TPPE74
Design and Development of Manufacturing Operations

ie3 Industrial Engineering and Management of European Higher Education

Seminar 3

System Simulation

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Co-funded by the Erasmus+ Programme of the European Union
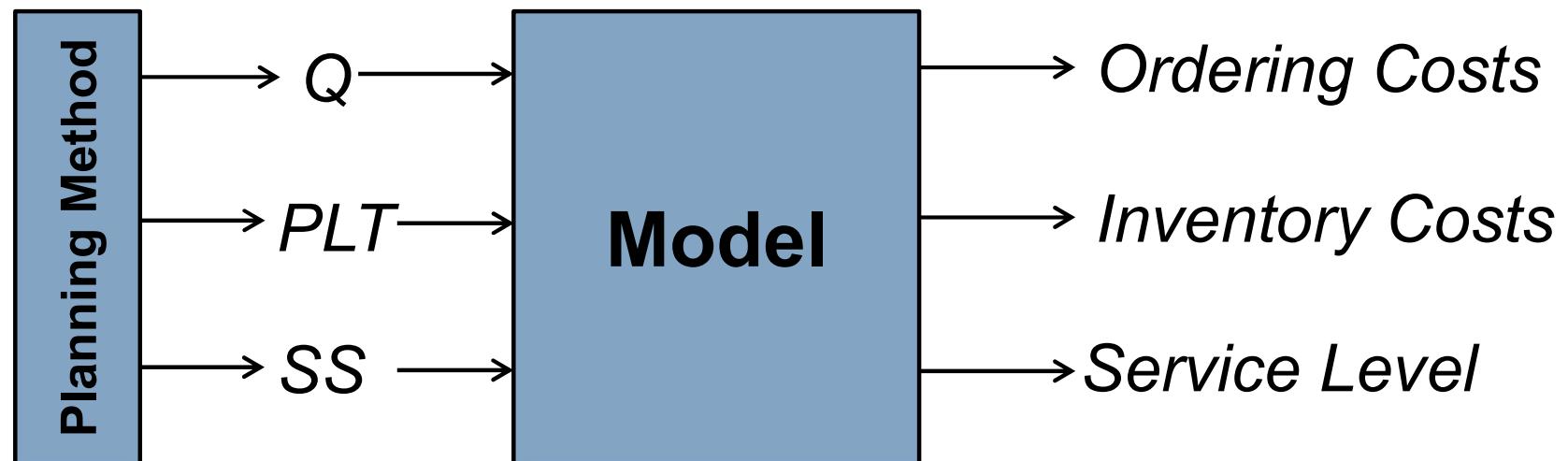
Content

- The Project Tasks

- The Manufacturing System

- Task B

- Simulating the system

- Example: ROP simulation #1
  - Q
  - PLT
  - SS
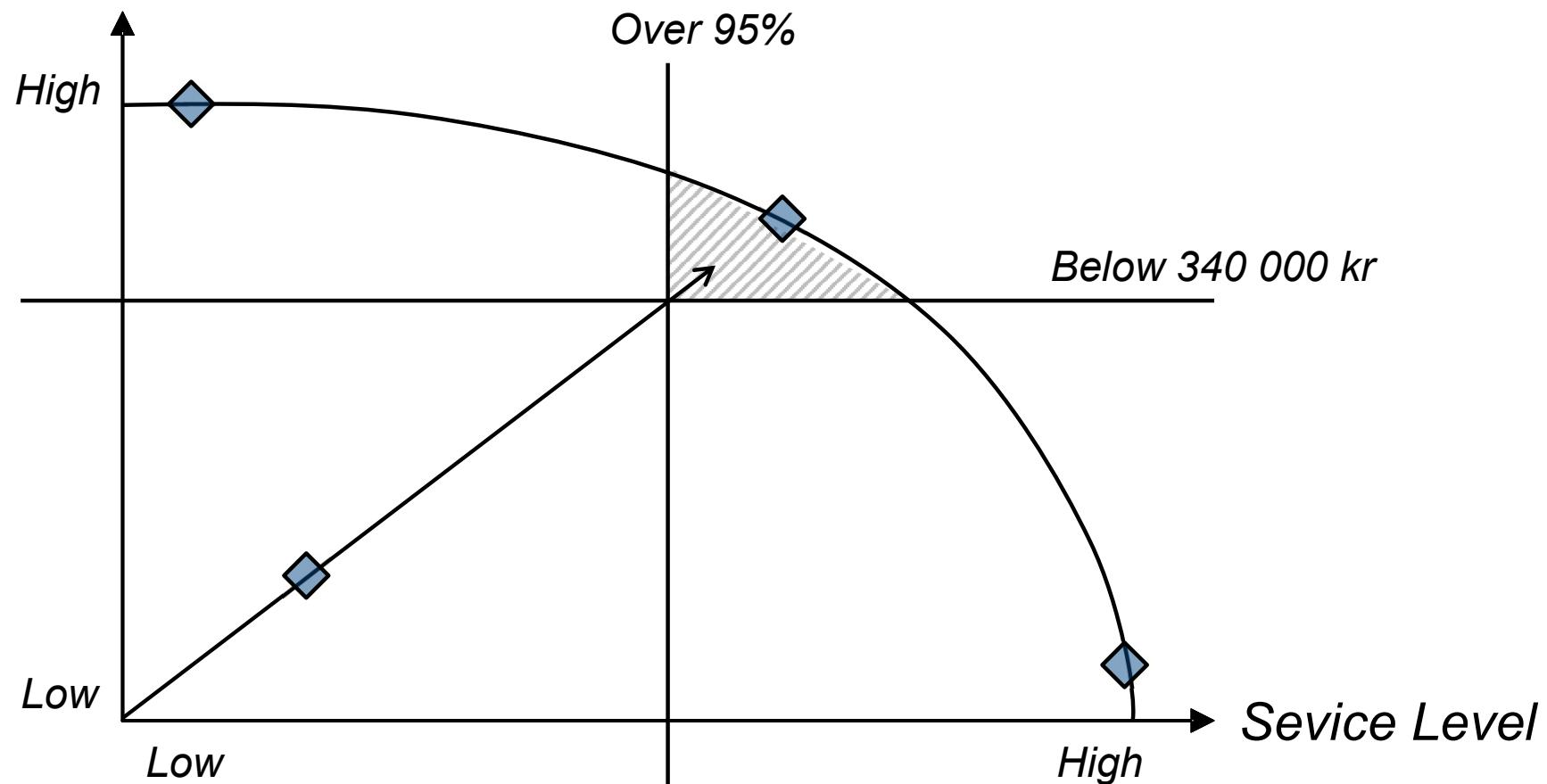
PicSim

