Scheduling in the Short-Term

15

PowerPoint presentation to accompany
Heizer and Render
Operations Management, Global Edition, Eleventh Edition
Principles of Operations Management, Global Edition, Ninth Edition

PowerPoint slides by Jeff Heyl

Outline

- **Global Company Profile:** Delta Air Lines
- The Importance of Short-Term Scheduling
- Scheduling Issues
- Scheduling Process-Focused Facilities

Outline - Continued

- Loading Jobs
- Scheduling Jobs
- Finite Capacity Scheduling (FCS)
- Scheduling Services

Learning Objectives

When you complete this chapter you should be able to:

1. **Explain** the relationship between short-term scheduling, capacity planning, aggregate planning, and a master schedule
2. **Draw** Gantt loading and scheduling charts
3. **Apply** the assignment method for loading jobs

Learning Objectives

When you complete this chapter you should be able to:

4. **Name** and describe each of the priority sequencing rules
5. **Use** Johnson's rule
6. **Define** finite capacity scheduling
7. **Use** the cyclical scheduling technique

Delta Airlines

- About 10% of Delta's flights are disrupted per year, half because of weather
- Cost is $440 million in lost revenue, overtime pay, food and lodging vouchers
- The $33 million Operations Control Center adjusts to changes and keeps flights flowing
- Saves Delta $35 million per year

Short-Term Scheduling

The objective of scheduling is to allocate and prioritize demand (generated by either forecasts or customer orders) to available facilities

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 Issues

- Scheduling deals with the timing of operations
- The task is the allocation and prioritization of demand
- Significant factors are
  1. Forward or backward scheduling
  2. Finite or infinite loading
  3. The criteria for sequencing jobs

Scheduling Decisions

TABLE 15.1 Scheduling Decisions

ORGANIZATION	MANAGERS SCHEDULE THE FOLLOWING
Delta Air Lines	Maintenance of aircraft Departure timetables Flight crews, catering, gate, ticketing personnel
Arnold Palmer Hospital	Operating room use Patient admissions Nursing, security, maintenance staffs Outpatient treatments
University of Alabama	Classrooms and audiovisual equipment Student and instructor schedules Graduate and undergraduate courses
Amway Center	Ushers, ticket takers, food servers, security personnel Delivery of fresh foods and meal preparation Orlando Magic games, concerts, arena football
Lockheed Martin Factory	Production of goods Purchases of materials Workers

Scheduling Flow

Figure 15.1

Capacity Planning
(Long term; years)
Changes in Facilities
Changes in Equipment
See Chapter 7 and Supplement 7

Capacity Plan for New Facilities
Adjust capacity to the demand suggested by strategic plan

Aggregate Planning
(Intermediate term; quarterly or monthly)
Facility utilization
Personnel changes
Subcontracting
See Chapter 13

Aggregate Production Plan for All Bikes
(Determine personnel or subcontracting necessary to match aggregate demand to existing facilities/capacity)

Month	1	2
Bike Production	800	850

Master Schedule
(Intermediate term; weekly)
Material requirements planning
Disaggregate the aggregate plan
See Chapters 13 and 14

Master Production Schedule for Bike Models
(Determine weekly capacity schedule)

	Month 1				Month 2			
Week	1	2	3	4	5	6	7	8
Model 22		200		200		200		200
Model 24	100		100		150		100	
Model 26	100		100		100		100	

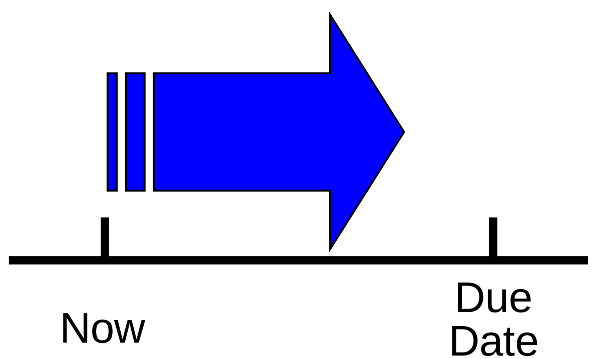
Short Term Scheduling
(Short term; days, hours, minutes)
Work center loading
Job sequencing/dispatching
See this chapter

Work Assigned to Specific Personnel and Work Centers
Make finite capacity schedule by matching specific tasks to specific people and machines

Assemble Model 22 in work center 6

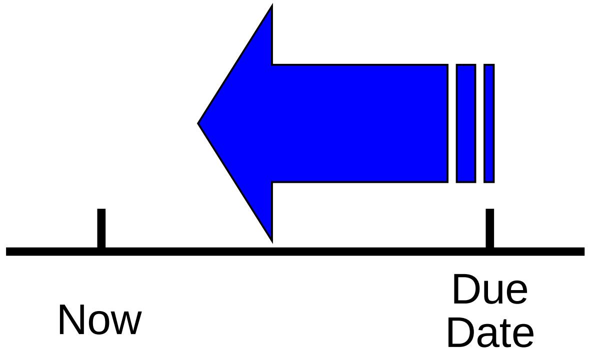
Forward and Backward Scheduling

- *Forward scheduling* starts *as soon as the requirements are known*
- Produces a feasible schedule though it may not meet due dates
- Frequently results in buildup of work-in-process inventory



Forward and Backward Scheduling

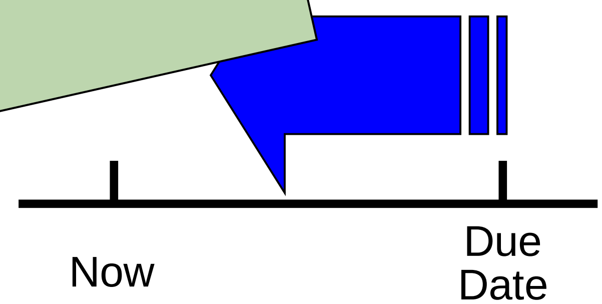
- *Backward scheduling* begins with the due date and schedules the *final* operation first
- Schedule is produced by working backwards though the processes
- Resources may not be available to accomplish the schedule



