Scheduling

Chapter 16

Scheduling Operations

Scheduling in High-Volume Systems

Flow systems

Flow-shop scheduling

1. Process and product design.
2. Preventive maintenance.
3. Rapid repair when breakdowns occur.
4. Optimal product mixes.
5. Minimization of quality problems.
6. Reliability and timing of supplies.

Scheduling in Intermediate-Volume Systems

Run size

Timing of jobs

Sequence

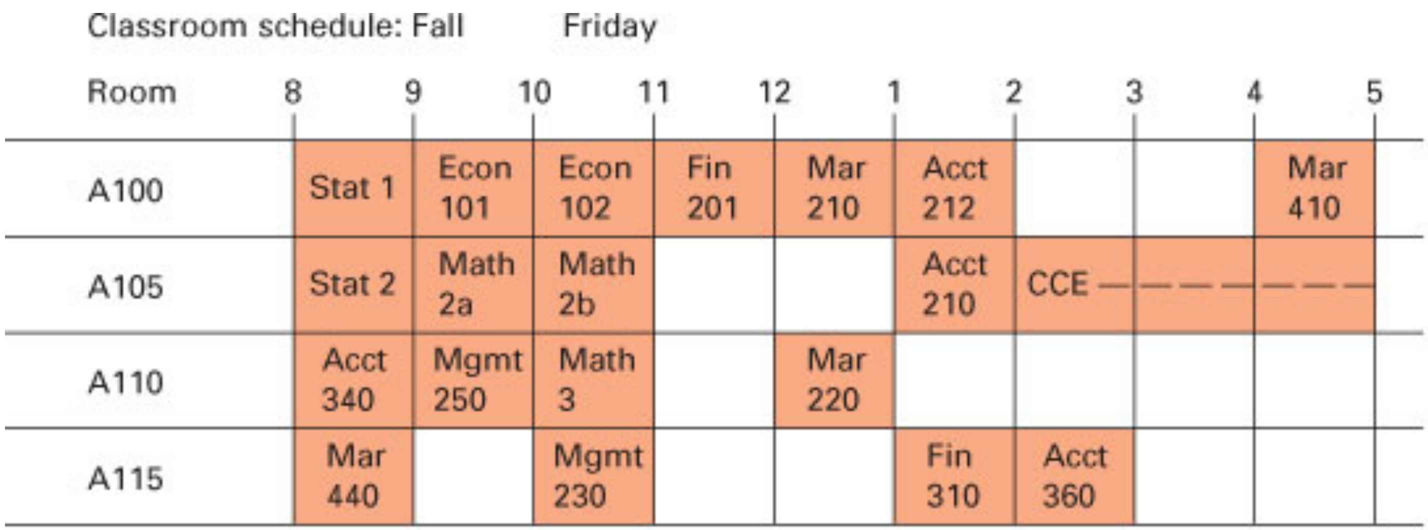
$$Q_0 = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-u}}$$