- Production and Inventory Control Simulator (PicSim)

- Simulation model

  - 3 years of production

  - 1 year "Warm-up"

  - 2 years data collection

  - …takes apr. 0.1 second…

PicSim

Also: Total Cost below 680 000 kr

Inventory cost efficiency

Over 95%

High

Below 340 000 kr

Low

Low

High

Sevice Level

Simulation Result for the Case Company

Simulation Results

Simulation Results

Group No.	1									
Run No.	0									

Input data

Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	3	4	3	4	4	3	3	3	3
Order quantity	495	632	692	1611	2619	2000	226	1732	1342
Safety stock	200	100	300	400	600	1400	100	1200	900

Costs

Ordering cost	158400	Total Ordering Cost		158400
Inventory of raw materials	94587	Total Inventory Cost		498498
Work in process	347459			
Semi-finished and finished goods inventory	56452			
Total	656898			

Max 680 000

Max 340 000

Service levels (%)

Product 1	28.3
Product 2	72.8
Product 3	20.8
Overall	28.5

Min 95%

Statistics

	A1	A2	A3	A4	A5	A6	A7	A8	A9
Stockouts of finished products	3583.00	680.50	5940.00						
Average inventory level A1-A9	-434.00	186.00	-1149.00	721.50	975.00	2040.00	177.50	3103.00	4858.50
Average actual lead time A1-A5 (weeks)	7.09	8.69	7.36	11.20	15.25				
Average queueing time P1-P5 (hours)	51.34	37.77	44.98	88.66	53.36				
Average load P1-P5 (%)	82.46	67.13	66.21	78.77	73.03				

Inventory turnover rates

Raw material inventory	8.54
Work in process	5.89
Semi-finished and finished goods inventory	36.23
Total	5.72

Four Tasks in the Project

- Task A
  - Create graphs over nine different relationships.
  - Lisam Quiz to test conceptual shape.

- Task B
  - Run 10 simulations (we run the model) with the target to reach:
    Inventory cost: 340 000 kr
    Service level: 95 %
    Total Cost: 680 000 kr
  - Test all different planning methods
  - Lisam Quiz before simulations (at least one in each group needs to pass)

- Task C
  - Carry out a setup time reduction and study the effects.
  - Run 3 simulations (we run the model) to study the effects.

- Task D
  - Formulate system specific guidelines and rules that apply to the design parameters.
  - Run 3 simulations (we run the model) to "optimize" the system.
  - Competition!

Project Task

- Manufacturing System
  - 9 products, 3 end-products, 2 manufactured components and 4 purchased components
  - 5 planning groups (resources)
  - 5 planning methods, Reorder point, MRP, Cyclic planning, Cyclic planning with base period, and Lean Production

The Manufacturing System

Table 1. *Means and standard deviations for weekly demand.*

End product	Mean value	Standard Deviation
A1	100	12
A2	50	8
A3	150	15

Table 2. Product values in SEK per unit.

Products	Value
A1	1060
A2	500
A3	940
A4	370
A5	210
A6	70
A7	390
A8	80
A9	100

The Manufacturing System

Table 3. Processing times per unit (hours).

Planning Group \ Product		A1	A2	A3	A4	A5
P1	Assembly and Processing	0.03	0.05	0.07	0.02	0.04
P2	Surface treatment	0.06	0.08	-	0.02	0.04
P3	Processing	-	-	0.05	0.03	0.04
P4	Drilling	-	0.05	-	0.02	0.08
P5	Packing and Inspection	0.11	0.06	0.10	-	-

Table 4. Setup times and capacities for planning groups.

