PRODUCTION AND OPERATIONS
2023/2024

Lisbon School
of Economics
& Management

LISBOA | UNIVERSIDADE DE LISBOA

Short-Term Scheduling

Chapter 15

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 Decisions

TABLE 15.1	Scheduling Decisions
ORGANIZATION	**MANAGERS SCHEDULE THE FOLLOWING**
Alaska Airlines	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 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 Flow

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

Myrleen Pearson/Alamy

Figure 15.1

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	

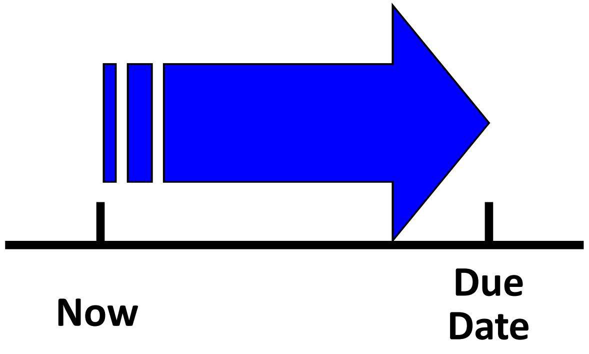
Short Term Scheduling
(Short term; days, hours, minutes)
Work center loading
Job sequencing/dispatching
See this chapter

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

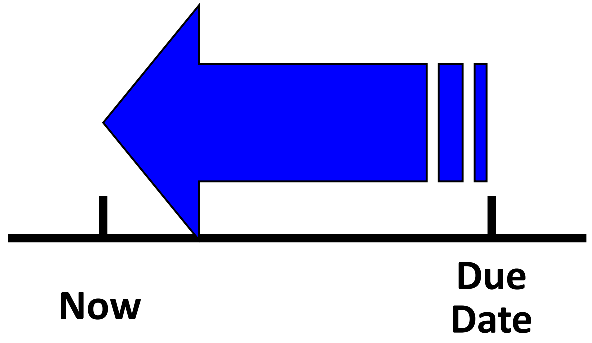
Forward and Backward **Scheduling**

- **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 (WIP) inventory
- Hospitals, restaurants, etc.

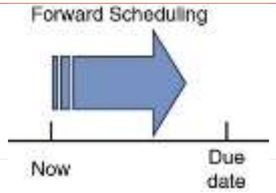


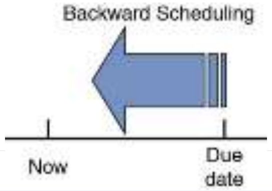
Forward and **Backward Scheduling**

- **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
- Catering, surgeries, etc.



