Scheduling

Lecture Outline

- **Scheduling**
- Loading
- Case study
- Sequencing
- Monitoring
- Employee Scheduling

What is Scheduling?

- Last stage of planning before production occurs

- Specifies when labor, equipment, and facilities are needed to produce a product or provide a service

important!!!!

Scheduling Services

MANUFACTURING	SERVICES
Schedules machines and materials	Schedule staff
Inventories used to smooth demand	Seldom maintain inventories
Machine-intensive and demand may be smooth	Labor-intensive and demand may be variable
Scheduling may be bound by union contracts	Legal issues may constrain flexible scheduling
Few social or behavioral issues	Social and behavioral issues may be quite important

- Service systems differ from manufacturing

Shop Floor Control (SFC)

- Schedule and monitor day-to-day job shop production
- Also called production control and production activity control (PAC)
- Performed by production control department
  - Loading - check availability of material, machines, and labor
  - Sequencing - release work orders to shop and issue dispatch lists for individual machines
  - Monitoring - maintain progress reports on each job until it is complete

Scheduling Services

- **Hospitals** have complex scheduling system to handle complex processes and material requirements
- **Banks** use a cross-trained and flexible workforce and part-time workers
- **Retail stores** use scheduling optimization systems that track sales, transactions, and customer traffic to create work schedules in less time and with improved customer satisfaction
- **Airlines** must meet complex and union regulations and often use linear programming to develop optimal schedules
- **24/7 operations** like police/fire departments, emergency hot lines, and mail order businesses use flexible workers and variable schedules, often created using computerized systems

Objectives/Criteria in Scheduling

- Meet customer due dates
- Minimize job lateness
- Minimize response time
- Minimize completion time
- Minimize time in the system
- Minimize overtime
- **Maximize machine or labor utilization**
- Minimize idle time
- Minimize work-in-process inventory

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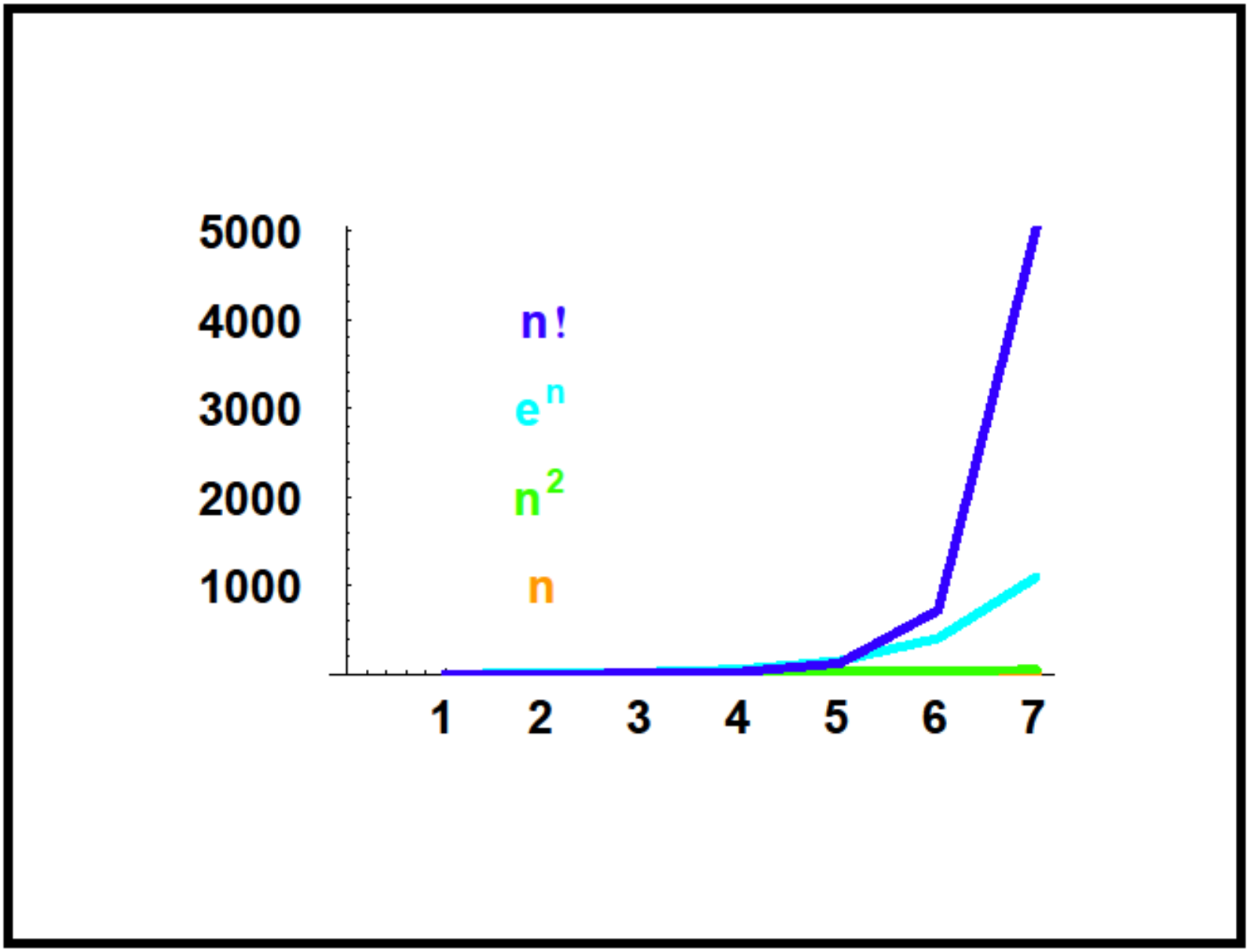
Loading

- Process of assigning work to limited resources
- Perform work with most efficient resources
- Use assignment method of linear programming to determine allocation

Example 1: Assigning work at WEBSTAR

WEBSTAR has four web projects to complete and four workers with varying degrees of expertise in web development for particular industries. Estimates of processing times (in hours) for each project by each worker are shown below. Development time costs an average of $100 an hour. Assign each worker to project so that cost is minimized.

Initial	PROJECT			
Matrix	*1*	*2*	*3*	*4*
Bryan	10	5	6	10
Kari	6	2	4	6
Noah	7	6	5	6
Chris	9	5	4	10


5000
4000
3000
2000
1000
n!
e^n
n^2
n
1
2
3
4
5
6
7

Assignment Method

1. Perform row reductions
   - subtract minimum value in each row from all other row values
2. Perform column reductions
   - subtract minimum value in each column from all other column values
3. Cross out all zeros in matrix
   - use minimum number of horizontal and vertical lines
4. If number of lines equals number of rows in matrix, then optimum solution has been found. Make assignments where zeros appear
   - Else modify matrix:
   - subtract minimum uncrossed value from all uncrossed values
   - add it to all cells where two lines intersect
   - other values in matrix remain unchanged
5. Repeat steps 3 and 4 until optimum solution is reached

Assignment Method

Initial Matrix	PROJECT 1	2	3	4
Bryan	10	5	6	10
Kari	6	2	4	6
Noah	7	6	5	6
Chris	9	5	4	10

Row reduction

5	0	1	5
4	0	2	4
2	1	0	1
5	1	0	6

Column reduction

3	0	1	4
2	0	2	3
0	1	0	0
3	1	0	5

Cover all zeros

3	0	1	4
2	0	2	3
0	1	0	0
3	1	0	5

Number lines ≠ number of rows so modify matrix

Assignment Method

Modify matrix

1	0	1	2
0	0	2	1
0	3	2	0
1	1	0	3

Cover all zeros

1	0	1	2
0	0	2	1
0	3	2	0
1	1	0	3

Number of lines = number of rows so at optimal solution

	PROJECT			
	1	*2*	*3*	*4*
Bryan	1	0	1	2
Kari	0	0	2	1
Noah	0	3	2	0
Chris	1	1	0	3

	PROJECT			
	1	*2*	*3*	*4*
Bryan	10	5	6	10
Kari	6	2	4	6
Noah	7	6	5	6
Chris	9	5	4	10

Project Cost = (5 + 6 + 4 + 6) X $100 = $2,100

Assignment Method - Setup

I14 =SUMPRODUCT(B8:E11,H8:K11)*C13

Example 17.1 - WebStar, Inc.

