analysis
- if change boundry variables
- how does the objective change?
- What is the marginal cost / benefit?
- What is change in the objective function?

Can try this out when a cust proposes a contract
What is the marginal rev we are losing from this ← op cost
So we must get at least this amt
By changing LP slightly / sensitivity analysis

Can rerun - after you get more data
Can run again
Like we did w/ markdowns

RM - limited inventory
- sell it to right person
- hedge againts people who pay more
- Segment / differentiate products
- Need right data
  - hard to do

Announcements

1. Simulation Report is due May 11 (last class)

2. Next (last) class agenda:

    - Game debrief + winners acknowledgement
    - Course summary + takeaways
    - Follow-up courses

Transportation National Group

1. What are the key management challenges?

2. Critique lease performance measures

3. Is RM viable at TNG?

4. Quantify the maximum upshot to RM at TNG

5. What are your immediate recommendations?

Management Challenges

Performance Measures

Solutions

5/16

RM at TNG - Possible?

Yakima Branch

Fleet Size 470
Initial Inv. 119.0
Total Rev $ 4,714
(x$1000)

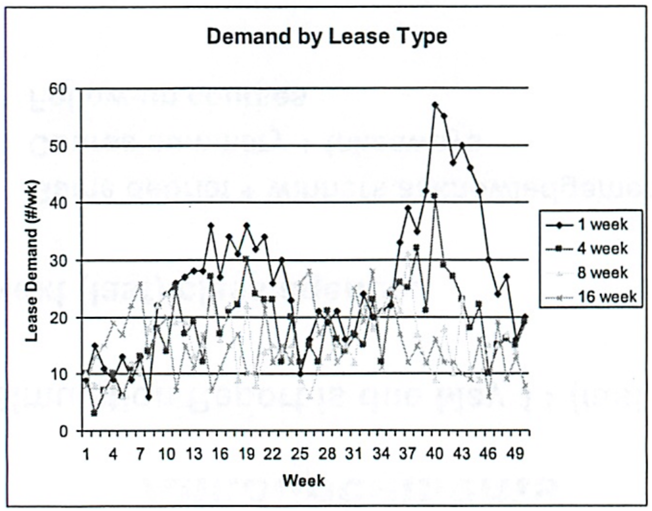
Decisions made by TNG in 1997

Due to return based on decisions prior to week ending 1/5/97

Week End	WK#	Start of WK Inv.		1-WK $/Day	Demd.	Accpt.	Ret.	4-WK $/Day	Demd.	Accpt.	Ret.	8-WK $/Day	Demd.	Accpt.	Ret.	16-WK $/Day	Demd.
1/6/01	1	119.0		CLOSED FOR HOLIDAY													
1/13/01	2	161.0	37.0	$ 26.00	9	9	2.0	$ 23.40	10	10	17.0	$ 22.10	10	10	12.0	$ 20.80	8
1/20/01	3	172.0	39.0	$ 29.00	15	15	9.0	$ 26.10	3	3	11.0	$ 24.85	6	6	16.0	$ 23.20	13
1/27/01	4	192.0	40.0	$ 30.50	11	11	15.0	$ 27.45	7	7	17.0	$ 25.83	7	7	12.0	$ 24.40	15
2/3/01	5	211.0	46.0	$ 27.50	9	9	11.0	$ 24.75	10	10	10.0	$ 23.38	6	6	21.0	$ 22.00	19
2/10/01	6	204.0	42.0	$ 29.00	13	13	9.0	$ 26.10	6	6	10.0	$ 24.85	6	6	9.0	$ 23.20	17
2/17/01	7	204.0	54.0	$ 27.50	9	9	13.0	$ 24.75	11	11	3.0	$ 23.38	12	12	10.0	$ 22.00	22
2/24/01	8	194.0	62.0	$ 27.50	13	13	8.0	$ 24.75	13	13	7.0	$ 23.38	10	10	7.0	$ 22.00	26
3/3/01	9	172.0	51.0	$ 29.00	6	6	13.0	$ 26.10	14	14	10.0	$ 24.85	18	18	3.0	$ 23.20	13
3/10/01	10	150.0	90.0	$ 35.00	22	22	6.0	$ 31.50	18	18	6.0	$ 29.75	22	22	10.0	$ 28.00	19
3/17/01	11	120.0	82.0	$ 35.00	24	24	22.0	$ 31.50	14	14	11.0	$ 29.75	24	24	8.0	$ 28.00	20
3/24/01	12	94.0	77.0	$ 36.50	26	26	24.0	$ 32.85	25	25	13.0	$ 31.03	19	19	7.0	$ 29.20	7
3/31/01	13	80.0	79.0	$ 35.00	27	27	26.0	$ 31.50	17	17	14.0	$ 29.75	19	19	8.0	$ 28.00	15
4/7/01	14	62.0	62.0	$ 35.00	28	24	27.0	$ 31.50	19	18	18.0	$ 29.75	13	10	6.0	$ 28.00	11
4/14/01	15	66.0	66.0	$ 41.00	28	23	24.0	$ 36.90	12	12	14.0	$ 34.85	15	15	12.0	$ 32.80	17
4/21/01	16	68.0	68.0	$ 42.50	36	14	23.0	$ 38.25	27	26	25.0	$ 36.13	24	22	10.0	$ 34.00	7
4/28/01	17	58.0	58.0	$ 45.50	27	20	14.0	$ 40.95	17	16	17.0	$ 38.68	18	14	18.0	$ 36.40	11
5/5/01	18	68.0	68.0	$ 47.00	34	18	20.0	$ 42.30	21	18	18.0	$ 39.95	22	18	22.0	$ 37.60	15
5/12/01	19	68.0	68.0	$ 44.00	31	23	19.0	$ 39.60	22	22	12.0	$ 37.40	8	8	24.0	$ 35.20	17
5/19/01	20	63.0	63.0	$ 45.50	36	23	23.0	$ 40.95	30	28	26.0	$ 38.68	22	22	19.0	$ 36.40	18
5/26/01	21	77.0	74.0	$ 42.50	32	32	23.0	$ 38.25	24	24	16.0	$ 36.13	8	8	19.0	$ 34.00	19
6/2/01	22	80.0	80.0	$ 41.00	34	26	32.0	$ 36.90	23	22	18.0	$ 34.85	14	12	10.0	$ 32.80	22
6/9/01	23	85.0	75.0	$ 41.00	26	26	26.0	$ 36.90	23	23	22.0	$ 34.85	15	15	15.0	$ 32.80	12
6/16/01	24	112.0	71.0	$ 35.00	30	30	26.0	$ 31.50	12	12	29.0	$ 29.75	14	14	22.0	$ 28.00	18
6/23/01	25	122.0	78.0	$ 35.00	23	23	30.0	$ 31.50	20	20	24.0	$ 29.75	15	15	14.0	$ 28.00	12
6/30/01	26	134.0	57.0	$ 30.50	10	10	23.0	$ 27.45	12	12	22.0	$ 25.83	9	9	18.0	$ 24.40	26
7/7/01	27	138.0	85.0	$ 29.00	16	16	10.0	$ 26.10	15	15	23.0	$ 24.85	6	6	8.0	$ 23.20	28
7/14/01	28	130.0	61.0	$ 32.00	21	21	16.0	$ 28.80	12	12	12.0	$ 27.20	11	11	22.0	$ 25.60	17
7/21/01	29	133.0	73.0	$ 35.00	19	19	21.0	$ 31.50	21	21	20.0	$ 29.75	13	13	8.0	$ 28.00	20
7/28/01	30	112.0	64.0	$ 35.00	21	21	19.0	$ 31.50	16	16	12.0	$ 29.75	15	15	12.0	$ 28.00	12
8/4/01	31	115.0	59.0	$ 35.00	16	16	21.0	$ 31.50	14	14	15.0	$ 29.75	15	15	15.0	$ 28.00	14
8/11/01	32	104.0	71.0	$ 32.00	17	17	16.0	$ 28.80	17	17	12.0	$ 27.20	12	12	14.0	$ 25.60	25
8/18/01	33	94.0	90.0	$ 36.50	24	24	17.0	$ 32.85	16	16	21.0	$ 31.03	22	22	15.0	$ 29.20	19

Total Revenue = $4.71m
Operating Expenses = 0.4M
Gross Profit = $4.3m
ROI = $4.3m/(470 x $80k) = 11.4%

Demand



Yakima Branch RM

- Resources: Trailer availability during given week.
- Products: Trailer lease over 1,4,8, or 16 week intervals.
- Problem: Allocate capacity to each product
  - Cant lease more trailers than available
  - Cant sell more products than demand

- MAXIMIZE REVENUE

Upshot of RM (Optimistic)

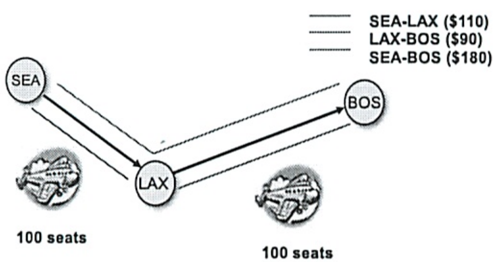
Total Revenue = $4.92m
Operating Expenses = 0.4m
Gross Profit = $4.52m
ROI = $4.52m/(470 x $80k) = 12.0%

60 bp. increase

Total Revenue = $4.71m
Operating Expenses = 0.4M
Gross Profit = $4.3m
ROI = $4.3m/(470 x $80k) = 11.4%

Next Steps?