Types of Scheduling





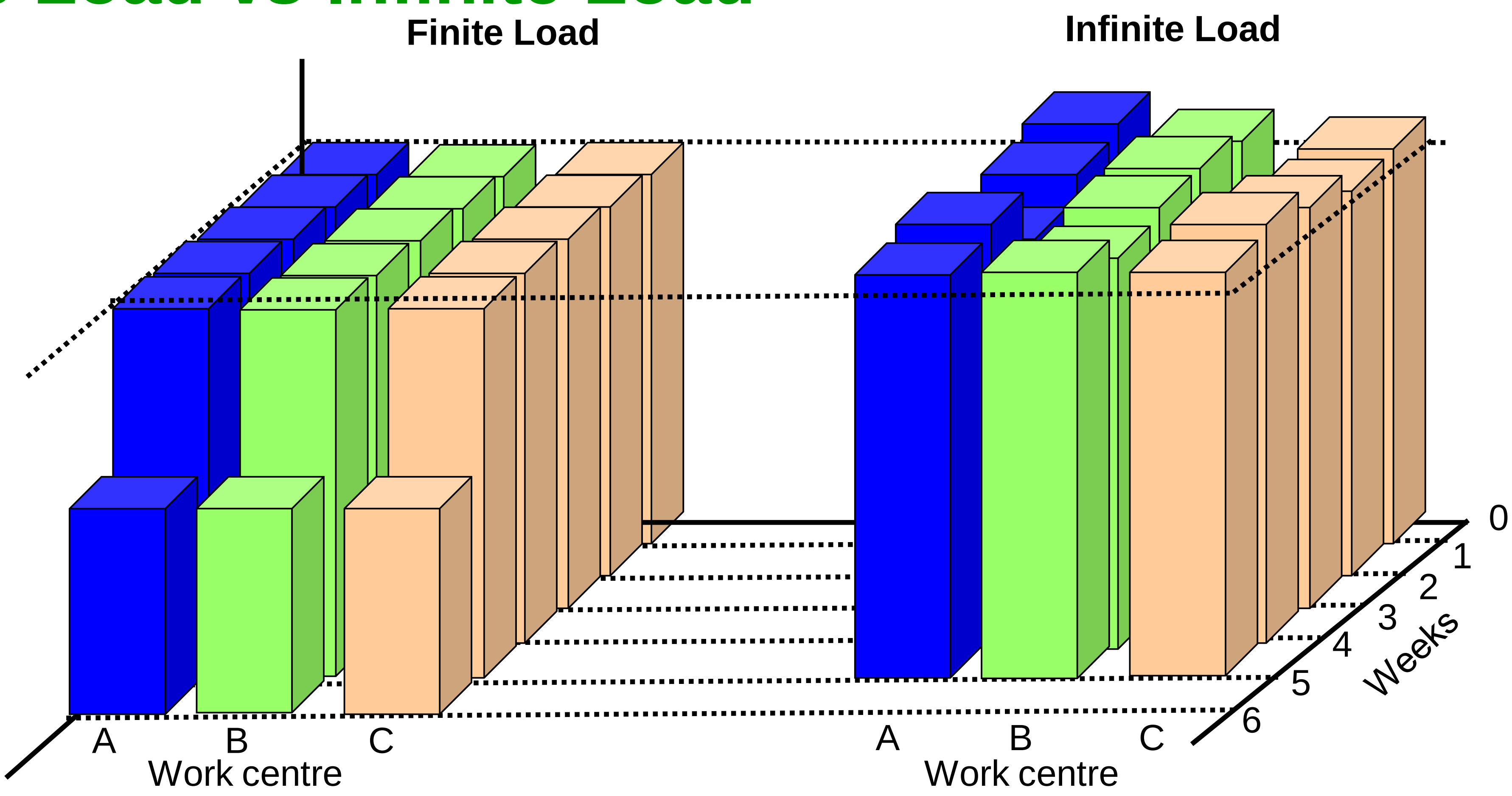
Forward scheduling	Backward scheduling
- Forward scheduling begins **as soon as production requirements are known** • Products are delivered **as soon as possible** - Creates a feasible schedule, although **it may not meet expected dates** - In most cases, it leads to an **accumulation of stocks of products** in the process of being manufactured	-Backward scheduling starts with a fixed deadline, scheduling the last task first -Products are delivered **when needed** - Sequencing is produced through retrospective work throughout the processes - Resources **may not be available** to meet the schedule
Advantages - **High labor utilization** - workers always start working to stay busy - **Flexíble** - slack in the system allows work to be loaded	**Advantages** **Lower material costs** - materials are only used when they have to be, thus delaying added value until the last moment - Less exposed to risk in case of changes to the calendar by the client - Tends to focus the operation on the delivery date to the customer

Finite and Infinite Loading

- **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

Short-term sequencing

Finite Load vs Infinite Load



Adapted from Slack, N., Chambers, S., & Johnston, R. (2013). *Operations Management*, Seventh edition, Prentice Hall.

Scheduling Criteria

Minimize completion time

Maximize utilization of facilities

Minimize work-in-process (WIP) inventory

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

Scheduling Process-Focused Facilities

- ***Intermittent*** or ***job-shop*** facilities
- High-variety, low volume
- Production items 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

- **Input–output control** is a technique that allows operations personnel to manage facility work flows.
- Identifies **overloading** (if the work is arriving faster than it is being processed, the facility is overloaded, and a backlog develops, causing crowding in the facility, and leading to inefficiencies and quality problems), and **underloading** (if the work is arriving at a slower rate than jobs are being performed, the facility is underloaded, and the work center may run out of work, resulting in idle capacity and wasted resources conditions).
- Prompts managerial action to resolve scheduling problems.
- Can be maintained using **ConWIP** *(constant work-in-process)* cards that control the scheduling of batches.