Planning Group \ Product		Setup time [hours]	Capacity [hours/week]
P1	Assembly and Processing	2	40
P2	Surface treatment	2	40
P3	Processing	3	40
P4	Drilling	3	40
P5	Packing and Inspection	1	40

The Tasks

- Task B
  - Improve the system in maximum 10 simulation runs
  - Chose your runs carefully.
  - Give a suggestion for "optimal" planning and control for the company.
  - The evaluation…
    - **Service level more than 95%**
    - **Total inventory holding costs less than 340 000 SEK**
    - **Total costs less than 680 000 kr**
  - Reorder point systems, MRP, cyclic planning (base period, common cycle), and Lean production.
    - Motivate recommended values.
    - Note that, in order to dismiss a planning system, strong empirical evidence is needed as motivation.
  - Only control parameters may be changed in this task.
    - Planned Lead time, PLT
    - Order quantity, Q
    - Safety stock, SS
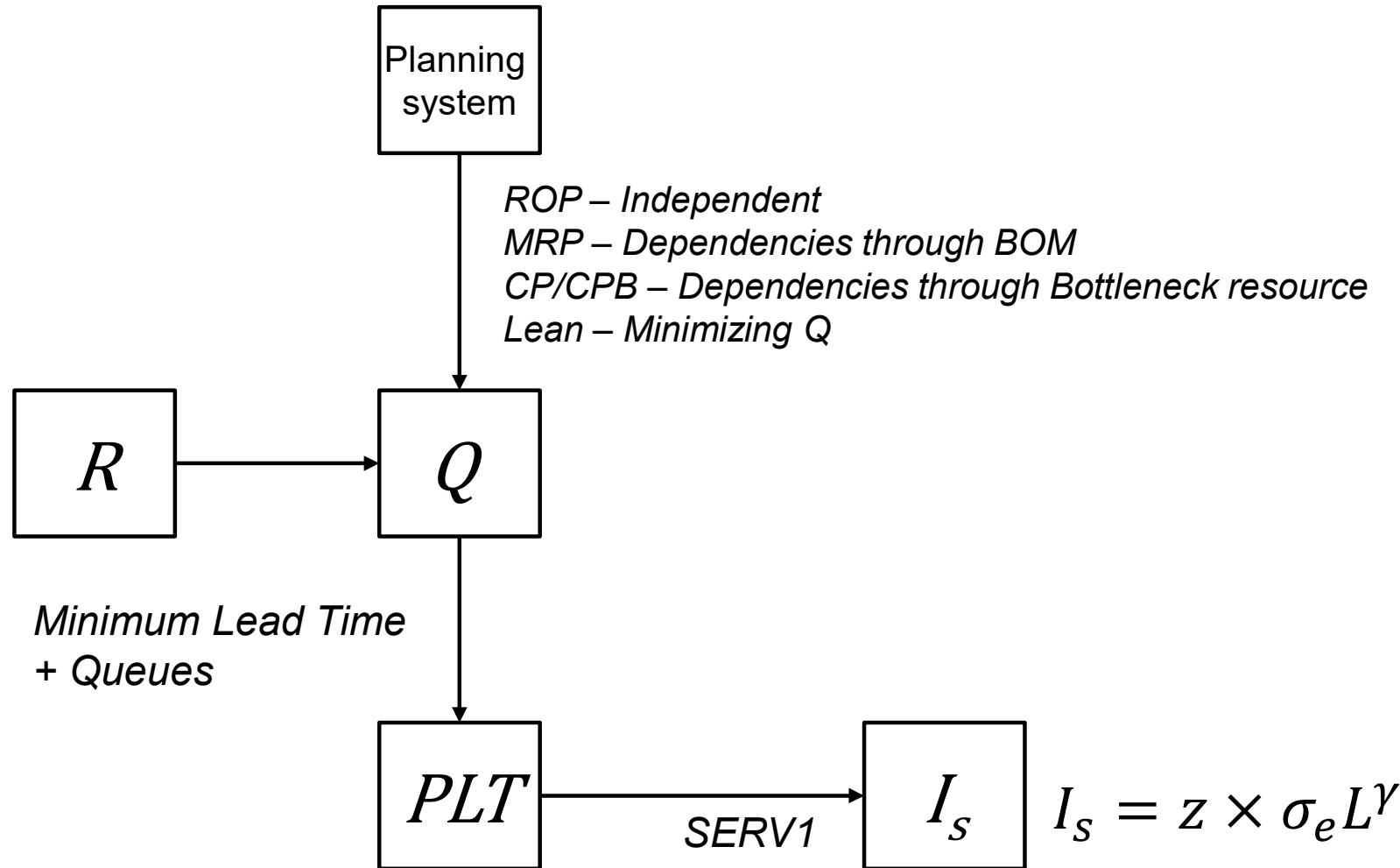
Examination – Grading Criteria

- Grade Pass requires the following:

- Active participation in the project group.

