Operations & Supply Planning
PGDM 2018-20

Operations Scheduling

Vinay Kumar Kalakbandi
Assistant Professor
Operations Management

Introduction

- Manufacturing execution system (MES): An information system that schedules, dispatches, tracks, monitors, and controls production
  - Real-time linkage to:
    - MRP
    - Product and process planning
    - Systems that extend beyond the factory
- Service execution system (SES): An information system that links schedules, dispatches, tracks, monitors, and controls the customer's encounters with the service organization

The Nature and Importance of Work Centers

- Work center: an area in which production resources are organized and work is completed
  - May be a single machine, a group of machines, or an area where work is done
  - Can be organized according to function, product in a flow, or group technology
- Jobs need to be routed between functionally organized work centers to complete the work

Loading

- Infinite loading: work is assigned to a work center based on what is needed
  - No consideration to capacity
- Finite loading: schedules each resource using the setup and run time required for each order
  - Determines exactly what will be done by each resource at every moment during the day

Scheduling

- Forward scheduling: the system takes an order and schedules each operation that must be completed forward in time
  - Can tell the earliest date an order can be completed
- Backward scheduling: starts with due date and schedules the required operations in reverse sequence
  - Can tell when an order must be started in order to be done by a specific date

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Limitations

- Machine-limited process: equipment is the critical resource that is scheduled
- Labor-limited process: people are the key resource that is scheduled
- Most actual processes are either labor limited or machine limited but not both

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Objectives of Work-Center Scheduling

- Meet due dates
- Minimize lead time
- Minimize setup time or cost
- Minimize work-in-process inventory
- Maximize machine utilization

Job Sequencing

- Sequencing: the process of determining the job order on machines or work centers
  - Also known as priority sequencing
- Priority rules: the rules used in obtaining a job sequence
  - Can be simple or complex
  - Can use one or more pieces of information

Priority Rules for Job Sequencing

- FCFS – first come first served
- LCFS – last come first served
- SOT – Shortest Operating time
- EDD – Earliest Due Date
- STR – Slack Time Remaining

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Priority Rules for Job Sequencing

1 **FCFS** (first-come, first-served). Orders are run in the order they arrive in the department.

2 **SOT** (shortest operating time). Run the job with the shortest completion time first, next-shortest second, and so on. This is sometimes also referred to as SPT (shortest processing time). Often this rule is combined with a lateness rule to prevent jobs with longer times being delayed too long.

3 **EDD** (earliest due date first). Run the job with the earliest due date first.

4 **STR** (slack time remaining). This is calculated as the time remaining before the due date minus the processing time remaining. Orders with the shortest slack time remaining (STR) are run first.

STR = Time remaining before due date − Remaining processing time

5 **STR/OP** (slack time remaining per operation). Orders with the shortest slack time per number of operations are run first.

STR/OP = STR/Number of remaining operations

6 **CR** (critical ratio). This is calculated as the difference between the due date and the current date divided by the number of work days remaining. Orders with the smallest CR are run first.

7 **LCFS** (last-come, first-served). This rule occurs frequently by default. As orders arrive, they are placed on the top of the stack; the operator usually picks up the order on top to run first.

8 **Random** order or whim. The supervisors or the operators usually select whichever job they feel like running.

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Standard Measures of Schedule Performance

- Meeting due dates
- Minimizing the flow time
- Minimizing work-in-process inventory
- Minimizing idle time

Example 22.1: n Jobs on One Machine

Job (in Order of Arrival)	Processing Time (Days)	Due Date (Days Hence)
A	3	5
B	4	6
C	2	7
D	6	9
E	1	2

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Example 22.1: FCFS Rules

FCFS Schedule

Job Sequence	Processing Time (Days)	Due Date (Days Hence)	Flow Time (Days)
A	3	5	0 + 3 = 3
B	4	6	3 + 4 = 7
C	2	7	7 + 2 = 9
D	6	9	9 + 6 = 15
E	1	2	15 + 1 = 16

Total flow time = 3 + 7 + 9 + 15 + 16 = 50 days

Mean flow time $= \frac{50}{5} = 10$ days

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Example 22.1: SOT Rules

SOT Schedule

Job Sequence	Processing Time (Days)	Due Date (Days Hence)	Flow Time (Days)
E	1	2	0 + 1 = 1
C	2	7	1 + 2 = 3
A	3	5	3 + 3 = 6
B	4	6	6 + 4 = 10
D	6	9	10 + 6 = 16

Total flow time = 1 + 3 + 6 + 10 + 16 = 36 days

Mean flow time $= \frac{36}{5} = 7.2$ days

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Example 22.1: EDD Rules

EDD Schedule

Job Sequence	Processing Time (Days)	Due Date (Days Hence)	Flow Time (Days)
E	1	2	0 + 1 = 1
A	3	5	1 + 3 = 4
B	4	6	4 + 4 = 8
C	2	7	8 + 2 = 10
D	6	9	10 + 6 = 16

Total flow time = 1 + 4 + 8 + 10 + 16 = 39 days
Mean flow time = 7.8 days

Example 22.1: LCFS Rules

Job Sequence	Processing Time (Days)	Due Date (Days Hence)	Flow Time (Days)
LCFS Schedule			
E	1	2	0 + 1 = 1
D	6	9	1 + 6 = 7
C	2	7	7 + 2 = 9
B	4	6	9 + 4 = 13
A	3	5	13 + 3 = 16