Input-Output Control Example

Figure 15.2

Welding Work Center (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

Welding Work Center (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:

- Correcting performances
- Increasing capacity
- Increasing or reducing input to the work center

Gantt Chart

- 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

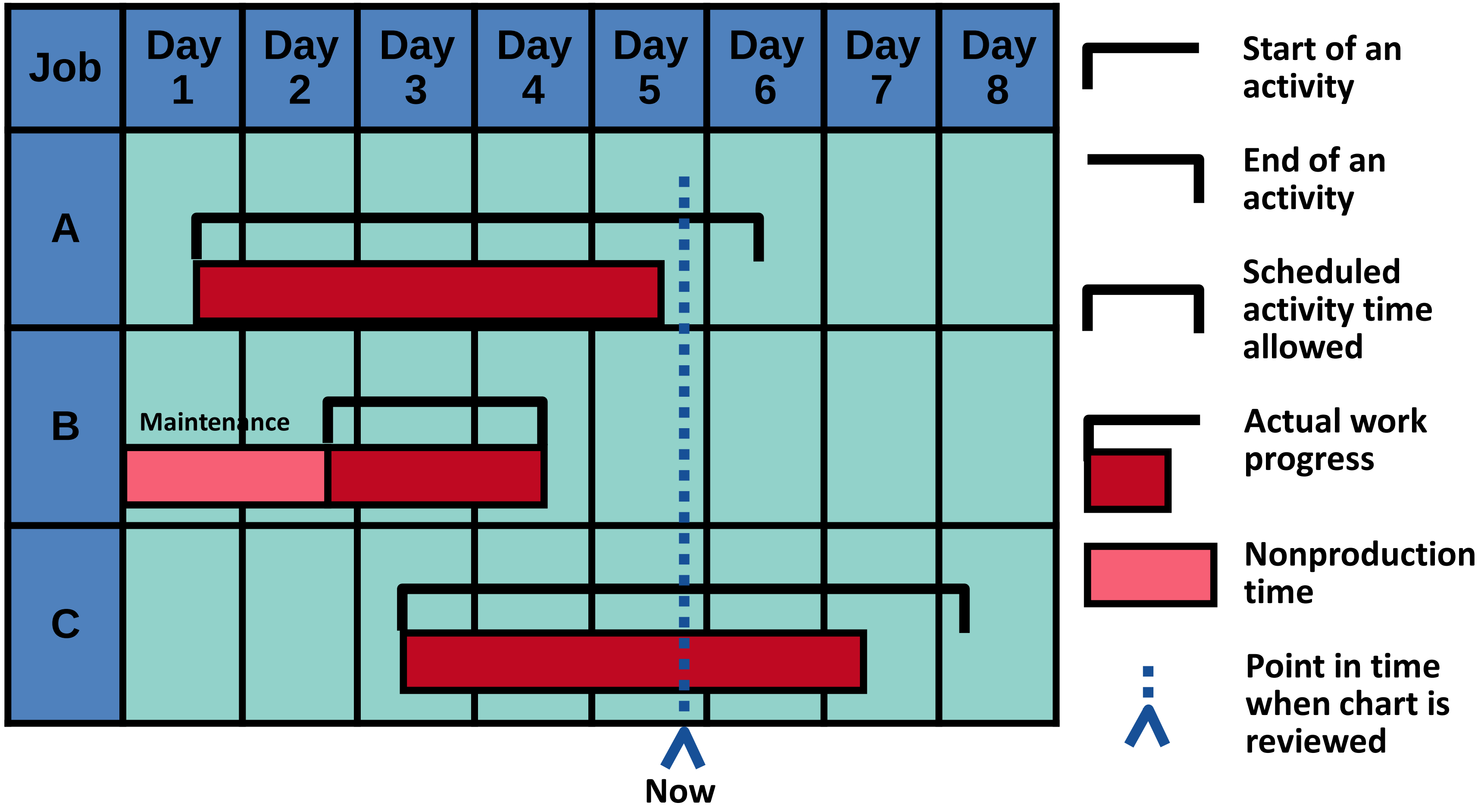
Work Center \ Day	Monday	Tuesday	Wednesday	Thursday	Friday
Metalworks	Job 349		←	Job 350	→
Mechanical		← Job 349	→	Job 408	
Electronics	Job 408			Job 349	
Painting	← Job 295	→	Job 408		Job 349

Processing

Unscheduled

Center not available

Gantt Load Chart Example



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 Method Example

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

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

14 – 6 = $8

5 – 2 = $3

Assignment Method 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

3 + 2 = $5

Assignment Method 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 job **R-34 to worker C** as this is the only possible assignment for worker C.