- For Task B:
  - Maximum of 10 simulation runs with at least 1 result is better or as good as the requirements (target values) for the total cost, total inventory cost and overall service level.
  - Theoretical motivation for all planning methods that show why or why not ROP, MRP, Cyclic planning and Cyclic planning with base period solution, or Lean Production is an appropriate planning method in this project.
  - Simulation results for all planning methods that show why or why not ROP, MRP, Cyclic planning and Cyclic planning with base period solution, or Lean Production is an appropriate planning method in this project.
  - Calculation and motivation for choice of Order quantities, Planned Lead Time, and Safety Stock and/or Safety Lead Time. For all runs.

Content
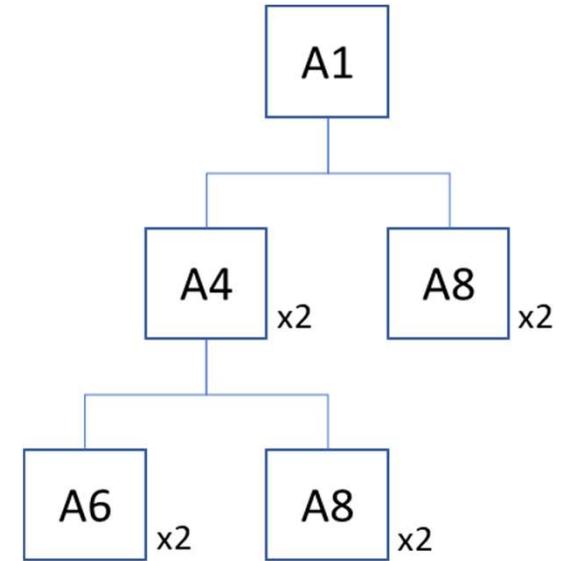
- The Project Tasks

- The Manufacturing System

- Task B

- Simulating the system

- Example: ROP simulation #1
  - Q
  - PLT
  - SS

System Design

Planning system

ROP – Independent
MRP – Dependencies through BOM
CP/CPB – Dependencies through Bottleneck resource
Lean – Minimizing Q

R

Q

Minimum Lead Time
+ Queues

PLT

SERV1

I_s

$I_s = z \times \sigma_e L^\gamma$

Synchronizing the planning design

- ROP
  - Totally independent

- MRP
  - Introducing dependency through the BOM
  - Level 0: EOQ – Level 1 and below: Multiples of EOQ (from BOM)

- CP Common Cycle Time
  - Introducing dependency through the BN Resource (PG)
  - Introducing indirect dependency through the BOM (end product R)

- CP Base Period
  - Same as CP Common Cycle Time, but with better utilization of the cost structure

- Lean Production
  - Dependency through the BOM
  - Minimizing Q

System Simulation

- Simulation setting

  - Run length: 2 years production

  - Warmup period: 1 year production

  - Replications: 1

- Output data

  - Yearly average over the run length

Example: ROP #1

- Set Q
  - Use EOQ as given in the directive

Plan.Ctrl. Parameters			Note: Please enter decimal number like ##.##							
Product	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead Time	3	4	3	4	4	3	3	3	3
Order Quantity	495	632	692	1611	2619	2000	226	1732	1342
Safety Stock	200	100	300	400	600	1400	100	1200	900

- Can any Q be updated?
  - Look at purchased products
  - Look at manufactured products

Example: ROP #1

Simulation Results							Simulation Results			
Group No.	1									
Run No.	0									
Input data										
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Costs										
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Total	656898									
Service levels (%)										
Product 1	28.3									
Product 2	72.8									
Product 3	20.8									
Overall	28.5									
Statistics										
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Average queueing time P1-P5 (hours)	51.34	37.77	44.98	88.66	53.36				
Average load P1-P5 (%)	82.46	67.13	66.21	78.77	73.03				
Inventory turnover rates										
Raw material inventory	8.54									
Work in process	5.89									
Semi-finished and finished goods inventory	36.23									
Total	5.72									

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- Can any Q be updated?
    - Look at purchased products
    - Look at manufactured products
- It is safe to change purchased products
    - Divide by 2
    - Q_{A6} = 2000 / 2 = 1000
    - Q_{A8} = 1732 / 2 = 866
    - Q_{A9} = 1342 / 2 = 671

Example: ROP #1

- Set PLT

Plan.Ctrl. Parameters				Note: Please enter decimal number like ##.##					
Product	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead Time	3	4	3	4	4	3	3	3	3
Order Quantity	495	632	692	1611	2619	2000	226	1732	1342
Safety Stock	200	100	300	400	600	1400	100	1200	900

- Is the rule-of-thumb of one planning group per week a good choice?

- Minimum PLT for A1
  - $PLT_{A1} = Q * (t1 + t2 + t5) + (s1 + s2 + s5) =$

    $= 495 * (0.03 + 0.06 + 0.11) + (2 + 2 + 1) = 104$ hours $= 2.6$ weeks

Example: ROP #1

Simulation Results

Simulation Results

Group No.	1								
Run No.	0								

Input data

	A1	A2	A3	A4	A5	A6	A7	A8	A9
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	3	4	3	4	4	3	3	3	3
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Inventory turnover rates

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Example: ROP #1

- Set PLT

Plan.Ctrl. Parameters				Note: Please enter decimal number like ##.##					
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- Is the rule-of-thumb of one planning group per week a good choice?

