Máster Universitario en Administración y Dirección de Empresas
Full Time MBA

Quantitative methods for decision making

Professor Andrea Saltelli

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Elements of quantification for decision making with emphasis on operation research

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In this set of slides:

18.

Queueing Theory

…. Hillier (2014) chapter 17 .

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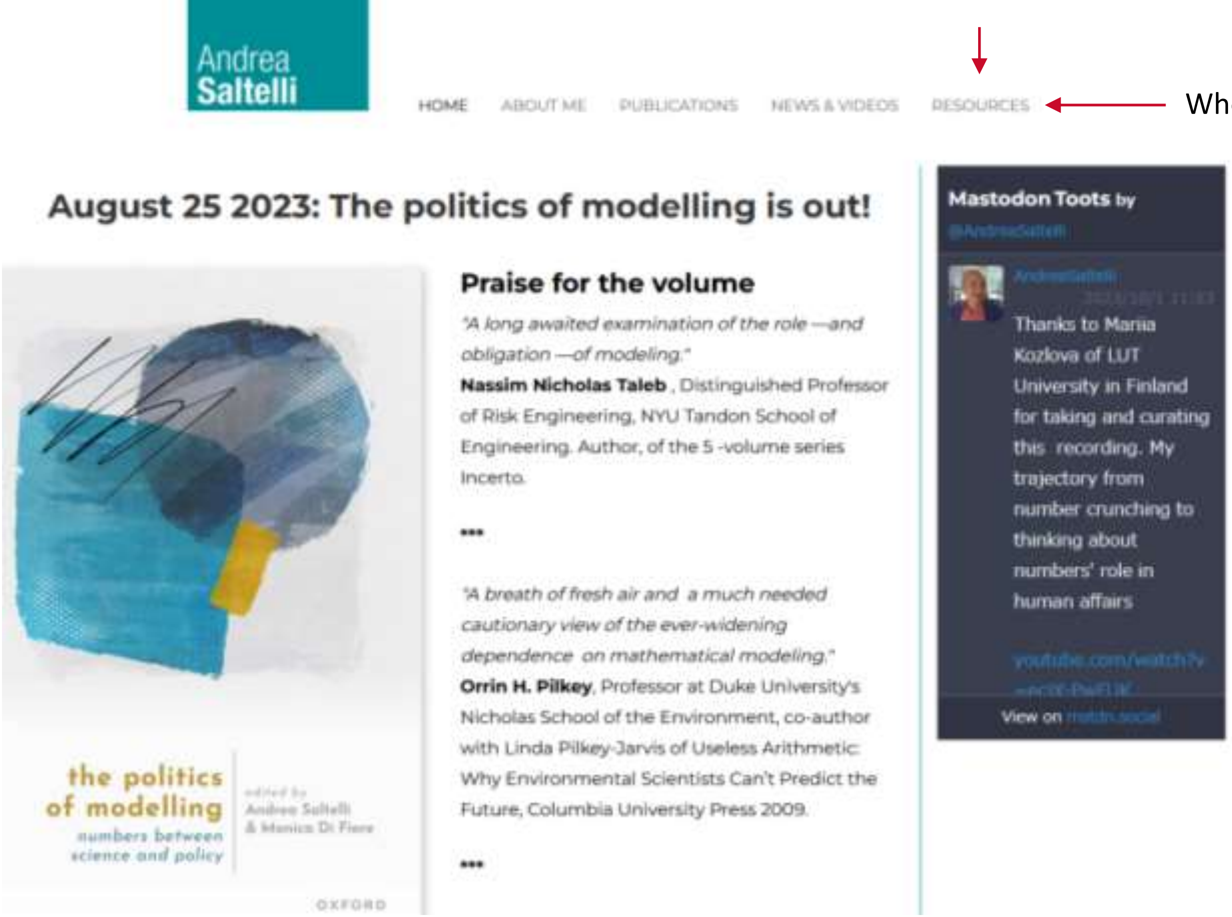
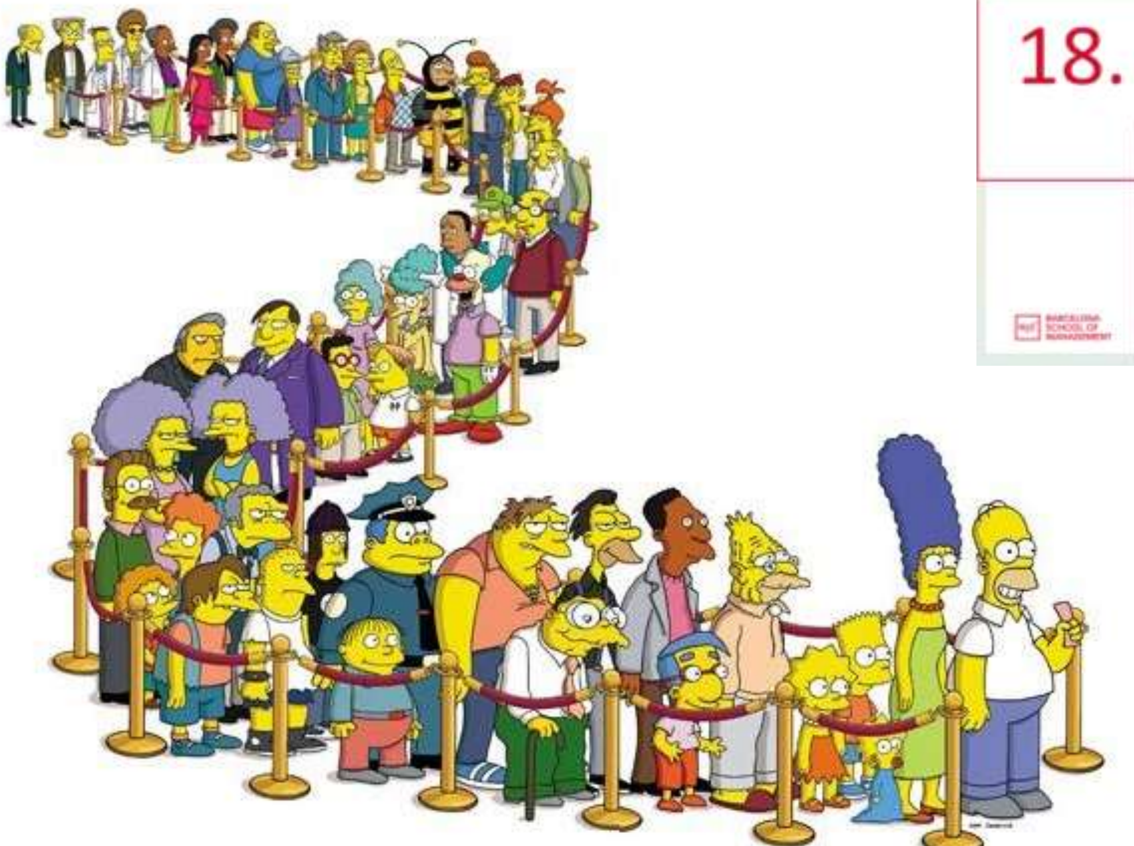


Where to find this talk

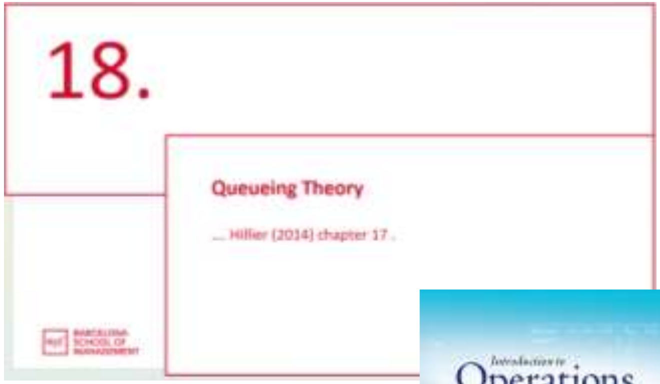
The talk is also at

https://ecampus.bsm.upf.edu/,

where you find additional reading material



The Simpsons, Twentieth Century Fox Film Corporation



18.

Queueing Theory

... Hillier (2014) chapter 17 .

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FIGURE 17.1
The basic queueing process.

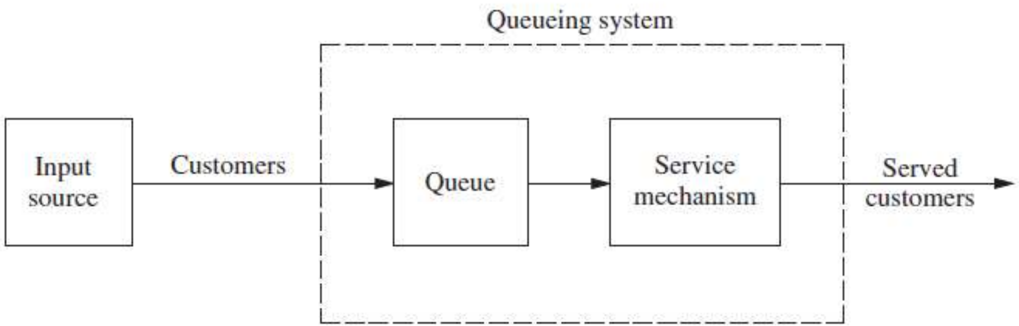
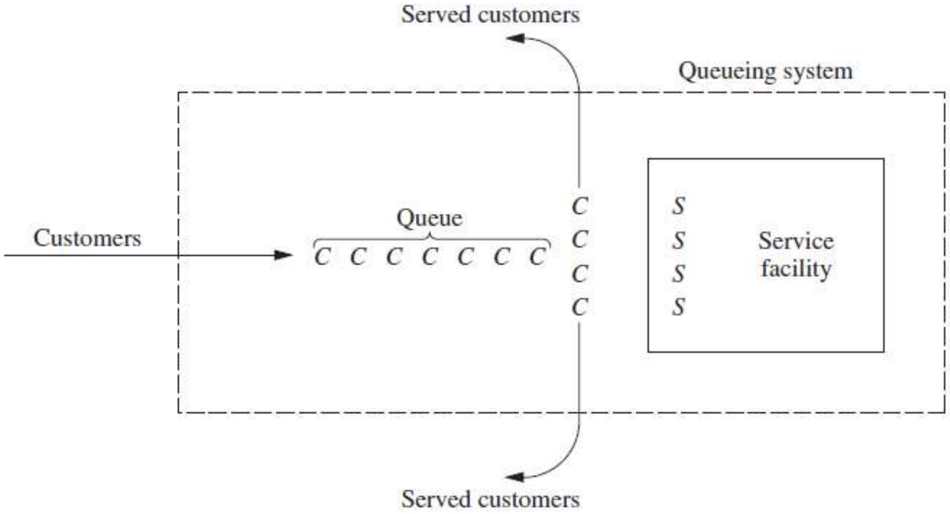
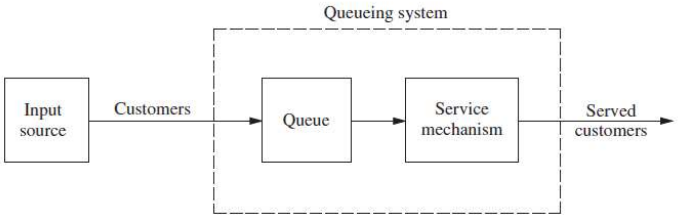


FIGURE 17.2
An elementary queueing system (each customer is indicated by a C and each server by an S).



