Operations Scheduling

Advanced Operations Management

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Ch 16: 539-544,

Scheduling opportunities

- Job shop scheduling
- Personnel scheduling
- Facilities scheduling
- Vehicle scheduling
- Vendor scheduling
- Project scheduling
- Dynamic vs. static scheduling

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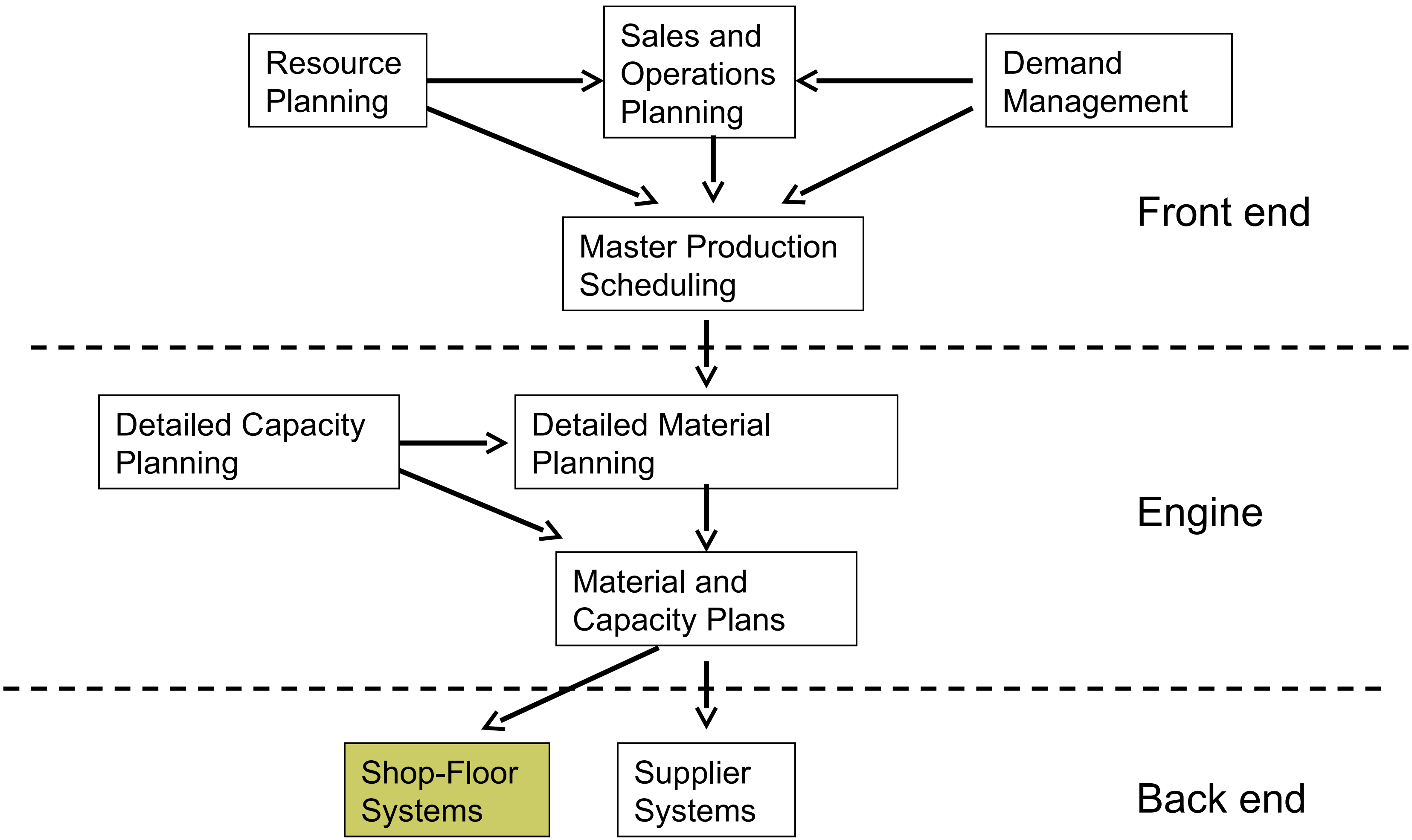


Resource Planning
Sales and Operations Planning
Demand Management
Master Production Scheduling
Front end
Detailed Capacity Planning
Detailed Material Planning
Material and Capacity Plans
Engine
Shop-Floor Systems
Supplier Systems
Back end

Example

Job	Processing Time	Due
1	6	18
2	2	6
3	3	9
4	4	11
5	5	8

What order should we do them in?