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  - $PLT_{A1} = Q * (t1 + t2 + t5) + (s1 + s2 + s5) =$

    $= 495 * (0.03 + 0.06 + 0.11) + (2 + 2 + 1) = 104$ hours $= 2.6$ weeks

- Total queueing in P1, P2, and P5 (worst case)

  - Queue $= 51.34 + 37.77 + 53.36 = 142.47$ hours ≈ 3.56 weeks

- PLT for A1 = 2.6 + 3.56 = 6.16 = 6.2 weeks (worst case)

- PLT for A1 = 2 * Minimum PLT = 5.2 weeks (simple rule)

Example: ROP #1

Minimum PLT					
Q	A1	A2	A3	A4	A5
100	0.63	0.80	0.70	0.48	0.75
200	1.13	1.40	1.25	0.70	1.25
300	1.63	2.00	1.80	0.93	1.75
400	2.13	2.60	2.35	1.15	2.25
500	2.63	3.20	2.90	1.38	2.75
600	3.13	3.80	3.45	1.60	3.25
700	3.63	4.40	4.00	1.83	3.75
800	4.13	5.00	4.55	2.05	4.25
900	4.63	5.60	5.10	2.28	4.75
1000	5.13	6.20	5.65	2.50	5.25
1100	5.63	6.80	6.20	2.73	5.75
1200	6.13	7.40	6.75	2.95	6.25
1300	6.63	8.00	7.30	3.18	6.75
1400	7.13	8.60	7.85	3.40	7.25
1500	7.63	9.20	8.40	3.63	7.75
1600	8.13	9.80	8.95	3.85	8.25
1700	8.63	10.40	9.50	4.08	8.75
1800	9.13	11.00	10.05	4.30	9.25
1900	9.63	11.60	10.60	4.53	9.75
2000	10.13	12.20	11.15	4.75	10.25
2100	10.63	12.80	11.70	4.98	10.75
2200	11.13	13.40	12.25	5.20	11.25
2300	11.63	14.00	12.80	5.43	11.75
2400	12.13	14.60	13.35	5.65	12.25
2500	12.63	15.20	13.90	5.88	12.75
2600	13.13	15.80	14.45	6.10	13.25

Minimum lead time in weeks as a function of Q

PLT for A1 = 2 * Minimum PLT
= 2 * 2.63 = 5.26 weeks
(simplest rule)
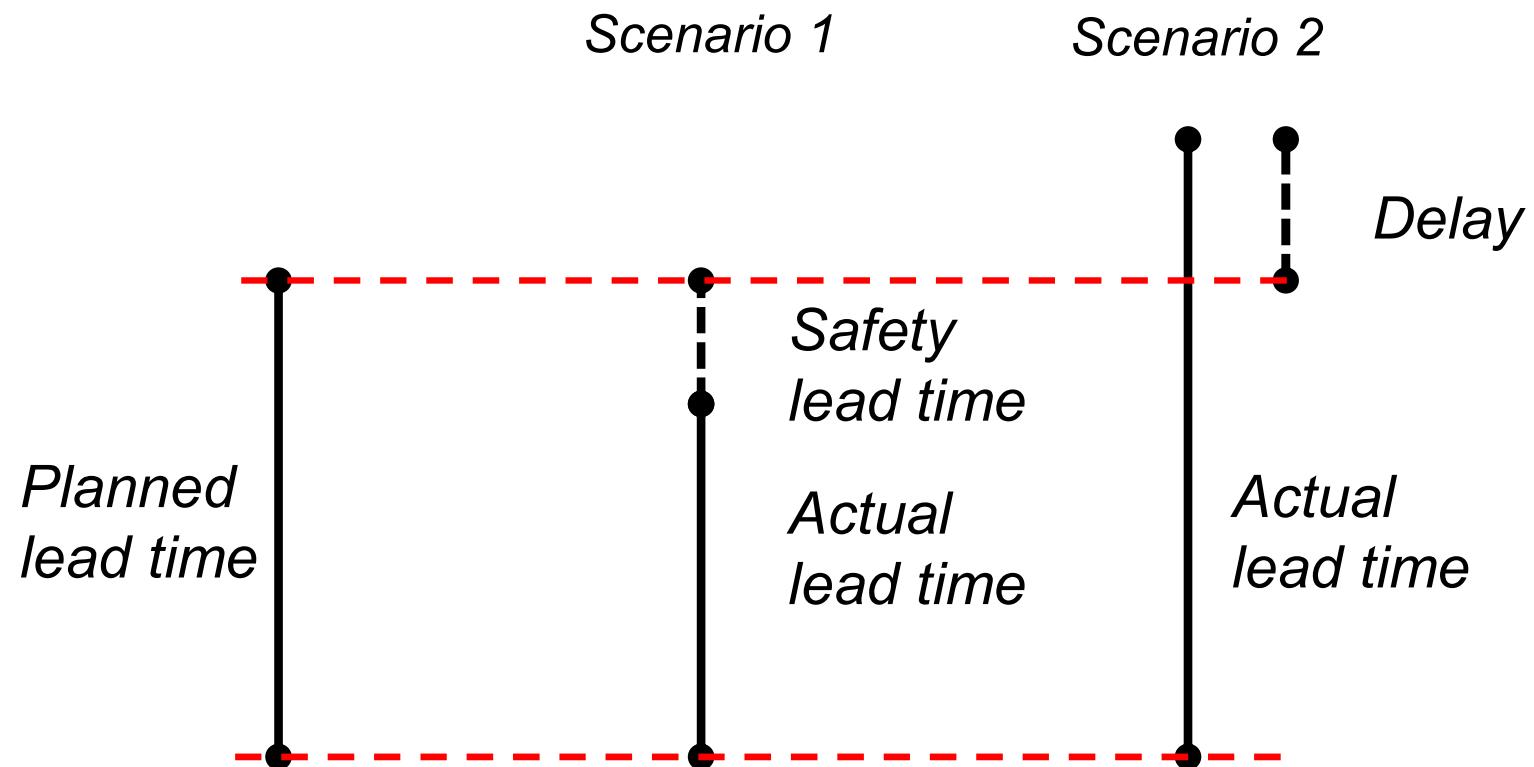
Example: ROP #1