The Network Effect



Max $110x1 + 90x2 + 180x3$

s.t. $x1 + x3 \le 100$
$x2 + x3 \le 100$
$0 \le x1 \le 65$
$0 \le x2 \le 30$
$0 \le x3 \le 60$

Solution:
$x1^* = 40$
$x2^* = 30$
$x3^* = 60$

Good proxy for 'Virtual Inventory'

TNG Wrap-Up

1. Revenue Management = Limited inventory sold to the right customers
2. Yield management = Hedging against high paying demand
3. Need to appropriately segment (differentiate) between products/services
4. RM requires appropriate data and is 'hard' to implement (centralized vs. local management)

15.761 5/12

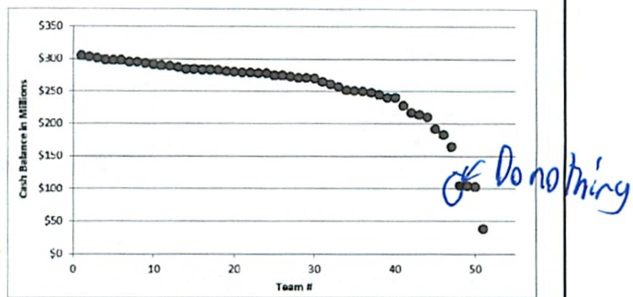
Course Wrap-up

1. Course and simulation debriefing
2. Sloan evaluation forms

---

3. Stellar final feedback survey *after class*
4. Wrap-up email (follow-up courses, TA)

Simulation Game Results



Source: 2nd Littlefield Simulation

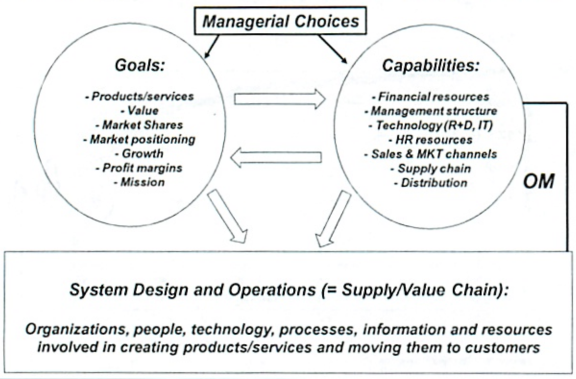
Course Outline

	Day	Date	Contents	Required-Readings	Textbook Coverage	Optional readings	Assignments	Sim
	Wed/Thu	2/3-Feb	Course Introduction		2.2-3,3.1			
Process& capacity analysis	Mon/Tue	7/8-Feb	Case: Burger King + McDonald's	Production Processes	2.6	Types of Processes		
	Wed/Thu	9/10-Feb	Lecture: Capacity	Wait-in-Line Blues	3.2-5,7.1-9			
	Mon/Tue	14/15-Feb	Case: Webvan			A Bombay Lunch Box		
	Wed/Thu	16/17-Feb	Case: American Express Travel				Short individual HW	
	Wed/Thu	23/24-Feb	Case: PATA	PATA Video			Case write-up	
Process re-engineering	Mon/Tue	28-Feb/1-Mar	Lecture: Process-Re Engineering +CVS	Reengineering Work				
	Wed/Thu	2/3-Mar	Case: Toyota		9.8,10.1-10	Decoding the DNA of TPS		
Inventory Control	Mon/Tue	7/8-Mar	Lecture: Inventory 1		2.4-5, 6.4-5, 11.1-7			
	Wed/Thu	9/10-Mar	Lecture: Inventory 2		13,14.1-3			
	Mon/Tue	28/29-Mar	Case: Obermeyer		12	Rocket Science Retailing	Case write-up	
	Wed/Thu	30/31-Mar	Case: HP Deskjet				Short individual HW	
Supply Chain& Production Management	Mon/Tue	4/5-Apr	Lecture: Production Control and SC Design	Dell (Automate)		ERP Technology Note		
	Wed/Thu	6/7-Apr	Case: Mark and Spencer vs. Zara	Zara Video		Fast, Global & Enrepr.	Goal report	
	Mon/Tue	11/12-Ap	Case: HP vs. Dell	Dell Video				
	Wed/Thu	13/14-Apr	Case: Barilla		16	Made to Measure		
	Wed/Thu	20/21-Apr	Lecture: Quality	Hank Kolb	9.1-6	Berwick, What is Sigma 6?		
Revenue Management	Mon/Tue	25/26-Apr	Case: Break.com					
	Wed/Thu	27/28-Apr	Lecture: Revenue Management 1	Varian				
	Mon/Tue	2/3-May	Lecture: Revenue Management 2	Netessine Shumsky	15.1-15.3			
	Wed/Thu	4/5-May	Case: TNG				Retailer report	
	Mon/Tue	9/10-May	Case: Video Vault		16.3-16.5			
	Wed/Thu	11/12-May	Course Wrap-up				Simulation report	

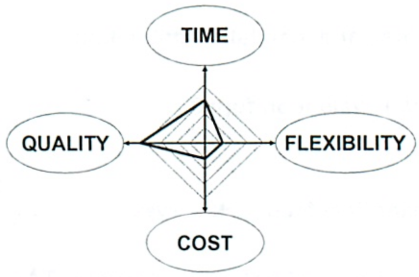
Course Goals

1. Use Scientific Approach to Analyze Business Operations:
   (flow-diagrams, capacity analysis,...)
2. Understand Basic Laws of the 'Physics' of Business Operations:
   (Role of uncertainty, Little's law, behavior of queues,...)
3. Recognize and Understand Fundamental Tradeoffs:
   (Capacity-inventory-service level, inventory-transportation,...)
4. Learn from Success Stories and Failures:
   (Dell, Webvan, Toyota, Barilla, Zara,.....)

Strategy = Develop Goals & Capabilities

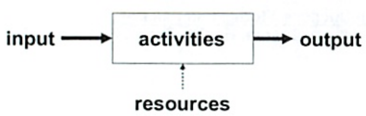


Operational Tradeoffs



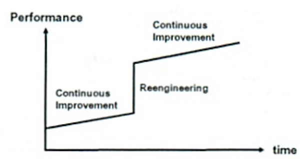
OM Definition: The Process View

- *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



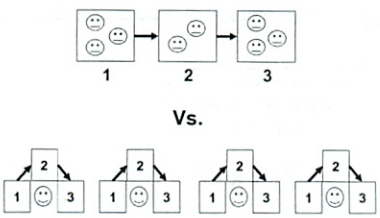
Processes, Processes, Processes

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

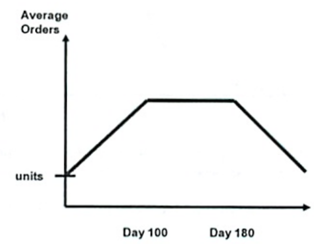


End-to-End Principle

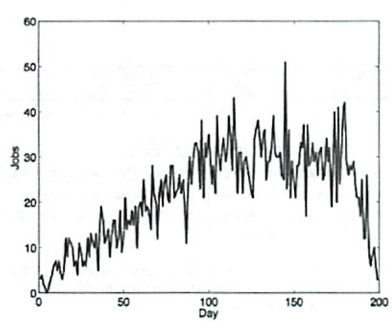
⇨ *Organize around outcomes, not tasks*



Predictable Variability



Unpredictable Variability



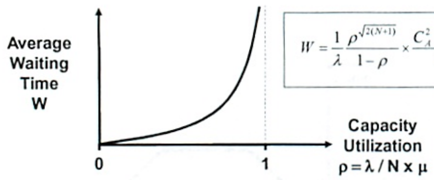
Source: 2nd Littlefield Simulation

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

All other cases ⇨ *Simulation / Experiments*

Queuing Theory



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

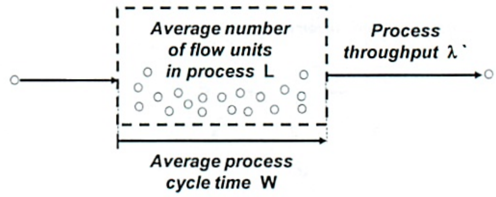
$\rho = \lambda / N \times \mu$

"What we did not realize was the importance of not working at full capacity since variability on the system would increment the queue time exponentially."

"Maybe having extra capacity would have helped us compensate for the peaks in demand."

"Contrary to The Goal, in the simulation reducing batch size did not seem to have strong benefits. It did reduce the idling time of our machines in station 3, boosting our capacity utilization to 1. But I don't think the net effect was positive."