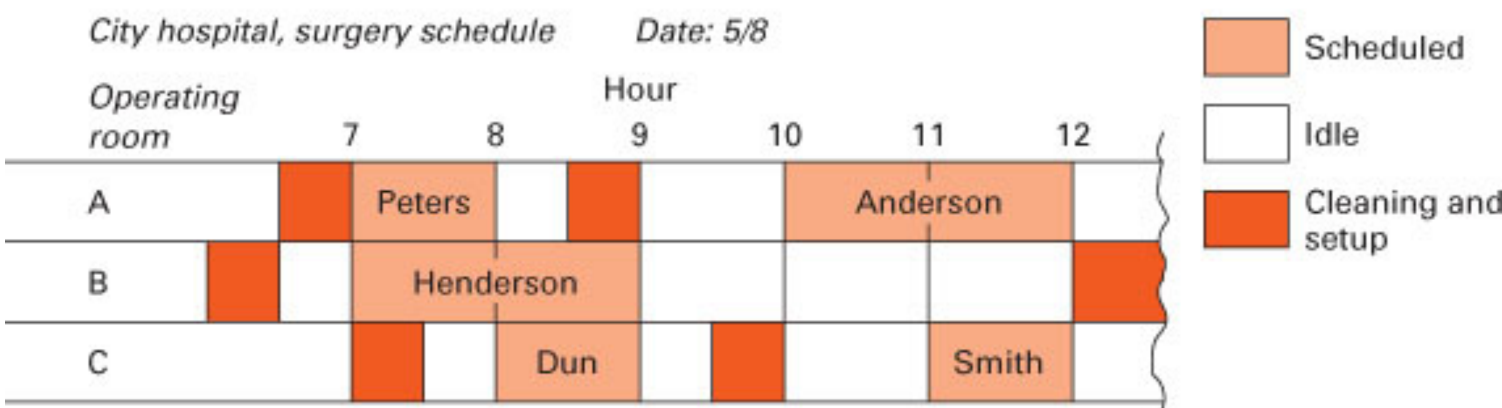
Scheduling in Low-Volume Systems

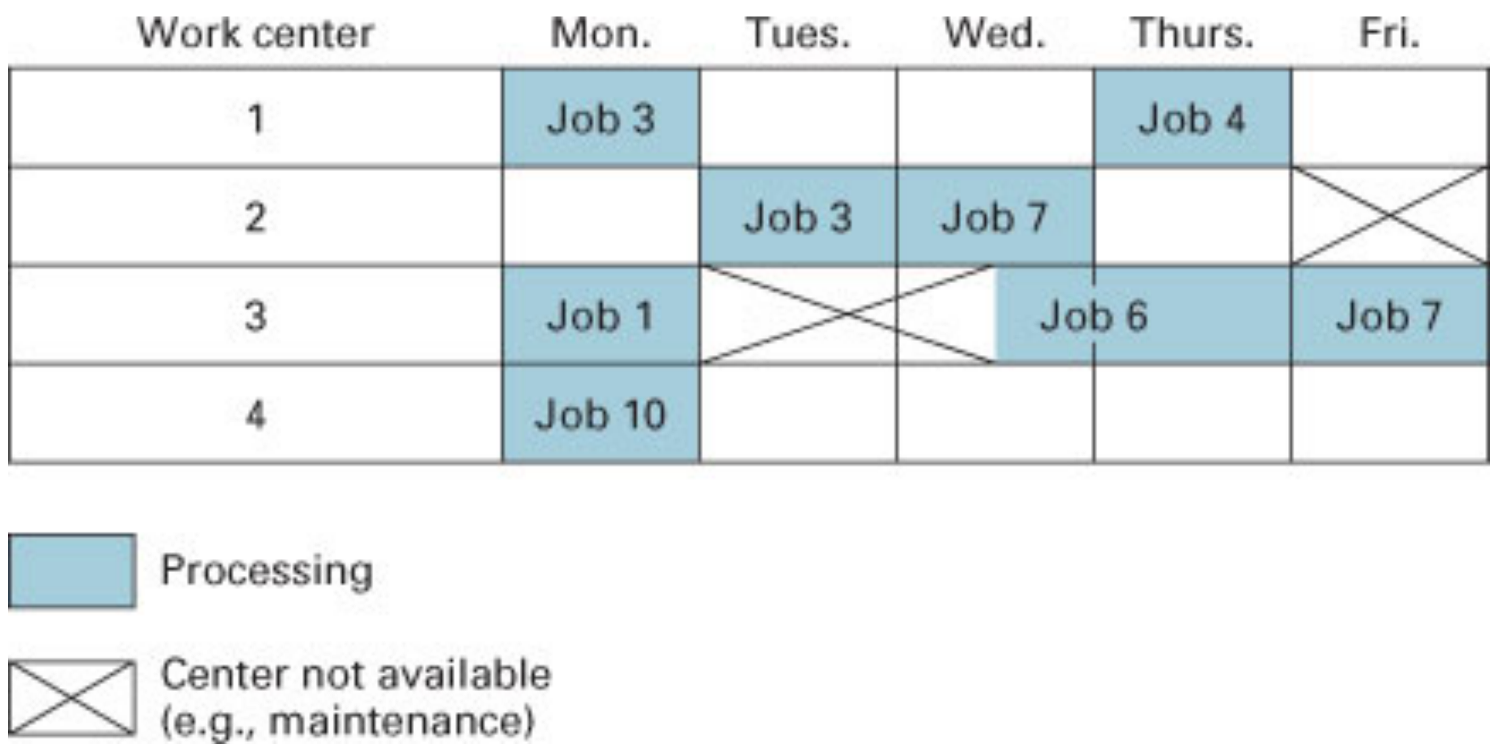
Job-shop scheduling

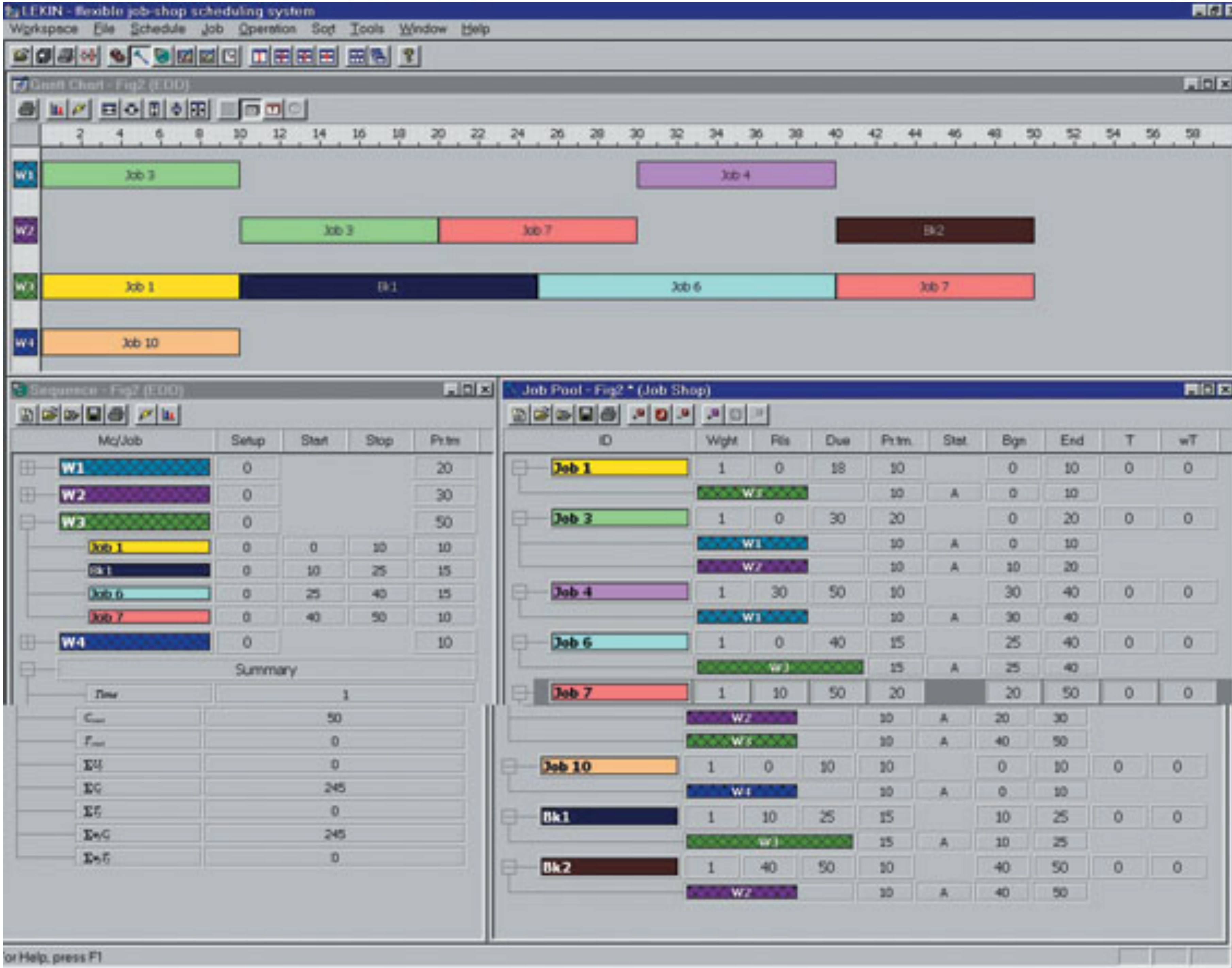
Loading

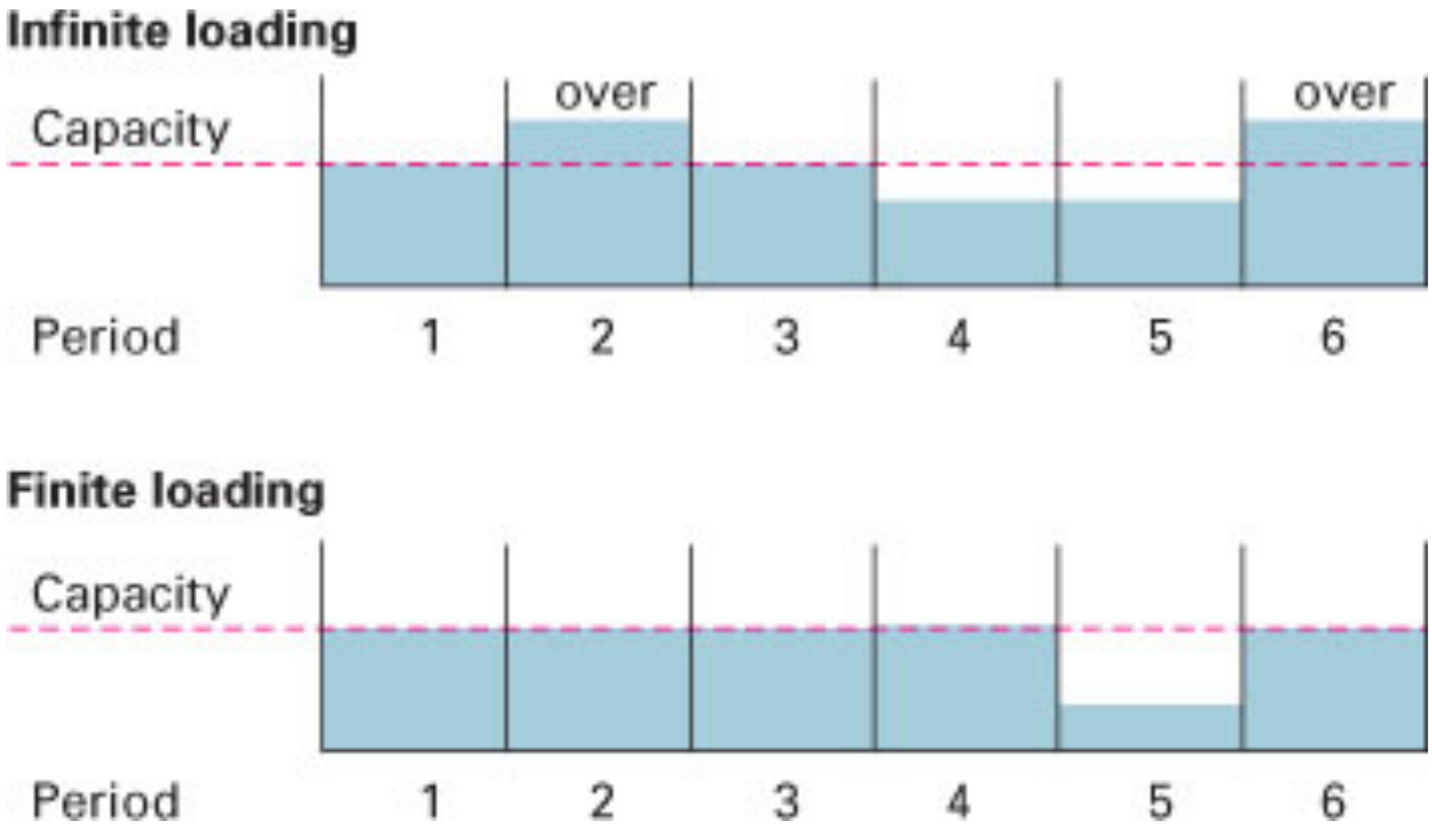
Gantt Charts

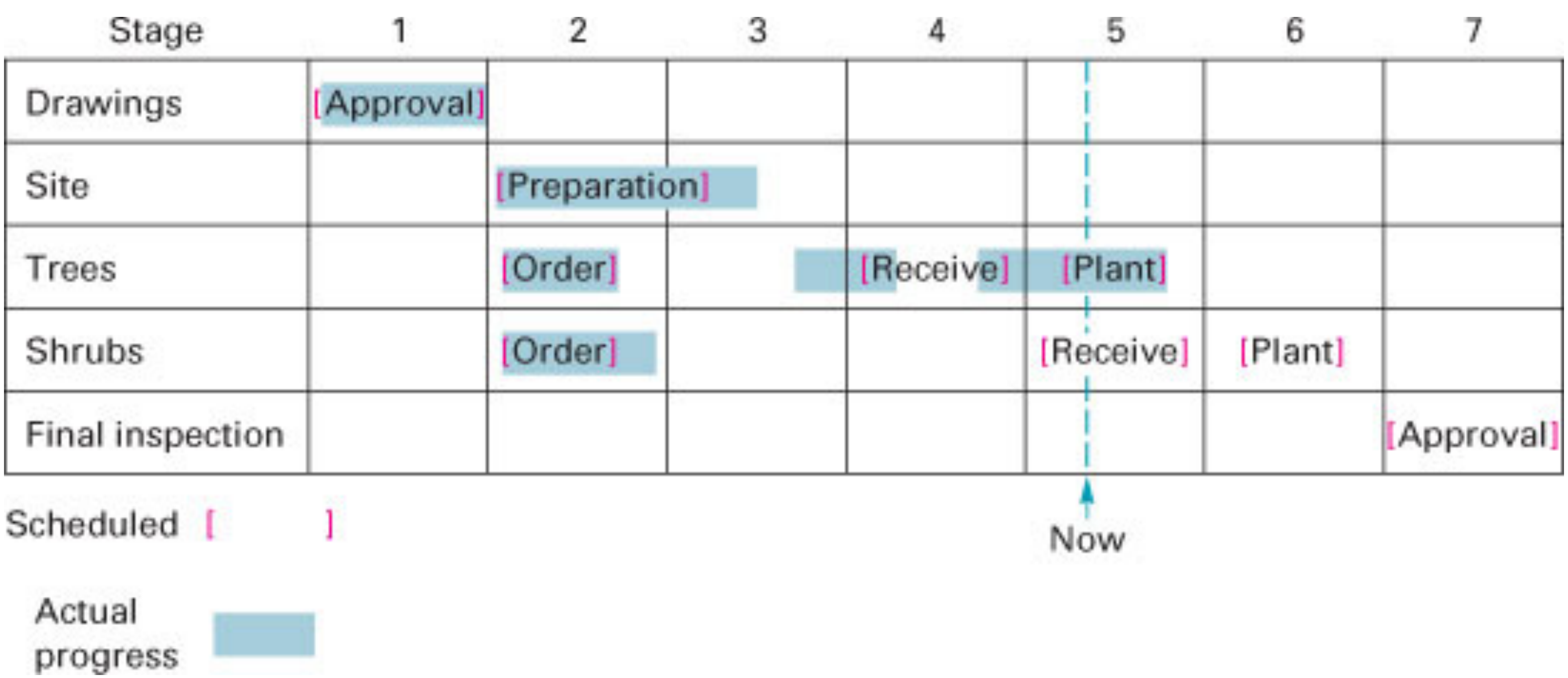





Work center
Mon.
Tues.
Wed.
Thurs.
Fri.
1
2
3
4
Job 3
Job 4
Job 3
Job 7
Job 1
Job 6
Job 7
Job 10
Processing
Center not available
(e.g., maintenance)


LEKIN - flexible job-shop scheduling system