Step 4 - Assignments

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

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

Assignment Method Example

Costs

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

Assignments

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

Example 1:

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

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

Example 1 (cont.):

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

Performance Criteria

- **Flow time** – the time between the release of a job to a work center until the job is finished

$$\textbf{Average completion time} = \frac{\text{Total flow time}}{\text{Number of jobs}}$$

$$\textbf{Utilization metric} = \frac{\text{Total job work (processing) time}}{\text{Total flow time}}$$

$$\textbf{Average number of jobs in the system} = \frac{\text{Total flow time}}{\text{Total job work (processing) time}}$$

$$\textbf{Average job lateness} = \frac{\text{Total late days}}{\text{Number of jobs}}$$

Sequencing Criteria

1. Minimize completion time → Average completion time
2. Maximize the utilization rate of facilities → Utilization metric
3. Minimize stocks of work-in-progress (WIP) → Average number of jobs in the system
4. Minimize waiting time → Average job lateness

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

Example 1 (cont.):

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

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

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

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

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

Example 1 (cont.):

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

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

Example 1 (cont.):

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

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

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

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

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

Example 1 (cont.):

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

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

Example 1 (cont.):

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

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

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

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

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

Example 1 (cont.):

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

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

Example 1 (cont.):

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

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

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

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

Summary of Rules

Example 1 (cont.):

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

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

Critical Ratio (CR) Example

Currently day 25

Job	Due Date	Workdays Remaining	Critical Ratio	Priority Order
A	30	4	(30 - 25)/4 = **1.25**	3
B	28	5	(28 - 25)/5 = **0.60**	1
C	27	2	(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.

Advantages of Critical Ratio (CR)