INPUT: Processing Times

Project leaders	Projects 1	2	3	4
Bryan	10	5	6	10
Kari	6	2	4	6
Noah	7	6	5	6
Chris	9	5	4	10

Cost per hour = $100

OUTPUT: Assignments (indicated by a matrix entry of 1)

Project leaders	Projects 1	2	3	4	
Bryan					0
Kari					0
Noah					0
Chris					0
	0	0	0	0	

Total cost = $0

Solution goes here
Only 1 leader can be assigned to each project

Solver Parameters

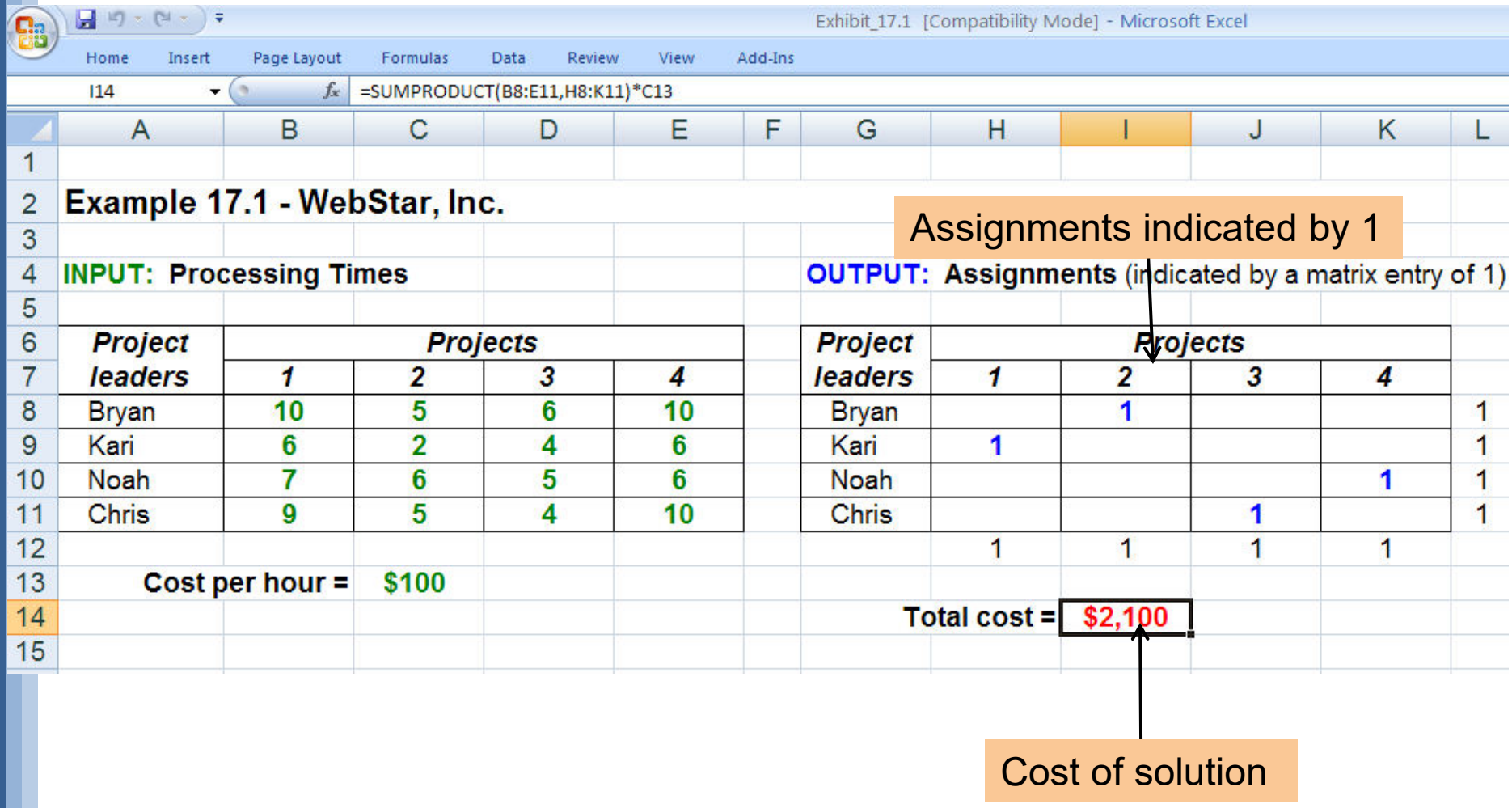
Set Target Cell: $I$14
Equal To: Max Min Value of: 0
By Changing Cells: $H$8:$K$11
Subject to the Constraints:
$H$12:$K$12 = 1
$H$8:$K$11 = integer
$L$8:$L$11 = 1

Solve
Close
Guess
Options
Add

Click “Solve” for solution

Sum of all rows and columns = 1

Assignment Method - Solution



Project leaders	Projects 1	2	3	4
Bryan	10	5	6	10
Kari	6	2	4	6
Noah	7	6	5	6
Chris	9	5	4	10

Project leaders	Projects 1	2	3	4	
Bryan		1			1
Kari	1				1
Noah				1	1
Chris			1		1
	1	1	1	1	

