Industrial Engineering and Management of European Higher Education

TPPE74
Design and Development of Manufacturing Operations

Le 7 Part 1

PicSim Summary

2021

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

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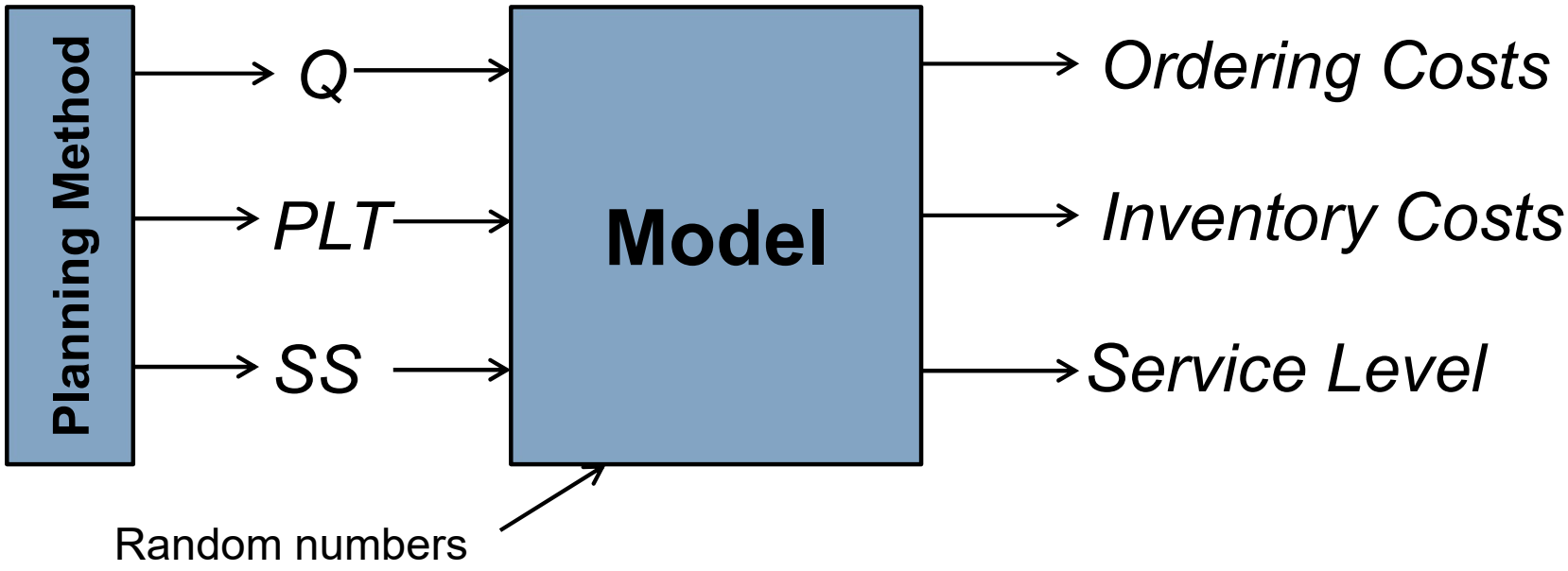
Content Le 7 Part 1

- The PICSIM project
  - Task A in the PICSIM project
- Pedagogical idea with PICSIM
- Open or Closed Box Approach
- Simple Regression Analysis

PICSIM Project

- The objectives of this project are:
  - to give a deeper understanding for decision making problems of this kind,
  - to illustrate how alternate planning and control systems can be analysed through simulation,
  - to give a deeper understanding for the interrelationships among parameters,
  - to analyse manufacturing operations through studying relationships between different variables,
  - to analyse the impact of different factors such as demand variations and load,
  - to study development of manufacturing operations through for example set-up time reduction.