Key parameters of these systems are customers' "interarrival time" and "service time"

■ FIGURE 17.1
The basic queueing process.



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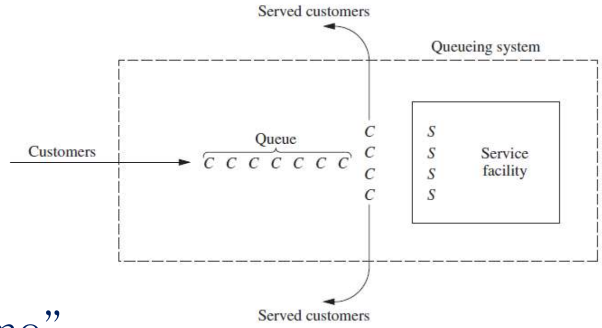


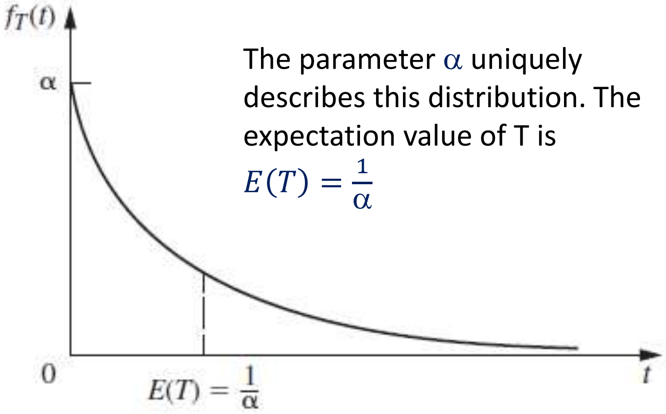
Ley T be either an "inter-arrival time" or a "service time". This time T can be often assumed to follow an exponential distribution

$$T \sim F_T(t) = \alpha e^{-\alpha t}$$

Math notations to say that T follows distribution F_T

■ FIGURE 17.3
Probability density function for the exponential distribution.

Mean value of T is $E(T) = \frac{1}{\alpha}$



The parameter α uniquely describes this distribution. The expectation value of T is $E(T) = \frac{1}{\alpha}$

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Ley T be either an "inter-arrival time" or a "service time".
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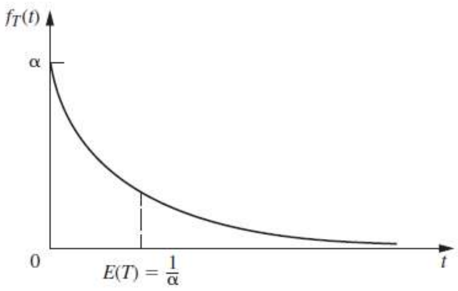

Properties of this distribution

The parameter α has the dimension of 1/time; small values of α correspond to longer waits

Small T are more likely then large T, where the scale of what is big or small is relative to α

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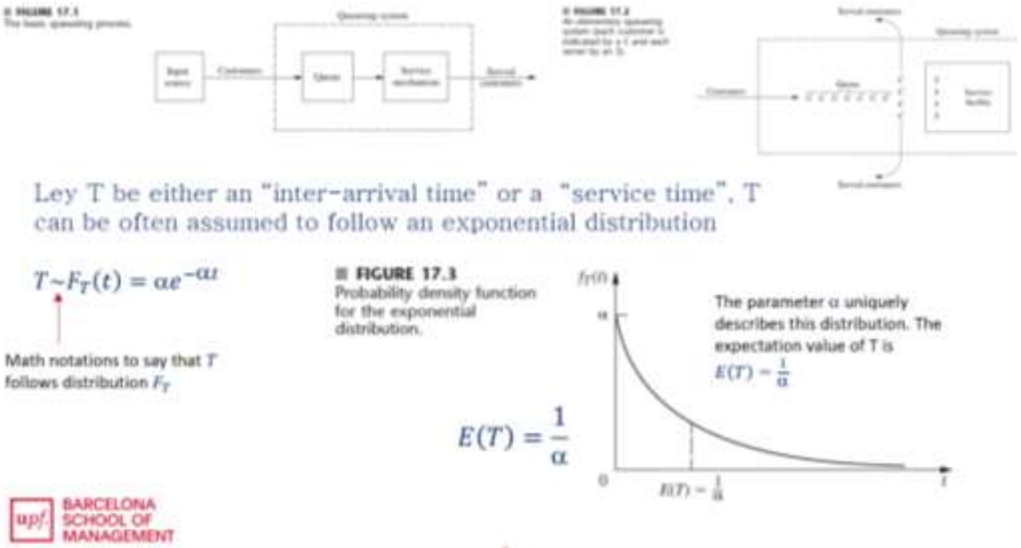

Assume this holds; then if *X(t)* is the *number* of times an event (arrivals or completions) occurs over a specified time *t* then *X*(*t*) follows a *Poisson distribution* with parameter αt

$$P\{X(t) = n\} = \frac{(\alpha t)^n e^{-\alpha t}}{n!}$$

Using these formulae different queueing problems can be formulated and solved

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Before leaving the Poisson distribution $P\{X(t) = n\} = \frac{(\alpha t)^n e^{-\alpha t}}{n!}$

It is normally stated as $P\{X = n\} = \frac{(\lambda)^n e^{-\lambda}}{n!}$ where P refers to events per unit time, λ is the average number of times an event occur per unit of time; so if λ is the average number of soldiers killed by a horse-kick in a given year, the probability of n soldier dying in a given year is given by $P\{X = n\} = \frac{(\lambda)^n e^{-\lambda}}{n!}$

Source: Wikipedia Commons

Ladislaus Bortkiewicz used this formula in the late 1800s, when investigating accidental deaths by horse kick of soldiers in the Prussian army. Also known for his work on Marxian theory

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An average of 0.61 soldiers died by horse kicks per year in each Prussian army corps. You want to calculate the probability that exactly two soldiers died in the VII Army Corps in 1898, assuming that the number of horse kick deaths per year follows a Poisson distribution $P\{X=n\}=\frac{(\lambda)^n e^{-\lambda}}{n!}$

$$P\{X=2\}=\frac{(0.61)^2 e^{-0.61}}{2!} \sim 0.101$$

Source: Wikipedia Commons

Since Bortkiewicz's time, Poisson distributions have been used to describe many other things. For example, a Poisson distribution could be used to explain or predict:

- Text messages per hour
- Male grizzly bears per hectare
- Machine malfunctions per year
- Website visitors per month
- Influenza cases per year

Source: https://www.scribbr.com/statistics/poisson-distribution/

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19.

Programming and Planning. PERT and CPM

…. Hillier chapter 22.

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PERT (program evaluation and review technique)

CPM (critical path method)

Perhaps the most widely used OR techniques (PERT may be required beside GANTT(*) charts for project submission e.g. at EU level)