Workspace File Schedule Job Operation Sort Tools Window Help
Job Pool - Fig2 * (Job Shop)
ID Wght Rls Due Pr.tm. Stat. Bgn End T wT
Job 1
Job 3
Job 4
Job 6
Job 7
Job 10
Bk1
Bk2
Mc/Job Setup Start Stop Pr.tm
W1
W2
W3
W4
Summary
For Help, press F1


Infinite loading
Capacity
over
over
Period
1
2
3
4
5
6
Finite loading
Capacity
Period
1
2
3
4
5
6


Stage
1
2
3
4
5
6
7
Drawings
[Approval]
Site
[Preparation]
Trees
[Order]
[Receive]
[Plant]
Shrubs
[Order]
[Receive]
[Plant]
Final inspection
[Approval]
Scheduled [ ]
Now
Actual progress

Input/Output Control

		Period					
		1	2	3	4	5	6
Input	Planned	100	100	90	90	90	90
	Actual	120	95	80	88	93	94
	Deviation	+20	−5	−10	−2	+3	+4
	Cum. dev.	+20	+15	+5	+3	+6	+10
Output	Planned	110	110	100	100	100	95
	Actual	110	105	95	101	103	96
	Deviation	0	−5	−5	+1	+3	+1
	Cum. dev.	0	−5	−10	−9	−6	−5

Backlog	40*	50	40	25	12	2	0

Note: Figures represent standard hours of processing time.
*Given, not derived from the data.