The PICSIM Solution…

- Base case
  - Reorder Point System
  - Total cost = 656 898 (target < 680 000)
  - Inventory cost = 498 498 kr (target < 340 000)
  - Service level = 28.5 % (target > 95 %)
- Different system solutions
  - ROP
  - MRP
  - CP
  - CP with base period
  - Lean
- 10 runs…
  - 2 run for ROP to introduce some ideas of inventory control
  - 2 runs for MRP
  - 2 runs for CP
  - 2 runs for CP with base period
  - 2 runs for Lean

PICSIM : ROP 1 – Run#0

- Base case

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								
Service levels (%)									
Product 1	28.3								
Product 2	72.8								
Product 3	20.8								
Overall	28.5								
Statistics									
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								

PICSIM : ROP 2

- 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

PICSIM : ROP 2

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								
Service levels (%)									
Product 1	28.3								
Product 2	72.8								
Product 3	20.8								
Overall	28.5								
Statistics									
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								

PICSIM : ROP 2

- 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
- 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)

PICSIM : ROP 2

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)

PICSIM : ROP 2

- 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

PICSIM : ROP 2

- SS calculation
  - D Stdev = {12, 8, 15} for items A1, A2, and A3
  - LT Stdev = 1,0 week
  - $SS = k\sqrt{L\sigma^2 + D^2[\sigma L]^2}$
  - Example SS(A1)
    - k = 2.33 (99% service level)
    - L = 5.2 weeks
    - σ = 12 units/week
    - D = 100 units/week
    - σL = 1 week
    - SS = 242
  - SS(A2, LT = 8.8) = 129
  - SS(A3, LT = 8.0) = 364
- All other items?
  - SS = 0

PICSIM : ROP 2

- Capacity Control

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

PICSIM : ROP 2 – Run#1

Simulation Results				Simulation Results					
Group No.	1								
Run No.	1								
Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	5.2	8.8	8	8.2	27.4	3	3	3	3
Order quantity	495	632	692	1611	2619	2000	226	1732	1342
Safety stock	242	129	364	0	0	0	0	0	0
Costs									
Ordering cost	158400		Total Ordering Cost			158400			
Inventory of raw materials	29262		Total Inventory Cost			607048			
Work in process	337177								
Semi-finished and finished goods inventory	240609								
Total	765448								
Service levels (%)									
Product 1	67.5								
Product 2	90.8								
Product 3	98.9								
Overall	85.9								
Statistics									
Stockouts of finished products	1625.50	231.00	82.00						
Average inventory level A1-A9	63.00	398.50	893.00	711.50	4942.00	1054.00	90.50	1468.00	663.00
Average actual lead time A1-A5 (weeks)	5.85	9.56	6.29	11.66	14.83				
Average queueing time P1-P5 (hours)	39.58	47.06	40.43	98.11	44.79				
Average load P1-P5 (%)	86.67	71.78	68.17	81.86	76.83				
Inventory turnover rates									
Raw material inventory	27.60								
Work in process	6.07								
Semi-finished and finished goods inventory	8.50								
Total	4.70								

PICSIM : ROP 3

- Capacity Control

Setup times

	A1	A2	A3	A4	A5
P1	0.40	0.16	0.43	0.50	0.46
P2	0.40	0.16		0.50	0.46
P3			0.65	0.74	0.69
P4		0.24		0.74	0.69
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	Sum
P1	3.40	2.66	10.93	4.50	12.46	33.95
P2	6.40	4.16	0.00	4.50	12.46	27.52
P3	0.00	0.00	8.15	6.74	12.69	27.58
P4	0.00	2.74	0.00	4.74	24.69	32.17
P5	11.20	3.08	15.22	0.00	0.00	29.50