- Set SS

Plan.Ctrl. Parameters			Note: Please enter decimal number like ##.##						
Product	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead Time	3	4	3	4	4	3	3	3	3
Order Quantity	495	632	692	1611	2619	2000	226	1732	1342
Safety Stock	200	100	300	400	600	1400	100	1200	900
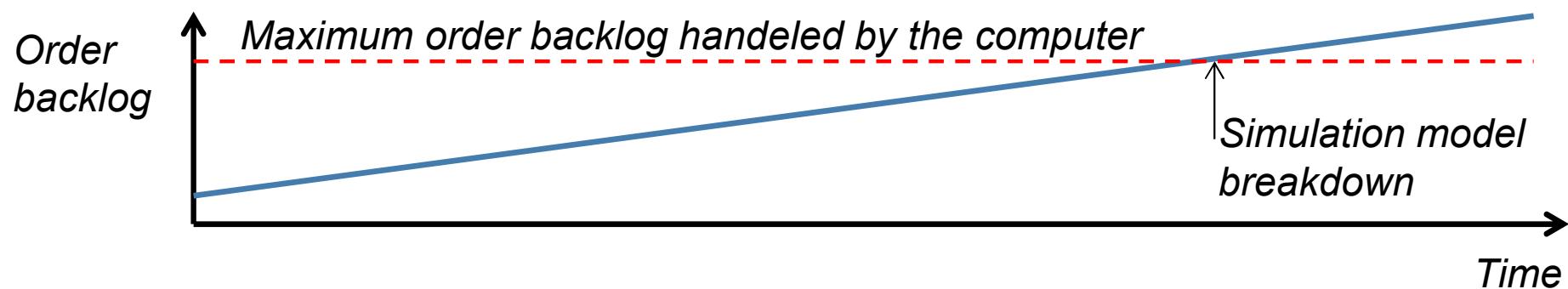
- Safety Stock or Safety Lead Time?

- Calculate using SERV1

Example: ROP #1

Example: ROP #1

- ## Capacity Control

  - A planning solution that needs more capacity than available will not be stable

Maximum order backlog handeled by the computer

Order backlog

Simulation model breakdown

Time

Example: ROP #1

Capacity Calculations

- The amount of capacity needed for each week depends on the batch size in production

- Capacity calculation methodology
  For each PG, Planning Group and an average week:
  1. Use weekly demand as number of products; N
  2. Calculate the total processing time by processing time (t) and weekly demand:
     - Total processing time $T = t * N$
  3. Add set-up time (s) as portion of the weekly demand divided by batch size (Q):
     - Total set-up time $S = s * (N / Q)$
  4. Add $T + S$ to get total time, compare with maximum capacity (C)

- If $C > (T + S)$ there is no problem,
  but if $C < (T + S)$ the system is unstable

Example: ROP #1

Setup times

	A1	A2	A3	A4	A5
P1	0.40	0.16	0.43	0.25	0.23
P2	0.40	0.16		0.25	0.23
P3			0.65	0.37	0.34
P4		0.24		0.37	0.34
P5	0.20	0.08	0.22		

Processing Times

	A1	A2	A3	A4	A5
P1	3.00	2.50	10.50	4.00	12.00
P2	6.00	4.00		4.00	12.00
P3			7.50	6.00	12.00
P4		2.50		4.00	24.00
P5	11.00	3.00	15.00		

Capacity

	A1	A2	A3	A4	A5
P1	3.40	2.66	10.93	4.25	12.23
P2	6.40	4.16	0.00	4.25	12.23
P3	0.00	0.00	8.15	6.37	12.34
P4	0.00	2.74	0.00	4.37	24.34
P5	11.20	3.08	15.22	0.00	0.00