(*) Developed by Henry L. Gantt in the 1910

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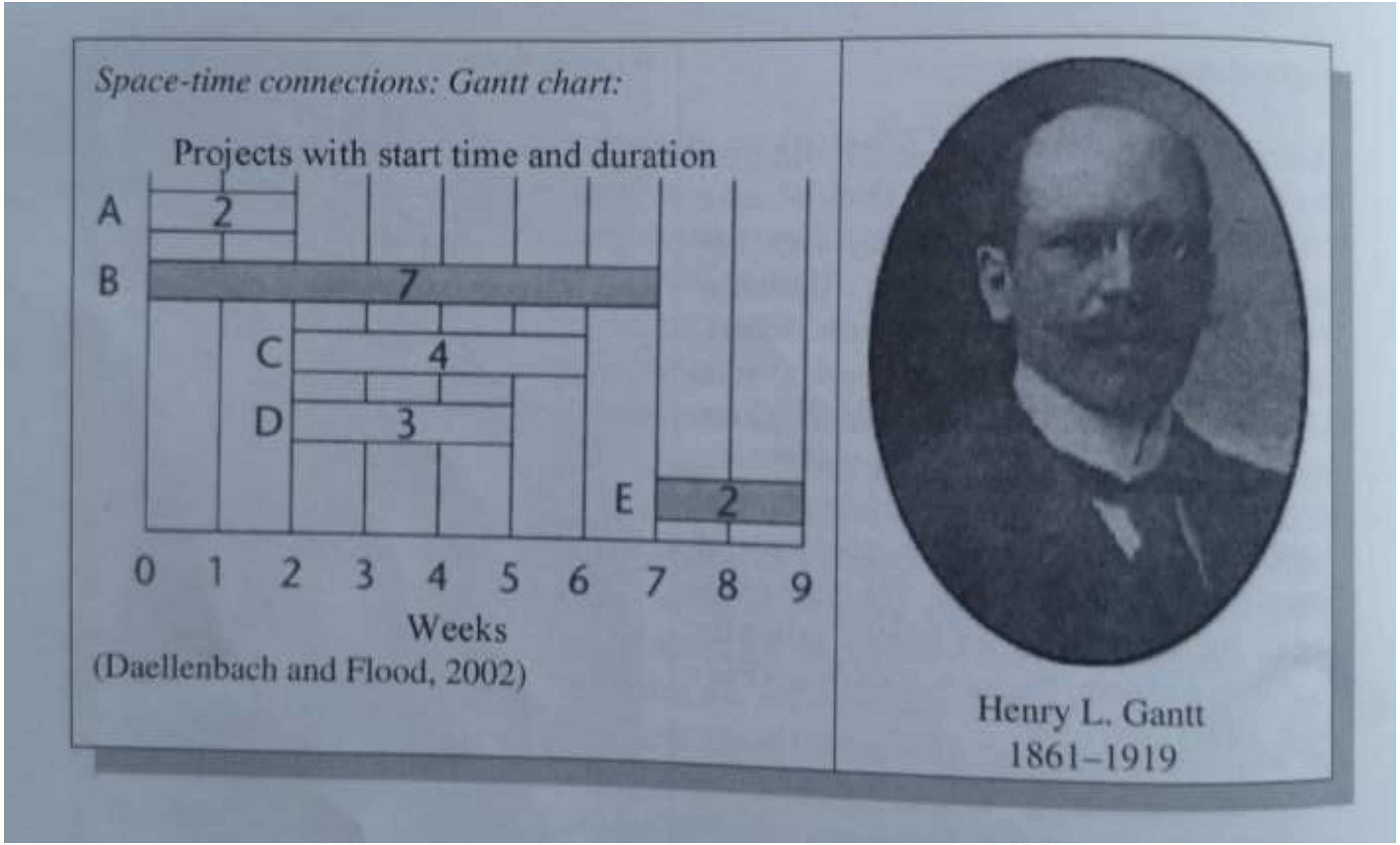
Worked with Frederick Taylor and possibly contributes as well with PERT and CPM developments (Gass and Assad, p. 116))



Source: p. 24, Gass, Saul I., and Arjang A. Assad. 2006. An Annotated Timeline Of Operations Research: An Informal History. 1st Corrected ed. 2005. Corr. 2nd printing 2006 edition. New York: Springer-Verlag New York Inc.

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Why PERT?

1. **Better Project Planning:** PERT analysis helps in breaking down the project into tasks, estimating the time required for each task, and identifying dependencies between tasks.
2. **Resource Allocation:**

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3. **Risk Assessment:** PERT analysis allows for the incorporation of uncertainty and risk into the project schedule. It helps in identifying critical paths and areas where schedule slippages could occur.
4. **Communication:** Using PERT analysis or similar project management methodologies can help in presenting a well-structured project plan.
5. **Monitoring and Control:** Once the project is underway, PERT analysis can be used to monitor progress, track deviations from the schedule, and make necessary adjustments to ensure the project stays on track.

A prototype example: Construction work with penalty for delays and premium for speedy completion (Hillier section 22.1)

Example: Cannot put up a roof without walls → D

TABLE 22.1 Activity list for the Reliable Construction Co. project

Activity	Activity Description	Immediate Predecessors	Estimated Duration
A	Excavate	—	2 weeks
B	Lay the foundation	*A*	4 weeks
C	Put up the rough wall	*B*	10 weeks
D	Put up the roof	*C*	6 weeks
E	Install the exterior plumbing	*C*	4 weeks
F	Install the interior plumbing	*E*	5 weeks
G	Put up the exterior siding	*D*	7 weeks
H	Do the exterior painting	*E, G*	9 weeks
I	Do the electrical work	*C*	7 weeks
J	Put up the wallboard	*F, I*	8 weeks
K	Install the flooring	*J*	4 weeks
L	Do the interior painting	*J*	5 weeks
M	Install the exterior fixtures	*H*	2 weeks
N	Install the interior fixtures	*K, L*	6 weeks

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The contract foresees

A penalty of $300,000 if construction not completed by 47 weeks
A bonus of $150,000 if it is completed within 40 weeks

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Questions for the analyst (1):

1. How can the project be displayed graphically to better visualize the flow of the activities?
2. What is the total time required to complete the project if no delays occur?
3. When do the individual activities need to start and finish (**at the latest**) to meet this project completion time?
4. When can the individual activities start and finish (**at the earliest**) if no delays occur?
5. Which are the **critical bottleneck** activities where any delays must be avoided to prevent delaying project completion?

Questions for the analyst (2):

6. For the other (=non bottleneck) activities, how much delay can be tolerated without delaying project completion?
7. Given the uncertainties in accurately estimating activity durations, what is the probability of completing the project by the deadline?
8. If extra money is spent to expedite the project, what is the least expensive way of attempting to meet the target completion time (40 weeks)?
9. How should ongoing costs be monitored to try to keep the project within budget?

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Project network representation

Is this a directed or undirected network?

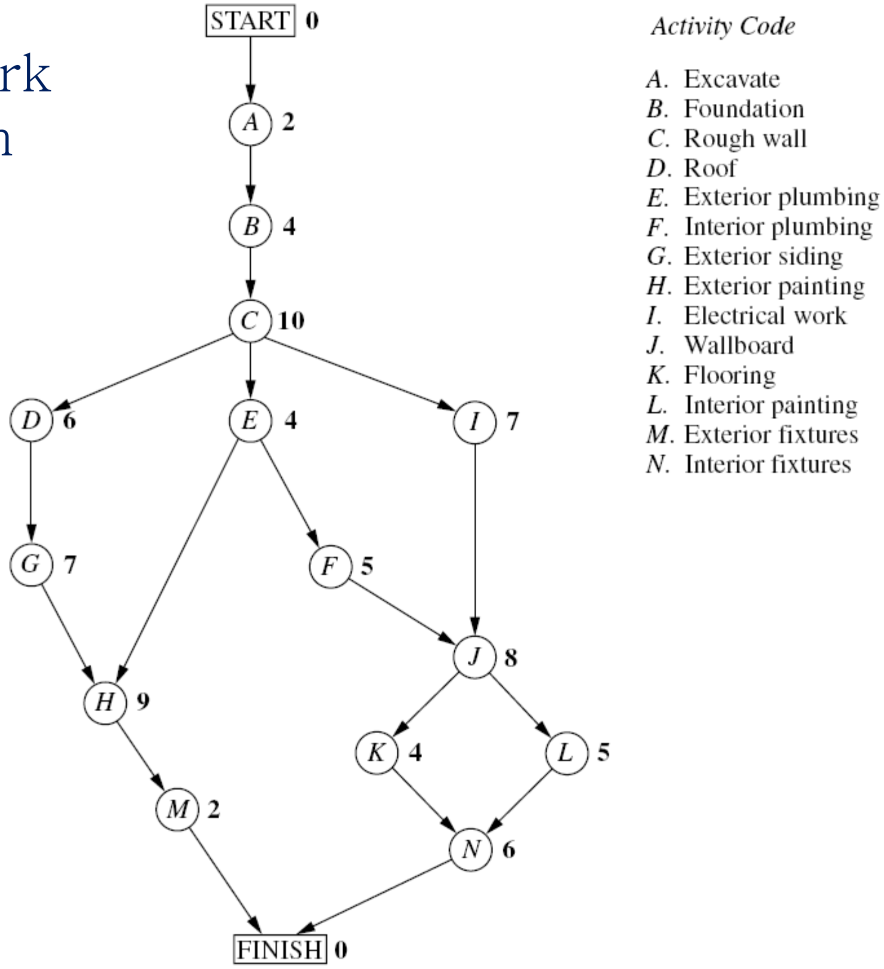

FIGURE 22.1
The project network for the Reliable Construction Co. project.

Question 1

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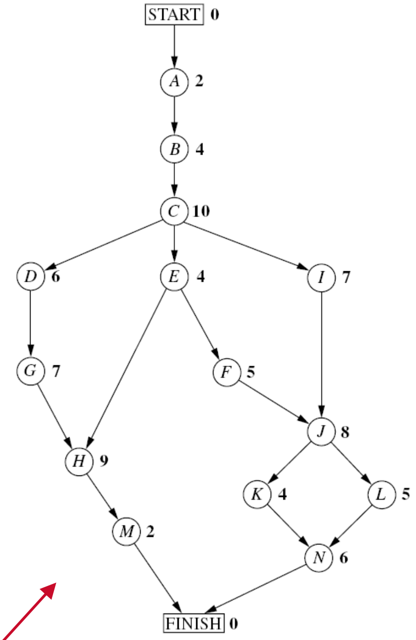

Activity Code

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J. Wallboard
K. Flooring
L. Interior painting
M. Exterior fixtures
N. Interior fixtures

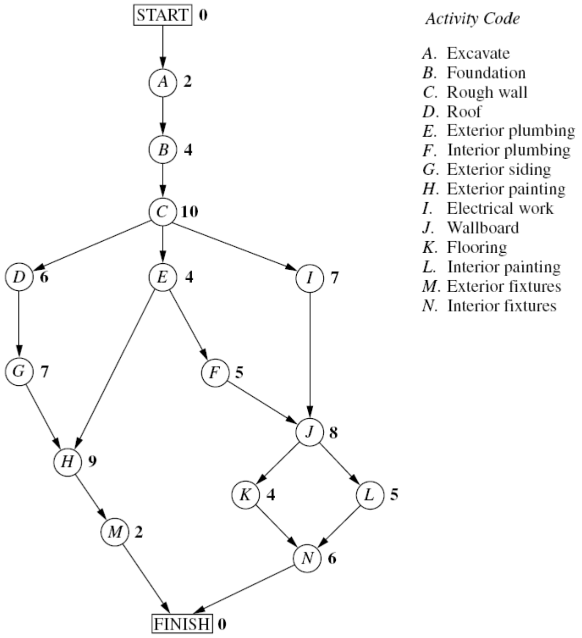
■ **FIGURE 22.1**
The project network for the Reliable Construction Co. project.