Total flow time = 46 days
Mean flow time = 9.2 days
Average lateness = 4.0 days

Example 22.1: STR Rules

STR Schedule				*Slack*
E	1	2	0 + 1 = 1	2 − 1 = 1
A	3	5	1 + 3 = 4	5 − 3 = 2
B	4	6	4 + 4 = 8	6 − 4 = 2
D	6	9	8 + 6 = 14	9 − 6 = 3
C	2	7	14 + 2 = 16	7 − 2 = 5

Total flow time = 43 days
Mean flow time = 8.6 days
Average lateness = 3.2 days

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Comparison of Priority Rules

Rule	Total Flow Time (Days)	Mean Flow Time (Days)	Average Lateness (Days)
FCFS	50	10	4.6
SOT	36	7.2	2.4
EDD	39	7.8	2.4
LCFS	46	9.2	4.0
Random	53	10.6	5.4
STR	43	8.6	3.2

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N JOBS TWO MACHINES

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Johnson's rule

- List the jobs and their times at each work center.
- Select the job with the shortest activity time.
  - If that activity time is for the first work center, then schedule the job first.
  - If that activity time is for the second work center then schedule the job last. Break ties arbitrarily.
- Eliminate the shortest job from further consideration.
- Repeat steps 2 and 3, working towards the center of the job schedule until all jobs have been scheduled.

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Lets Try an Example:

	M1	M2
J1	5	2
J2	1	6
J3	9	7
J4	3	8
J5	10	4

By Step 2: Select J2 and Schedule 1st (M1 time) X row 2 out!

Continuing: (sch. is: 2 ----)

	M1	M2
J1	5	2
J2	1	6
J3	9	7
J4	3	8
J5	10	4

Select J1 with M2 short time – schedule 5th X out row 1

Continuing: (sch. is 2 --- 1)

	M1	M2
J1	5	2
J2	1	6
J3	9	7
J4	3	8
J5	10	4

Select J4 short time on M1 Schedule it 2^{nd} (1^{st}!) X out Row 4

Continuing: (sch. is 2-4 -- 1)

	M1	M2
J1	5	2
J2	1	6
J3	9	7
J4	3	8
J5	10	4

Select J5 short time is M2 schedule 2^{nd} last

Now, since only J3 is left, schedule it 3^{rd} last (M2 short time)

Final Allocation

2 – 4 – 3 – 5 - 1

N JOBS N MACHINES

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N job N machine assignment problem Hungarian Algorithm

	J1	J2	J3	J4
W1	82	83	69	92
W2	77	37	49	92
W3	11	69	5	86
W4	8	9	98	23

Hungarian algorithm

- Step 1: Subtract row minima
  - For each row, find the lowest element and subtract it from each element in that row.
- Step 2: Subtract column minima
  - Similarly, for each column, find the lowest element and subtract it from each element in that column.
- Step 3: Cover all zeros with a minimum number of lines
  - Cover all zeros in the resulting matrix using a minimum number of horizontal and vertical lines. If n lines are required, an optimal assignment exists among the zeros. The algorithm stops.
- If less than n lines are required, continue with Step 4.
- Step 4: Create additional zeros
  - Find the smallest element (call it k) that is not covered by a line in Step 3. Subtract k from all uncovered elements, and add k to all elements that are covered twice.

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Hungarian algorithm

- Step 1: Subtract row minima

	J1	J2	J3	J4	
W1	13	14	0	23	(-69)
W2	40	0	12	55	(-37)
W3	6	64	0	81	(-5)
W4	0	1	90	15	(-8)

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Hungarian Algorithm

- Step 2: Subtract column minima

	J1	J2	J3	J4
W1	13	14	0	8
W2	40	0	12	40
W3	6	64	0	66
W4	0	1	90	0
				(-15)

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Hungarian Algorithm

- Step 3: Cover all zeros with a minimum number of lines

	J1	J2	J3	J4	
W1	13	14	**0**	8	
W2	**40**	**0**	**12**	**40**	**x**
W3	6	64	**0**	66	
W4	**0**	**1**	**90**	**0**	**x**
			x		

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Hungarian algorithm

- Step 4: If required, create additional zeros
  - Find that the smallest uncovered number. Subtract this number from all uncovered elements and add it to all elements that are covered twice.

	J1	J2	J3	J4
W1	7	8	0	2
W2	40	0	18	40
W3	0	58	0	60
W4	0	1	96	0

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Hungarian algorithm

- Step 3: Cover all zeros with a minimum number of lines

	J1	J2	J3	J4	
W1	**7**	**8**	**0**	**2**	x
W2	**40**	**0**	**18**	**40**	x
W3	**0**	**58**	**0**	**60**	x
W4	**0**	**1**	**96**	**0**	x

Optimal assignment

	J1	J2	J3	J4
W1	7	8	**0**	2
W2	40	**0**	18	40
W3	**0**	58	0	60
W4	0	1	96	**0**

	J1	J2	J3	J4
W1	82	83	**69**	92
W2	77	**37**	49	92
W3	**11**	69	5	86
W4	8	9	98	**23**

The End!

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