Sum
33.47
27.04
26.87
31.45
29.50

- Total processing time T = t * N = 0.03 * 100 = 3.00 hours

- Total set-up time S = s * (N / Q) = 2 * (100 / 495) = 0.40 hours

- Add T + S to get total time = 3.00 + 0.40 = 3.40 hours

Simulation Run Submission

Plan.Ctrl. Parameters		Note: Please enter decimal number like ##.##								
Product	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
Lead Time	3	4	3	4	4	3	3	3	3
Order Quantity	495	632	692	1611	2619	2000	226	1732	1342
Safety Stock	200	100	300	400	600	1400	100	1200	900

Change these numbers…

- Remember…
  - Keep Planned Lead Time in full days (4.0, 4.2, 4.4, 4.6, 4.8, …)
  - Paste numbers, not equations…
  - Round off Order Quantity and Safety Stock to integers

Simulation Runs in Task B

Input for each simulation run is uploaded on Lisam under submissions. There are 10 submissions, numbered, one for each run. Use the submissions in the correct order.
Simulation input is uploaded latest at the time (hand in) in the schedule below.
Results are available latest at the second time (results ready) in the schedule.

No.	Date	Latest hand in	Results ready
1	Monday, April 26	09:00	11:00
2	Monday, April 26	13:00	15:00
3	Tuesday, April 27	09:00	11:00
4	Tuesday, April 27	13:00	15:00
5	Wednesday, April 28	09:00	11:00
6	Wednesday, April 28	13:00	15:00
7	Thursday, April 29	09:00	11:00
8	Thursday, April 29	13:00	15:00
9	Monday, May 3	09:00	11:00
10	Monday, May 3	13:00	15:00
11	Tuesday, May 4	09:00	11:00
12	Tuesday, May 4	13:00	15:00
13	Wednesday, May 5	09:00	11:00
14	Wednesday, May 5	13:00	15:00
15	Thursday, May 6	09:00	11:00
16	Thursday, May 6	13:00	15:00
17	Friday, May 7	09:00	11:00

The Sheets

- Sheet 1

Input data for PICSIM

				Create Input File			Run PICSIM 2000	

Group No	1							

Basic System Data   *Note: Please enter decimal number like ##.##*

Product	A1	A2	A3					
Demand	100	50	150					
Demand Variance	144	64	225					
Demand Seed	87632							
Holding Cost Rate	0.10							

Operation Times

Product	A1	A2	A3	A4	A5
Planning Group P1	0.03	0.05	0.07	0.02	0.04
P2	0.06	0.08		0.02	0.04
P3			0.05	0.03	0.04
P4		0.05		0.02	0.08
P5	0.11	0.06	0.10		

Setup Times

Product	A1	A2	A3	A4	A5
Planning Group P1	2	2	2	2	2
P2	2	2		2	2
P3			3	3	3
P4		3		3	3
P5	1	1	1		

Product	A1	A2	A3	A4	A5	A6	A7	A8	A9
Setup Cost	2600	4000	3000	4800	4800	400	400	400	400

Plan.Ctrl. Parameters   *Note: Please enter decimal number like ##.##*

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The Sheets

- Sheet 2

Simulation Results

Simulation Results									
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Run No.	0								

Input data

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Inventory turnover rates

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Total	5.72

The Sheets

- Sheet 3

Simulation results (All runs)

Group No.

INPUT DATA		1	2	3	4	5	6	7	8	9	10
Running No.		1	2	3	4	5	6	7	8	9	10
Lead time	A1	3	3.8	3	3	3	3	3	3	3	3
	A2	4	4	5	4	4	4	4	4	4	4
	A3	3	3	3	3.8	3	3	3	3	3	3
	A4	4	4	4	4	5	4	4	4	4	4
	A5	4	4	4	4	4	5	4	4	4	4
	A6	3	3	3	3	3	3	3	3	3	3
	A7	3	3	3	3	3	3	3	3	3	3
	A8	3	3	3	3	3	3	3	3	3	3
	A9	3	3	3	3	3	3	3	3	3	3
Safety stock	A1	340	340	340	340	340	340	340	340	340	340
	A2	180	180	180	180	180	180	180	180	180	180
	A3	270	270	270	270	270	270	270	270	270	270
	A4	0	0	0	0	0	0	0	0	0	0
	A5	0	0	0	0	0	0	0	0	0	0
	A6	0	0	0	0	0	0	0	0	0	0
	A7	0	0	0	0	0	0	0	0	0	0
	A8	0	0	0	0	0	0	0	0	0	0
	A9	0	0	0	0	0	0	0	0	0	0
Order quantity	A1	646	646	646	646	646	646	808	646	646	646
	A2	890	890	890	890	890	890	890	1113	890	890
	A3	593	593	593	593	593	593	593	593	742	593
	A4	2186	2186	2186	2186	2186	2186	2186	2186	2186	2733
	A5	2334	2334	2334	2334	2334	2334	2334	2334	2334	2334
	A6	2268	2268	2268	2268	2268	2268	2268	2268	2268	2268
	A7	304	304	304	304	304	304	304	304	304	304
	A8	2258	2258	2258	2258	2258	2258	2258	2258	2258	2258
	A9	1149	1149	1149	1149	1149	1149	1149	1149	1149	1149