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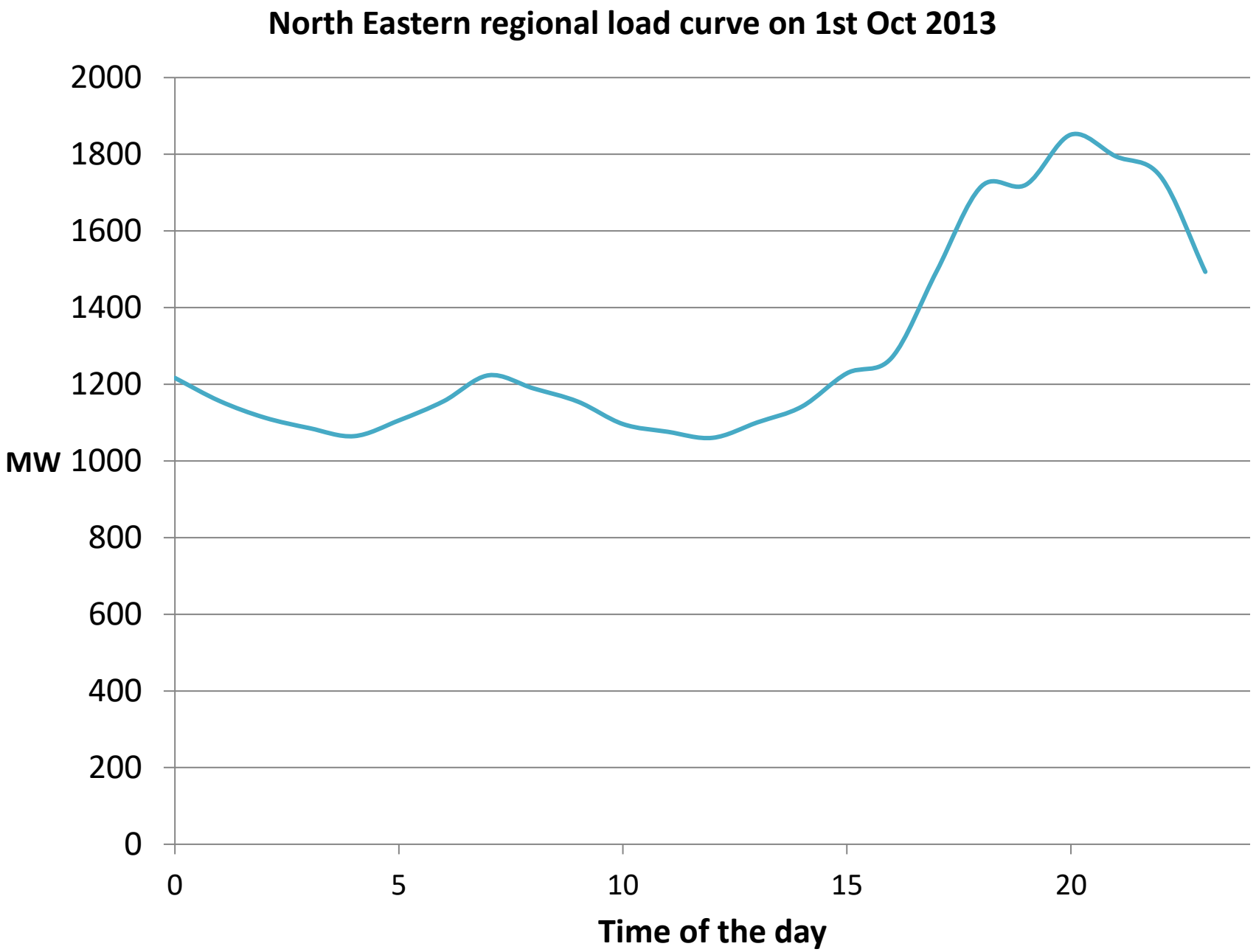
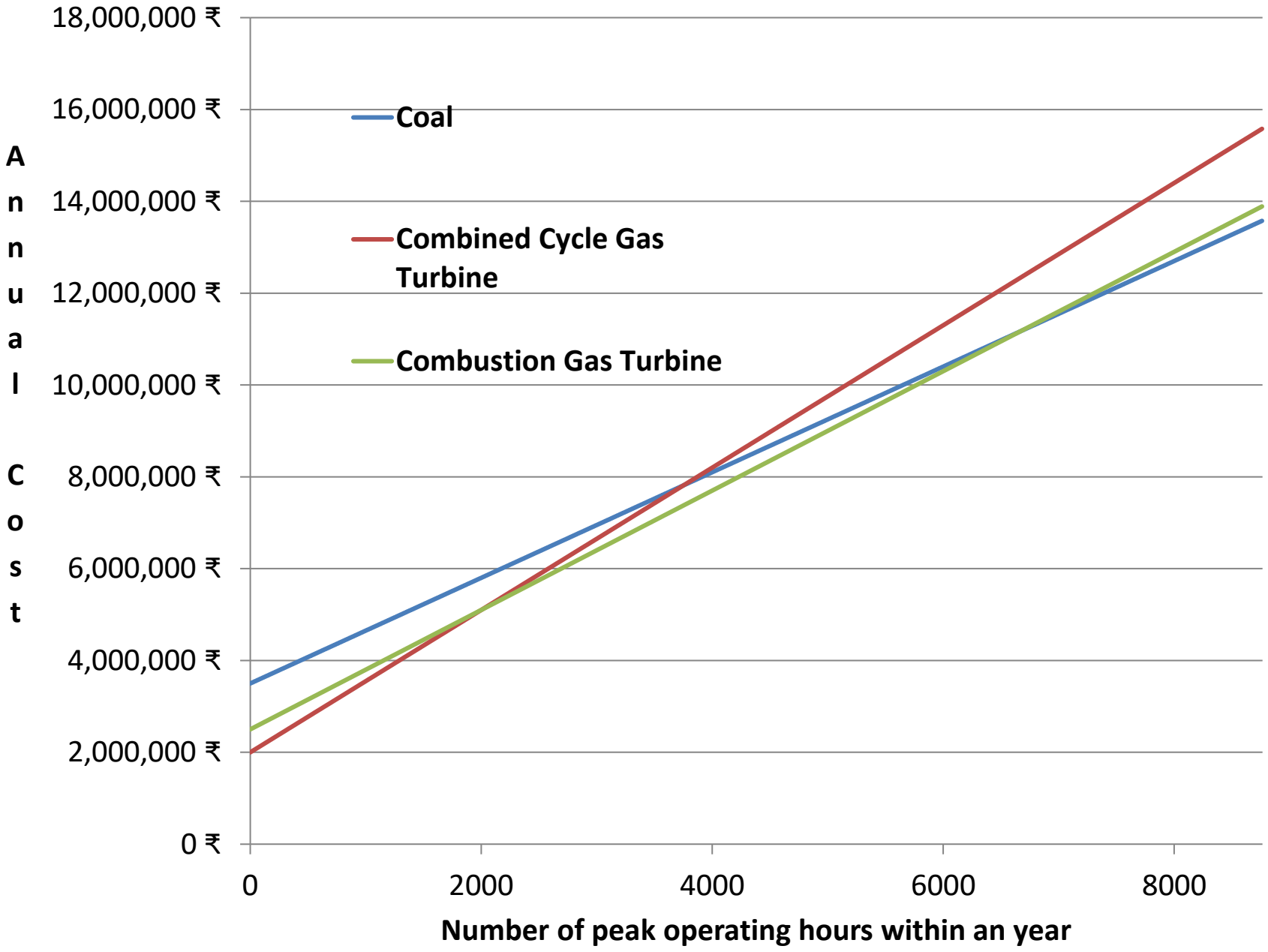
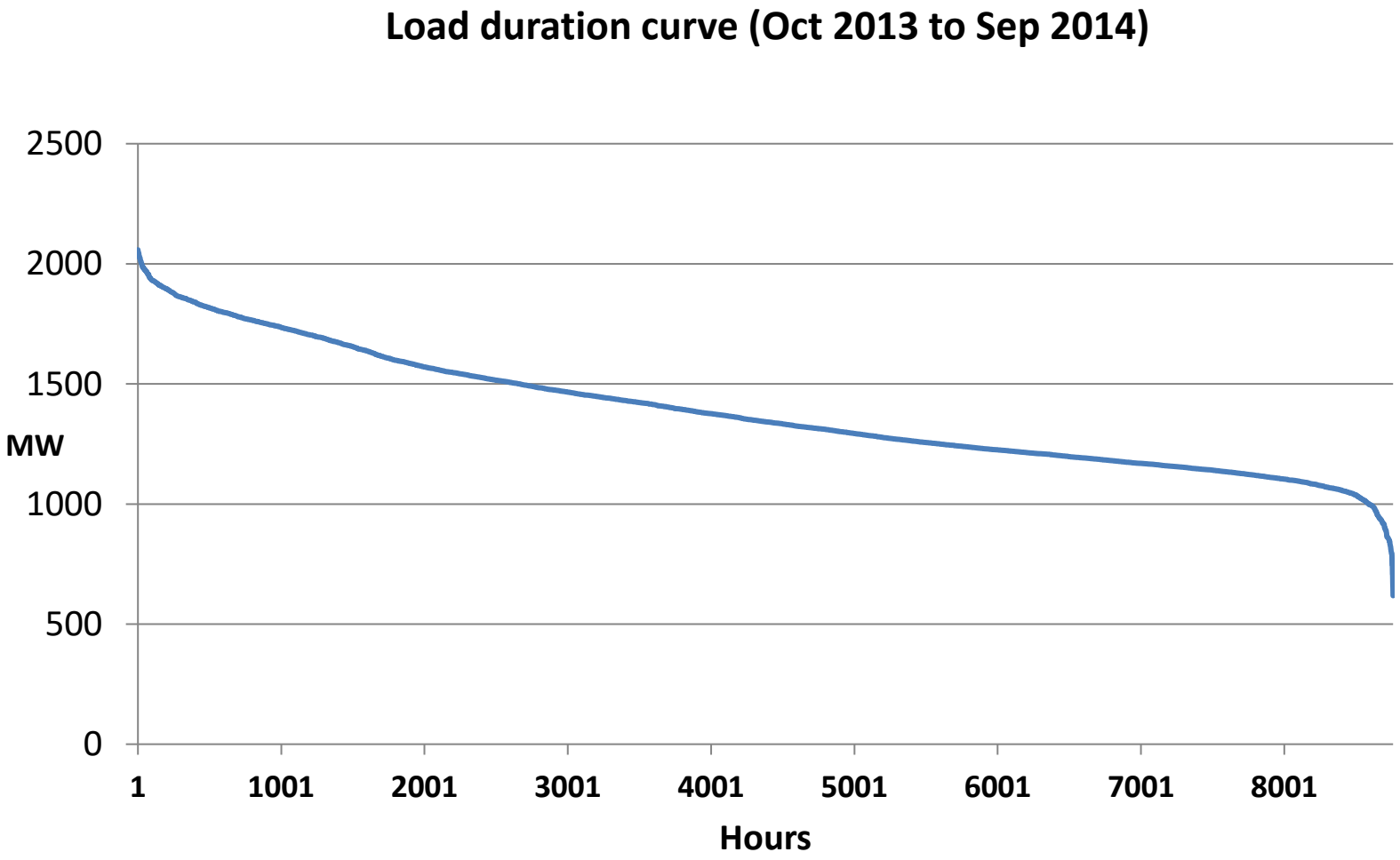