This is way more informative than this

Question 2 and 5 now:

Question 2: What is the total time required to complete the project if no delays occur?

Question 5: Which are the critical bottleneck activities where any delays must be avoided to prevent delaying project completion?



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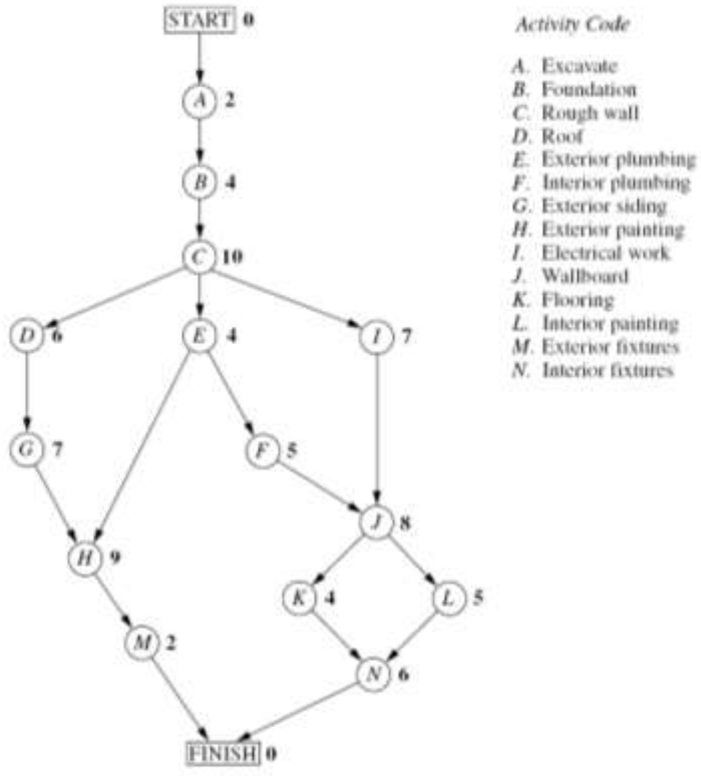
Question 2: What is the total time required to complete the project if no delays occur?



Adding the durations in the table gives 79 weeks but the network tells us that some activities can be run in parallel

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Adding the durations in the table gives 79 weeks but the network tells us that some activities can be run in parallel

What we need instead is to compute the duration over feasible paths

The first two paths are shown in red and green

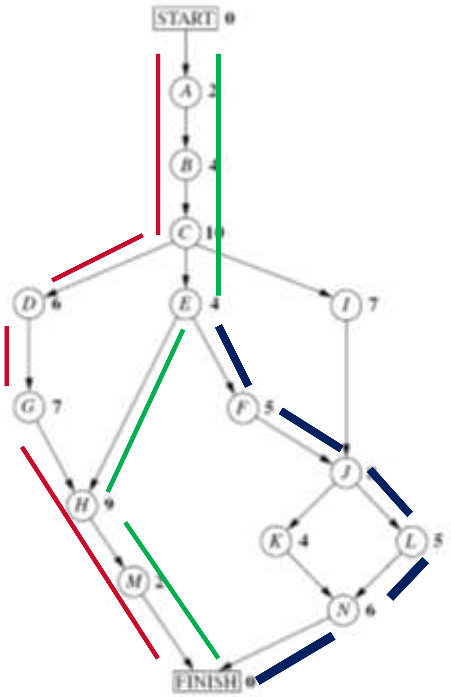
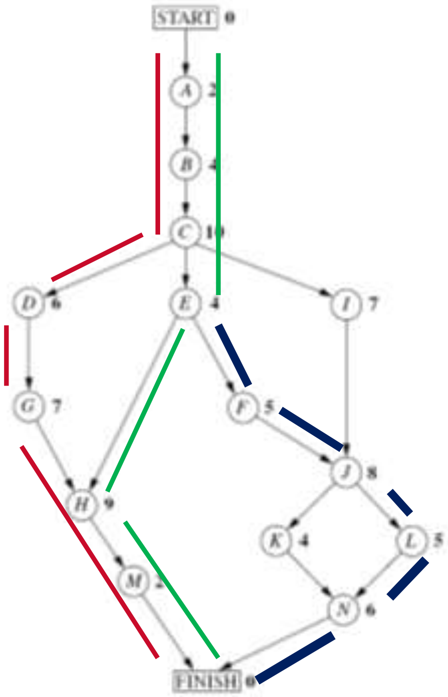


TABLE 22.2 The paths and path lengths through Reliable's project network

Path	Length
START → A → B → C → D → G → H → M → FINISH	2 + 4 + 10 + 6 + 7 + 9 + 2 = 40 weeks
START → A → B → C → E → H → M → FINISH	2 + 4 + 10 + 4 + 9 + 2 = 31 weeks
START → A → B → C → E → F → J → K → N → FINISH	2 + 4 + 10 + 4 + 5 + 8 + 4 + 6 = 43 weeks
START → A → B → C → E → F → J → L → N → FINISH	2 + 4 + 10 + 4 + 5 + 8 + 5 + 6 = 44 weeks
START → A → B → C → I → J → K → N → FINISH	2 + 4 + 10 + 7 + 8 + 4 + 6 = 41 weeks
START → A → B → C → I → J → L → N → FINISH	2 + 4 + 10 + 7 + 8 + 5 + 6 = 42 weeks

Note that the path are not inclusive of all steps, and that for example activity H in the green path needs both G and E to be completed; yet …

… the estimated project duration equals the length of the longest path through the project Network (=critical path, in blue)



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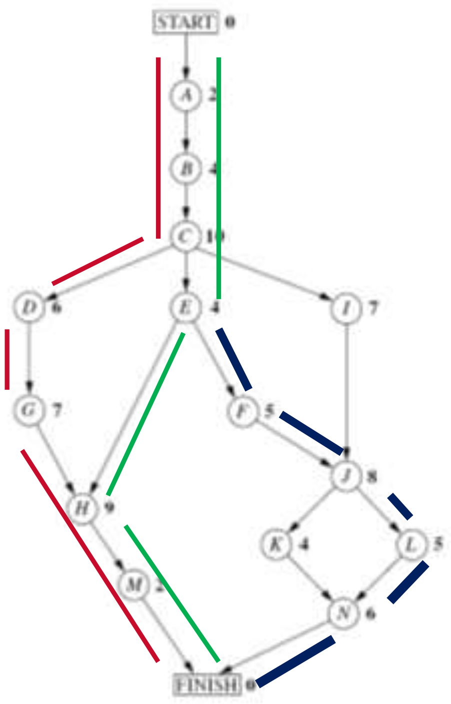
… the estimated project duration equals the length of the longest path through the project Network (=critical path)

All the shorter paths will reach the FINISH node no later than this critical path

➔ Project duration = 44 weeks and the critical bottlenecks are the nodes of this path



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Hold on a second; isn't it possible that a node that does not belong to the longest path becomes a bottleneck because it delays the critical node?

··· the estimated project duration equals the length of the longest path through the project Network (=critical path)

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➔ Project duration = 44 weeks and the critical bottlenecks are the nodes of this path

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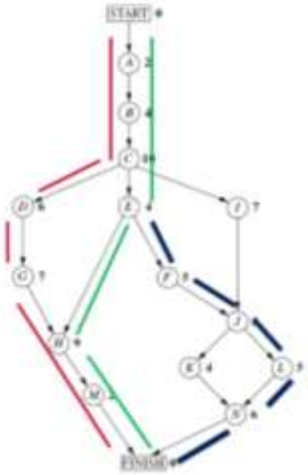

Question 2 and 5

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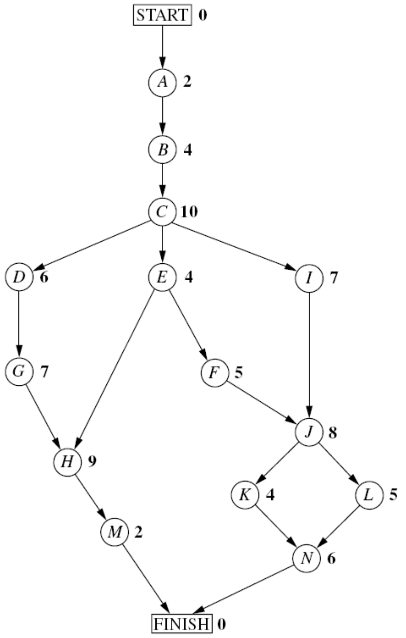
Question 5: Which are the critical bottleneck activities where any delays must be avoided to prevent delaying project completion?



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■ **FIGURE 22.1**
The project network for the Reliable Construction Co. project.

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Scheduling Individual Activities with PERT/CPM

Question 4

4. When can the individual activities start and finish (at the earliest) if no delays occur?

Logging earliest start time (**ES**) and the earliest finish time (**EF**) for each activity, starting with those with a single predecessor

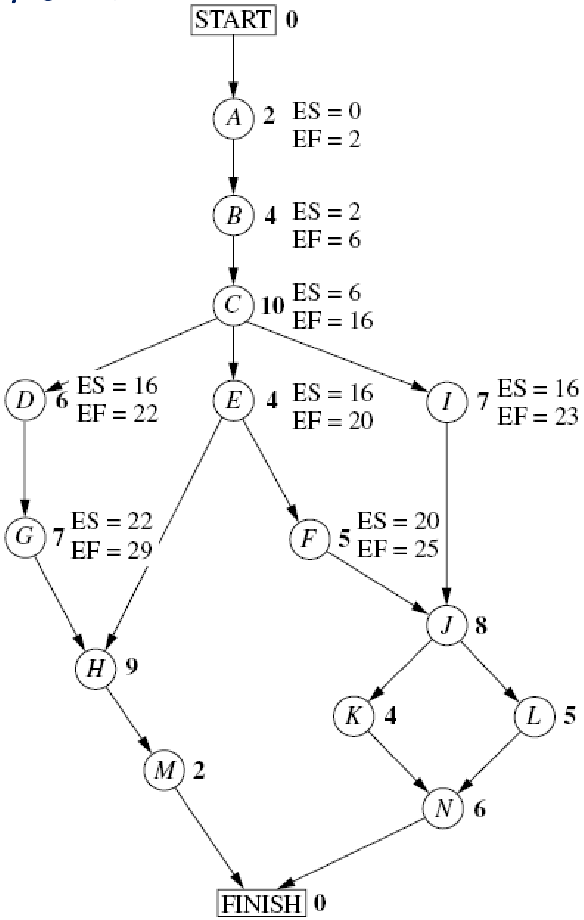

FIGURE 22.2
Earliest start time (ES) and earliest finish time (EF) values for the initial activities in Fig. 22.1 that have only a single immediate predecessor.