Forward and Backward Scheduling

- *Backward scheduling* begi… with the due date and sched… peration first
- S… ng … s
- F… b… ac… sc… dule

Often these approaches are combined to develop a trade-off between capacity constraints and customer expectations



Finite and Infinite Loading

- Assigning jobs to work stations
- Finite loading assigns work up to the capacity of the work station
  - All work gets done
  - Due dates may be pushed out
- Infinite loading does not consider capacity
  - All due dates are met
  - Capacities may have to be adjusted

Scheduling Criteria

1. Minimize completion time
2. Maximize utilization of facilities
3. Minimize work-in-process (WIP) inventory
4. Minimize customer waiting time

Different Processes/ Different Approaches

TABLE 15.2	Different Processes Suggest Different Approaches to Scheduling

Process-focused facilities (job shops)

- Scheduling to customer orders where changes in both volume and variety of jobs/clients/patients are frequent
- Schedules are often due-date focused, with loading refined by finite loading techniques
- Examples: foundries, machine shops, cabinet shops, print shops, many restaurants, and the fashion industry

Repetitive facilities (assembly lines)

- Schedule module production and product assembly based on frequent forecasts
- Finite loading with a focus on generating a forward-looking schedule
- JIT techniques are used to schedule components that feed the assembly line
- Examples: assembly lines for washing machines at Whirlpool and automobiles at Ford.

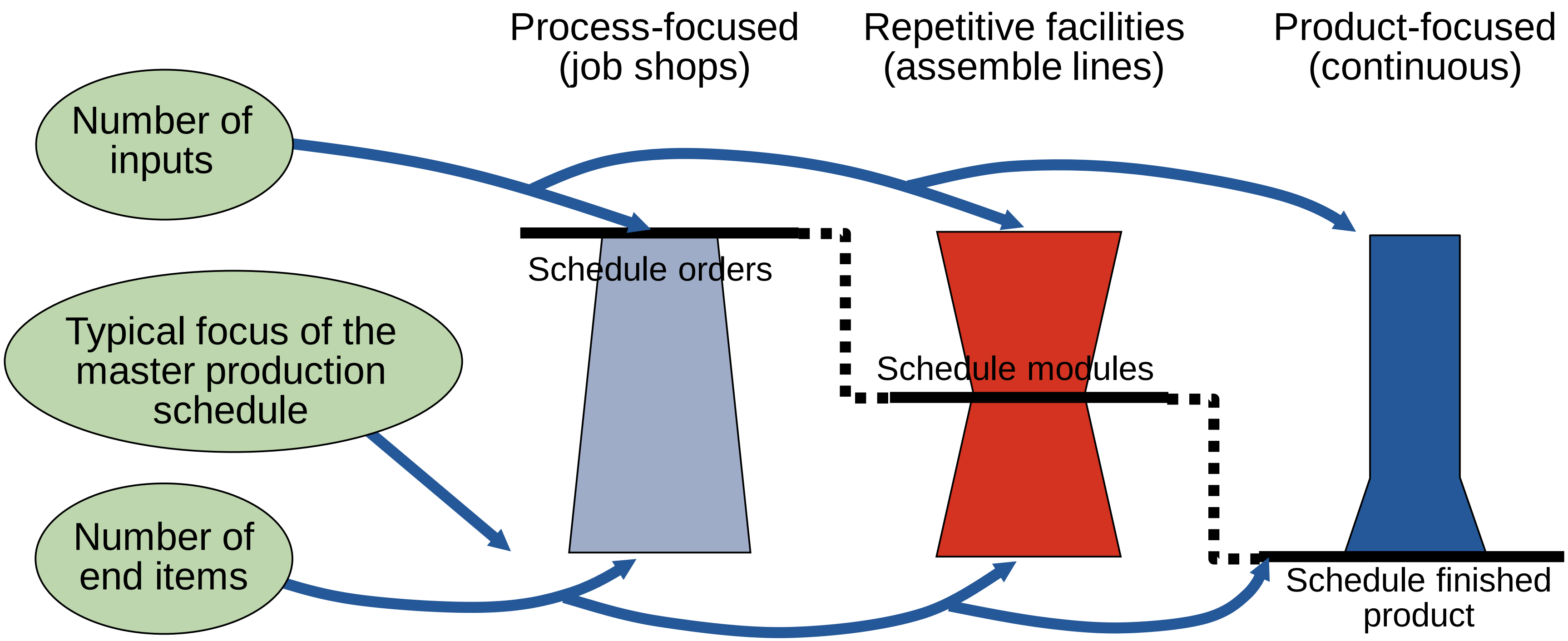
Different Processes/ Different Approaches

TABLE 15.2	Different Processes Suggest Different Approaches to Scheduling

Product-focused facilities (continuous)

- Schedule high volume finished products of limited variety to meet a reasonably stable demand within existing fixed capacity
- Finite loading with a focus on generating a forward-looking schedule that can meet known setup and run times for the limited range of products
- Examples: huge paper machines at International Paper, beer in a brewery at Anheuser-Busch, and potato chips at Frito-Lay

Focus for Different Process Strategies



Examples:	Print shop Machine shop Fine-dining restaurant	Motorcycles Autos, TVs Fast-food restaurant	Steel, Beer, Bread Lightbulbs Paper

Scheduling Process-Focused Facilities

- High-variety, low volume
- Production differ considerably
- Schedule incoming orders without violating capacity constraints
- Scheduling can be complex

Loading Jobs

- Assign jobs so that costs, idle time, or completion time are minimized
- Two forms of loading
  - Capacity oriented
  - Assigning specific jobs to work centers

Input-Output Control

- Identifies **overloading** and underloading conditions
- Prompts managerial action to resolve scheduling problems
- Can be maintained using **ConWIP** cards that control the scheduling of batches