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

Johnson´s Rule

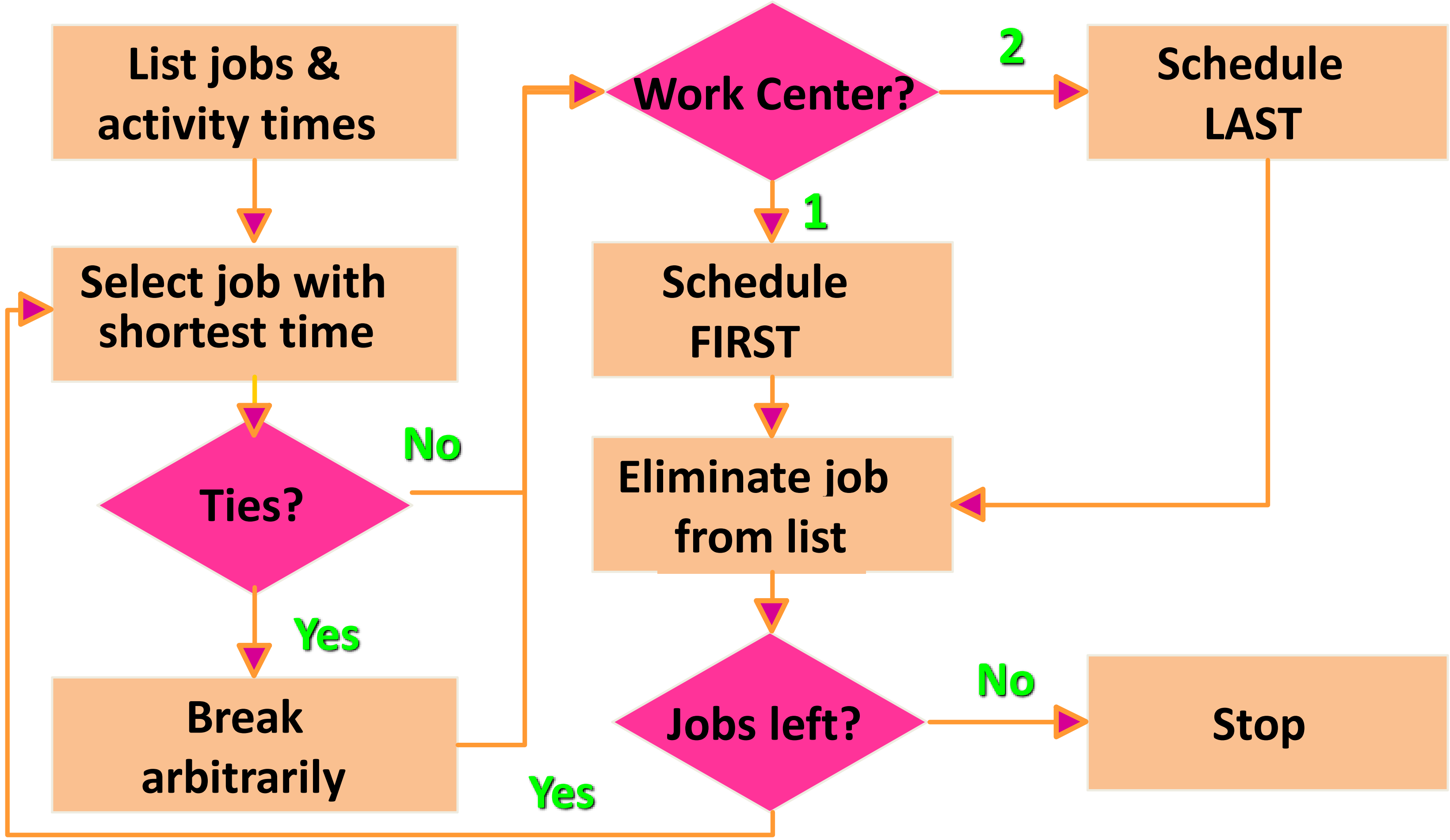
Sequencing *N* Jobs on Two Machines/ workstations (n/2)

- Works with two or more jobs that pass through the same two machines or work centers
- Minimizes total production time and idle time

Johnson´s Rule Steps

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.** Break ties arbitrarily.
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 Steps



Johnson´s Rule

Example 2:

Five jobs must be processed through two works centers (drill press and lathe), and the time (in hours) for processing each jobs is shown in the following table:

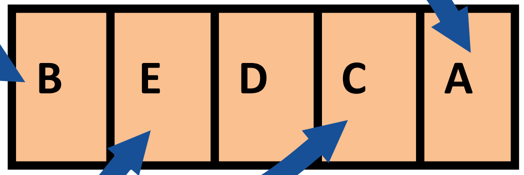
Job	Work Center 1 (drill press)	Work Center 2 (lathe)
A	5	2
B	3	6
C	8	4
D	10	7
E	7	12

The manager wants to set the sequence to minimize the total time for the five jobs.

Johnson´s Rule Example

Example 2 (cont.):