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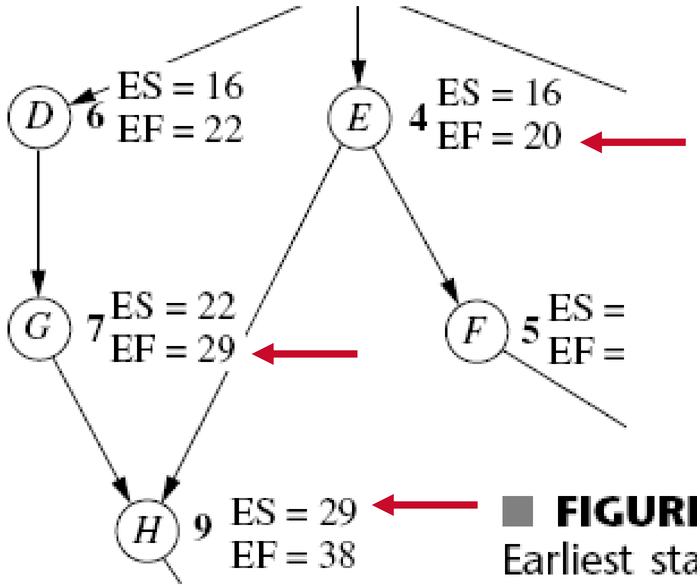
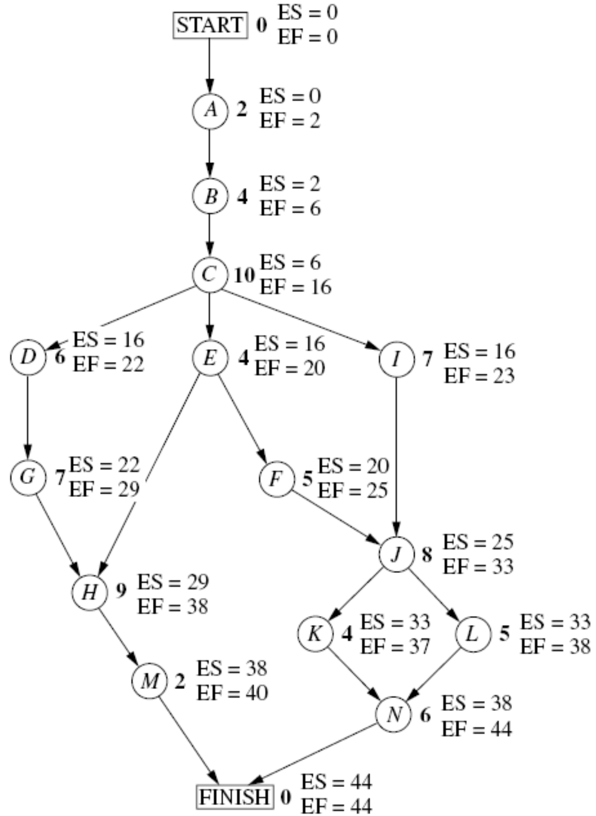
What when there are two predecessors (Example E and G for node H)?
Take the maximum EF (Example 29 of G > 20 of E)



■ **FIGURE 22.3**
Earliest start time (ES) and earliest finish time (EF) values for all the activities (plus the START and FINISH nodes) of the Reliable Construction Co. project.



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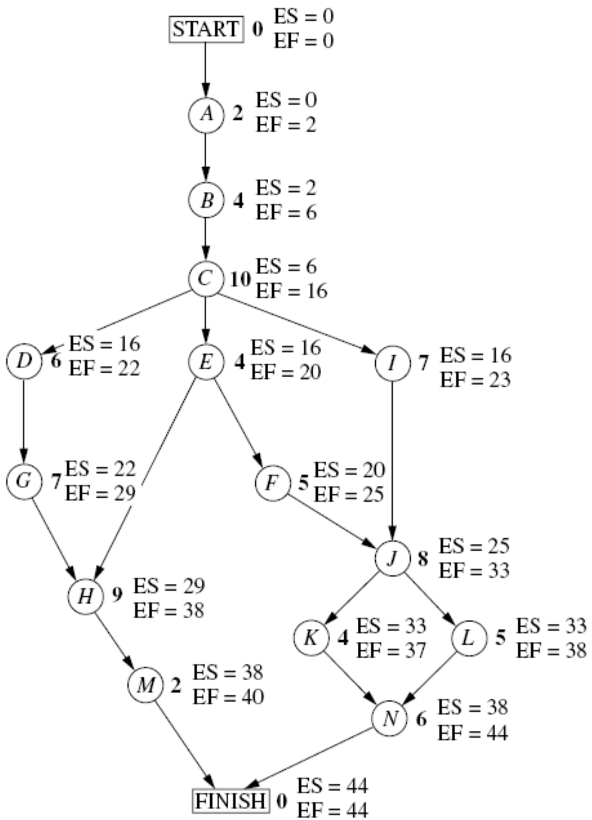
Question 4

4. When can the individual activities start and finish (at the earliest) if no delays occur?

This is a forward pass through the network



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What if there are delays? It is convenient to have for each activity also the latest start (**LS**) time and latest finish (**LF**) time, computed as not to engender delay of the subsequent nodes. We proceed backward

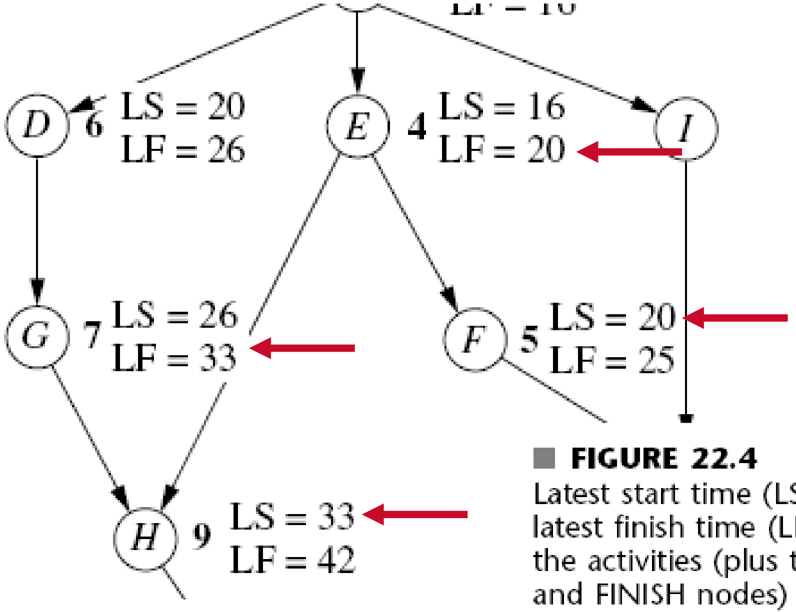
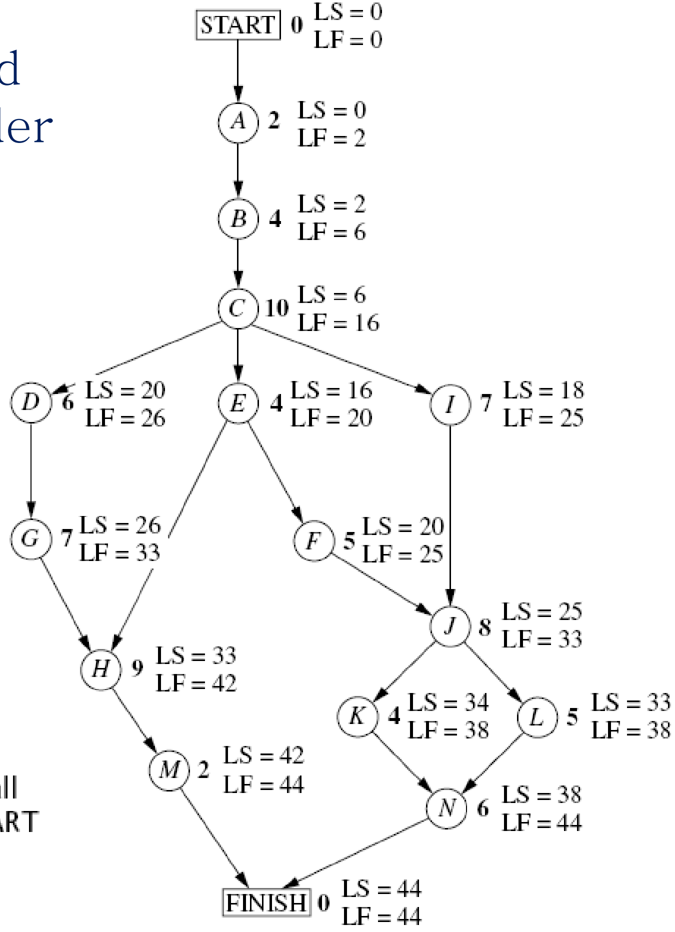


FIGURE 22.4
Latest start time (LS) and latest finish time (LF) for all the activities (plus the START and FINISH nodes) of the Reliable Construction Co. project.