Input-Output Control Example

Figure 15.2

Work Center DNC Milling (in standard hours)						
Week Ending	6/6	6/13	6/20	6/27	7/4	7/11
Planned Input	280	280	280	280	280	
Actual Input	270	250	280	285	280	
Cumulative Deviation	–10	–40	–40	–35		
Planned Output	320	320	320	320		
Actual Output	270	270	270	270		
Cumulative Deviation	–50	–100	–150	–200		
Cumulative Change in Backlog	0	–20	–10	+5		

Input-Output Control Example

Figure 15.2

Work Center DNC Milling (in standard hours)						
Week Ending	6/6	6/13	6/20	6/27	7/4	7/11
Planned Input	280	280	280	280	280	
Actual Input	270	250	280	285	280	
Cumulative Deviation	–10	–40	–40	–35		
Planned Output	320	320	320	320		
Actual Output	270	270	270	270		
Cumulative Deviation	–50	–100	–150	–200		
Cumulative Change in Backlog	0	–20	–10	+5		

Explanation:
270 input,
270 output implies
0 change

Explanation:
250 input,
270 output implies
–20 change

Input-Output Control Example

Options available to operations personnel include:

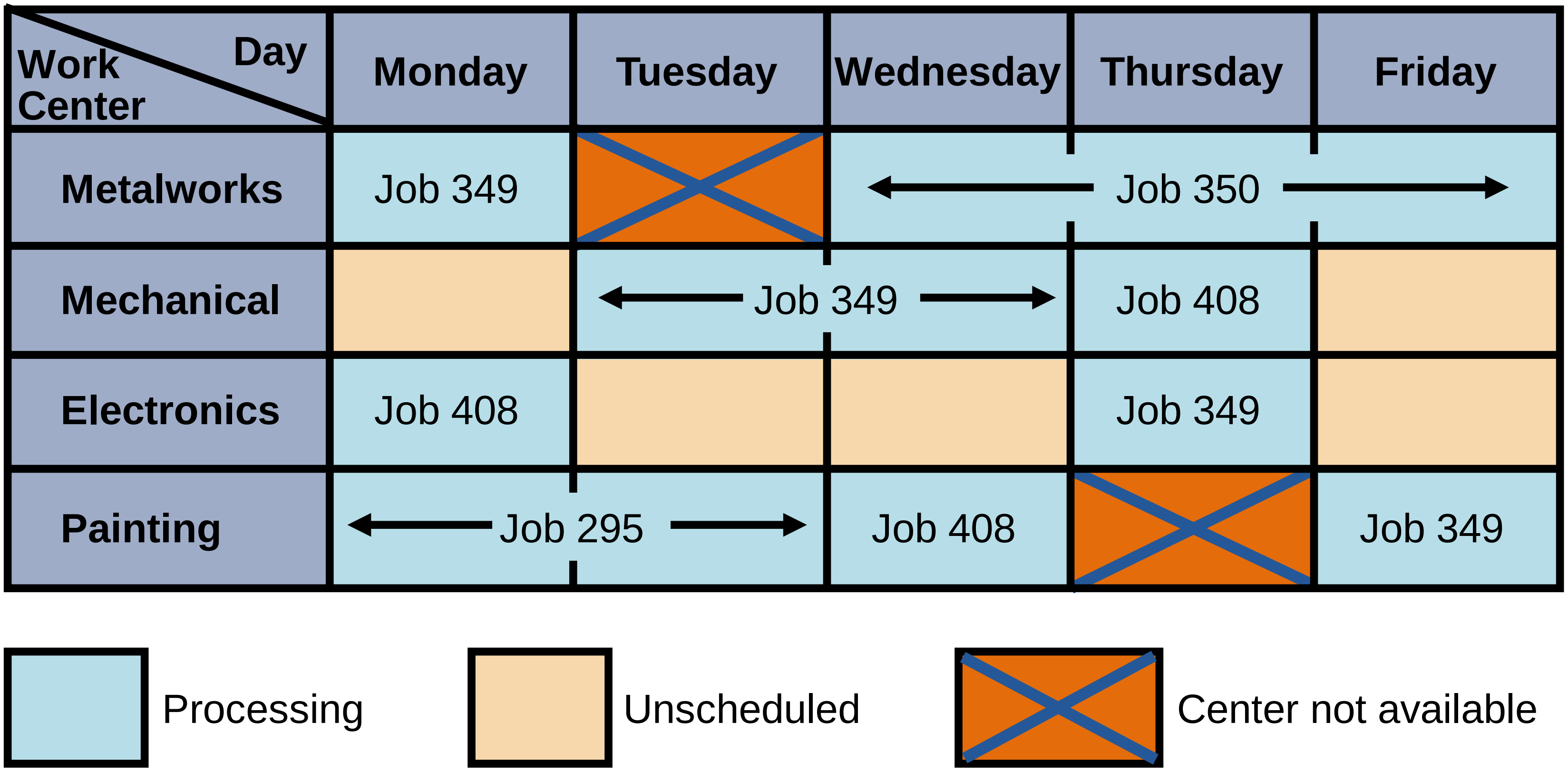
1. Correcting performances
2. Increasing capacity
3. Increasing or reducing input to the work center

Gantt Charts

- Load chart shows the loading and idle times of departments, machines, or facilities
- Displays relative workloads over time
- Schedule chart monitors jobs in process
- All Gantt charts need to be updated frequently to account for changes