North Eastern regional load curve on 1st Oct 2013
2000
1800
1600
1400
1200
MW 1000
800
600
400
200
0
0
5
10
15
20
Time of the day

Options:

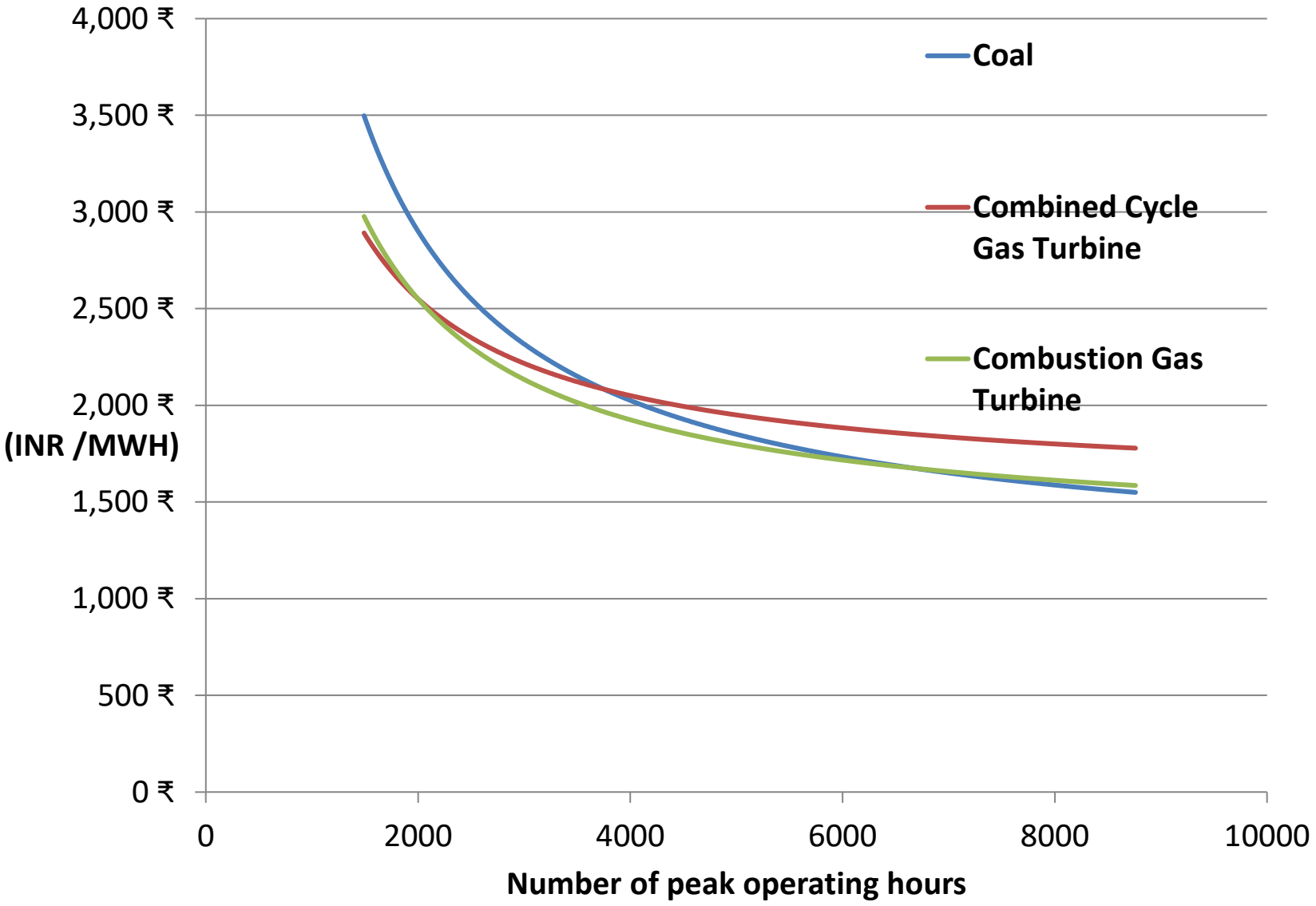
	Asset life (Years)	Capital expenditure (INR per MW)	Variable cost (INR per MWH)
Coal Plant	20	70,000,000	1,150
Combustion turbine Gas	20	40,000,000	1,550
Combined cycle combustion	20	50,000,000	1,300

Question: Which option to pick? Could a portfolio be better?


18,000,000 ₹
16,000,000 ₹
14,000,000 ₹
12,000,000 ₹
10,000,000 ₹
8,000,000 ₹
6,000,000 ₹
4,000,000 ₹
2,000,000 ₹
0 ₹
Annual Cost
Coal
Combined Cycle Gas Turbine
Combustion Gas Turbine
0
2000
4000
6000
8000
Number of peak operating hours within an year



Equivalent peak load = 5896 hours


4,000 ₹
3,500 ₹
3,000 ₹
2,500 ₹
2,000 ₹
(INR /MWH)
1,500 ₹
1,000 ₹
500 ₹
0 ₹
0
2000
4000
6000
8000
10000
Number of peak operating hours
Coal
Combined Cycle Gas Turbine
Combustion Gas Turbine