Example

Job Characteristics

- Arrival pattern: static or dynamic
- Number and variety of machines
  - We will assume they are all identical
- Number of workers
- Flow patterns of jobs:
  - all follow same, or many different
- Evaluation of alternative rules

Objectives

Many possible objectives:

- Meet due dates
- Minimize WIP
- Minimize average flow time through
- High worker/machine utilization
- Reduce setup times
- Minimize production and worker costs

Terminology

Flow shop: all jobs use M machines in same order

Job shop: jobs use different sequences

Parallel vs. sequential processing

Flow time: from start of first job until completion of job I

Makespan: start of first to finish of last

Tardiness: >= 0

Lateness: can be <0 or >0

Sequencing Rules

First-come, first-served (FCFS)

order they entered the shop

Shortest Processing Time (SPT)

longest job done last

Earliest Due Date (EDD)

job with last due date goes last

Critical Ratio (CR) - **processing time / time until due, smallest ratio goes first**

Other rules

- R - Random
- LWR - Least Work Remaining
- FOR - Fewest Operations Remaining
- ST - Slack Time
- ST/O-Slack Time per Operation
- NQ-Next Queue – choose job that is going next to the machine with smallest queue
- LSU - Least Setup

Performance

Quantities of interest

L_i Lateness of i: can be +/-

T_i Tardiness of i: always >= 0

E_i Earliness of i

T_{max} Maximum tardiness

Example: FCFS

Job	Time	Done	Due	Tardy
1	6	6	18	0
2	2	8	6	2
3	3	11	9	2
4	4	15	11	4
5	5	20	8	12
Total		50		20

Mean flow time = 50 / 5 = 10.0

Average tardiness = 20 / 5 = 4.0

Number of tardy jobs = 4

Max. Tardy 12

Example: SPT

Job	Time	Done	Due	Tardy
2	2	2	6	0
3	3	5	9	0
4	4	9	11	0
5	5	14	8	6
1	6	20	18	2
Total		50		8

Mean flow time = 50 / 5 =	10.0
Average tardiness = 8 / 5 =	1.6
Number tardy =	2
Max Tardy	6

Example: EDD

Job	Time	Done	Due	Tardy
2	2	2	6	0
5	5	7	8	0
3	3	10	9	1
4	4	14	11	3
1	6	20	18	2
Total		51		6

Mean flow time = 51 / 5 =	10.2
Average tardiness = 6 / 5 =	1.2
Number tardy =	3
Max Tardy =	3

Critical Ratio

Critical ratio:

- looks at time remaining between current time and due date
- considers processing time as a percentage of remaining time
- CR = 1.0 means just enough time
- CR > 1 .0 more than enough time
- CR < 1.0 not enough time

Example: Critical Ratio

- T = 0

Job	Process Time	Due	Critical Ratio
1	6	18	3.0
2	2	6	3.0
3	3	9	3.0
4	4	11	2.75
5	5	8	1.6

Job 5 is done first.

Example: Critical Ratio

- T = 5

Job	Process Time	Due - Current	Critical Ratio
1	6	13	2.17
2	2	1	0.5
3	3	4	1.33
4	4	6	1.5

Job 2 is done second.

Example: Critical Ratio

- T = 7

Job	Process Time	Due - Current	Critical Ratio
1	6	11	1.84
3	3	2	0.67
4	4	4	1.0

Job 3 is done third.

Example: Critical Ratio

- T = 10

Job	Process Time	Due - Current	Critical Ratio
1	6	8	1.84
4	4	1	0.25

Job 4 is done fourth, and job 1 is last.