Process Physics: Little's Law



$$L = \lambda \times W$$

- *"We tried applying G/G/N formula, but could not seem to relate the length of the queue to wait time (in retrospect this was a silly mistake, as we saw how easy it is to come Little's Law with G/G/N in the PATA case). Feeling stumped, we decided we needed 50% more capacity on average than our maximum demand, so we multiplied our projected need for machine #3 by 1.5…."*

And Queuing Practice

"…our model did not exploit the fluctuations in demand and the 'concept of queues'. It was a good reference but wasn't too helpful"

"…we again failed to effectively use our knowledge of standard deviation process times in our calculation"

"We panicked when the utilization got higher and over invested"

Capacity Analysis

	# Batches	Lambda	Mu	N	N * Mu	Utilization	L	W	Processing	Total
Station 1	3	3.75	0.25	18	4.5	0.83333333	1.95004785	0.52001276	4	4.52001276
Station 2	3	7.5	0.5	19	9.5	0.78947368	1.06512346	0.14201646	2	2.14201646
Station 3	3	3.75	0.5	10	5	0.75	1.03763682	0.27670315	2	2.27670315
									11	**11.938732**
									TARGET	**14**

Capacity utilization:

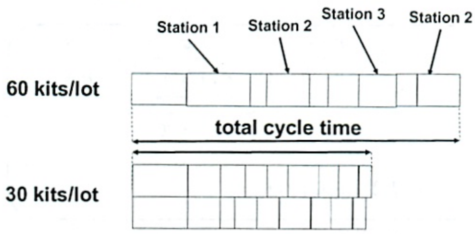
$\rho = \lambda / N \times (\text{\# Lots/order} \times \text{Setup time} + \text{Processing Time})^{-1}$

"although we have learned that a mix of art and science is important in operational decision making, if we ran this simulation again, we would follow the numbers predicted by our models"

"The goal of machine purchase is to have sufficient capacity in the system to minimize delays in processing and generate maximum throughput. However, machines are highly capital intensive."

"Unless costs are prohibitive, buy capacity early if you think you will need it later. Extra capacity early ensures you can meet all orders…"

Cycle Time Analysis



"Despite what Jonah says, halving the batch size is not always the best idea. One must consider the station setup times."

"We also believed that splitting jobs into multiple batches would not be beneficial because of the long setup time per lot at station 3. One lot of 60 units would require 1.5666 hours to process while one lot of 6 units would require 1.5066 hours. This savings of 0.06 hour is negligible [...]."

...Among Other Approaches

"we were also injured by an impulsive order of too many machines near the end" / "we ended up with too few machines in round 1, then binged"

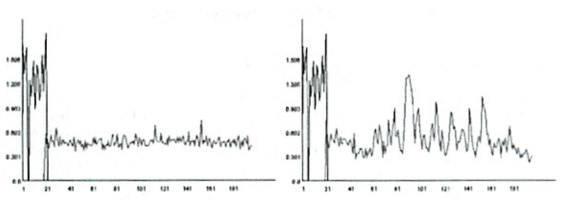
"our approach was reasonable, except the timing of our decision was suboptimal"

"we found ourselves into troubles when the demand was suddenly jumping above our predictions"

"...we bought machines for the stations where utilization was getting closer to 100%..."

"Without having a concrete strategy...we were led to rely on impromptu judgment calls throughout the game."

When to Buy Machines?

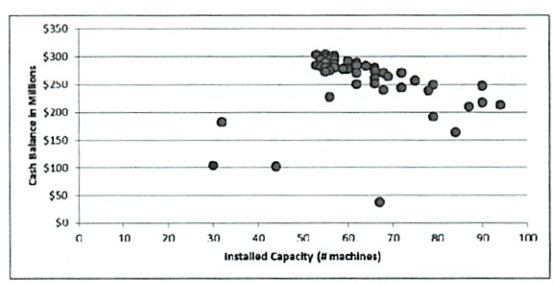


"Our strategy suggested we wake up at 4am the next day, run a regression, plug the updated parameters to the model and buy machines. Therefore, we bought all the machines beforehand"

"... this strategy did not work very well because at times our forecasted demand and utilization rates were much lower than we saw in practice. Then, we would go into reactionery mode and add machines"

Very interesting graph

Max Capacity



when

Source: 2nd Littlefield Simulation

Totter decision important

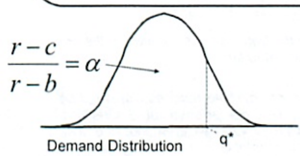
Why Hold Inventory? How Much?

Type of Inventory	*Decision Tool*
Buffer/Decoupling	**Build-up diagrams**
Seasonal/Anticipation	**Build-up diagrams**
Cycle stock	**EOQ**
Safety stock	**Newsvendor**
Pipeline	**Little's Law**

Newsvendor Formula

$$\underbrace{P(D \le q^*)}_{\text{In-Stock Probability}} = \frac{r-c}{r-b} = \frac{r-c}{\underbrace{(r-c)}_{\text{cost of under-stocking}} + \underbrace{(c-b)}_{\text{cost of over-stocking}}} = \frac{u}{u+o}$$

$$q^* - E[D] = \text{safety stock}$$

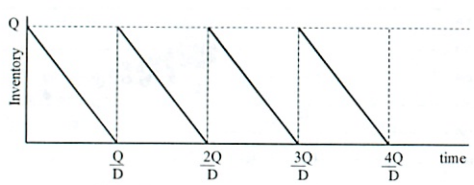


Remark: If D is Normal(μ,σ),

$q^* = \mu + k.\sigma$ with

α = 95% → k = 1.64
α = 99% → k = 2.32
α = 99.9% → k = 3.09

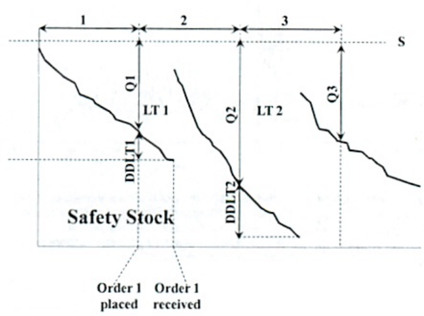
EOQ Formula



$$Q^* = \sqrt{\frac{2DF}{CH}}, \quad T^* = \sqrt{\frac{2F}{DCH}}$$

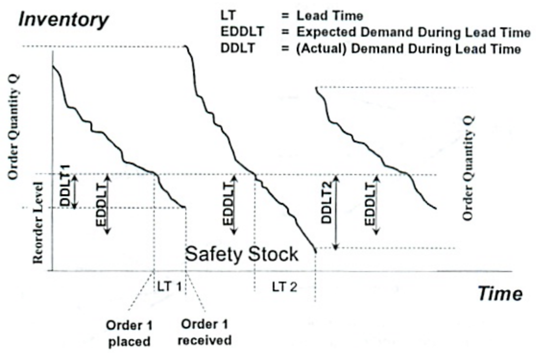
Periodic Review System

⇨ **"order back to S every review period"**

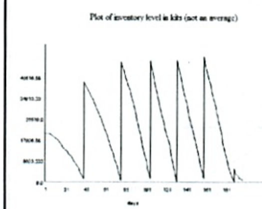


LT = Lead Time
T = Cycle Time or Review Period
DDLT = Actual Demand During Lead Time
Qi = Order Size
S = Order Up To Level

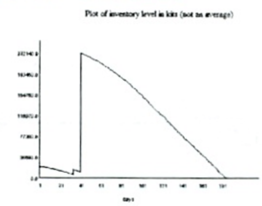
Continuous Review System



How Much to Order?



"To determine Q we developed a mathematical model that took as inputs our forecasted demand as well as ordering and holding costs. Close to reaching the order point R, Q was calculated by running Excel's Solver to minimize cost"



"The first order issue was not to stock out. Since the opportunity cost was much higher than holding costs, we filled up the warehouse from day 20"

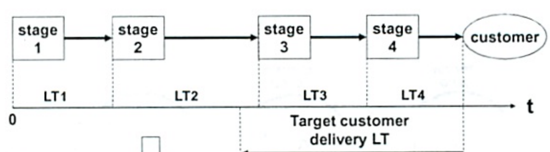
People Issues

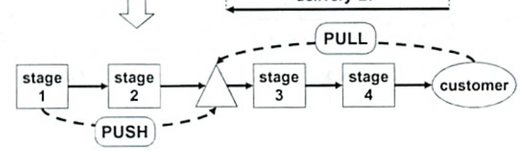
"When multiple managers are involved, communication is key"

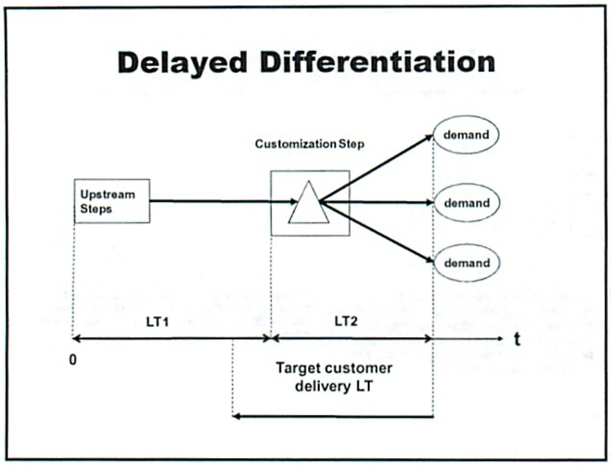
"That missed call cost us around $5 million"