Assignment Method of Linear Programming

		MACHINE			
		A	B	C	D
Job	1	8	6	2	4
	2	6	7	11	10
	3	3	5	7	6
	4	5	10	12	9

Sequencing

Possible priority rules:

First come, first served (FCFS): Jobs are processed in the order in which they arrive at a machine or work center.

Shortest processing time (SPT): Jobs are processed according to processing time at a machine or work center, shortest job first.

Earliest due date (EDD): Jobs are processed according to due date, earliest due date first.

Critical ratio (CR): Jobs are processed according to smallest ratio of time remaining until due date to processing time remaining.

Slack per operation (S/O): Jobs are processed according to average slack time (time until due date minus remaining time to process). Compute by dividing slack time by number of remaining operations, including the current one.

Rush: Emergency or preferred customers first.

Assumptions of priority rules:

The set of jobs is known; no new jobs arrive after processing begins; and no jobs are canceled.

Setup time is independent of processing sequence.

Setup time is deterministic.

Processing times are deterministic rather than variable.

There will be no interruptions in processing such as machine breakdowns, accidents, or worker illness.

Performance Measures:

Job flow time. This is the length of time a job is at a particular workstation or work center.

Job lateness. This is the length of time the job completion date is expected to exceed the date the job was due or promised to a customer.

Makespan. Makespan is the total time needed to complete a *group* of jobs. It is the length of time between the start of the first job in the group and the completion of the last job in the group.

Average number of jobs. Jobs that are in a shop are considered to be work-in-process inventory.

$$\text{Average number of jobs} = \text{Total flow time} \div \text{Makespan}$$

Example

Processing times (including setup times) and due dates for six jobs waiting to be processed at a work center are given in the following table. Determine the sequence of jobs, the average flow time, average tardiness, and average number of jobs at the work center, for each of these rules:

FCFS

SPT

EDD

CR

Job	Processing Time (days)	Due Date (days)
A	2	7
B	8	16
C	4	4
D	10	17
E	5	15
F	12	18

The FCFS sequence is simply A-B-C-D-E-F. The measures of effectiveness are as follows (see table):

1. *Average flow time:* 120÷6 = 20 days.
2. *Average tardiness:* 54÷6 = 9 days.
3. The *makespan* is 41 days.
   Average number of jobs at the work center: 120÷41 = 2.93.

Job Sequence	(1) Processing Time	(2) Flow Time	(3) Due Date	(2) − (3) Days Tardy [0 if negative]
A	2	2	7	0
B	8	10	16	0
C	4	14	4	10
D	10	24	17	7
E	5	29	15	14
F	12	41	18	23
	41	120		54

Using the SPT rule, the job sequence is A-C-E-B-D-F (see the following table). The resulting values for the three measures of effectiveness are

1. *Average flow time:* 108÷6 = 18 days.
2. *Average tardiness:* 40÷6 = 6.67 days.
3. *Average number of jobs at the work center:* 108÷41 = 2.63.

Job Sequence	(1) Processing Time	(2) Flow Time	(3) Due Date	(2) − (3) Days Tardy [0 if negative]
A	2	2	7	0
C	4	6	4	2
E	5	11	15	0
B	8	19	16	3
D	10	29	17	12
F	12	41	18	23
	41	108		40

Using earliest due date as the selection criterion, the job sequence is C-A-E-B-D-F. The measures of effectiveness are as follows (see table):

1. *Average flow time:* 110÷6 = 18.33 days.
2. *Average tardiness:* 38÷6 = 6.33 days.
3. *Average number of jobs at the work center:* 110÷41 = 2.68.

Job Sequence	(1) Processing Time	(2) Flow Time	(3) Due Date	(2) − (3) Days Tardy [0 if negative]
C	4	4	4	0
A	2	6	7	0
E	5	11	15	0
B	8	19	16	3
D	10	29	17	12
F	12	41	18	23
	41	110		38

Using the critical ratio we find

Job Sequence	Processing Time	Due Date	Critical Ratio Calculation
A	2	7	(7 − 0)/ 2 = 3.5
B	8	16	(16 − 0)/ 8 = 2.0
C	4	4	(4 − 0)/ 4 = 1.0 (lowest)
D	10	17	(17 − 0)/10 = 1.7
E	5	15	(15 − 0)/ 5 = 3.0
F	12	18	(18 − 0)/12 = 1.5

At day 4 [C completed], the critical ratios are

Job Sequence	Processing Time	Due Date	Critical Ratio Calculation
A	2	7	(7 − 4)/ 2 = 1.5
B	8	16	(16 − 4)/ 8 = 1.5
C	—	—	—
D	10	17	(17 − 4)/10 = 1.3
E	5	15	(15 − 4)/ 5 = 2.2
F	12	18	(18 − 4)/12 = 1.17 (lowest)