PICSIM : ROP 3 – Run#2

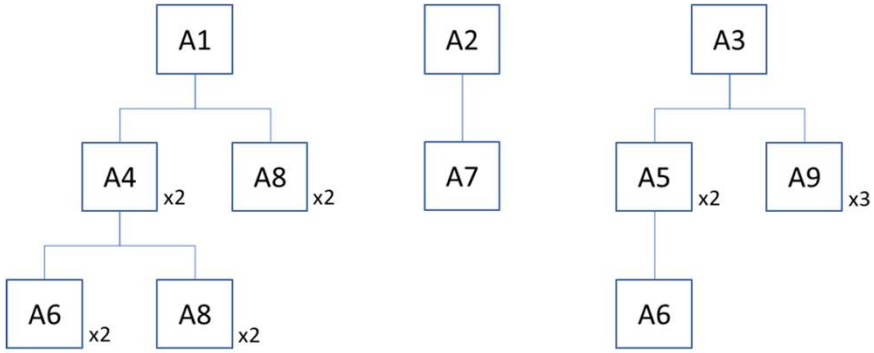
Simulation Results

Simulation Results

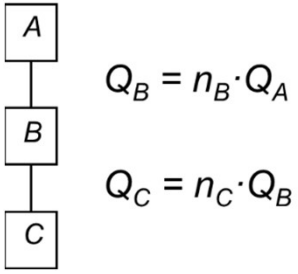
Group No.	1								
Run No.	2								
Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	5.2	8.8	8	4	13.6	3	3	3	3
Order quantity	495	632	692	806	1310	1000	226	866	1342
Safety stock	242	129	364	0	0	0	0	0	0
Costs									
Ordering cost	229400		**Total Ordering Cost**			229400			
Inventory of raw materials	23653		**Total Inventory Cost**			461173			
Work in process	221048								
Semi-finished and finished goods inventory	216472								
Total	690573								
Service levels (%)									
Product 1	77.3								
Product 2	100.0								
Product 3	100.0								
Overall	91.1								
Statistics									
Stockouts of finished products	1136.50	0.00	0.00						
Average inventory level A1-A9	220.50	467.50	1059.00	611.50	2269.00	535.00	90.50	1221.50	663.00
Average actual lead time A1-A5 (weeks)	4.23	7.90	5.06	6.82	8.81				
Average queueing time P1-P5 (hours)	36.12	25.32	27.04	54.72	30.83				
Average load P1-P5 (%)	85.23	68.82	69.94	80.86	74.15				
Inventory turnover rates									
Raw material inventory	34.14								
Work in process	9.25								
Semi-finished and finished goods inventory	9.45								
Total	6.19								

PICSIM : MRP 1

- Use BOM to calculate Q
- EOQ on end item level



  - EOQ(A1) = 495
    EOQ(A2) = 632
    EOQ(A3) = 692
  - Q(A4) = 2*EOQ(A1) = 990
  - Q(A5) = 2*EOQ(A3) = 1 384
  - Q(A6) = 2*Q(A4) = = 1 980 or Q(A6) = Q(A5) = 1 384
  - Q(A7) = EOQ(A2) = 632
  - Q(A8) = 2*Q(A4) = 1 980 or 2*Q(A1) = 2*495 = 990
  - Q(A9) = 3*EOQ(A3) = 2 076



- Update PLT for A4 and A5

PICSIM : MRP 1

- Capacity Control

Setup times

	A1	A2	A3	A4	A5
P1	0.53	0.20	0.37	0.69	0.32
P2	0.53	0.20		0.69	0.32
P3			0.56	1.03	0.48
P4		0.30		1.03	0.48
P5	0.26	0.10	0.19		

Processing Times

	A1	A2	A3	A4	A5
P1	5.10	4.50	7.70	6.80	8.80
P2	10.20	7.20		6.80	8.80
P3			5.50	10.20	8.80
P4		4.50		6.80	17.60
P5	18.70	5.40	11.00		

Capacity

	A1	A2	A3	A4	A5	Sum
P1	5.63	4.70	8.07	7.49	9.12	35.00
P2	10.73	7.40	0.00	7.49	9.12	34.73
P3	0.00	0.00	6.06	11.23	9.28	26.56
P4	0.00	4.80	0.00	7.83	18.08	30.71
P5	18.96	5.50	11.19	0.00	0.00	35.65