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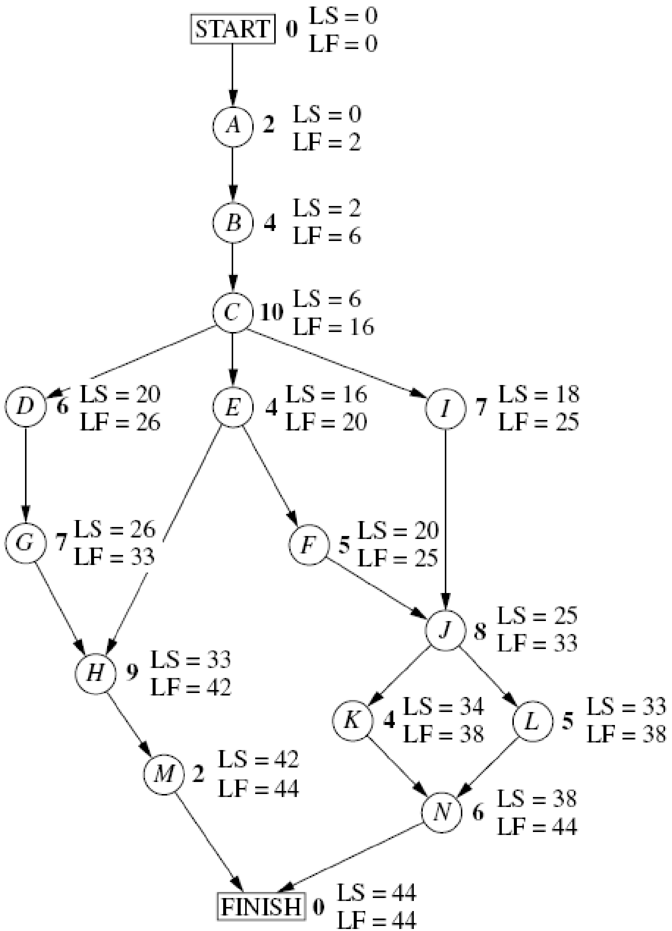

This is a backward pass through the network

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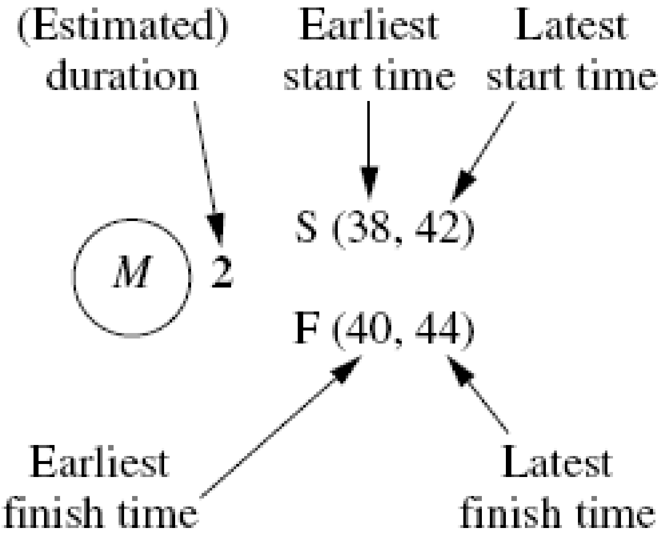
One last effort: combining earliest and latest time information as to identify and quantify **slack**



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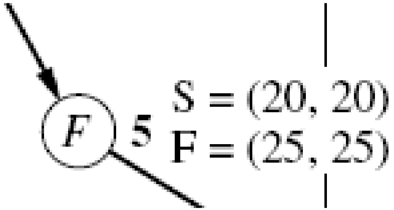
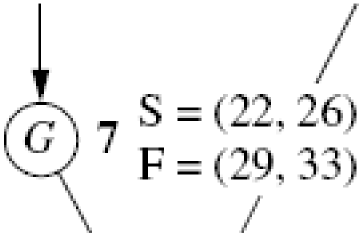
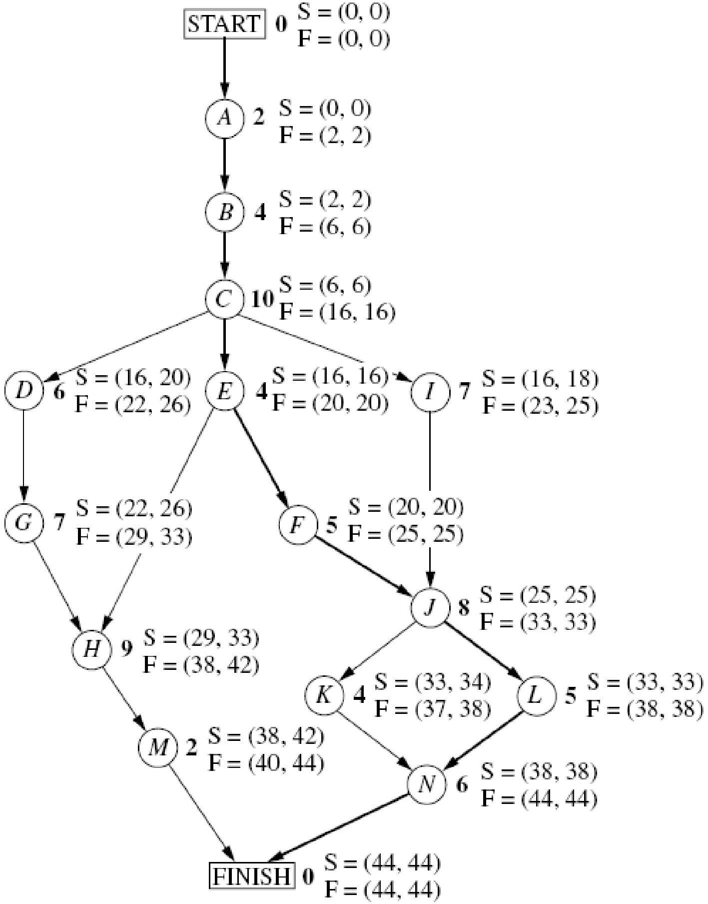
The full picture



No slack; critical path



Slack; not critical path

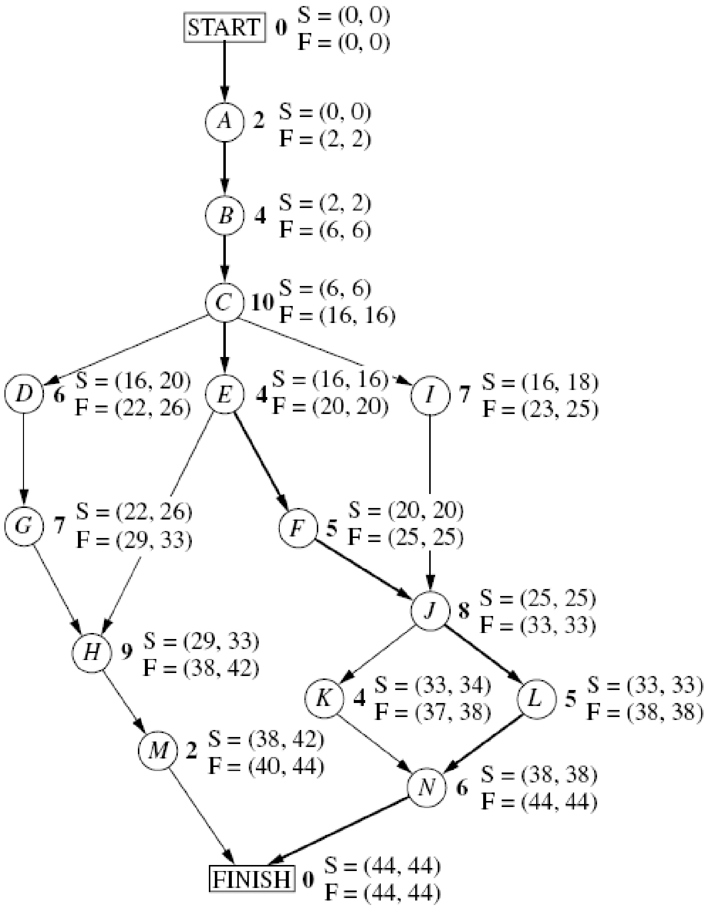


upf. BARCELONA SCHOOL OF MANAGEMENT

The full picture

■ **TABLE 22.3** Slack for Reliable's activities

Activity	Slack (LF − EF)	On Critical Path?
A	0	Yes
B	0	Yes
C	0	Yes
D	4	No
E	0	Yes
F	0	Yes
G	4	No
H	4	No
I	2	No
J	0	Yes
K	1	No
L	0	Yes
M	4	No
N	0	Yes



Solved

1. Project display
2. Time to completion
3. Latest start and finish time per activity
4. Earliest start and finish time per activity
5. Bottlenecks
6. Slacks

The full picture

TABLE 22.3 Slack for Reliable's activities

Activity	Slack (LF − EF)	On Critical Path?
A	0	Yes
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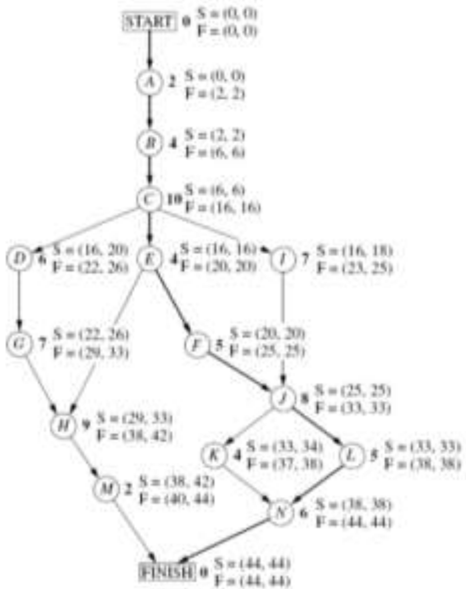

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Task	Task Description	Tasks that Must Precede	Time
A	Buy the mozzarella cheese*		30 minutes
B	Slice the mozzarella	A	5 minutes
C	Beat 2 eggs		2 minutes
D	Mix eggs and ricotta cheese	C	3 minutes
E	Cut up onions and mushrooms		7 minutes
F	Cook the tomato sauce	E	25 minutes
G	Boil large quantity of water		15 minutes
H	Boil the lasagna noodles	G	10 minutes
I	Drain the lasagna noodles	H	2 minutes
J	Assemble all the ingredients	I, F, D, B	10 minutes
K	Preheat the oven		15 minutes
L	Bake the lasagna	J, K	30 minutes

*There is none in the refrigerator.