At day 16 [C and F completed], the critical ratios are

Job Sequence	Processing Time	Due Date	Critical Ratio Calculation
A	2	7	(7 − 16)/ 2 = −4.5 (lowest)
B	8	16	(16 − 16)/ 8 = 0.0
C	—	—	—
D	10	17	(17 − 16)/10 = 0.1
E	5	15	(15 − 16)/ 5 = −0.2
F	—	—	—

At day 18 [C, F, and A completed], the critical ratios are

Job Sequence	Processing Time	Due Date	Critical Ratio Calculation
A	—	—	—
B	8	16	(16 − 18)/ 8 = −0.25
C	—	—	—
D	10	17	(17 − 18)/10 = −0.10
E	5	15	(15 − 18)/ 5 = −0.60 (lowest)
F	—	—	—

At day 23 [C, F, A, and E completed], the critical ratios are

Job Sequence	Processing Time	Due Date	Critical Ratio Calculation
A	—	—	—
B	8	16	(16 − 23)/ 8 = −0.875 (lowest)
C	—	—	—
D	10	17	(17 − 23)/10 = −0.60
E	—	—	—
F	—	—	—

The job sequence is C-F-A-E-B-D, and the resulting values for the measures of effectiveness are as follows:

1. *Average flow time:* 133÷6 = 22.17 days.
2. *Average tardiness:* 58÷6 = 9.67 days.
3. *Average number of jobs at the work center:* 133÷41 = 3.24.

Sequence	(1) Processing Time	(2) Flow Time	(3) Due Date	(2) − (3) Days Tardy
C	4	4	4	0
F	12	16	18	0
A	2	18	7	11
E	5	23	15	8
B	8	31	16	15
D	10	41	17	24
	41	133		58

Rule	Average Flow Time (days)	Average Tardiness (days)	Average Number of Jobs at the Work Center
FCFS	20.00	9.00	2.93
SPT	18.00	6.67	2.63
EDD	18.33	6.33	2.68
CR	22.17	9.67	3.24

Example

Use the S/O rule to schedule the following jobs. Note that processing time includes the time remaining for the current and subsequent operations. In addition, you will need to know the number of operations remaining, including the current one.

Job	Remaining Processing Time	Due Date	Remaining Number of Operations
A	4	14	3
B	16	32	6
C	8	8	5
D	20	34	2
E	10	30	4
F	18	30	2

Determine the difference between the due date and the processing time for each operation. Divide the difference by the number of remaining operations, and rank them from low to high. This yields the sequence of jobs:

Job	(1) Remaining Processing Time	(2) Due Date	(3) (2) − (1) Slack	(4) Remaining Number of Operations	(5) (3) ÷ (4) Ratio	(6) Rank
A	4	14	10	3	3.33	3
B	16	32	16	6	2.67	2
C	8	8	0	5	0	1
D	20	34	14	2	7.00	6
E	10	30	20	4	5.00	4
F	18	30	12	2	6.00	5

Sequencing Jobs through Two Work Centers

For the technique to work, several conditions must be satisfied:

Job time (including setup and processing) must be known and constant for each job at each work center.

Job times must be independent of the job sequence.

All jobs must follow the same two-step work sequence.

Job priorities cannot be used.

All units in a job must be completed at the first work center before the job moves on to the second work center.

Determination of the optimum sequence involves these steps:

List the jobs and their times at each work center.

Select the job with the shortest time. If the shortest time is at the first work center, schedule that job first; if the time is at the second work center, schedule the job last. Break ties arbitrarily.

Eliminate the job and its time from further consideration.

Repeat steps 2 and 3, working toward the center of the sequence, until all jobs have been scheduled.

Example

A group of six jobs is to be processed through a two-machine flow shop. The first operation involves cleaning and the second involves painting. Determine a sequence that will minimize the total completion time for this group of jobs. Processing times are as follows:

	PROCESSING TIME (HOURS)	
Job	Work Center 1	Work Center 2
A	5	5
B	4	3
C	8	9
D	2	7
E	6	8
F	12	15

Select the job with the shortest processing time. It is job D, with a time of two hours.

Since the time is at the first center, schedule job D first. Eliminate job D from further consideration.

Job B has the next shortest time. Since it is at the second work center, schedule it last and eliminate job B from further consideration. We now have