PICSIM : MRP 1 – Run#3

Simulation Results

Simulation Results

Group No.	1								
Run No.	3								
Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	5.2	8.8	8	5	14.4	3	3	3	3
Order quantity	495	632	692	990	1384	1980	632	1980	2076
Safety stock	242	129	364	0	0	0	0	0	0
Costs									
Ordering cost	195400		**Total Ordering Cost**			195400			
Inventory of raw materials	14069		**Total Inventory Cost**			435853			
Work in process	229030								
Semi-finished and finished goods inventory	192754								
Total	631253								
Service levels (%)									
Product 1	83.9								
Product 2	100.0								
Product 3	100.0								
Overall	93.7								
Statistics									
Stockouts of finished products	803.50	0.00	0.00						
Average inventory level A1-A9	260.50	499.00	969.00	198.00	1992.00	811.50	0.00	1049.00	0.00
Average actual lead time A1-A5 (weeks)	4.23	7.38	5.69	7.26	8.42				
Average queueing time P1-P5 (hours)	34.51	19.77	30.10	53.21	30.70				
Average load P1-P5 (%)	85.41	68.02	69.13	80.87	74.12				
Inventory turnover rates									
Raw material inventory	57.40								
Work in process	8.93								
Semi-finished and finished goods inventory	10.61								
Total	6.54								

PICSIM : MRP 2

- Capacity Control

Setup times

	A1	A2	A3	A4	A5
P1	0.69	0.28	0.32	0.69	0.64
P2	0.69	0.28		0.69	0.64
P3			0.48	1.03	0.95
P4		0.43		1.03	0.95
P5	0.34	0.14	0.16		

Processing Times

	A1	A2	A3	A4	A5
P1	5.10	4.50	7.70	6.80	8.80
P2	10.20	7.20		6.80	8.80
P3			5.50	10.20	8.80
P4		4.50		6.80	17.60
P5	18.70	5.40	11.00		

Capacity

	A1	A2	A3	A4	A5	Sum
P1	5.79	4.78	8.02	7.49	9.44	35.51
P2	10.89	7.48	0.00	7.49	9.44	35.29
P3	0.00	0.00	5.98	11.23	9.75	26.96
P4	0.00	4.93	0.00	7.83	18.55	31.31
P5	19.04	5.54	11.16	0.00	0.00	35.74

PICSIM : MRP 2 – Run#4

Simulation Results

Simulation Results

Group No.	1								
Run No.	4								
Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	5.2	8.8	8	5	7.2	3	3	3	3
Order quantity	495	632	692	990	692	1980	632	1980	2076
Safety stock	242	129	364	0	0	0	0	0	0
Costs									
Ordering cost	249700		**Total Ordering Cost**			249700			
Inventory of raw materials	9420		**Total Inventory Cost**			395722			
Work in process	166799								
Semi-finished and finished goods inventory	219503								
Total	645422								
Service levels (%)									
Product 1	100.0								
Product 2	100.0								
Product 3	100.0								
Overall	100.0								
Statistics									
Stockouts of finished products	0.00	0.00	0.00						
Average inventory level A1-A9	498.00	518.50	1190.50	257.00	926.50	668.00	0.00	593.50	0.00
Average actual lead time A1-A5 (weeks)	4.14	7.28	4.36	4.59	5.43				
Average queueing time P1-P5 (hours)	23.94	15.72	12.77	31.61	30.36				
Average load P1-P5 (%)	86.60	69.75	71.05	81.99	74.44				
Inventory turnover rates									
Raw material inventory	85.72								
Work in process	12.26								
Semi-finished and finished goods inventory	9.32								
Total	7.21								

PICSIM : CP 1

- Common Cycle Time T* = 3.86 weeks
- Tmin = 1.25 weeks
- Calculate Q(T*)

Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	4.2	2.8	6.8	4	6.2	3	3	3	3
Order quantity	386	193	579	772	1158	1544	193	1544	1737
Safety stock	240	122	379	0	0	0	0	0	0

- Update PLT and SS

PICSIM : CP 1

- Capacity Control

Setup times

	A1	A2	A3	A4	A5
P1	0.52	0.52	0.52	0.52	0.52
P2	0.52	0.52		0.52	0.52
P3			0.78	0.78	0.78
P4		0.78		0.78	0.78
P5	0.26	0.26	0.26		

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	Sum
P1	3.52	3.02	11.02	4.52	12.52	34.59
P2	6.52	4.52	0.00	4.52	12.52	28.07
P3	0.00	0.00	8.28	6.78	12.78	27.83
P4	0.00	3.28	0.00	4.78	24.78	32.83
P5	11.26	3.26	15.26	0.00	0.00	29.78

?