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

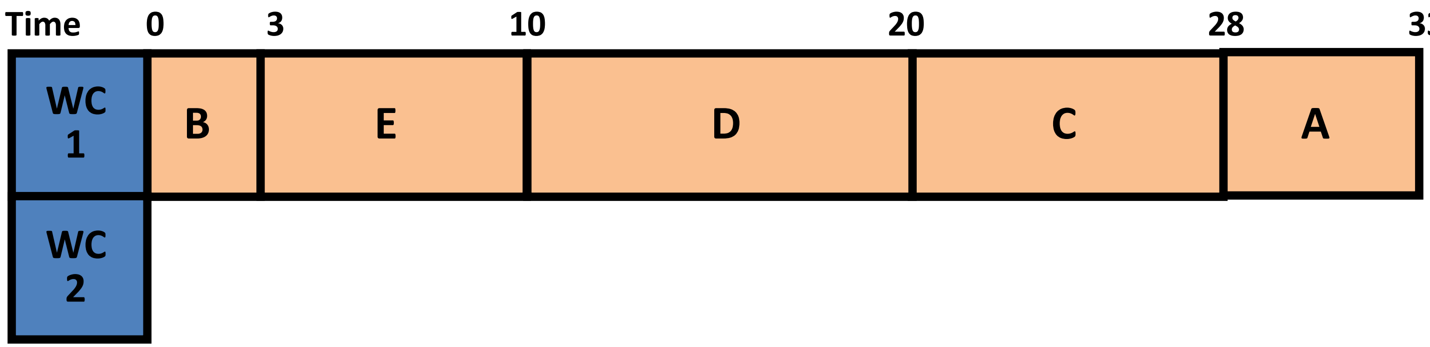


Johnson´s Rule Example

Example 2 (cont.):

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

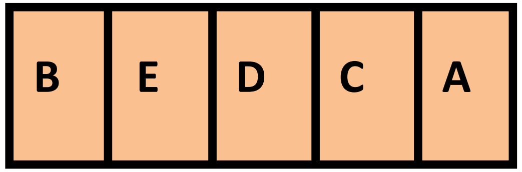
B	E	D	C	A

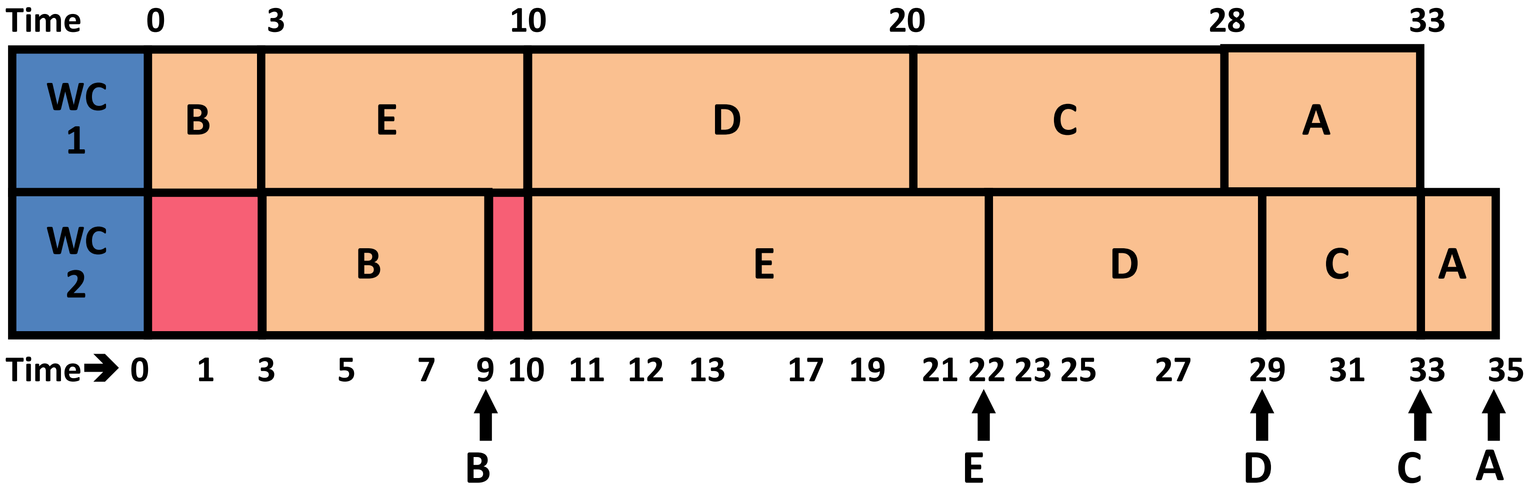


Johnson´s Rule Example

Example 2 (cont.):

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

Example 2 (cont.):

The sequence that minimize the total time for the five jobs is: **B – E – D – C – A**

The five jobs are completed in **35 hours.**

Limitations of Rule-Based Dispatching Systems

1. Scheduling is dynamic and rules need to be revised to adjust to changes in orders, process, equipment, product mix, and so forth.
2. Rules do not look upstream or downstream. Idle resources, and bottleneck resources, in other departments may not be recognized.
3. Rules do not look beyond due dates.

OPEN
MINDS.
GRAB
THE FUTURE.

iseg.ulisboa.pt