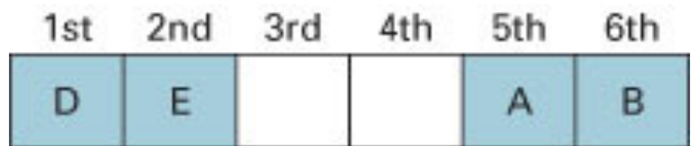
1st	2nd	3rd	4th	5th	6th
D					B

The remaining jobs and their times are

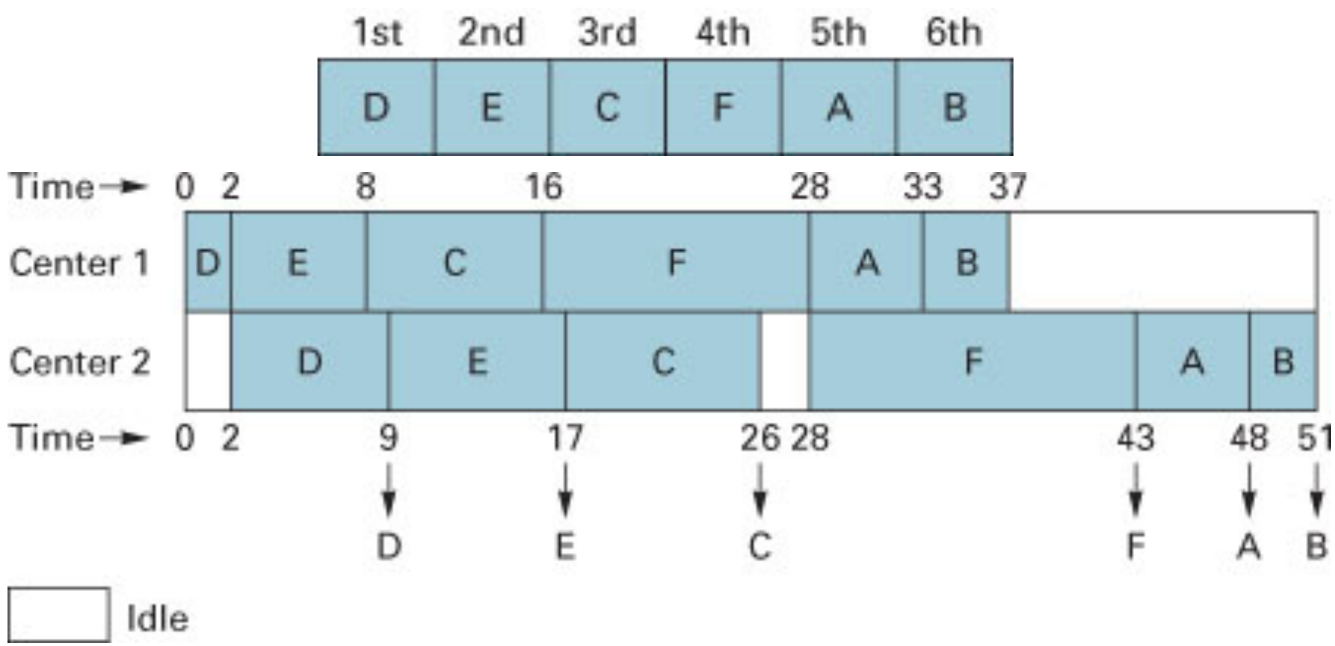
Job	1	2
A	5	5
C	8	9
E	6	8
F	12	15

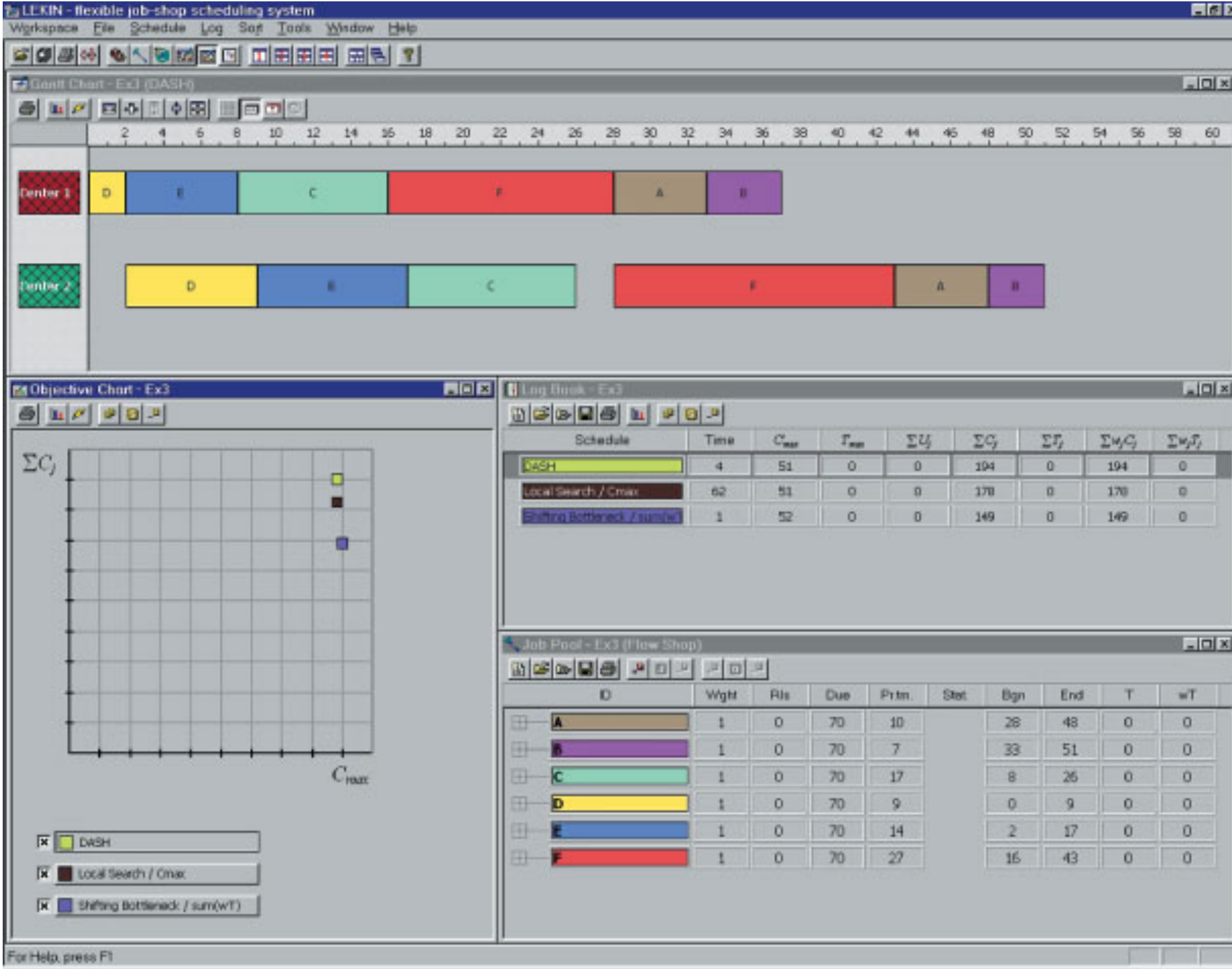
1st	2nd	3rd	4th	5th	6th
D				A	B

The shortest remaining time is six hours for job E at work center 1. Thus, schedule that job toward the beginning of the sequence (after job D). Thus,



Job C has the shortest time of the remaining two jobs. Since it is for the first work center, place it third in the sequence. Finally, assign the remaining job (F) to the fourth position and the result is




LEKIN - flexible job-shop scheduling system
Workspace File Schedule Log Sort Tools Window Help
Gantt Chart - Ex3 (DASH)
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60
Center 1
D E C F A B
Center 2
D E C F A B
Objective Chart - Ex3
$\sum C_j$
C_{max}
DASH
Local Search / Cmax
Shifting Bottleneck / sum(wT)
Log Book - Ex3
Schedule Time C_{max} T_{max} $\sum U_j$ $\sum C_j$ $\sum T_j$ $\sum w_jC_j$ $\sum w_jT_j$
DASH 4 51 0 0 194 0 194 0
Local Search / Cmax 62 51 0 0 178 0 178 0
Shifting Bottleneck / sum(wT) 1 52 0 0 149 0 149 0
Job Pool - Ex3 (Flow Shop)
ID Wght Rls Due Pr.tm. Stat. Bgn End T wT
A 1 0 70 10 28 48 0 0
B 1 0 70 7 33 51 0 0
C 1 0 70 17 8 26 0 0
D 1 0 70 9 0 9 0 0
E 1 0 70 14 2 17 0 0
F 1 0 70 27 16 43 0 0
For Help, press F1

Sequencing Jobs When Setup Times Are Sequence-Dependent

		Setup time (hrs.)	Resulting following job setup time (hrs.) is: A	B	C
If the preceding job is	A	3	—	6	2
	B	2	1	—	4
	C	2	5	3	—

Sequence	Setup Times Total
A-B-C	3 + 6 + 4 = 13
A-C-B	3 + 2 + 3 = 8
B-A-C	2 + 1 + 2 = 5 (best)
B-C-A	2 + 4 + 5 = 11
C-A-B	2 + 5 + 6 = 13