PICSIM : CP 1 – Run#5

Simulation Results			Simulation Results						
Group No.	1								
Run No.	5								
Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	4.2	2.8	6.8	4	6.2	3	3	3	3
Order quantity	386	193	579	772	1158	1544	193	1544	1737
Safety stock	240	122	379	0	0	0	0	0	0
Costs									
Ordering cost	278700		Total Ordering Cost			278700			
Inventory of raw materials	16030		Total Inventory Cost			307659			
Work in process	177006								
Semi-finished and finished goods inventory	114623								
Total	586359								
Service levels (%)									
Product 1	80.2								
Product 2	92.7								
Product 3	100.0								
Overall	91.6								
Statistics									
Stockouts of finished products	990.00	183.50	0.00						
Average inventory level A1-A9	192.00	143.50	784.50	192.50	301.00	428.00	0.00	848.50	625.00
Average actual lead time A1-A5 (weeks)	3.52	4.25	4.38	5.90	7.42				
Average queueing time P1-P5 (hours)	24.10	18.71	22.41	45.80	24.46				
Average load P1-P5 (%)	87.01	70.22	70.18	82.08	74.22				
Inventory turnover rates									
Raw material inventory	50.37								
Work in process	11.55								
Semi-finished and finished goods inventory	17.84								
Total	9.27								

PICSIM : CP 2

- Capacity Control

Setup times

	A1	A2	A3	A4	A5
P1	0.52	0.52	0.52	0.52	1.04
P2	0.52	0.52		0.52	1.04
P3			0.78	0.78	1.55
P4		0.78		0.78	1.55
P5	0.26	0.26	0.26		

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	Sum
P1	3.52	3.02	11.02	4.52	13.04	35.11
P2	6.52	4.52	0.00	4.52	13.04	28.59
P3	0.00	0.00	8.28	6.78	13.55	28.61
P4	0.00	3.28	0.00	4.78	25.55	33.61
P5	11.26	3.26	15.26	0.00	0.00	29.78

PICSIM : CP 2 – Run#6

Simulation Results

Simulation Results

Group No.	1								
Run No.	6								
Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	4.2	2.8	6.8	4	6.2	3	3	3	3
Order quantity	386	193	579	772	579	1544	193	1544	869
Safety stock	240	122	379	0	0	0	0	0	0
Costs									
Ordering cost	343500		**Total Ordering Cost**			343500			
Inventory of raw materials	6422		**Total Inventory Cost**			316375			
Work in process	133921								
Semi-finished and finished goods inventory	176032								
Total	659875								
Service levels (%)									
Product 1	99.5								
Product 2	96.0								
Product 3	100.0								
Overall	99.4								
Statistics									
Stockouts of finished products	27.00	101.00	0.00						
Average inventory level A1-A9	419.50	149.50	1056.50	223.50	793.00	358.50	0.00	462.50	22.50
Average actual lead time A1-A5 (weeks)	3.16	4.05	3.98	3.94	4.61				
Average queueing time P1-P5 (hours)	17.79	10.40	8.91	33.40	28.40				
Average load P1-P5 (%)	88.44	70.95	72.11	84.99	74.64				
Inventory turnover rates									
Raw material inventory	125.74								
Work in process	15.27								
Semi-finished and finished goods inventory	11.62								
Total	9.02								

PICSIM : CPB 1

- Base Period Cycle Time W* = 3.15 weeks
- Multiples = {1, 2, 1, 1, 2, 1, 1, 1, 1}
- Calculate Q(nW*)

Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	4.2	5.2	5.8	3.6	19.4	3	3	3	3
Order quantity	315	315	472	630	1890	2205	158	1890	1418
Safety stock	240	125	360	0	0	0	0	0	0

- Update PLT and SS

PICSIM : CPB 2

- Capacity Control

Setup times

	A1	A2	A3	A4	A5
P1	0.63	0.32	0.64	0.63	0.32
P2	0.63	0.32		0.63	0.32
P3			0.95	0.95	0.48
P4		0.48		0.95	0.48
P5	0.32	0.16	0.32		

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	Sum
P1	3.63	2.82	11.14	4.63	12.32	34.54
P2	6.63	4.32	0.00	4.63	12.32	27.90
P3	0.00	0.00	8.45	6.95	12.48	27.88
P4	0.00	2.98	0.00	4.95	24.48	32.40
P5	11.32	3.16	15.32	0.00	0.00	29.79