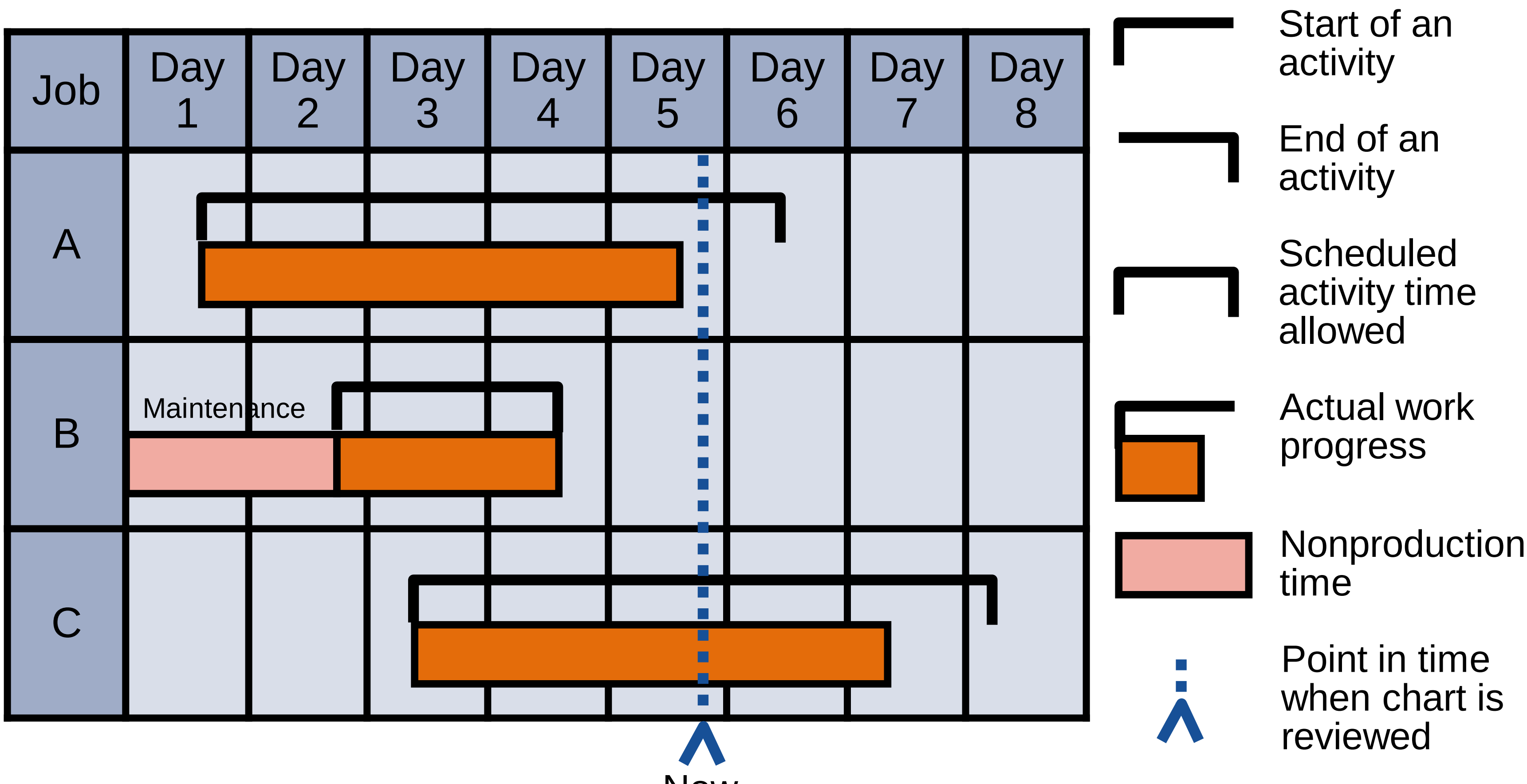
Gantt Load Chart Example

Figure 15.3



Gantt Schedule Chart Example

Figure 15.4



Assignment Method

- A special class of linear programming models that assigns tasks or jobs to resources
- Objective is to minimize cost or time
- Only one job (or worker) is assigned to one machine (or project)

Assignment Method

- Build a table of costs or time associated with particular assignments

JOB	TYPESETTER		
	A	B	C
R-34	$11	$14	$ 6
S-66	$ 8	$10	$11
T-50	$ 9	$12	$ 7

Assignment Method

1. Create zero opportunity costs by repeatedly subtracting the lowest costs from each row and column
2. Draw the minimum number of vertical and horizontal lines necessary to cover all the zeros in the table. If the number of lines equals either the number of rows or the number of columns, proceed to step 4. Otherwise proceed to step 3.

Assignment Method

3. Subtract the smallest number not covered by a line from all other uncovered numbers. Add the same number to any number at the intersection of two lines. Return to step 2.
4. Optimal assignments are at zero locations in the table. Select one, draw lines through the row and column involved, and continue to the next assignment.

Assignment Example

Typesetter / Job	A	B	C
R-34	$11	$14	$ 6
S-66	$ 8	$10	$11
T-50	$ 9	$12	$ 7

Step 1a - Rows

Typesetter / Job	A	B	C
R-34	$ 5	$ 8	$ 0
S-66	$ 0	$ 2	$ 3
T-50	$ 2	$ 5	$ 0

Step 1b - Columns

Typesetter / Job	A	B	C
R-34	$ 5	$ 6	$ 0
S-66	$ 0	$ 0	$ 3
T-50	$ 2	$ 3	$ 0

Assignment Example

Step 2 - Lines

Typesetter / Job	A	B	C
R-34	$ 5	$ 6	$ 0
S-66	$ 0	$ 0	$ 3
T-50	$ 2	$ 3	$ 0

Smallest uncovered number

Because only two lines are needed to cover all the zeros, the solution is not optimal

The smallest uncovered number is 2 so this is subtracted from all other uncovered numbers and added to numbers at the intersection of lines

Step 3 - Subtraction

Typesetter / Job	A	B	C
R-34	$ 3	$ 4	$ 0
S-66	$ 0	$ 0	$ 5
T-50	$ 0	$ 1	$ 0

Assignment Example

Step 2 - Lines

Typesetter / Job	A	B	C
R-34	$ 3	$ 4	$ 0
S-66	$ 0	$ 0	$ 5
T-50	$ 0	$ 1	$ 0

Because three lines are needed, the solution is optimal and assignments can be made

Start by assigning R-34 to worker C as this is the only possible assignment for worker C.

Job T-50 must go to worker A as worker C is already assigned. This leaves S-66 for worker B.