(a) Construct the project network for preparing this dinner.

(b) Find all the paths and path lengths through this project network. Which of these paths is a critical path?

Exercise in class

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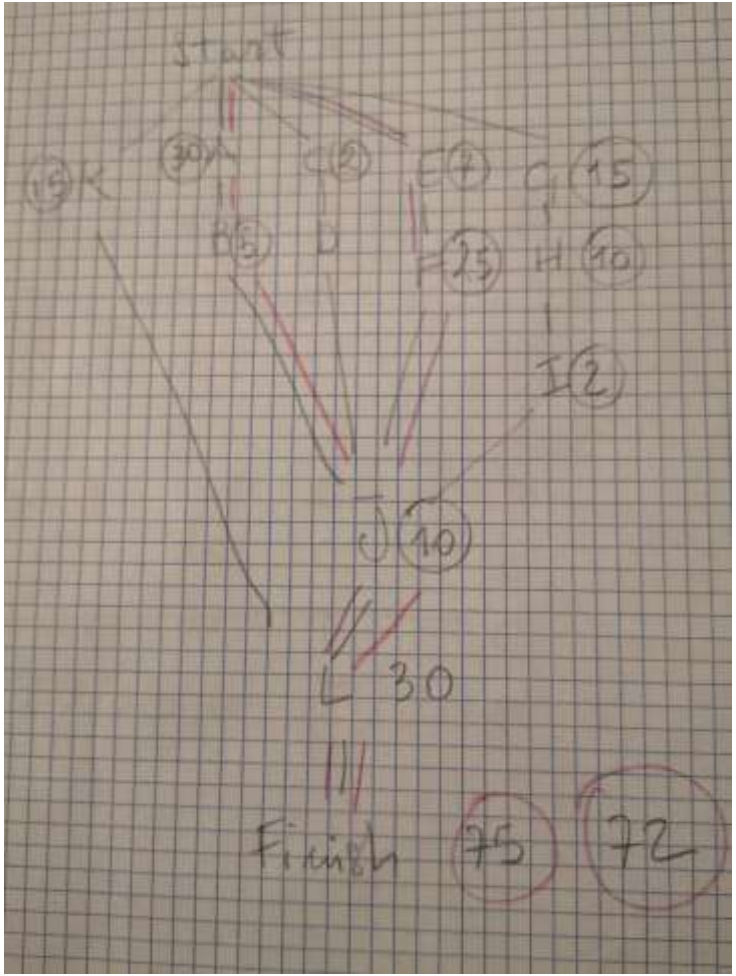

My take

20.

Ethical considerations for OR

From Condorcet to Bentham. Sociology of quantification. Scheduling software and its consequences. Responsible modelling. Partly based on O'Neil, C. (2016) Weapons of math destruction. Random House Publishing Group.

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‘Mathématique sociale’: We still use today terms such as ‘Condorcet method’, ‘Condorcet winner’, ‘Condorcet-ranking procedure’

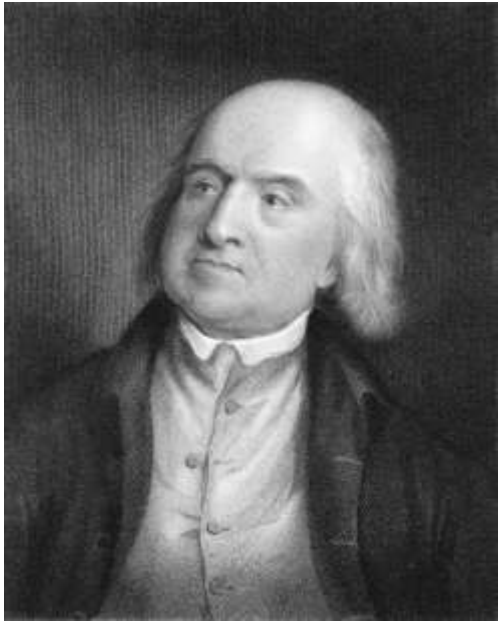
Nicolas de Caritat,
marquis de Condorcet
(1743- 1794)
‘

Feldman, J., 2005, Condorcet et la mathematique sociale: enthousiasmes et bemols, Mathematics and Social Sciences, 172(4), 7-41, http://www.ehess.fr/revue-msh/pdf/N172R955.pdf

Munda G. (2007) - Social multi-criteria evaluation, Springer-Verlag, Heidelberg, New York, Economics Series

Condorcet's Mathématique sociale had its continuation in Jeremy Bentham's utilitarianism

Marquis de Condorcet (1743- 1794)



Jeremy Bentham (1748-1832)

Felicific calculus: 'The greatest good for the greatest number'
(utility or hedonistic calculus)

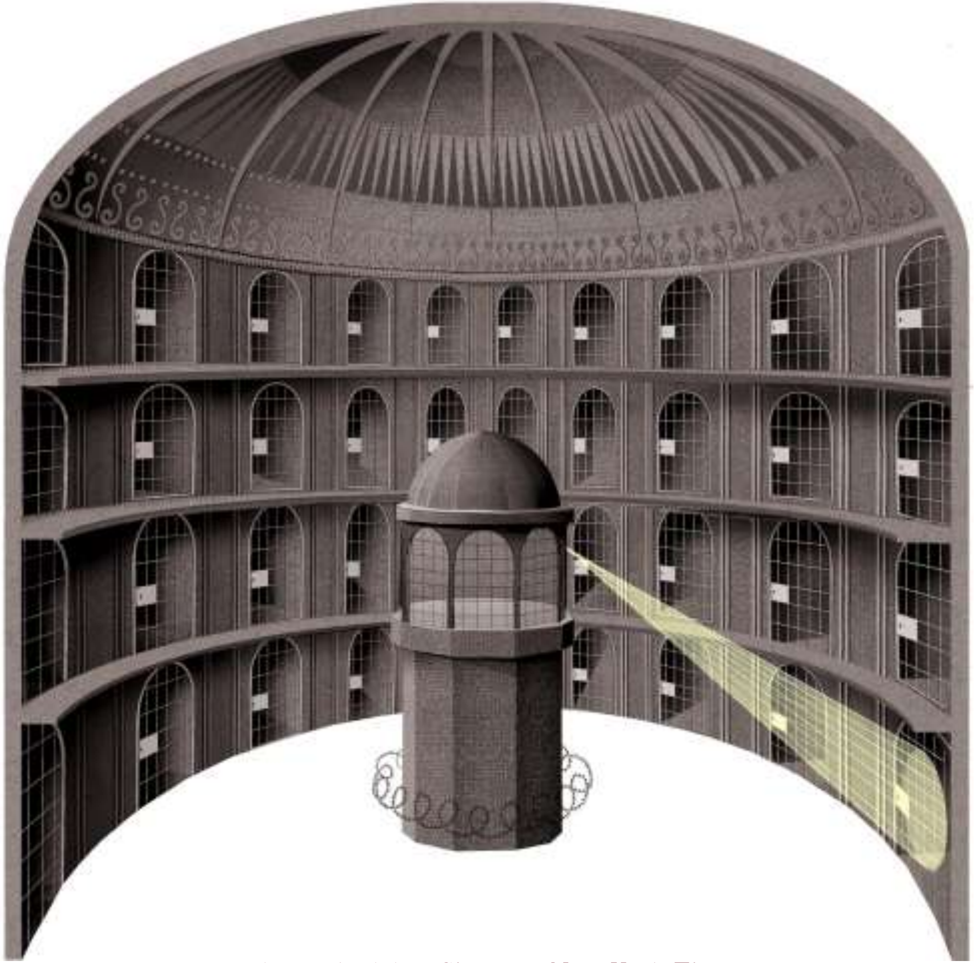
Artork: Adam Simpson, New York Times

- Intensity: How strong is the pleasure?
- Duration: How long will the pleasure last?
- Certainty or uncertainty: How likely or unlikely is it that the pleasure will occur?
- Propinquity or remoteness: How soon will the pleasure occur?
- Fecundity: The probability that the action will be followed by sensations of the same kind.
- Purity: The probability that it will not be followed by sensations of the opposite kind.
- Extent: How many people will be affected?

Remember from Lesson 1?

Jeremy Bentham

Bentham's Panopticon

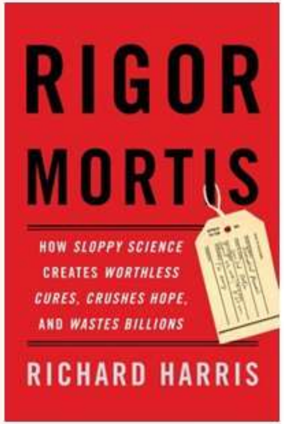


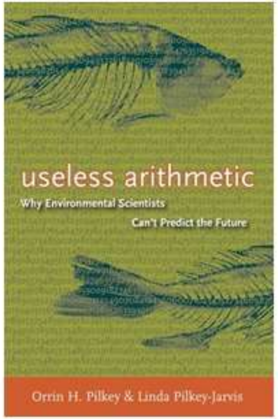
Artwork: Adam Simpson, New York Times

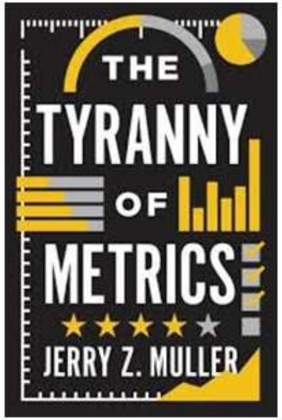
Sociology of quantification,
for numbers, visible and invisible…

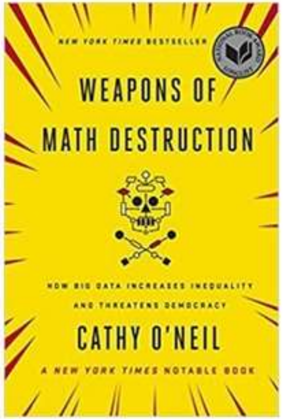
Sociology of quantification, an explosion of works from many disciplines