C-B-A	2 + 3 + 1 = 6

Why Scheduling Can Be Difficult

Setting realistic due dates.

Focusing on bottleneck operations: First, try to increase the capacity of the operations. If that is not possible or feasible, schedule the bottleneck operations first, and then schedule the nonbottleneck operations around the bottleneck operations.

Considering lot splitting for large jobs. This probably works best when there are relatively large differences in job times.

The Theory of Constraints

Determine what is constraining the operation.

Exploit the constraint (i.e., make sure the constraining resource is used to its maximum).

Subordinate everything to the constraint (i.e., focus on the constraint).

Determine how to overcome (eliminate) the constraint.

Repeat the process for the next highest constraint.

Scheduling Services

Appointment Systems

Reservation Systems

Yield Management

Scheduling the Workforce

Cyclical Scheduling

Day	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Staff needed	**2**	**4**	**3**	**4**	**6**	**5**	**5**

Day	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Staff needed	**2**	**4**	**3**	**4**	**6**	**5**	**5**
Worker 1	2	4	3	4	6	5	5

Day	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Staff needed	**2**	**4**	**3**	**4**	**6**	**5**	**5**
Worker 1	2	4	3	4	6	5	5
Worker 2	2	4	2	3	5	4	4

Day	Mon	Tue	Wed	Thu	Fri	Sat	Sun	
Staff needed	**2**	**4**	**3**	**4**	**6**	**5**	**5**	
Worker 1	2	4	3	4	6	5	5	
Worker 2	2	4	2	3	5	4	4	
Worker 3	1	3	2	3	4	3	3	
Worker 4	1	3	1	2	3	2	2	(tie)
Worker 5	1	2	0	1	2	1	2	
Worker 6	0	1	0	1	1	0	1	(multiple ties)
Worker 7	0	1	0	0	0	0	0	(tie)
No. working:	**2**	**4**	**3**	**4**	**6**	**5**	**5**	

Scheduling Multiple Resources