Step 4 - Assignments

Typesetter / Job	A	B	C
R-34	$ 3	$ 4	$ 0
S-66	$ 0	$ 0	$ 5
T-50	$ 0	$ 1	$ 0

Assignment Example

Typesetter / Job	A	B	C
R-34	$11	$14	$ 6
S-66	$ 8	$10	$11
T-50	$ 9	$12	$ 7

Typesetter / Job	A	B	C
R-34	$ 3	$ 4	$ 0
S-66	$ 0	$ 0	$ 5
T-50	$ 0	$ 1	$ 0

From the original cost table

Minimum cost = $6 + $10 + $9 = $25

Sequencing Jobs

- Specifies the order in which jobs should be performed at work centers
- Priority rules are used to dispatch or sequence jobs
  - FCFS: **First come, first served**
  - SPT: **Shortest processing time**
  - EDD: **Earliest due date**
  - LPT: **Longest processing time**

Sequencing Example

Apply the four popular sequencing rules to these five jobs

Job	Job Work (Processing) Time (Days)	Job Due Date (Days)
A	6	8
B	2	6
C	8	18
D	3	15
E	9	23

Sequencing Example

FCFS: Sequence A-B-C-D-E

Job Sequence	Job Work (Processing) Time	Flow Time	Job Due Date	Job Lateness
A	6	6	8	0
B	2	8	6	2
C	8	16	18	0
D	3	19	15	4
E	9	28	23	5
	28	77		11

Sequencing Example

FCFS: Sequence A-B-C-D-E

$$\text{Average completion time} = \frac{\text{Sum of total flow time}}{\text{Number of jobs}} = 77/5 = 15.4 \text{ days}$$

$$\text{Utilization metric} = \frac{\text{Total job work time}}{\text{Sum of total flow time}} = 28/77 = 36.4\%$$

$$\text{Average number of jobs in the system} = \frac{\text{Sum of total flow time}}{\text{Total job work time}} = 77/28 = 2.75 \text{ jobs}$$

$$\text{Average job lateness} = \frac{\text{Total late days}}{\text{Number of jobs}} = 11/5 = 2.2 \text{ days}$$

Sequencing Example

SPT: Sequence B-D-A-C-E

Job Sequence	Job Work (Processing) Time	Flow Time	Job Due Date	Job Lateness
B	2	2	6	0
D	3	5	15	0
A	6	11	8	3
C	8	19	18	1
E	9	28	23	5
	28	65		9

Sequencing Example

SPT: Sequence B-D-A-C-E

$$\text{Average completion time} = \frac{\text{Sum of total flow time}}{\text{Number of jobs}} = 65/5 = 13 \text{ days}$$

$$\text{Utilization metric} = \frac{\text{Total job work time}}{\text{Sum of total flow time}} = 28/65 = 43.1\%$$

$$\text{Average number of jobs in the system} = \frac{\text{Sum of total flow time}}{\text{Total job work time}} = 65/28 = 2.32 \text{ jobs}$$

$$\text{Average job lateness} = \frac{\text{Total late days}}{\text{Number of jobs}} = 9/5 = 1.8 \text{ days}$$

Sequencing Example

EDD: Sequence B-A-D-C-E

Job Sequence	Job Work (Processing) Time	Flow Time	Job Due Date	Job Lateness
B	2	2	6	0
A	6	8	8	0
D	3	11	15	0
C	8	19	18	1
E	9	28	23	5
	28	68		6

Sequencing Example

EDD: Sequence B-A-D-C-E

$$\text{Average completion time} = \frac{\text{Sum of total flow time}}{\text{Number of jobs}} = 68/5 = 13.6 \text{ days}$$

$$\text{Utilization metric} = \frac{\text{Total job work time}}{\text{Sum of total flow time}} = 28/68 = 41.2\%$$

$$\text{Average number of jobs in the system} = \frac{\text{Sum of total flow time}}{\text{Total job work time}} = 68/28 = 2.43 \text{ jobs}$$

$$\text{Average job lateness} = \frac{\text{Total late days}}{\text{Number of jobs}} = 6/5 = 1.2 \text{ days}$$

Sequencing Example

LPT: Sequence E-C-A-D-B

Job Sequence	Job Work (Processing) Time	Flow Time	Job Due Date	Job Lateness
E	9	9	23	0
C	8	17	18	0
A	6	23	8	15
D	3	26	15	11
B	2	28	6	22
	28	103		48

Sequencing Example

LPT: Sequence E-C-A-D-B

$$\text{Average completion time} = \frac{\text{Sum of total flow time}}{\text{Number of jobs}} = 103/5 = 20.6 \text{ days}$$

$$\text{Utilization metric} = \frac{\text{Total job work time}}{\text{Sum of total flow time}} = 28/103 = 27.2\%$$

$$\text{Average number of jobs in the system} = \frac{\text{Sum of total flow time}}{\text{Total job work time}} = 103/28 = 3.68 \text{ jobs}$$

$$\text{Average job lateness} = \frac{\text{Total late days}}{\text{Number of jobs}} = 48/5 = 9.6 \text{ days}$$

Sequencing Example

Summary of Rules

Rule	Average Completion Time (Days)	Utilization Metric (%)	Average Number of Jobs in System	Average Lateness (Days)
FCFS	15.4	36.4	2.75	2.2
SPT	13.0	43.1	2.32	1.8
EDD	13.6	41.2	2.43	1.2
LPT	20.6	27.2	3.68	9.6

Comparison of Sequencing Rules

- No one sequencing rule excels on all criteria

    1. SPT does well on minimizing flow time and number of jobs in the system
        - But SPT moves long jobs to the end which may result in dissatisfied customers
    2. FCFS does not do especially well (or poorly) on any criteria but is perceived as fair by customers
    3. EDD minimizes maximum lateness

Critical Ratio (CR)

- An index number found by dividing the time remaining until the due date by the work time remaining on the job
- Jobs with low critical ratios are scheduled ahead of jobs with higher critical ratios
- Performs well on average job lateness criteria

$$\text{CR} = \frac{\text{Time remaining}}{\text{Workdays remaining}} = \frac{\text{Due date} - \text{Today's date}}{\text{Work (lead) time remaining}}$$

Critical Ratio Example

Currently Day 25

JOB	DUE DATE	WORKDAYS REMAINING
A	30	4
B	28	5
C	27	2

JOB	CRITICAL RATIO	PRIORITY ORDER
A	(30 - 25)/4 = 1.25	3
B	(28 - 25)/5 = .60	1
C	(27 - 25)/2 = 1.00	2

With CR < 1, Job B is late. Job C is just on schedule and Job A has some slack time.