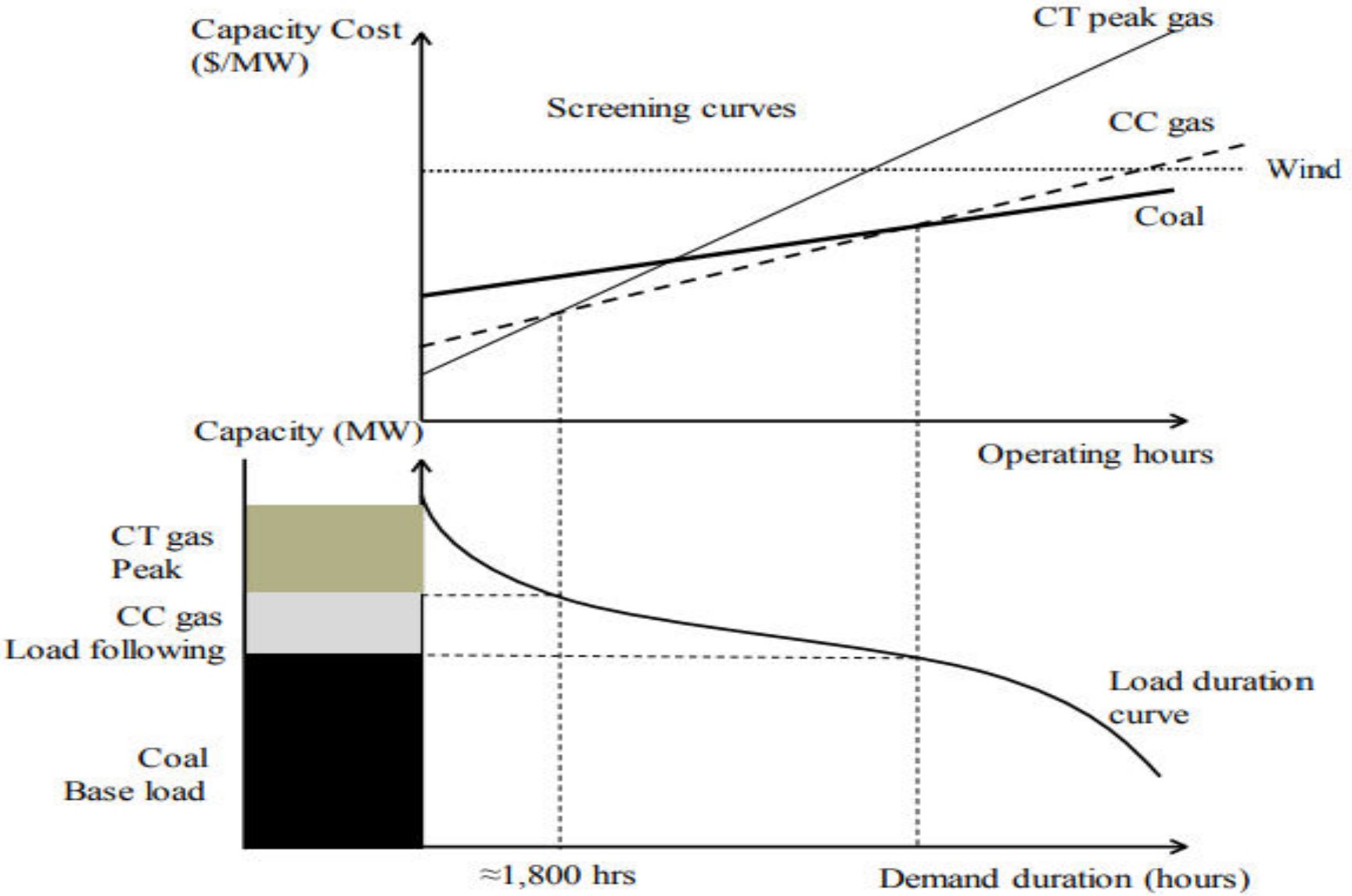
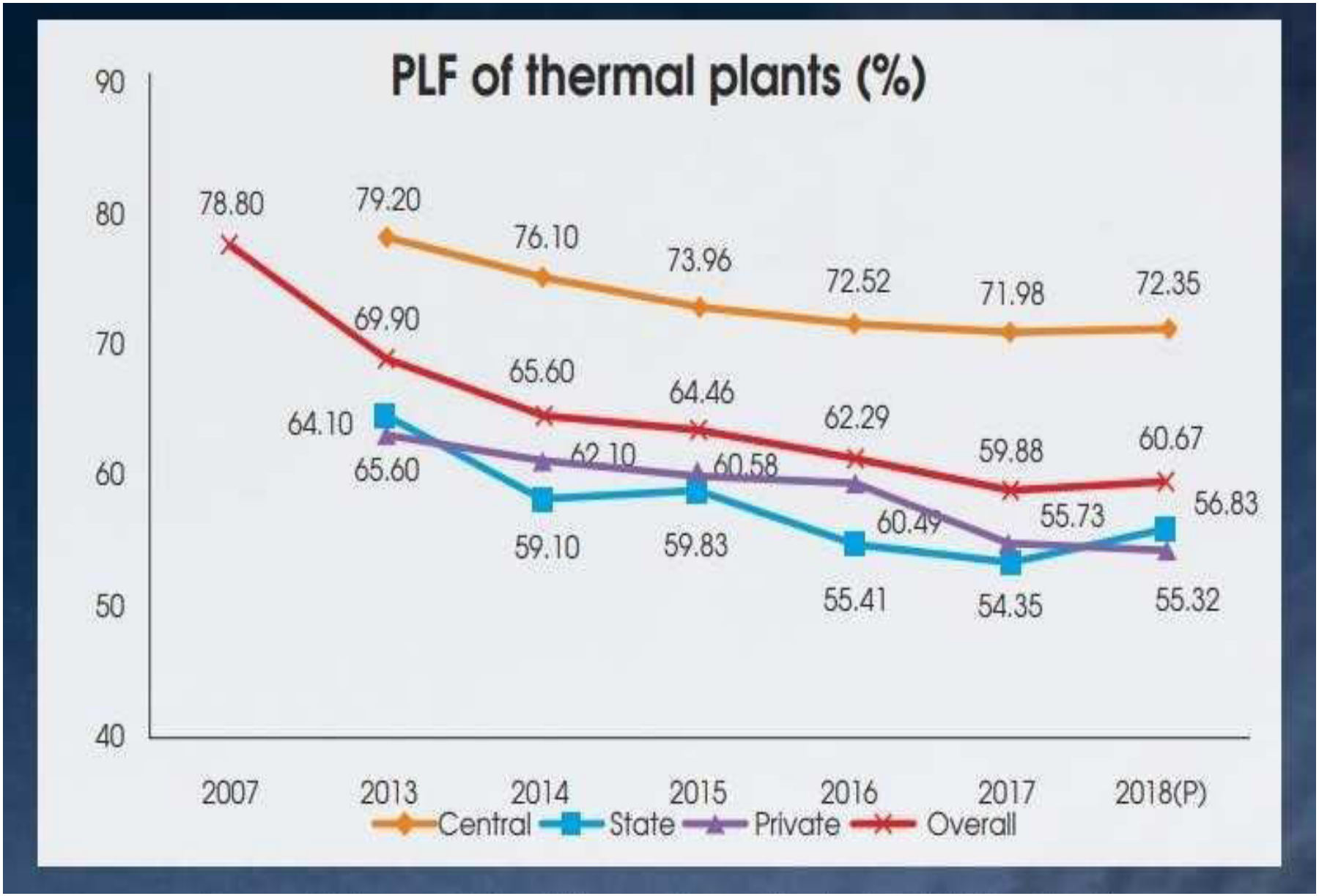


Fig. 1. Use of screening curves to determine optimal investment in generating capacity.



https://powermin.nic.in/en/content/power-sector-glance-all-india

Importance of Short-Term Scheduling

- Effective and efficient scheduling can be a competitive advantage
  - Faster movement of goods through a facility means better use of assets and lower costs
  - Additional capacity resulting from faster throughput improves customer service through faster delivery
  - Good schedules result in more dependable deliveries
- Scheduling deals with the timing of operations
- The task is the allocation and prioritization of demand

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Case: Because of approaching holiday season, Joe is scheduled to work seven days a week for the next two months. March's work for Joe consists of five jobs, A, B, C, D, and E. Job A takes five days to complete and is due on day 10, job B takes 10 days to complete and is due on day 15, job C takes two days to process and is due on day 5, job D takes eight days to process and is due on day 12, and job E, which takes six days to process, due on day 8.

How should Joe process his work?