Critical Ratio Solution

Job	Time	Done	Due	Tardy
5	5	5	8	0
2	2	7	6	1
3	3	10	9	1
4	4	14	11	3
1	6	20	18	2
Total		56		7

Mean flow time = 56 / 5 = 11.2
Average tardiness = 7 / 5 = 1.4
Number tardy = 4
Max Tardy 3

Summary

Method	Flow	Average Tardiness	Number tardy	Max Tardy
FCFS	10.0	4.0	4	12
SPT	10.0	1.6	2	6
EDD	10.0	1.2	3	3
CR	11.2	1.4	4	3

Minimizing Average Lateness

- Mean flow time minimized by SPT
- For single-machine scheduling, minimizing the following is equivalent:
  - Mean flow time
  - Mean waiting time
  - Mean lateness

Minimize Max Lateness

- Earliest Due Date (EDD) minimizes maximum lateness

Minimizing Number of Tardy Jobs

Moore's Algorithm:

1. Start with EDD solution
2. Find first tardy job, i. None? Goto 4
3. Reject longest job in 1- i. Goto 2.
4. Form schedule by doing rejected jobs after scheduled jobs.

- Rejects can be in any order, because they will all be late.

Moore’s Example

Start with EDD schedule

Job	Time	Done	Due	Tardy
2	2	2	6	0
5	5	7	8	0
3	3	10	9	1
4	4	14	11	3
1	6	20	18	2

Job 3 is first late job.
Job 2 is longest of jobs 2,5,3.

Moore's Example

Job	Time	Done	Due	Tardy
2	2	2	6	0
3	3	5	9	0
4	4	9	11	0
1	6	15	18	0
5	5	20	8	12

Average Flow = 51 / 5 =	10.2
Average tardiness = 12 / 5 =	2.4
Number tardy =	1
Max. Tardy =	12

Summary 2

Method	Flow	Average Tardiness	Number Tardy	Max tardy
FCFS	10.0	4.0	4	12
SPT	10.0	1.6	2	6
EDD	10.0	1.2	3	3
CR	11.2	1.4	4	3
Moore’s	10.2	2.4	1	12

Multiple Machines

- N jobs on M machines:
- $(N!)^M$ possible sequences.
- For 5 jobs and 5 machines = 25 billion
- Complete enumeration is not the way

Multiple Machines

- 2 jobs, 2 machines.

Job	M1	M2
I	4	1
J	1	4

Four possible sequences:

Multiple Machines

- 2 jobs, 2 machines.