Critical Ratio Technique

1. Helps determine the status of specific jobs
2. Establishes relative priorities among jobs on a common basis
3. Adjusts priorities automatically for changes in both demand and job progress
4. Dynamically tracks job progress

Sequencing N Jobs on Two Machines: Johnson's Rule

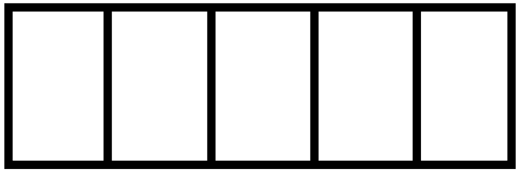
- Works with two or more jobs that pass through the same two machines or work centers
- Minimizes total production time and idle time
- An $N/2$ problem, N number of jobs through 2 workstations

Johnson's Rule

1. List all jobs and times for each work center
2. Choose the job with the shortest activity time. If that time is in the first work center, schedule the job first. If it is in the second work center, schedule the job last.
3. Once a job is scheduled, it is eliminated from the list
4. Repeat steps 2 and 3 working toward the center of the sequence

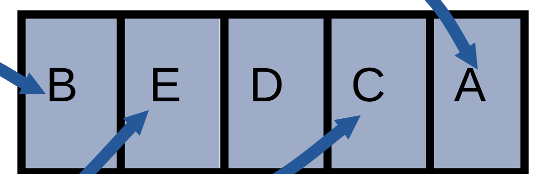
Johnson's Rule Example

JOB	WORK CENTER 1 (DRILL PRESS)	WORK CENTER 2 (LATHE)
A	5	2
B	3	6
C	8	4
D	10	7
E	7	12



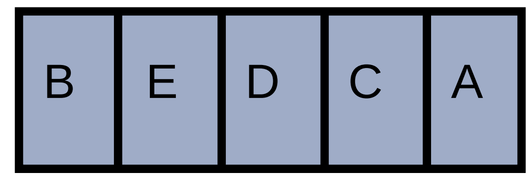
Johnson's Rule Example

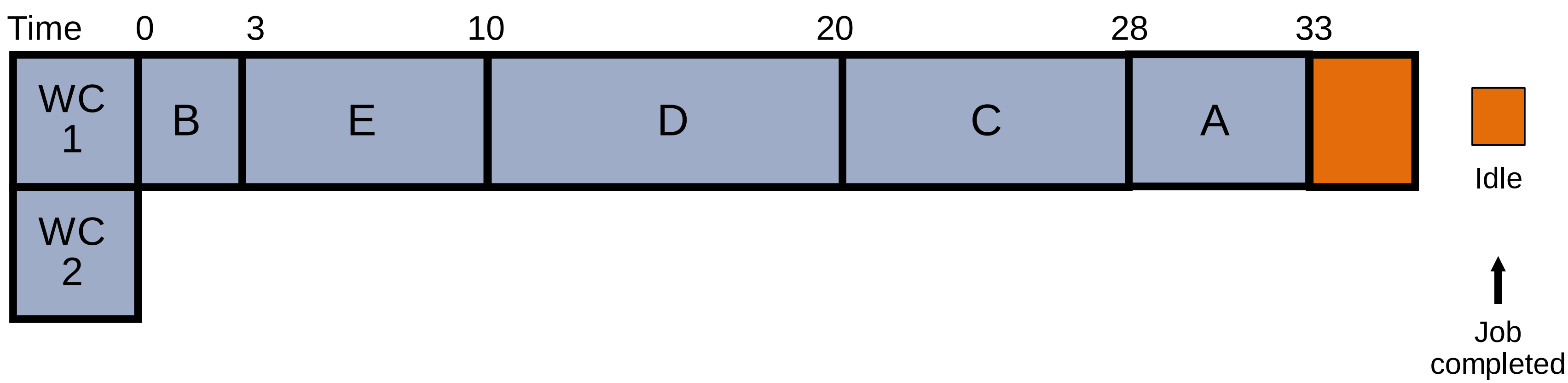
JOB	WORK CENTER 1 (DRILL PRESS)	WORK CENTER 2 (LATHE)
~~A~~	~~5~~	~~2~~
~~B~~	~~3~~	~~6~~
~~C~~	~~8~~	~~4~~
D	10	7
~~E~~	~~7~~	~~12~~



Johnson's Rule Example

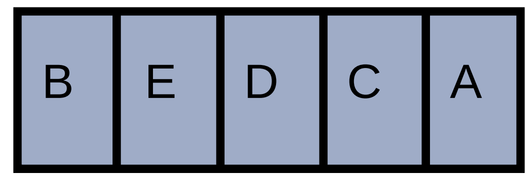
JOB	WORK CENTER 1 (DRILL PRESS)	WORK CENTER 2 (LATHE)
A	5	2
B	3	6
C	8	4
D	10	7
E	7	12