Simple Sequencing Rules

JOB	PROCESSING TIME	DUE DATE
A	5	10
B	10	15
C	2	5
D	8	12
E	6	8

Sequencing

- Prioritize jobs assigned to a resource
- If no order specified use first-come first-served (FCFS)
- Other Sequencing Rules
  - FCFS - first-come, first-served
  - LCFS - last come, first served
  - DDATE - earliest due date
  - CUSTPR - highest customer priority
  - SETUP - similar required setups
  - SLACK - smallest slack
  - CR - smallest critical ratio
  - SPT - shortest processing time
  - LPT - longest processing time

Minimum Slack & Smallest Critical Ratio

- SLACK considers both work and time remaining

SLACK = (due date – today's date) – (processing time)

- CR recalculates sequence as processing continues and arranges information in ratio form

$$CR = \frac{\text{time remaining}}{\text{work remaining}} = \frac{\text{due date - today's date}}{\text{remaining processing time}}$$

If CR > 1, job ahead of schedule
If CR < 1, job behind schedule
If CR = 1, job on schedule

Sequencing Jobs Through One Process

- Flow time (completion time)
  - Time for a job to flow through system
- Makespan
  - Time for a group of jobs to be completed
- Tardiness
  - Difference between a late job's due date and its completion time

Simple Sequencing Rules: FCFS

FCFS SEQUENCE	START TIME	PROCESSING TIME	COMPLETION TIME	DUE DATE	TARDINESS
A	0	5	5	10	0
B	5	10	15	15	0
C	15	2	17	5	12
D	17	8	25	12	13
E	25	6	31	8	23
		Total	93		48
		Average	93/5 = 18.60		48/5 = 9.6

Simple Sequencing Rules: DDATE

DDATE SEQUENCE	START TIME	PROCESSING TIME	COMPLETION TIME	DUE DATE	TARDINESS
C	0	2	2	5	0
E	2	6	8	8	0
A	8	5	13	10	3
D	13	8	21	12	9
B	21	10	31	15	16
		Total	75		28
		Average	75/5 = 15.00		28/5 = 5.6

Simple Sequencing Rules: SLACK

A(10-0) – 5 = 5
B(15-0) – 10 = 5
C(5-0) – 2 = 3
D(12-0) – 8 = 4
E(8-0) – 6 = 2

SLACK SEQUENCE	START TIME	PROCESSING TIME	COMPLETION TIME	DUE DATE	TARDINESS
E	0	6	6	8	0
C	6	2	8	5	3
D	8	8	16	12	4
A	16	5	21	10	11
B	21	10	31	15	16
		Total	82		34
		Average	82/5 = 16.40		34/5 = 6.8

Simple Sequencing Rules: SPT

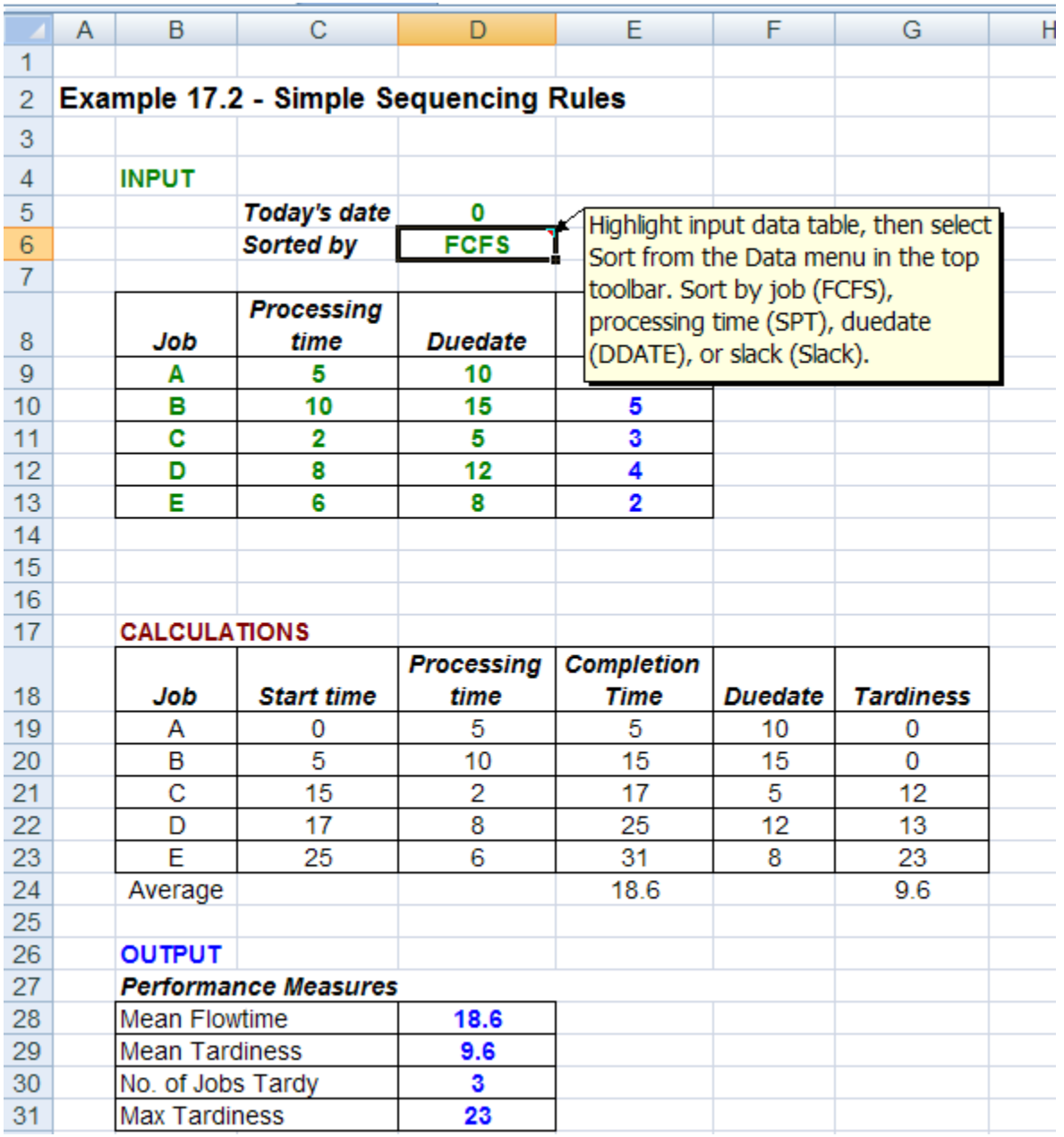
SPT SEQUENCE	START TIME	PROCESSING TIME	COMPLETION TIME	DUE DATE	TARDINESS
C	0	2	2	5	0
A	2	5	7	10	0
E	7	6	13	8	5
D	13	8	21	12	9
B	21	10	31	15	16
		Total	74		30
		Average	74/5 = 14.80		30/5 = 6

Simple Sequencing Rules: Summary

RULE	AVERAGE COMPLETION TIME	AVERAGE TARDINESS	NO. OF JOBS TARDY	MAXIMUM TARDINESS
FCFS	18.60	9.6	3	23
DDATE	15.00	5.6	3	16
SLACK	16.40	6.8	4	16
SPT	14.80	6.0	3	16

Best values

Sequencing With Excel



Example 17.2 - Simple Sequencing Rules

INPUT

Today's date	0
Sorted by	FCFS

Highlight input data table, then select Sort from the Data menu in the top toolbar. Sort by job (FCFS), processing time (SPT), duedate (DDATE), or slack (Slack).

Job	*Processing time*	*Duedate*	
A	5	10	
B	10	15	5
C	2	5	3
D	8	12	4
E	6	8	2

CALCULATIONS

Job	*Start time*	*Processing time*	*Completion Time*	*Duedate*	*Tardiness*
A	0	5	5	10	0
B	5	10	15	15	0
C	15	2	17	5	12
D	17	8	25	12	13
E	25	6	31	8	23
Average			18.6		9.6

OUTPUT

Performance Measures

Mean Flowtime	18.6
Mean Tardiness	9.6
No. of Jobs Tardy	3
Max Tardiness	23

Guidelines for Selecting a Sequencing Rule

- SPT most useful when shop is highly congested
- Use SLACK for periods of normal activity
- Use DDATE when only small tardiness values can be tolerated
- Use LPT if subcontracting is anticipated
- Use FCFS when operating at low-capacity levels
- Do not use SPT to sequence jobs that have to be assembled with other jobs at a later date

VERY VERY IMPORTANT

Sequencing jobs through two serial processes

Johnson's Fine Restorations has received a rush order to refinish five carousel animals- an alligator, a bear, a cat, and an elephant. The restoration involves two major processes: sanding and painting. Mr Johnson takes care of the sanding, and his son does the painting. The time required for each refinishing job differs with the state of disrepair and degree of detail of each animal. Given the following processing times (in hours), determine the order in which the jobs should be processed so that the rush order can be completed as soon as possible.