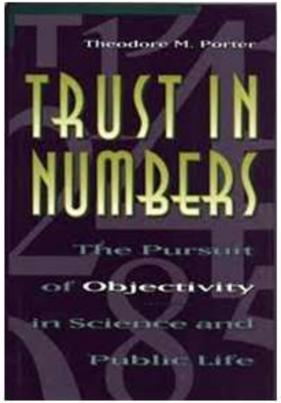
Algorithms, models, metrics, statistics…



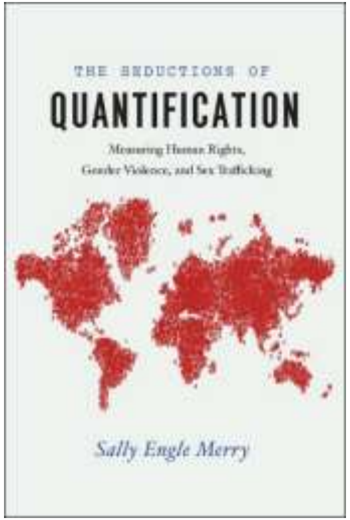


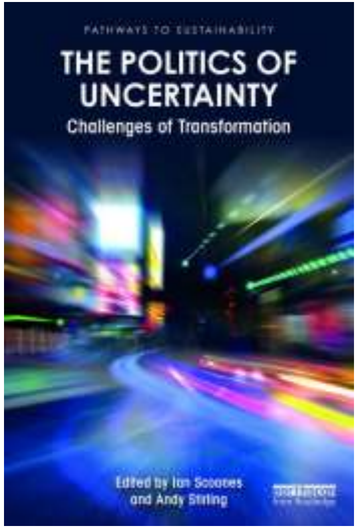


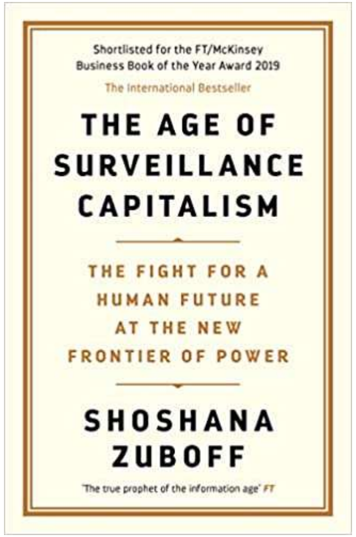


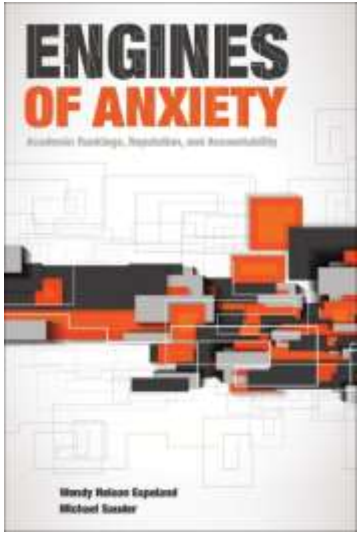


Algorithms, models, metrics, statistics…









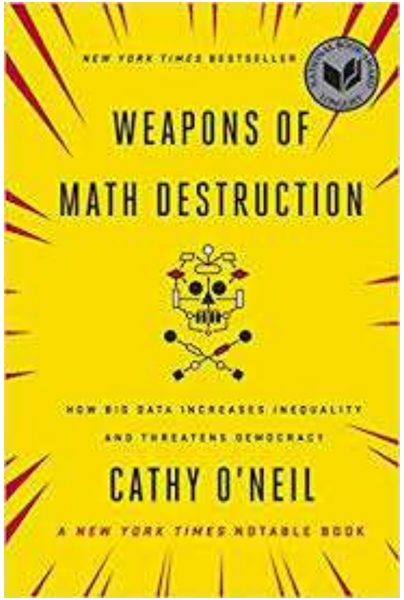
Numbers and their ‘reactivity’
(Espeland and Sauder, 2016)

Incumbent numbers affect what society will measure in the future (Merry 2016)

Numbers “create the environment that justifies their assumptions”
(O’Neil, 2016)

Alarm for Weapons of Math Destruction

Cathy O'Neil

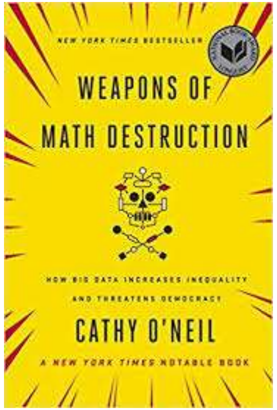


O'Neil, C. (2016). Weapons of math destruction : how big data increases inequality and threatens democracy. Random House Publishing Group.

OR and "clopening" (portmanteau of opening and closing)

Software scheduling programs – continuous adjusting of working assignment (day by day) may be unfavourable to workers making hard for them to plan for study, work, children

Clopening implies the same worker closes a shop and the open it the next morning at companies like Starbucks, McDonald's and Walmart



O'Neil, C. (2016). Weapons of math destruction : how big data increases inequality and threatens democracy. Random House Publishing Group.

NYT running the story of one worker working difficult hours

The New York Times

Working Anything but 9 to 5

Scheduling Technology Leaves Low-Income Parents With Hours of Chaos

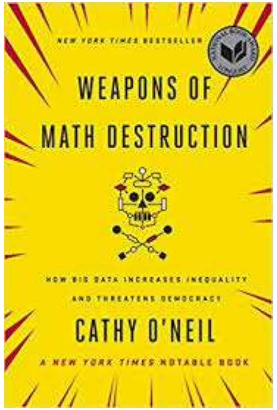
By **JODI KANTOR**, Photographs by **SAM HODGSON**

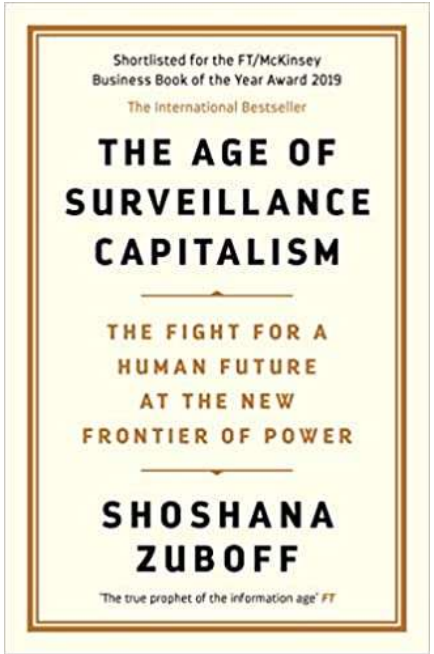
AUGUST 13, 2014

https://www.nytimes.com/interactive/2014/08/13/us/starbucks-workers-scheduling-hours.html “managers’ pay is contingent upon the efficiency of their staff measured by revenue for employee hour” p. 126

“I consider scheduling software one of the more appalling WMD [Weapon of Math Destruction]” p. 128

O’Neil, C. (2016). Weapons of math destruction : how big data increases inequality and threatens democracy. Random House Publishing Group.

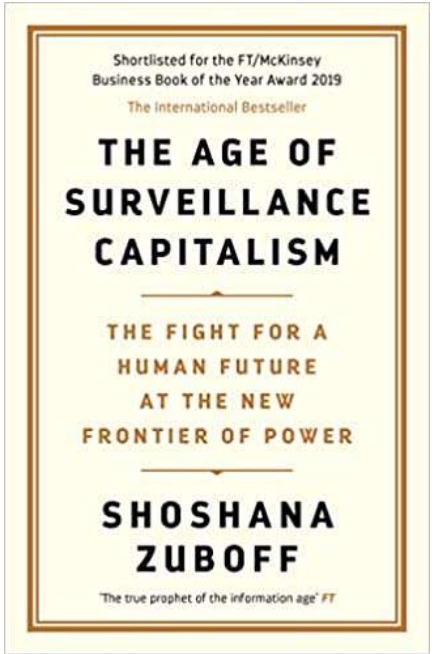




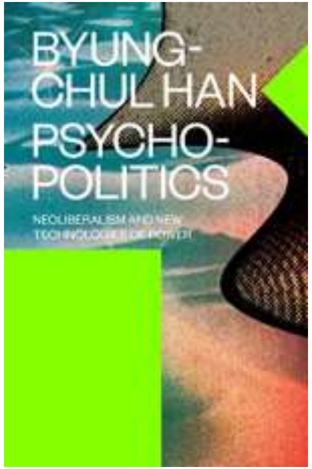
A project of domination of consumers and voters is made possible by artificial intelligence, big data & cognitive psychology

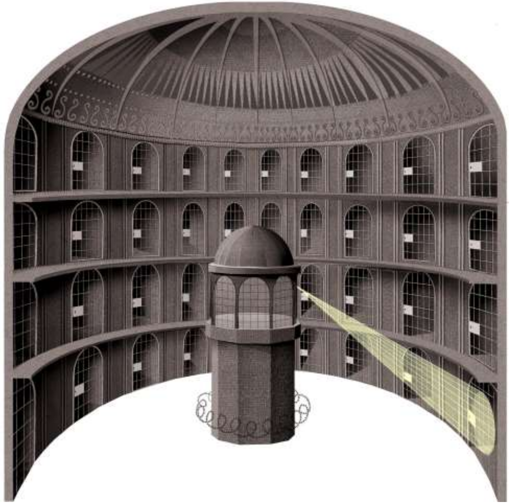
Inequality, power asymmetries and the world of surveillance capitalism

… and the surveillance is voluntarily accepted



Byung Chul Han 'virtual panopticon'





The New York Review of Books

The Boss Will See You Now

Zephyr Teachout

We are experiencing a major turning point in the surveillance of workers, driven by wearable tech, artificial intelligence, and Covid.

Working Anything but 9 to 5

Scheduling Technology Leaves Low-Income Parents With Hours of Chaos

Please read these two articles in your e-Campus

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Thank you

www.andreasaltelli.eu
https://orcid.org/0000-0003-4222-6975
@AndreaSaltelli@mstdn.social
https://www.youtube.com/channel/UCz26ZK04xchekUy4GevA3DA

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