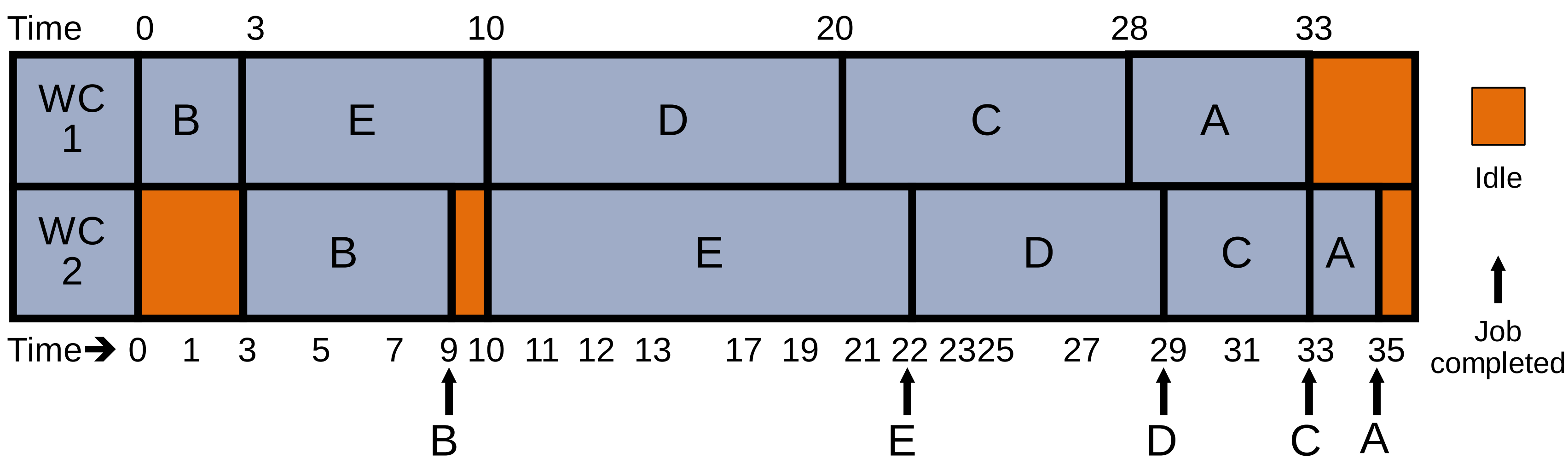




Johnson's Rule Example

JOB	WORK CENTER 1 (DRILL PRESS)	WORK CENTER 2 (LATHE)
A	5	2
B	3	6
C	8	4
D	10	7
E	7	12





Limitations of Rule-Based Dispatching Systems

1. Scheduling is dynamic and rules need to be revised to adjust to changes
2. Rules do not look upstream or downstream
3. Rules do not look beyond due dates

Finite Capacity Scheduling

- Overcomes disadvantages of rule-based systems by providing an interactive, computer-based graphical system
- May include rules and expert systems or simulation to allow real-time response to system changes
- FCS allows the balancing of delivery needs and efficiency