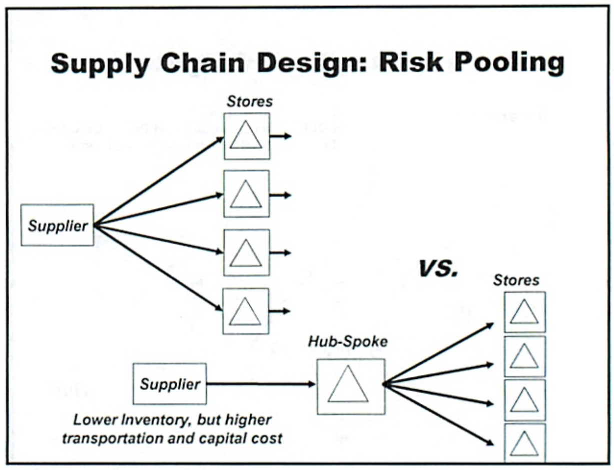
"Among the many tradeoffs involved in the game, was the one between personal life and the factory"

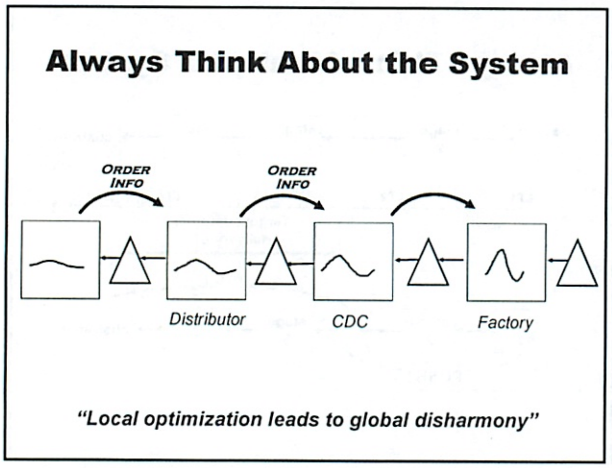
Always Think About the System

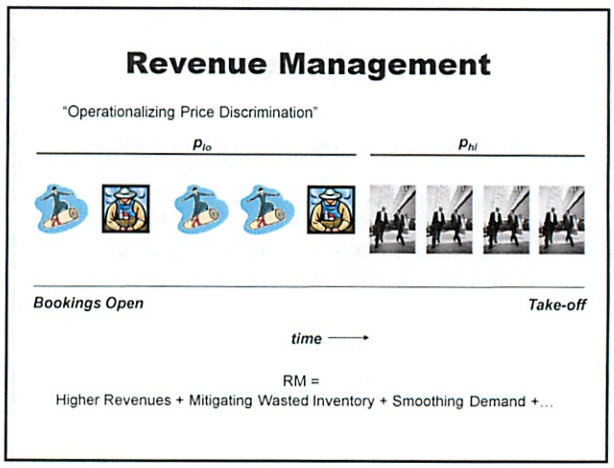





Delayed Differentiation
Customization Step
Upstream Steps
demand
demand
demand
LT1
LT2
t
0
Target customer delivery LT


Supply Chain Design: Risk Pooling
Stores
Supplier
VS.
Stores
Hub-Spoke
Supplier
Lower Inventory, but higher transportation and capital cost

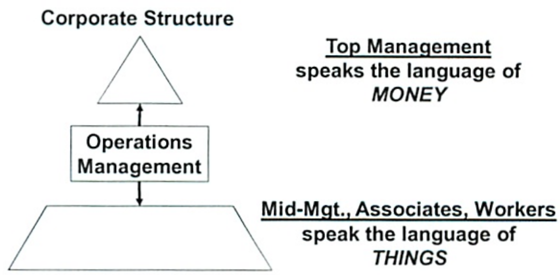

Always Think About the System
ORDER INFO
ORDER INFO
Distributor
CDC
Factory
"Local optimization leads to global disharmony"


Revenue Management
"Operationalizing Price Discrimination"
p_{lo}
p_{hi}
Bookings Open
Take-off
time
RM =
Higher Revenues + Mitigating Wasted Inventory + Smoothing Demand +…

Stories

BREAK.COM
Barilla
TOYOTA
amazon.com
i'm lovin' it
DELL
ZARA
hp
webvan
BURGER KING
YOUR M&S
MASSACHUSETTS GENERAL HOSPITAL
ANESTHESIA, CRITICAL CARE AND PAIN MEDICINE
obermeyer

A Translation Challenge



OM merges physical and financial analyses, and requires great care to people issues!

The Road From Here

- 15.768 - Service Operations (Fall)
- 15.769 - Operations Strategy (Fall and Spring)
- 15.762 - Supply Chain Planning (Spring H1)
- 15.763 - Manufacturing Systems and Supply Chain Design (Spring H2)
- 15.783 - Product Design and Development
- 15.S03 (previously 15.967) - Intro to Healthcare Delivery in the U.S.: Market & System Challenges (Fall 2011)

Final Thanks

- Anna Piccolo
- TAs: Puneet Newaskar, Kanaka Pattabiraman, Rajan Prasanna

Do Keep in Touch and...
GOOD LUCK!!!

15.761

5/12

Last class
Different room

Sim results

All fairly linear
Then some people did bad

E72 team (#6)

- regression (same as us
- saftey level
- depends utilization
- did fast investment
- set higher saftey inventory
  - Then cut it for last order
- wait time depends on utilization
  - 80% .10

(so I was mistaken that util < 100 meant
0 wait)

They targeted 60% util *

(2) Sensitivity analysis
Contract 2

During game kept monitoring (like us)

Lot size ? 20 kits/lot

(The only thing diff seemed 60% util

They wish they made reordering higher

They saw much higher interest

(Did I do that right?)

SWS #4

lot size ?

regression

GGN Queuing, Little's Law

Sum of ~~[illegible]~~ wait time should not > 15 hrs

Util should not exceed 90% ↑

1 st dev

ended up being far below

(3)

(~~a~~ R, Q)

↑ Newsvendor ↖ EOQ

Update every 10 days

Ran out of inventory 3 days early

Really tried to avoid running out of inv

Didn't switch to 2 till day 40

(They made a bunch of mistakes as well)

Top 2 teams purchased inventory ~~more~~ more frequently

Would have had higher st dev

Wrap Up

Process + capacity

Process re-engineering

Inventory control

Supply Chain Management

Revenue Management

(4)

Managers pick strategy

Choose from ~~stn~~ trade offs

Process view is basic component of OR

Reengineer completly can be a big win

Organize arand outcomes, not tasks

Predictable variability vs Unpredictable

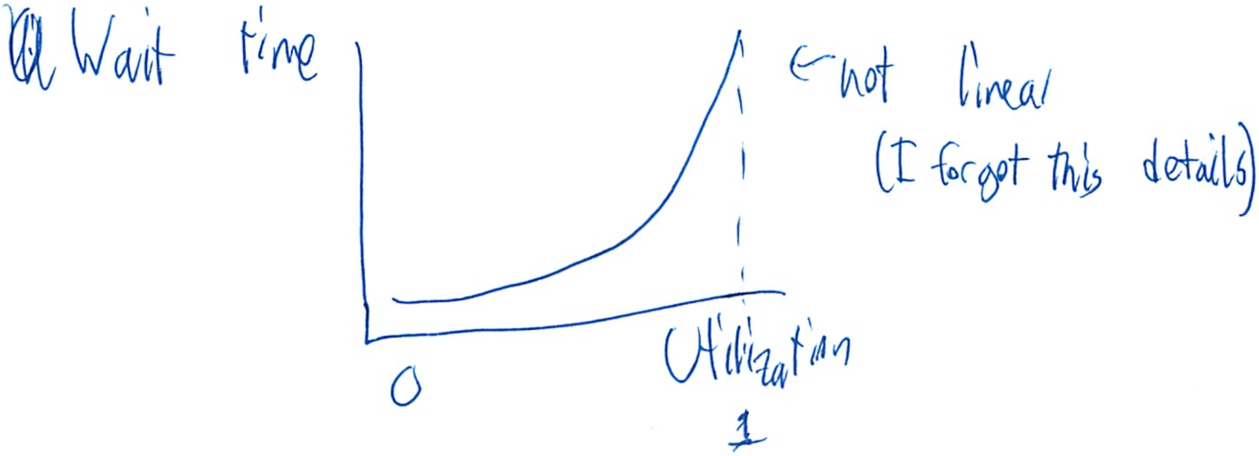
└ general shape of demand

└ day to day variation

Build up diagrams simple

- for predictable variability

Queuing theory - for unpredictable variability



(5)

Formulas - levers where to change things

Can also ↓ variability

Little's Law

$$L = \lambda W$$

- L ↑ # units in process
- λ ↑ throughput
- W ← avg process cycle time

Utilization

$$\rho = \frac{\lambda}{N} \cdot \left(\frac{\#\text{ lots}}{\text{order}} \cdot \text{setup time} + \text{processing time} \right)^{-1}$$

Lot size vs setup time

When to buy machines?