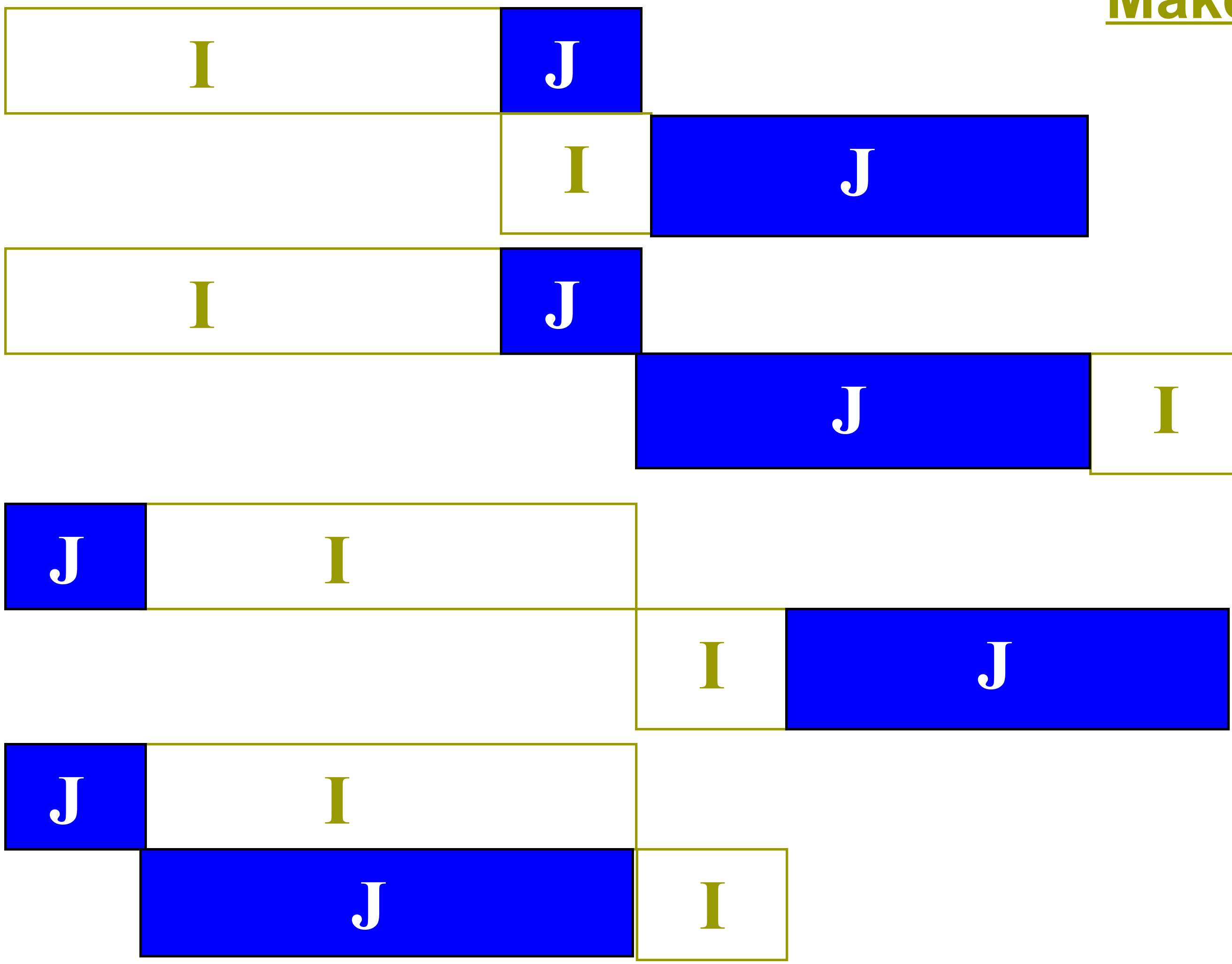
Job	M1	M2
I	4	1
J	1	4

Four possible sequences:

	M1	M2
1	I J	I J
2	I J	J I
3	J I	J I
4	J I	I J

Two Machines

Sequence | **Makespan**



Sequence	Makespan
IJ IJ	9
IJ JI	10
JI IJ	10
JI JI	6

Two Machines

- Permutation schedules: IJ IJ, JI JI
  - Jobs processed same sequence on both
- For N jobs on two machines, there will always be an <u>optimal</u> permutation schedule.

2 Machines, N Jobs (Johnson's Algorithm)

A_i **= processing time of job I on machine A**

B_i **= processing time of job I on machine B**

1. **List** A_i **and** B_i **in two columns**
2. **Find smallest in two columns. If it is in** A**, schedule it next, if it's in** B**, then last.**
3. **Continue until all jobs scheduled.**

Johnson Example

Job	A	B
1	5	2
2	1	6
3	9	7
4	3	8
5	10	4

1. Job 2 is smallest, so it goes first.

Seq: 2, , , ,

Johnson Example

Job	A	B
1	5	2
~~2~~	~~1~~	~~6~~
3	9	7
4	3	8
5	10	4

1. Job 2 goes first.
2. Job 1 is next smallest, in B, so goes last.

Seq: 2, , , , 1

Johnson Example

Job	A	B
~~1~~	~~5~~	~~2~~
~~2~~	~~1~~	~~6~~
3	9	7
4	3	8
5	10	4

1. Job 2 goes first.
2. Job 1 goes last.
3. Job 4 is smallest, in A column, so it goes next.

Seq: 2, 4 , , , 1

Johnson Example

Job	A	B
~~1~~	~~5~~	~~2~~
~~2~~	~~1~~	~~6~~
3	9	7
~~4~~	~~3~~	~~8~~
5	10	4

1. Job 2 goes first.
2. Job 1 goes last.
3. Job 4 goes next.
4. Job 5 smallest in B, comes next to last.

Seq: 2, 4, , 5, 1

Johnson Example

Job	A	B
~~1~~	~~5~~	~~2~~
~~2~~	~~1~~	~~6~~
3	9	7
~~4~~	~~3~~	~~8~~
~~5~~	~~10~~	~~4~~