		4	5	6	7	8	9	10	11	12	13
Running No.		4	5	6	7	8	9	10	11	12	13
COSTS											
Ordering cost		180300	179000	180300	183100	179000	182900	177200	174600	176900	172500
Inventory of raw materials		75165	72402	70666	72132	70270	68798	64893	73437	82780	66619
Work in process		433126	400088	416637	420049	398604	415531	376393	441322.5	451896	393265
Semi-finished and finished goods inventory		63893	65962	68991	60373	66443	63450	75538	58920	59791	66655
Total		752484	717452	736594	735654	714317	730679	694024	748280	771367	699039
STATISTICS											
Stockouts of finished products	A1	6172.50	5832.50	6168.00	6213.50	5832.50	6224.50	6452.50	6.17E+03	6299.50	6054.50
	A2	1859.00	1738.50	1239.00	2036.50	1738.50	1998.50	1376.50	2.21E+03	2122.00	2184.50
	A3	4604.00	4756.00	4534.00	4675.50	4756.00	4634.00	4590.50	4.56E+03	4796.50	4575.50
Average inventory level	A1	-1121.00	-675.00	-933.50	-998.00	-675.00	-933.50	-696.50	-1198.5	-1250.00	-733.50
	A2	118.50	145.00	243.00	83.00	145.00	92.00	216.50	53.5	65.00	56.50
	A3	-1001.50	-912.50	-954.00	-794.50	-912.50	-847.50	-740.50	-901	-1148.00	-758.50
	A4	930.00	950.00	900.50	885.00	963.00	956.50	1114.50	884.5	1023.50	1089.00
	A5	1123.00	1122.00	1121.00	1118.00	1122.00	1118.50	1120.50	1122.5	890.50	1122.00
	A6	1263.50	1308.50	1263.50	1280.00	1352.50	1280.00	1229.50	1263.5	1314.50	1107.00
	A7	182.00	182.00	181.00	182.00	182.00	182.00	182.00	1.21E+02	182.00	182.00
	A8	3432.50	3136.00	3097.00	3213.50	2831.00	3110.00	2489.50	3562	3613.50	2634.50
	A9	3177.50	3106.50	2999.50	3037.00	3106.50	2786.00	2928.00	3142	3758.00	3070.50
Average actual lead time (weeks)	A1	6.29	5.93	6.23	6.32	5.92	6.24	6.21	6.607693	6.66	6.33
	A2	9.38	9.14	8.90	9.74	9.16	9.64	8.14	11.03333	10.08	9.92
	A3	8.42	7.90	8.34	7.95	7.91	8.20	6.91	7.65	8.75	6.72
	A4	11.69	10.42	10.79	11.20	10.34	10.69	8.98	12.08571	12.02	9.99
	A5	13.74	13.74	13.50	13.30	13.74	13.54	13.20	13.48	14.80	13.46
Average queueing time (hours)	P1	47.26	44.62	50.60	48.02	44.44	46.31	42.27	45.808	64.59	50.74
	P2	37.71	36.09	36.29	36.18	34.80	35.76	34.26	36.44794	34.58	34.74
	P3	47.44	42.13	41.96	47.05	41.89	45.92	34.98	44.51341	46.63	40.03
	P4	91.60	87.63	82.37	84.84	87.72	85.77	68.27	93.60345	97.11	73.85
	P5	74.51	64.77	73.21	63.77	64.13	68.66	60.48	72.14937	69.11	55.12
Average load (%)	P1	85.05	85.05	85.77	86.05	85.05	86.05	86.00	85.6695	85.65	85.44
	P2	69.24	69.20	69.71	70.22	69.20	70.22	69.70	69.89124	70.19	69.16
	P3	64.31	63.90	65.17	64.16	63.90	64.16	64.27	64.19851	64.96	64.63
	P4	80.92	79.74	80.67	79.28	79.74	79.28	79.99	79.28751	81.88	80.51
	P5	74.97	74.28	76.53	74.13	74.28	74.13	76.05	77.23801	73.21	74.71
Turnover: Raw material inventory		14.15	14.69	15.05	14.74	15.13	15.46	16.39	14.4818	12.85	15.96
Work in process		5.78	6.26	6.01	5.96	6.28	6.02	6.65	5.671589	5.54	6.36
Semi-finished and finished goods inventory		39.17	37.95	36.28	41.46	37.67	39.45	33.14	42.48133	41.86	37.55
Total		6.23	6.62	6.41	6.45	6.66	6.51	6.90	6.216886	6.00	6.77
SERVICE LEVELS											
Product 1		27.4	31.4	27.4	26.9	31.4	26.8	24.1	27.4	25.9	28.8
Product 2		58.7	61.4	72.5	54.7	61.4	55.6	69.4	50.9	52.8	51.5
Product 3		16.3	13.5	17.6	15	13.5	15.7	16.5	17.1	12.8	16.8
Overall		28.2	29.9	30.5	27	29.9	27.2	27.9	27.4	25.5	28.1