Inventory

Lots of models

EOQ

Periodic review

[illegible]

(e)

People issues
- work life balance
- think about how workers feel

Delayed Differentiation

Risk Pooling
- know what tradeoffs are
- pros/cons

Don't locally optimize risk
- optimize entire system
- understand incentives
- automated tools like cord pulling

Revenue Management
- deny cust now to wait for more profitable custs later

Lots of cases

Actually [illegible] executing is a big challenge

(7) Future Classes

15,783 product Design + Dev

Lots of options

More case based

Not quantative

Was his 1st time teaching

After Class 15.761 5/12

This MBA consultant came up to me to offer unsolicitate feedback

what I remember

engage the class more
- turn towards them
- not so rapid fire qu
- learn more from class
- off putting
- only an a-hole consultant would do that
- work the room more
- don't be so internal nerdy

Thoughts

I didn't think of doing that
Thought it was more me + prof
- esp in 4.211

I could consider that more

Could it also been I was making rest of room look bad
Or not on track - esp w/ RM

②

I will try + turn more towards class

~~And~~ undo

But still say same things

I will keep what he said in mind

and see what this changes

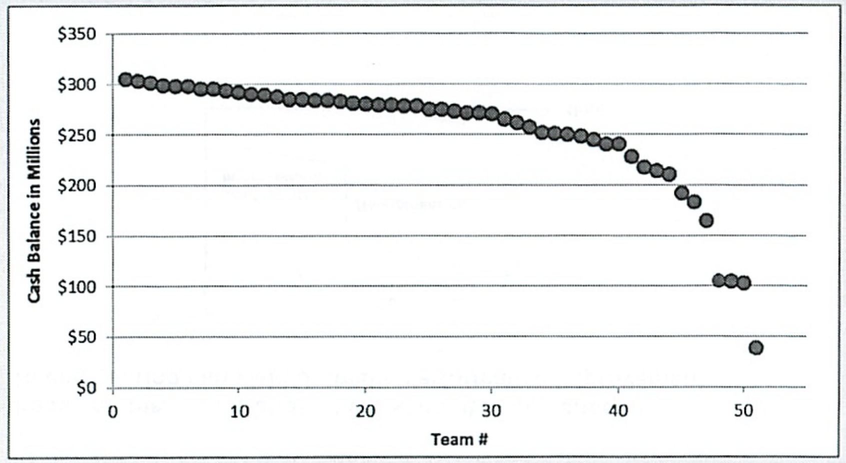
Course Wrap-up

1. Course and simulation debriefing
2. Sloan evaluation forms

---

3. Stellar final feedback survey *after class*
4. Wrap-up email (follow-up courses, TA)

Simulation Game Results



Source: 2nd Littlefield Simulation

Solutions

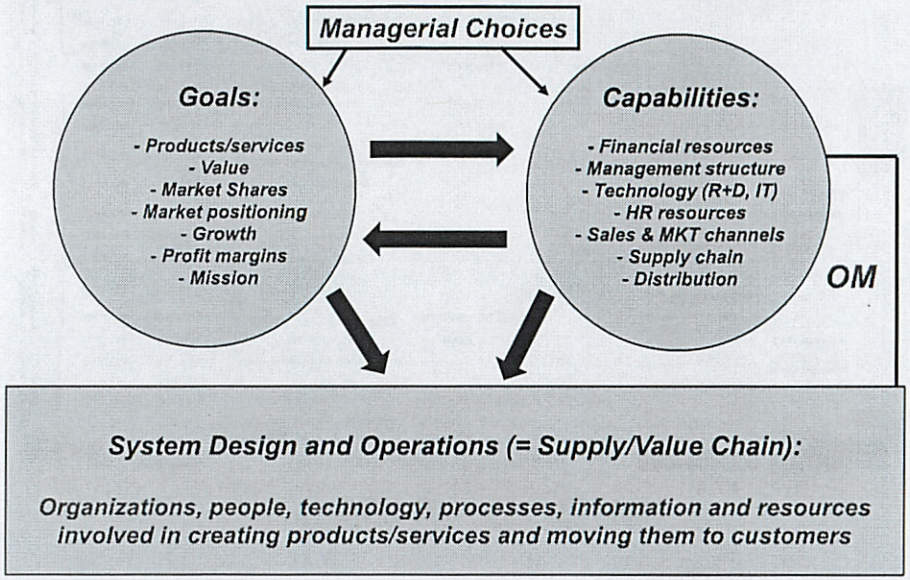
Course Outline

	Day	Date	Contents	Required-Readings	Textbook Coverage	Optional readings	Assignments	Sim
	Wed/Thu	2/3-Feb	Course Introduction		2.2-3,3.1			
Process& capacity analysis	Mon/Tue	7/8-Feb	Case: Burger King + McDonald's	Production Processes	2.6	Types of Processes		
	Wed/Thu	9/10-Feb	Lecture: Capacity	Wait-in-Line Blues	3.2-5,7.1-9			
	Mon/Tue	14/15-Feb	Case: Webvan			A Bombay Lunch Box		
	Wed/Thu	16/17-Feb	Case: American Express Travel				Short individual HW	
	Wed/Thu	23/24-Feb	Case: PATA	PATA Video			Case write-up	
Process re-engineering	Mon/Tue	28-Feb/1-Mar	Lecture: Process-Re Engineering + CVS	Reengineering Work				
	Wed/Thu	2/3-Mar	Case: Toyota		9.8,10.1-10	Decoding the DNA of TPS		
Inventory Control	Mon/Tue	7/8-Mar	Lecture: Inventory 1		2.4-5, 6.4-5, 11.1-7			
	Wed/Thu	9/10-Mar	Lecture: Inventory 2		13,14.1-3			
	Mon/Tue	28/29-Mar	Case: Obermeyer		12	Rocket Science Retailing	Case write-up	
	Wed/Thu	30/31-Mar	Case: HP Deskjet				Short individual HW	
Supply Chain& Production Management	Mon/Tue	4/5-Apr	Lecture: Production Control and SC Design	Dell (Automate)		ERP Technology Note		
	Wed/Thu	6/7-Apr	Case: Mark and Spencer vs. Zara	Zara Video		Fast, Global & Enrepr.	Goal report	
	Mon/Tue	11/12-Ap	Case: HP vs. Dell	Dell Video				
	Wed/Thu	13/14-Apr	Case: Barilla		16	Made to Measure		
	Wed/Thu	20/21-Apr	Lecture: Quality	Hank Kolb	9.1-6	Berwick, What is Sigma 6?		
Revenue Management	Mon/Tue	25/26-Apr	Case: Break.com					
	Wed/Thu	27/28-Apr	Lecture: Revenue Management 1	Varian				
	Mon/Tue	2/3-May	Lecture: Revenue Management 2	Neetessine Shumsky	15.1-15.3			
	Wed/Thu	4/5-May	Case: TNG				Retailer report	
	Mon/Tue	9/10-May	Case: Video Vault		16.3-16.5			
	Wed/Thu	11/12-May	Course Wrap-up				Simulation report	

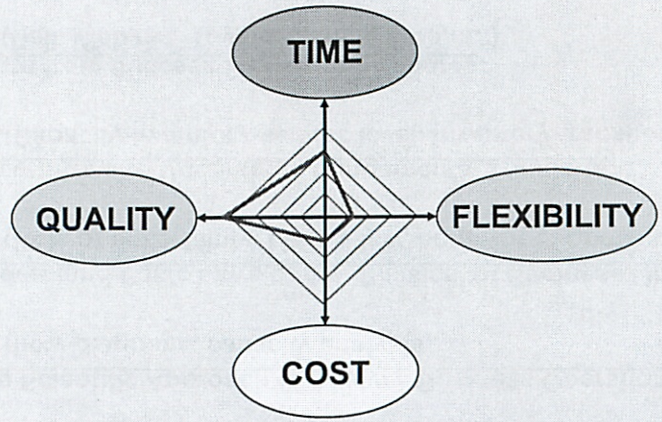
Course Goals

1. <u>Use Scientific Approach to Analyze Business Operations</u>:
   (flow-diagrams, capacity analysis,…)
2. <u>Understand Basic Laws of the `Physics' of Business Operations</u>:
   (Role of uncertainty, Little's law, behavior of queues,…)
3. <u>Recognize and Understand Fundamental Tradeoffs</u>:
   (Capacity-inventory-service level, inventory-transportation,…)
4. <u>Learn from Success Stories and Failures</u>:
   (Dell, Webvan, Toyota, Barilla, Zara,…..)