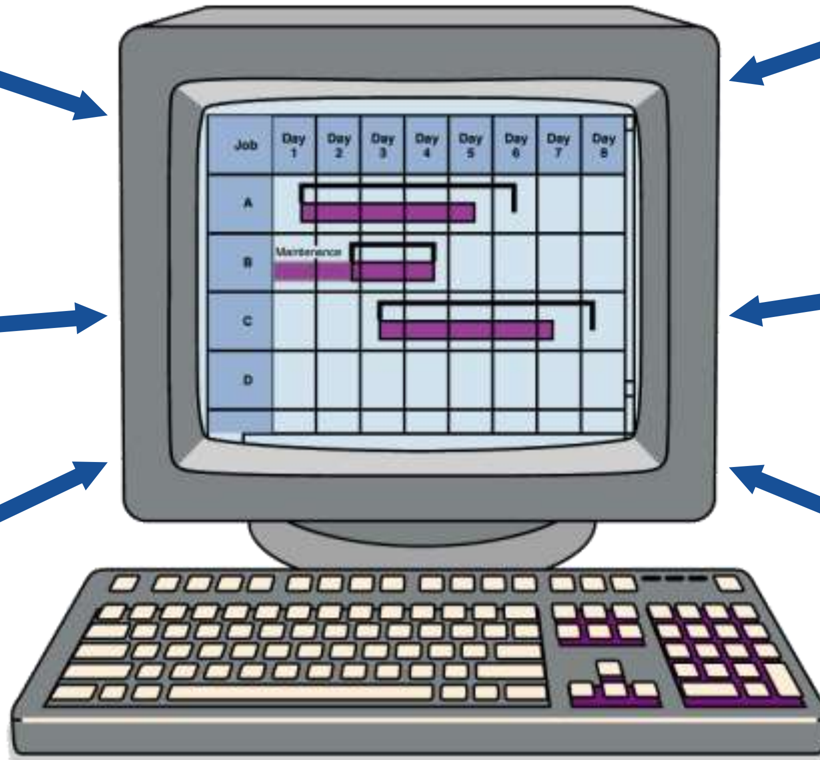
Finite Capacity Scheduling

Planning Data
- Master schedule
- BOM
- Inventory

Priority rules

- Expert systems
- Simulation models

Interactive Finite Capacity Scheduling



- Routing files
- Work center information

Tooling and other resources

Setups and run time

Figure 15.5

Finite Capacity Scheduling

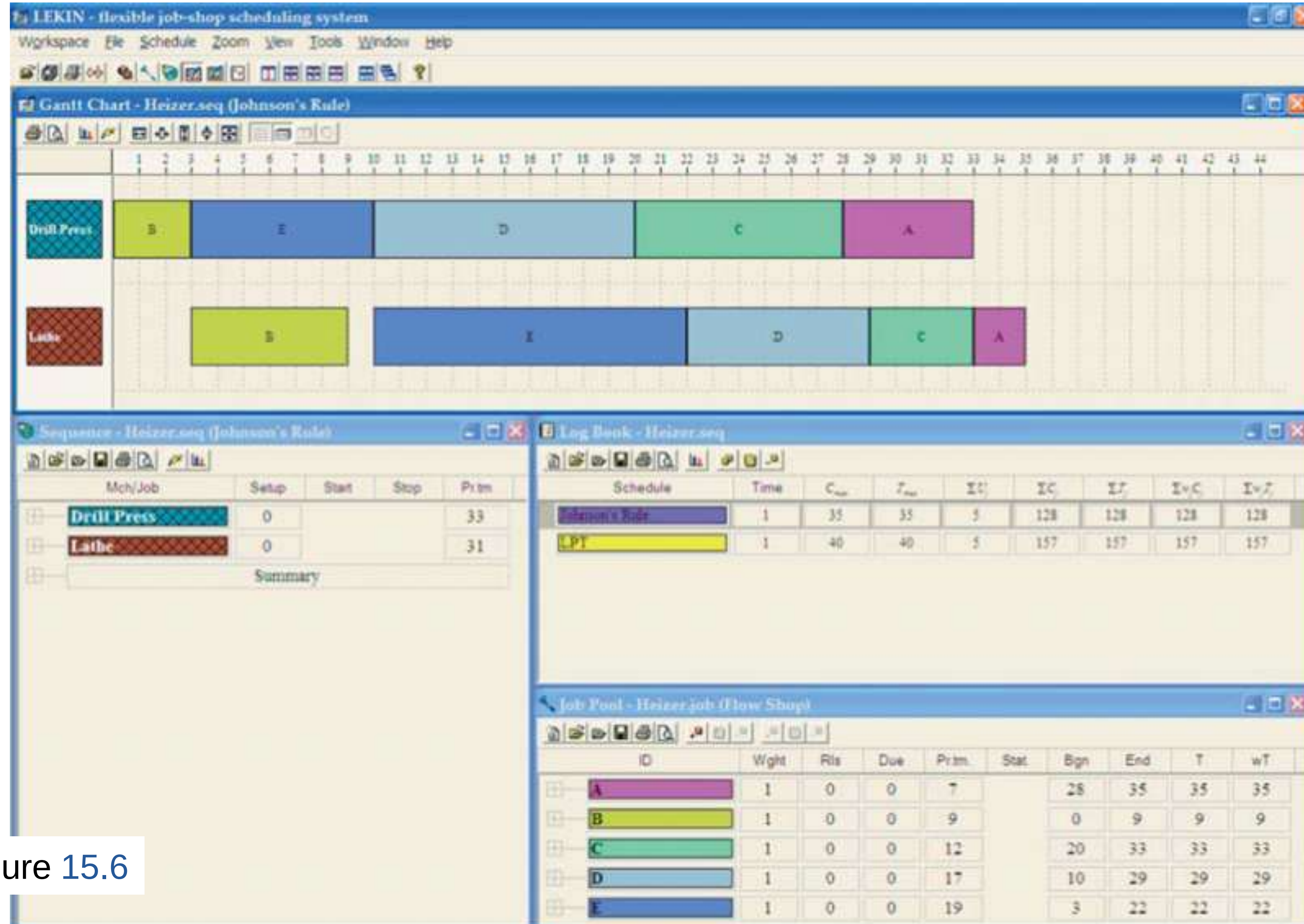


Figure 15.6

Scheduling Services

Service systems differ from manufacturing

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

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

Scheduling Services

- **Airlines** must meet complex FAA 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

Scheduling Service Employees With Cyclical Scheduling

- Objective is to meet staffing requirements with the minimum number of workers
- Schedules need to be smooth and keep personnel happy
- Many techniques exist from simple algorithms to complex linear programming solutions

Cyclical Scheduling Example

1. Determine the staffing requirements
2. Identify two consecutive days with the lowest total requirements and assign these as days off
3. Make a new set of requirements subtracting the days worked by the first employee
4. Apply step 2 to the new row
5. Repeat steps 3 and 4 until all requirements have been met

Cyclical Scheduling Example

DAY	M	T	W	T	F	S	S
Staff required	5	5	6	5	4	3	3

	M	T	W	T	F	S	S
Employee 1	5	5	6	5	4	3	3

Capacity (Employees)

Excess Capacity

Cyclical Scheduling Example

DAY	M	T	W	T	F	S	S
Staff required	5	5	6	5	4	3	3

	M	T	W	T	F	S	S
Employee 1	5	5	6	5	4	3	3
Employee 2	4	4	5	4	3	3	3

Capacity (Employees)

Excess Capacity

Cyclical Scheduling Example

DAY	M	T	W	T	F	S	S
Staff required	5	5	6	5	4	3	3

	M	T	W	T	F	S	S
Employee 1	5	5	6	5	4	3	3
Employee 2	4	4	5	4	3	3	3
Employee 3	3	3	4	3	2	3	3

Capacity (Employees)

Excess Capacity

Cyclical Scheduling Example

DAY	M	T	W	T	F	S	S
Staff required	5	5	6	5	4	3	3

	M	T	W	T	F	S	S
Employee 1	5	5	6	5	4	3	3
Employee 2	4	4	5	4	3	3	3
Employee 3	3	3	4	3	2	3	3
Employee 4	2	2	3	2	2	3	2

Capacity (Employees)

Excess Capacity

Cyclical Scheduling Example

DAY	M	T	W	T	F	S	S
Staff required	5	5	6	5	4	3	3

	M	T	W	T	F	S	S
Employee 1	5	5	6	5	4	3	3
Employee 2	4	4	5	4	3	3	3
Employee 3	3	3	4	3	2	3	3
Employee 4	2	2	3	2	2	3	2
Employee 5	1	1	2	2	2	2	1

Capacity (Employees)

Excess Capacity

Cyclical Scheduling Example

DAY	M	T	W	T	F	S	S
Staff required	5	5	6	5	4	3	3

	M	T	W	T	F	S	S
Employee 1	5	5	6	5	4	3	3
Employee 2	4	4	5	4	3	3	3
Employee 3	3	3	4	3	2	3	3
Employee 4	2	2	3	2	2	3	2
Employee 5	1	1	2	2	2	2	1
Employee 6	1	1	1	1	1	1	0

Capacity (Employees)

Excess Capacity

Cyclical Scheduling Example

DAY	M	T	W	T	F	S	S
Staff required	5	5	6	5	4	3	3

	M	T	W	T	F	S	S
Employee 1	5	5	6	5	4	3	3
Employee 2	4	4	5	4	3	3	3
Employee 3	3	3	4	3	2	3	3
Employee 4	2	2	3	2	2	3	2
Employee 5	1	1	2	2	2	2	1
Employee 6	1	1	1	1	1	1	0
Employee 7						1	
Capacity (Employees)	5	5	6	5	4	3	3
Excess Capacity	0	0	0	0	0	1	0