JOB	PROCESS 1	PROCESS 2
A	6	8
B	11	6
C	7	3
D	9	7
E	5	10

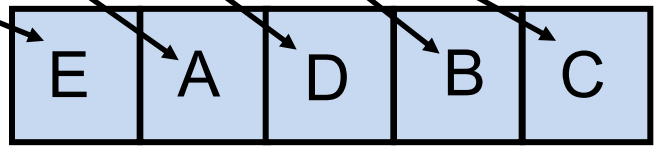
Sequencing Jobs Through Two Serial Process

Johnson's Rule

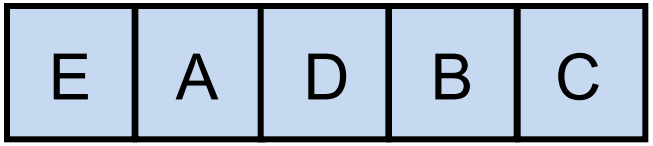
1. List time required to process each job at each process. Set up a one-dimensional matrix to represent desired sequence with # of slots equal to # of jobs.
2. Select smallest processing time at either process. If that time is on process 1, put the job as near to beginning of sequence as possible.
3. If smallest time occurs on process 2, put the job as near to the end of the sequence as possible.
4. Remove job from list.
5. Repeat steps 2-4 until all slots in matrix are filled and all jobs are sequenced.

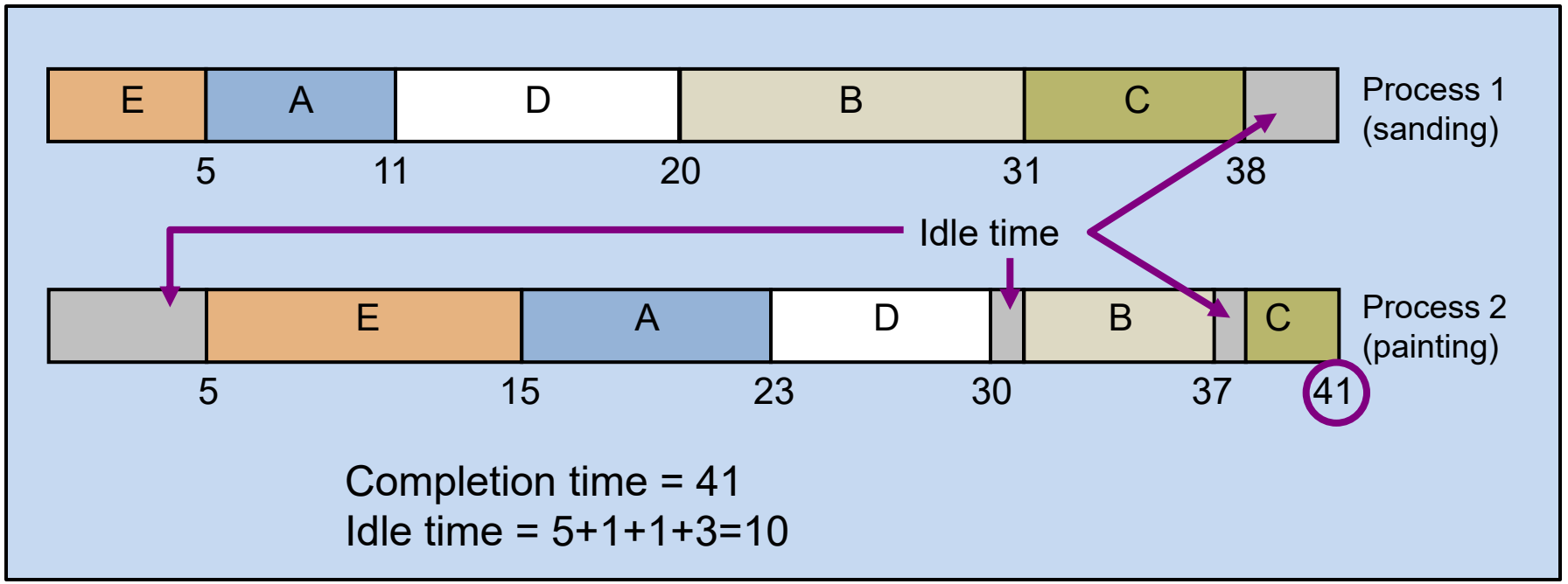
Johnson's Rule

JOB	PROCESS 1	PROCESS 2
A	6	8
B	11	6
C	7	3
D	9	7
E	5	10

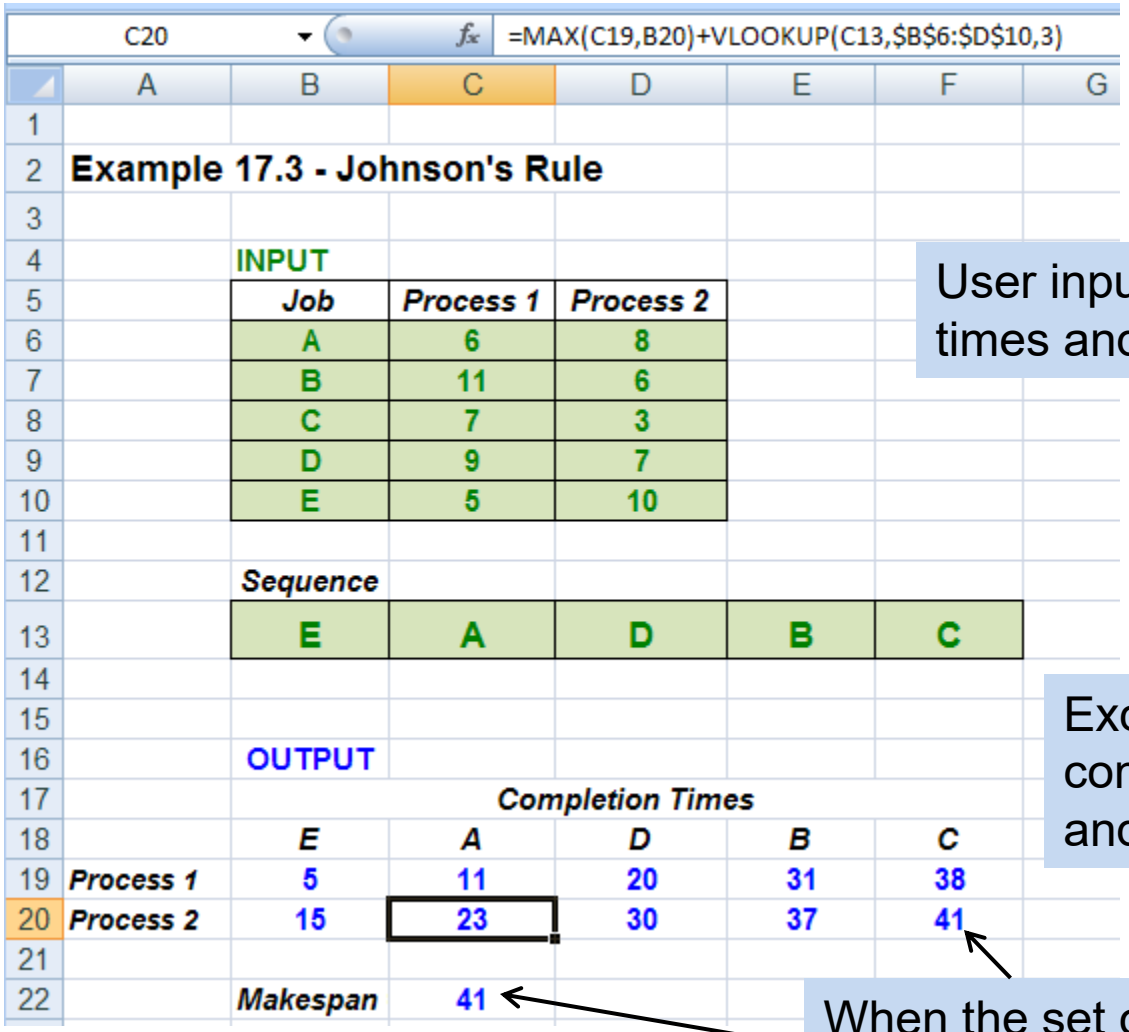


Johnson's Rule





Excel for Johnson's Rule



C20 | =MAX(C19,B20)+VLOOKUP(C13,$B$6:$D$10,3)