Strategy = Develop Goals & Capabilities

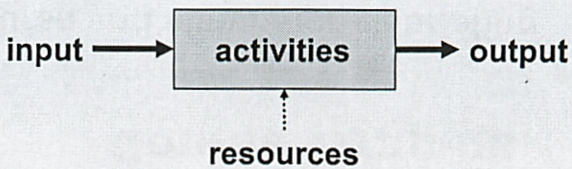


Operational Tradeoffs



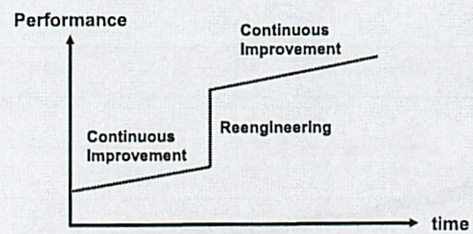
OM Definition: The Process View

- *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



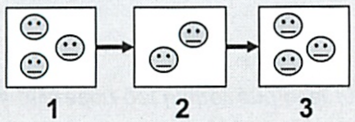
Processes, Processes, Processes

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

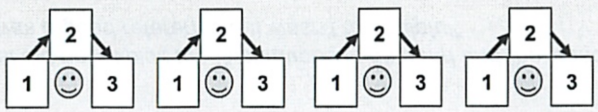


End-to-End Principle

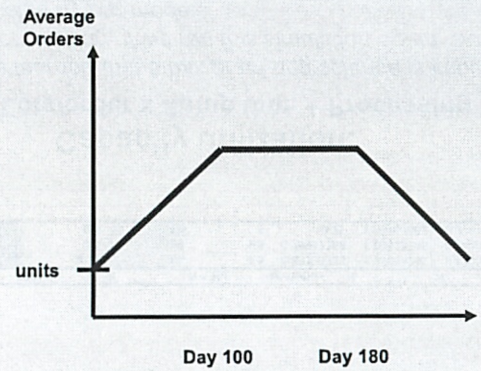
➡ *Organize around outcomes, not tasks*



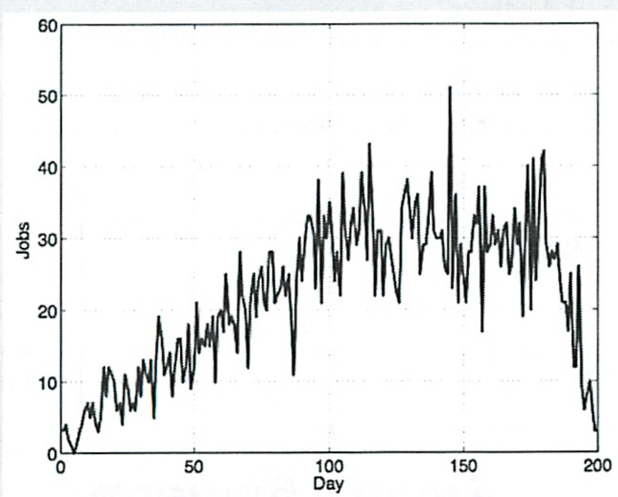
Vs.



Predictable Variability



Unpredictable Variability



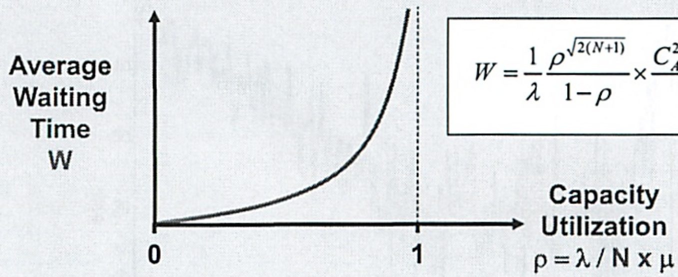
Source: 2nd Littlefield Simulation

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

All other cases ➡ *Simulation / Experiments*

Queuing Theory



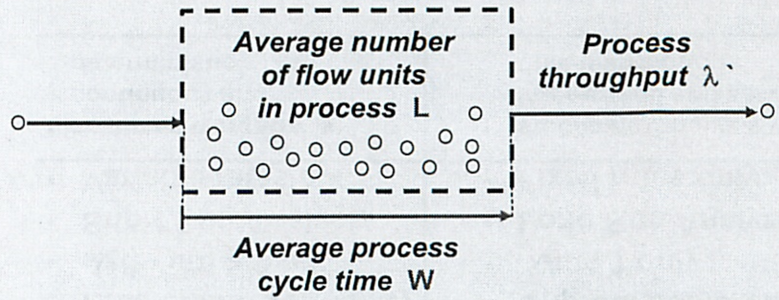
$$W = \frac{1}{\lambda}\,\frac{\rho^{\sqrt{2(N+1)}}}{1-\rho} \times \frac{C_A^2 + C_S^2}{2}$$

"What we did not realize was the importance of not working at full capacity since variability on the system would increment the queue time exponentially."

"Maybe having extra capacity would have helped us compensate for the peaks in demand."

"Contrary to The Goal, in the simulation reducing batch size did not seem to have strong benefits. It did reduce the idling time of our machines in station 3, boosting our capacity utilization to 1. But I don't think the net effect was positive."

Process Physics: Little's Law



$$L = \lambda \times W$$

- *"We tried applying G/G/N formula, but could not seem to relate the length of the queue to wait time (in retrospect this was a silly mistake, as we saw how easy it is to come Little's Law with G/G/N in the PATA case). Feeling stumped, we decided we needed 50% more capacity on average than our maximum demand, so we multiplied our projected need for machine #3 by 1.5…."*

And Queuing Practice

"…our model did not exploit the fluctuations in demand and the 'concept of queues'. It was a good reference but wasn't too helpful"

"…we again failed to effectively use our knowledge of standard deviation process times in our calculation"

"We panicked when the utilization got higher and over invested"

Capacity Analysis

	# Batches	Lambda	Mu	N	N * Mu	Utilization	L	W	Processing	Total
Station 1	3	3.75	0.25	18	4.5	0.83333333	1.95004785	0.52001276	4	4.52001276
Station 2	3	7.5	0.5	19	9.5	0.78947368	1.06512346	0.14201646	2	2.14201646
Station 3	3	3.75	0.5	10	5	0.75	1.03763682	0.27670315	2	2.27670315
									11	11.938732
									TARGET	14

Capacity utilization:

$\rho = \lambda / N \times (\text{\# Lots/order} \times \text{Setup time} + \text{Processing Time})^{-1}$

"although we have learned that a mix of art and science is important in operational decision making, if we ran this simulation again, we would follow the numbers predicted by our models"

"The goal of machine purchase is to have sufficient capacity in the system to minimize delays in processing and generate maximum throughput. However, machines are highly capital intensive."

"Unless costs are prohibitive, buy capacity early if you think you will need it later. Extra capacity early ensures you can meet all orders..."

...Among Other Approaches

"we were also injured by an impulsive order of too many machines near the end" / "we ended up with too few machines in round 1, then binged"

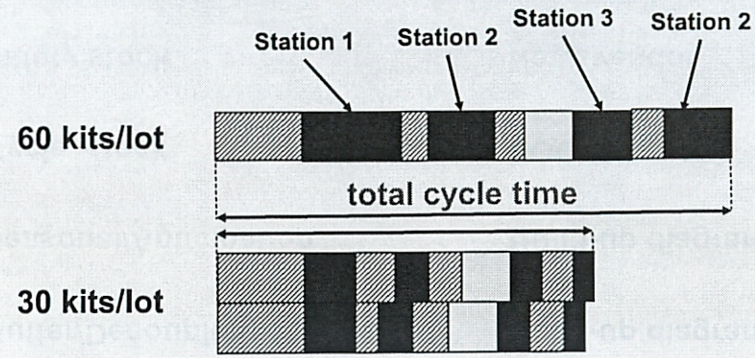
"our approach was reasonable, except the timing of our decision was suboptimal"

"we found ourselves into troubles when the demand was suddenly jumping above our predictions"

"...we bought machines for the stations where utilization was getting closer to 100%..."

"Without having a concrete strategy...we were led to rely on impromptu judgment calls throughout the game."

Cycle Time Analysis



"Despite what Jonah says, halving the batch size is not always the best idea. One must consider the station setup times."

"We also believed that splitting jobs into multiple batches would not be beneficial because of the long setup time per lot at station 3. One lot of 60 units would require 1.5666 hours to process while one lot of 6 units would require 1.5066 hours. This savings of 0.06 hour is negligible [...]."

And More Queuing Practice

"...our model did not exploit the fluctuations in demand and the 'concept of queues'. It was a good reference but wasn't too helpful"

"...we again failed to effectively use our knowledge of standard deviation process times in our calculation"

"We panicked when the utilization got higher and over invested"

Capacity Analysis

	# Batches	Lambda	Mu	N	N * Mu	Utilization	L	W	Processing	Total
Station 1	3	3.75	0.25	18	4.5	0.83333333	1.95004785	0.52001276	4	4.52001276
Station 2	3	7.5	0.5	19	9.5	0.78947368	1.06512346	0.14201646	2	2.14201646
Station 3	3	3.75	0.5	10	5	0.75	1.03763682	0.27670315	2	2.27670315
									11	11.938732
									TARGET	14

Capacity utilization:

$$\rho = \lambda / N \times (\text{\# Lots/order} \times \text{Setup time} + \text{Processing Time})^{-1}$$

"although we have learned that a mix of art and science is important in operational decision making, if we ran this simulation again, we would follow the numbers predicted by our models"

"The goal of machine purchase is to have sufficient capacity in the system to minimize delays in processing and generate maximum throughput. However, machines are highly capital intensive."

"Unless costs are prohibitive, buy capacity early if you think you will need it later. Extra capacity early ensures you can meet all orders..."