Seq: 2, 4, 3, 5, 1

1. Job 2 goes first.
2. Job 1 goes last.
3. Job 4 goes next.
4. Job 5 next to last.
5. Job 3 comes next.

Conclusions

- Single machine scheduling:
  - FCFS, SPT, EDD, CR, Moore’s Algorithm
- Two machines:
  - Johnson’s Algorithm
- Performance:
  - Avg Lateness, Max Tardy, Avg Tardy, Number of jobs Tardy

Scheduling Days Off

1. Compute no. people needed each day.
2. Find the smallest two consecutive days
   - Highest number in the pair is <= highest number in any other pair
   - Those two days will be the first worker's days off
1. Subtract one from the days the first worker wasn't scheduled
2. Repeat

Example – Workers needed each day

M	T	W	Th	F	Sa	Su
4	3	4	2	3	1	2

Example

	M	T	W	Th	F	Sa	Su
#1	4	3	4	2	3	1	2
#2	3	2	3	1	2	1	2
#3	2	1	2	0	1	1	2
#4	1	0	1	0	1	0	1
#5	0	0	0	0	1	0	0

Example - Retry

	M	T	W	Th	F	Sa	Su
#1	4	3	4	2	3	1	2
#2	3	2	3	1	2	1	2
#3	2	1	2	0	2	1	1
#4	1	0	1	0	1	1	1
#5	0	0	1	0	0	0	0

Example – 4 days

	M	T	W	Th	F	Sa	Su
#1	4	3	4	2	3	1	2
#2	3	2	3	1	2	1	2
#3	2	1	2	0	1	1	2
#4	1	0	1	0	1	0	1

Do you want to work the #4 schedule?

Scheduling Daily Work Times

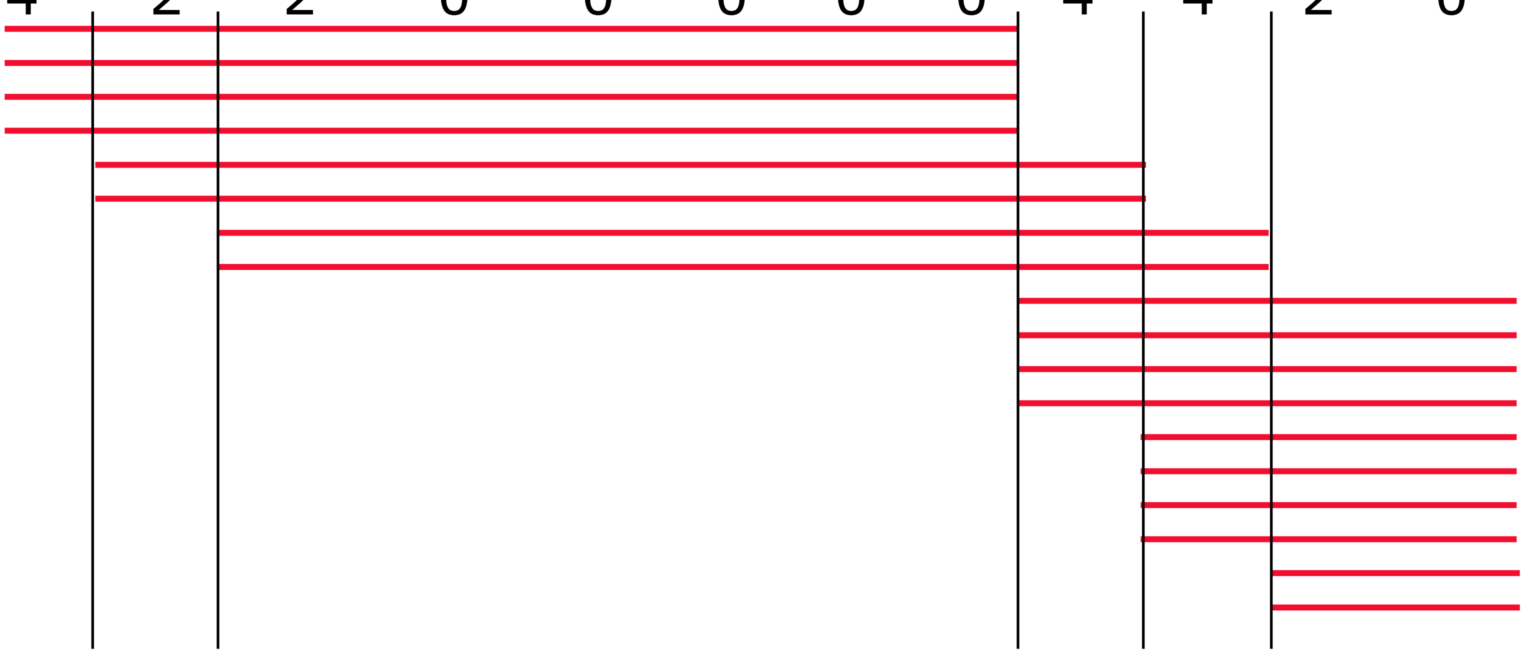
- Different # people needed in different areas at different times