	A	B	C	D	E	F	G
1							
2	**Example 17.3 - Johnson's Rule**						
3							
4		INPUT					
5		*Job*	*Process 1*	*Process 2*			
6		A	6	8			
7		B	11	6			
8		C	7	3			
9		D	9	7			
10		E	5	10			
11							
12		*Sequence*					
13		E	A	D	B	C	
14							
15							
16		OUTPUT					
17				*Completion Times*			
18		*E*	*A*	*D*	*B*	*C*	
19	*Process 1*	5	11	20	31	38	
20	*Process 2*	15	23	30	37	41	
21							
22		*Makespan*	41				

User inputs processing times and sequence

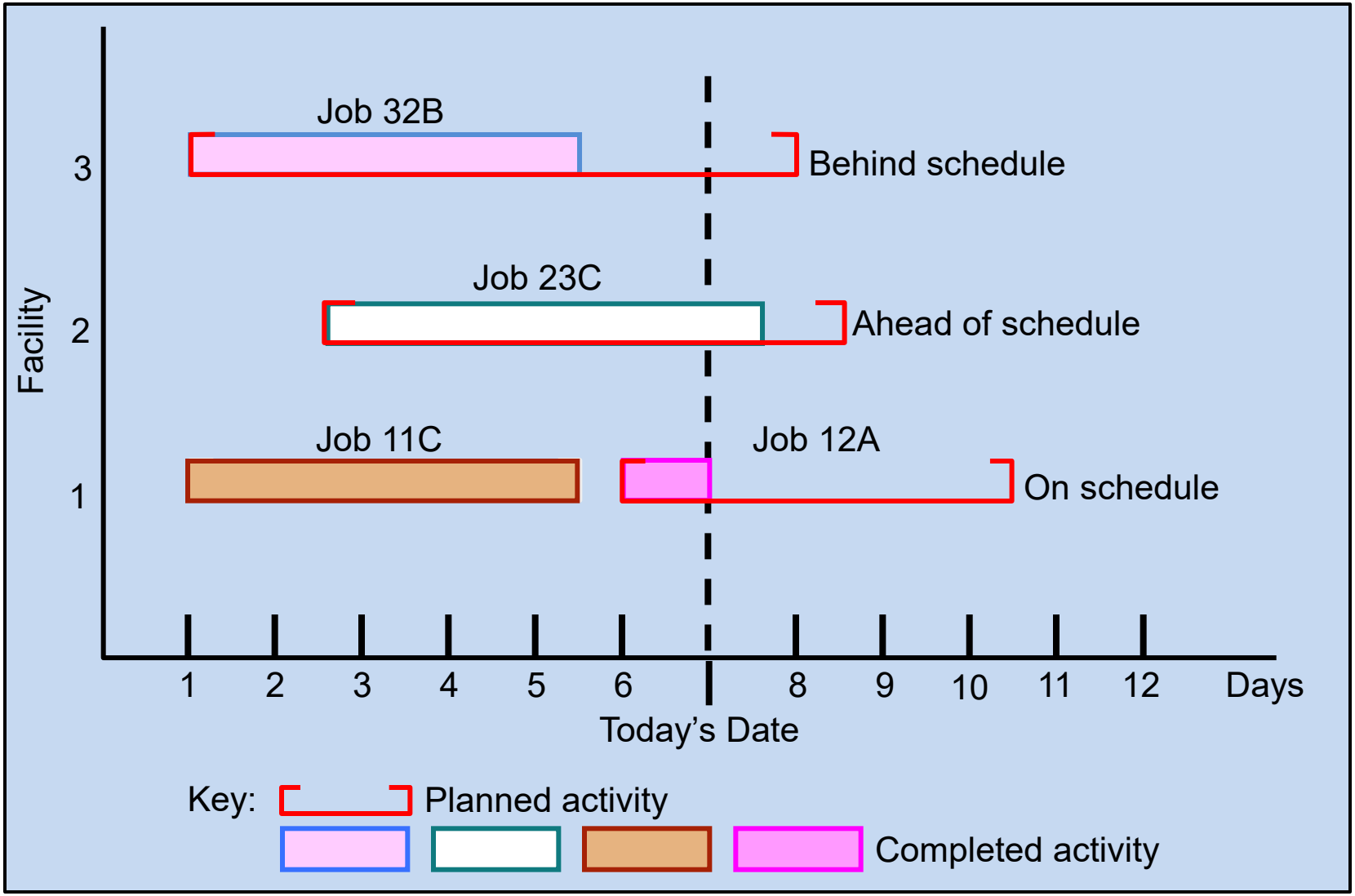
Excel calculates completion times and makespan

When the set of jobs is completed

Monitoring

- Work package
  - Shop paperwork that travels with a job
- Gantt Chart
  - Shows both planned and completed activities against a time scale
- Input/Output Control
  - Monitors the input and output from each work center

Gantt Chart


Job 32B
Behind schedule
Job 23C
Ahead of schedule
Job 11C
Job 12A
On schedule
Facility
3
2
1
1
2
3
4
5
6
8
9
10
11
12
Days
Today's Date
Key:
Planned activity
Completed activity

Lecture Outline

- Scheduling
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- **Employee Scheduling**

Employee Scheduling

- Labor is very flexible resource
- Scheduling workforce is complicated, repetitive task
- Assignment method can be used
- Heuristics are commonly used

Employee Scheduling Heuristic

1. Let N = no. of workers available
   D_i = demand for workers on day i
   X = day working
   O = day off
2. Assign the first N - D_1 workers day 1 off. Assign the next N - D_2 workers day 2 off. Continue in a similar manner until all days are have been scheduled
3. If number of workdays for full time employee < 5, assign remaining workdays so consecutive days off are possible
4. Assign any remaining work to part-time employees
5. If consecutive days off are desired, consider switching schedules among days with the same demand requirements

Employee Scheduling

DAY OF WEEK	M	T	W	TH	F	SA	SU
MIN NO. OF WORKERS REQUIRED	3	3	4	3	4	5	3
Taylor							
Smith							
Simpson							
Allen							
Dickerson							

Employee Scheduling

DAY OF WEEK	M	T	W	TH	F	SA	SU
MIN NO. OF WORKERS REQUIRED	3	3	4	3	4	5	3
Taylor	O	X	X	O	X	X	X
Smith	O	X	X	O	X	X	X
Simpson	X	O	X	X	O	X	X
Allen	X	O	X	X	X	X	O
Dickerson	X	X	O	X	X	X	O

Completed schedule satisfies requirements but has no consecutive days off

Employee Scheduling

DAY OF WEEK	M	T	W	TH	F	SA	SU
MIN NO. OF WORKERS REQUIRED	3	3	4	3	4	5	3
Taylor	O	O	X	X	X	X	X
Smith	O	O	X	X	X	X	X
Simpson	X	X	O	O	X	X	X
Allen	X	X	X	O	X	X	O
Dickerson	X	X	X	X	O	X	O

Revised schedule satisfies requirements with consecutive days off for most employees

Automated Scheduling Systems

- Staff Scheduling
  - Assign workers to standardize shift patterns
- Schedule Bidding
  - Workers bid for certain shift positions or schedules
- Schedule Optimization
  - Creates demand-driven forecast of labor needs
  - Assigns workers to variable schedules
  - Uses mathematical programming and artificial intelligence techniques