...Among Other Approaches

"we were also injured by an impulsive order of too many machines near the end" / "we ended up with too few machines in round 1, then binged"

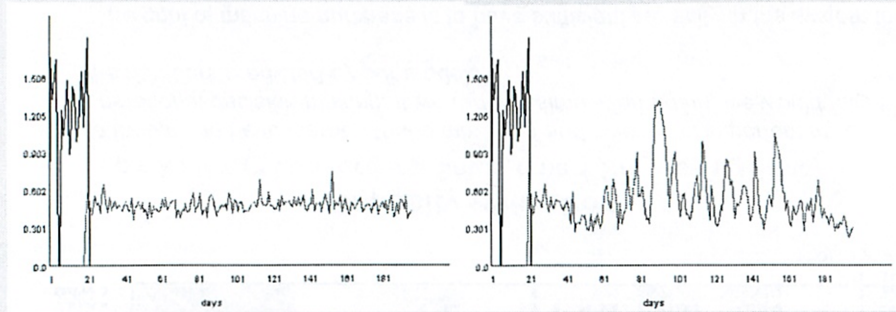
"our approach was reasonable, except the timing of our decision was suboptimal"

"we found ourselves into troubles when the demand was suddenly jumping above our predictions"

"...we bought machines for the stations where utilization was getting closer to 100%..."

"Without having a concrete strategy...we were led to rely on impromptu judgment calls throughout the game."

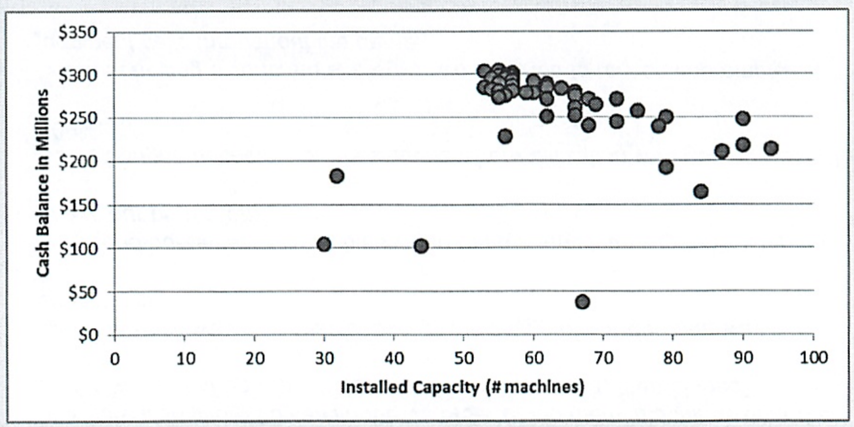
When to Buy Machines?



"Our strategy suggested we wake up at 4am the next day, run a regression, plug the updated parameters to the model and buy machines. Therefore, we bought all the machines beforehand"

"... this strategy did not work very well because at times our forecasted demand and utilization rates were much lower than we saw in practice. Then, we would go into reactionery mode and add machines"

Max Capacity



Source: 2nd Littlefield Simulation

Why Hold Inventory? How Much?

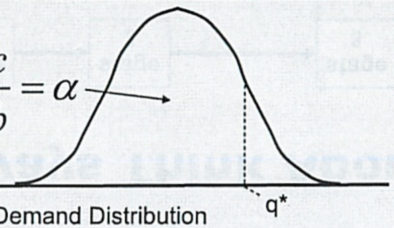
Type of Inventory	*Decision Tool*
Buffer/Decoupling	Build-up diagrams
Seasonal/Anticipation	Build-up diagrams
Cycle stock	EOQ
Safety stock	Newsvendor
Pipeline	Little's Law

Newsvendor Formula

$$\underbrace{P(D \le q^*)}_{\text{In-Stock Probability}} = \frac{r-c}{r-b} = \frac{r-c}{\underbrace{(r-c)}_{\text{cost of under-stocking}} + \underbrace{(c-b)}_{\text{cost of over-stocking}}} = \frac{u}{u+o}$$

$$q^* - E[D] = \text{safety stock}$$

$$\frac{r-c}{r-b} = \alpha$$

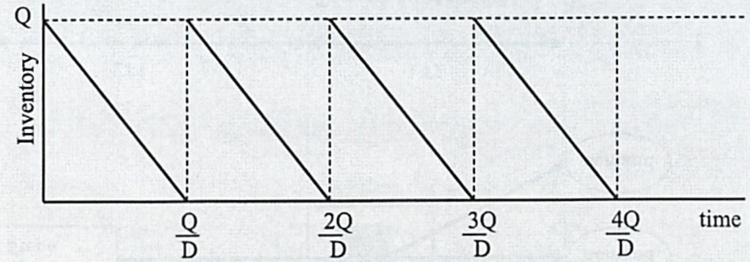


Remark: If D is Normal(μ,σ),

$q^* = \mu + k.\sigma$ with

$\alpha = 95\%$ → $k = 1.64$
$\alpha = 99\%$ → $k = 2.32$
$\alpha = 99.9\%$ → $k = 3.09$

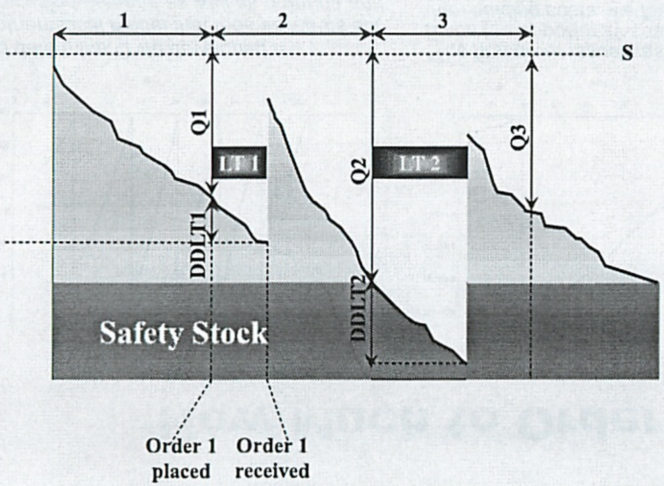
EOQ Formula



$$Q^* = \sqrt{\frac{2DF}{CH}}, \quad T^* = \sqrt{\frac{2F}{DCH}}$$

Periodic Review System

➡ "order back to S every review period"

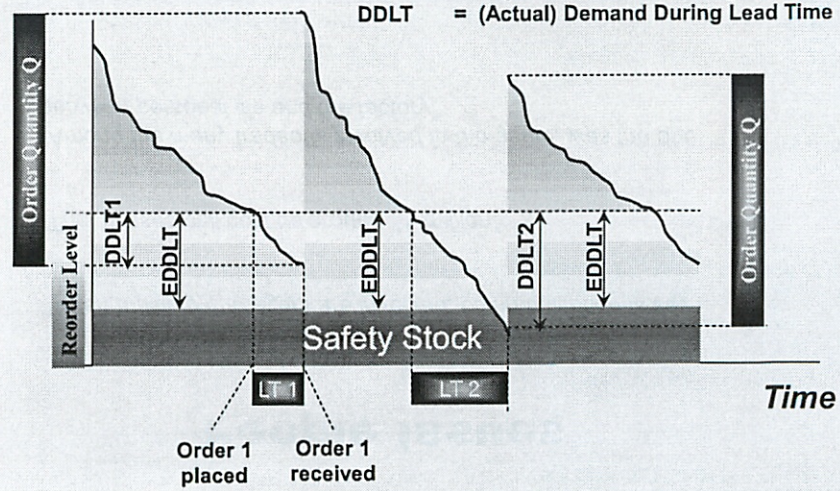


LT = Lead Time
T = Cycle Time or Review Period
DDLT = Actual Demand During Lead Time
Qi = Order Size
S = Order Up To Level

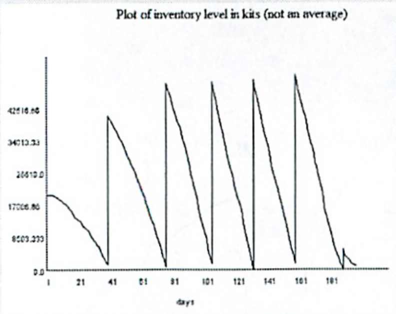
Continuous Review System

Inventory

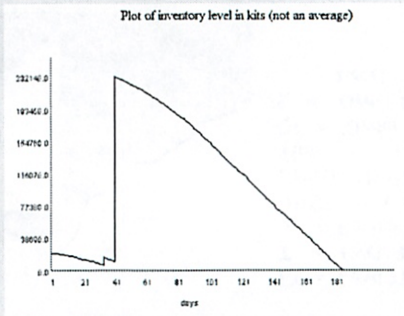
LT = Lead Time
EDDLT = Expected Demand During Lead Time
DDLT = (Actual) Demand During Lead Time



How Much to Order?