Scheduling Hourly Times

- When should people start shifts?
- “First Hour” principle:
  - For first hour, assign # people needed that hour
  - Each additional hour, add more if needed
  - When shift ends, add more, only if needed

Hourly Work Times

	10	11	12	1	2	3	4	5	6	7	8	9
Need	4	6	8	8	6	4	4	6	8	10	10	6
Start	4	2	2	0	0	0	0	0	4	4	2	0

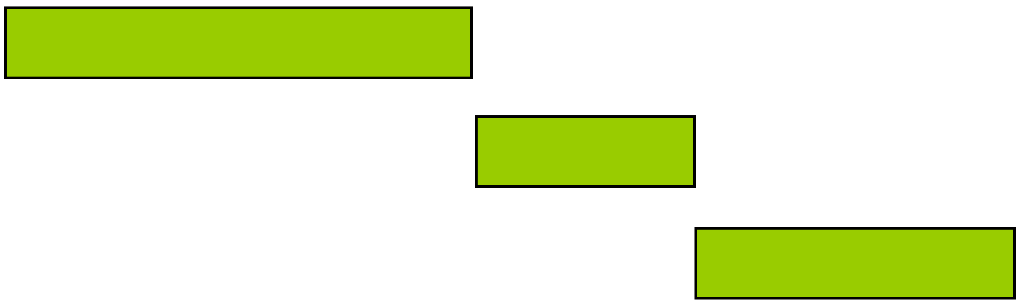


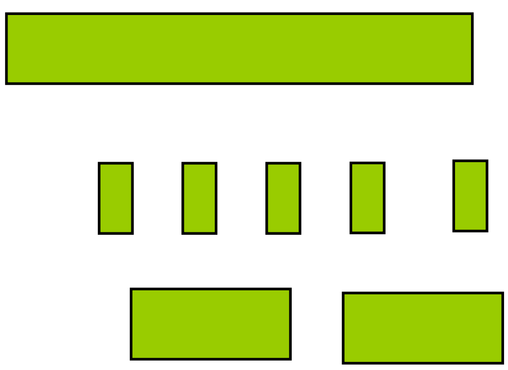
On	4	6	8	8	8	8	8	8	8	10	10	10

Production vs. Transfer batch sizes

p. 552

Lot Sizes all 1,000





Production Lot Size = 1,000

Transfer Batch Size = 100

Production Lot Size = 200

Transfer Batch Size = 100

Production Lot Size = 500

HW, p. 567 – Due 12/9

- DQ: 4
- Problems: 1,2,3,4,5