"To determine Q we developed a mathematical model that took as inputs our forecasted demand as well as ordering and holding costs. Close to reaching the order point R, Q was calculated by running Excel's Solver to minimize cost"



"The first order issue was not to stock out. Since the opportunity cost was much higher than holding costs, we filled up the warehouse from day 20"

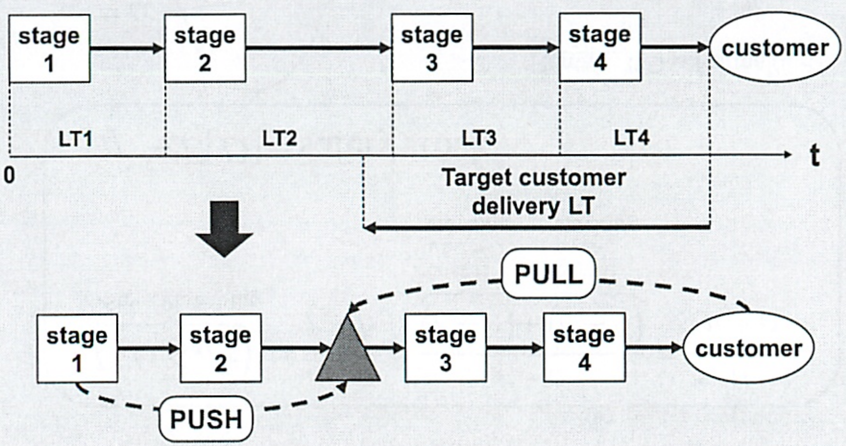
People Issues

"When multiple managers are involved, communication is key"

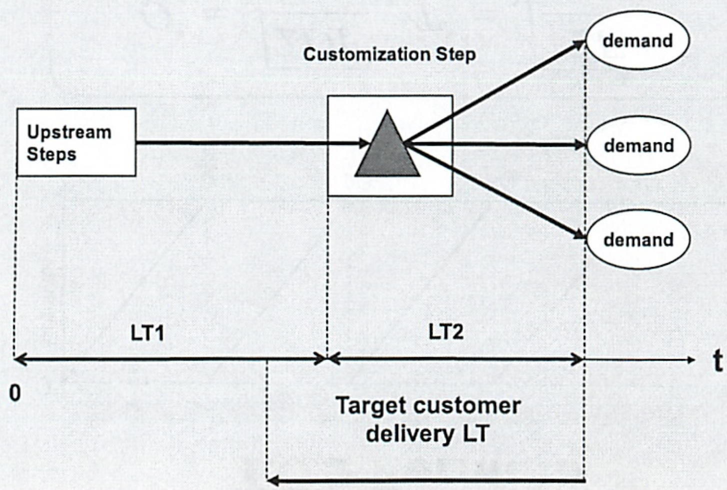
"That missed call cost us around $5 million"

"Among the many tradeoffs involved in the game, was the one between personal life and the factory"

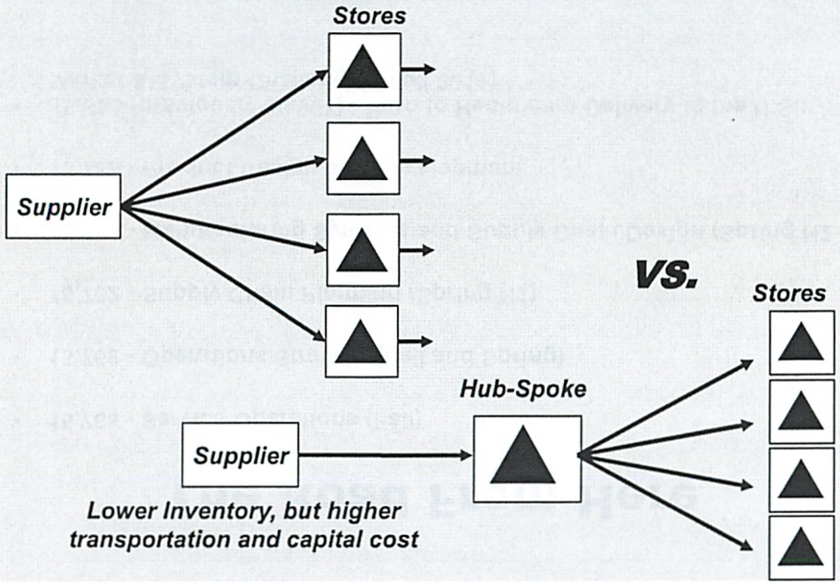
Always Think About the System



Delayed Differentiation

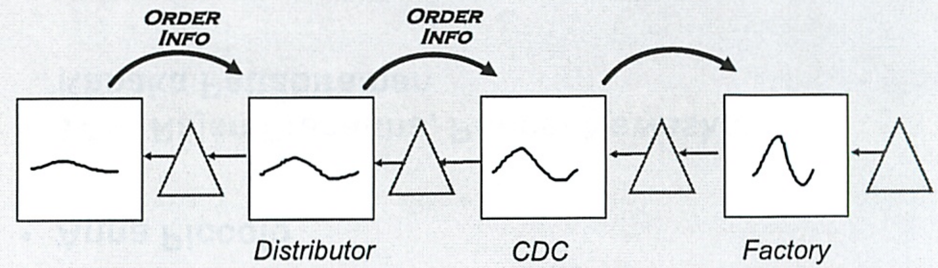


Supply Chain Design: Risk Pooling



Lower Inventory, but higher transportation and capital cost

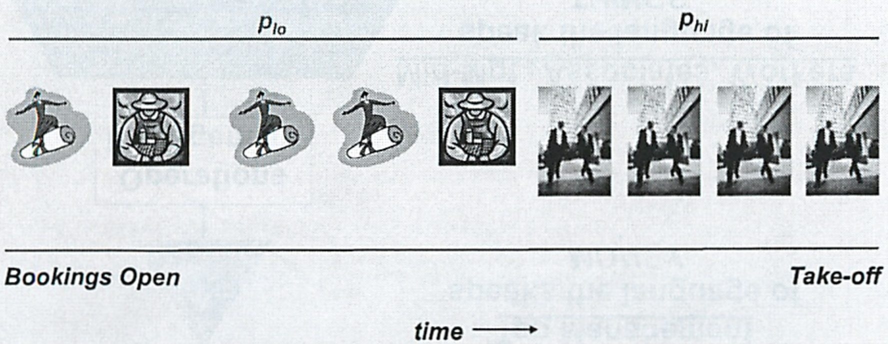
Always Think About the System



"Local optimization leads to global disharmony"

Revenue Management

"Operationalizing Price Discrimination"



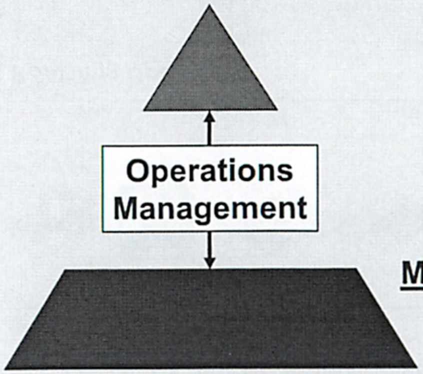
RM =

Higher Revenues + Mitigating Wasted Inventory + Smoothing Demand +…

Stories

A Translation Challenge

Corporate Structure



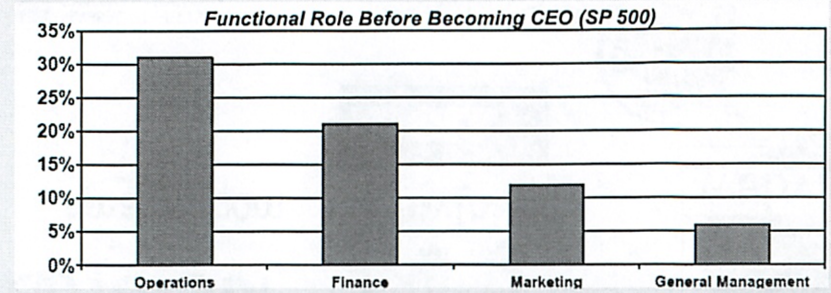
Top Management speaks the language of *MONEY*

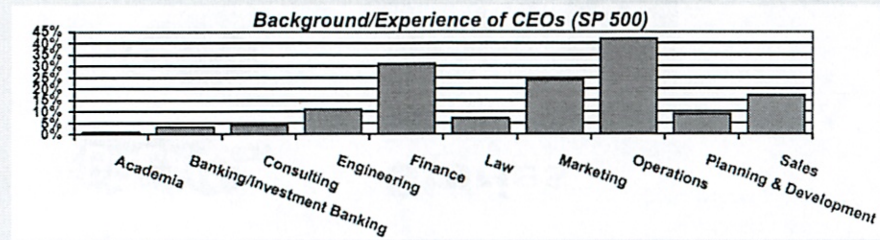
Mid-Mgt., Associates, Workers speak the language of *THINGS*

OM merges physical and financial analyses, and requires great care to people issues!

Career Paths

SpencerStuart 2008





The Road From Here

- 15.768 - Service Operations (Fall)
- 15.769 - Operations Strategy (Fall and Spring)
- 15.762 - Supply Chain Planning (Spring H1)
- 15.763 - Manufacturing Systems and Supply Chain Design (Spring H2)
- 15.783 - Product Design and Development
- 15.S03 (previously 15.967) - Intro to Healthcare Delivery in the U.S.: Market & System Challenges (Fall 2011)

Final Thanks

- Anna Piccolo
- TAs: Rajan Prasanna, Puneet Newaskar, Kanaka Pattabiraman

Do Keep in Touch and…
GOOD LUCK!!!