PICSIM : CPB 1 – Run#7

Simulation Results

Simulation Results

Group No.	1								
Run No.	7								
Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	4.2	5.2	5.8	3.6	19.4	3	3	3	3
Order quantity	315	315	472	630	1890	2205	158	1890	1418
Safety stock	240	125	360	0	0	0	0	0	0
Costs									
Ordering cost	262200		**Total Ordering Cost**			262200			
Inventory of raw materials	16479		**Total Inventory Cost**			391248			
Work in process	202223								
Semi-finished and finished goods inventory	172546								
Total	653448								
Service levels (%)									
Product 1	68.6								
Product 2	100.0								
Product 3	100.0								
Overall	87.8								
Statistics									
Stockouts of finished products	1568.00	0.00	0.00						
Average inventory level A1-A9	113.00	317.50	682.00	195.00	3495.50	418.50	13.50	1562.00	55.00
Average actual lead time A1-A5 (weeks)	2.66	4.23	4.84	7.81	10.04				
Average queueing time P1-P5 (hours)	27.51	25.40	35.68	67.93	22.25				
Average load P1-P5 (%)	87.60	69.80	70.06	81.27	74.20				
Inventory turnover rates									
Raw material inventory	49.00								
Work in process	10.11								
Semi-finished and finished goods inventory	11.85								
Total	7.29								

PICSIM : CPB 1

- Capacity Control

Setup times

	A1	A2	A3	A4	A5
P1	0.63	0.32	0.64	0.63	0.63
P2	0.63	0.32		0.63	0.63
P3			0.95	0.95	0.95
P4		0.48		0.95	0.95
P5	0.32	0.16	0.32		

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	Sum
P1	3.63	2.82	11.14	4.63	12.63	34.86
P2	6.63	4.32	0.00	4.63	12.63	28.22
P3	0.00	0.00	8.45	6.95	12.95	28.36
P4	0.00	2.98	0.00	4.95	24.95	32.88
P5	11.32	3.16	15.32	0.00	0.00	29.79

PICSIM : CPB 2 – Run#8

Simulation Results

Simulation Results

Group No.	1								
Run No.	8								
Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	4.2	5.2	5.8	3.6	9.6	3	3	3	3
Order quantity	315	315	472	630	945	2205	158	945	1418
Safety stock	240	125	360	0	0	0	0	0	0
Costs									
Ordering cost	307000		Total Ordering Cost			307000			
Inventory of raw materials	13815		Total Inventory Cost			333008			
Work in process	137644								
Semi-finished and finished goods inventory	181549								
Total	640008								
Service levels (%)									
Product 1	99.8								
Product 2	100.0								
Product 3	100.0								
Overall	99.9								
Statistics									
Stockouts of finished products	10.50	0.00	0.00						
Average inventory level A1-A9	406.00	295.50	852.00	232.50	1671.50	1042.00	13.50	683.00	55.00
Average actual lead time A1-A5 (weeks)	2.84	4.25	3.68	4.20	5.73				
Average queueing time P1-P5 (hours)	10.62	15.74	21.96	36.89	22.32				
Average load P1-P5 (%)	88.68	72.26	73.26	85.28	75.04				
Inventory turnover rates									
Raw material inventory	58.45								
Work in process	14.86								
Semi-finished and finished goods inventory	11.26								
Total	8.57								

PICSIM: Lean 1

- Try to get as close to 1 piece flow as possible
- Use Cyclic Planning T_{min} = 1.25 weeks (1.29)

Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	2.6	1.2	2.8	1.8	4.4	3	3	3	3
Order quantity	125	63	188	250	375	875	63	750	563
Safety stock	238	119	355	0	0	0	0	0	0

- Adjust PLT and SS

PICSIM: Lean 1

- Capacity Control

Setup times

	A1	A2	A3	A4	A5
P1	1.60	1.59	1.60	1.60	1.60
P2	1.60	1.59		1.60	1.60
P3			2.39	2.40	2.40
P4		2.38		2.40	2.40
P5	0.80	0.79	0.80		

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		

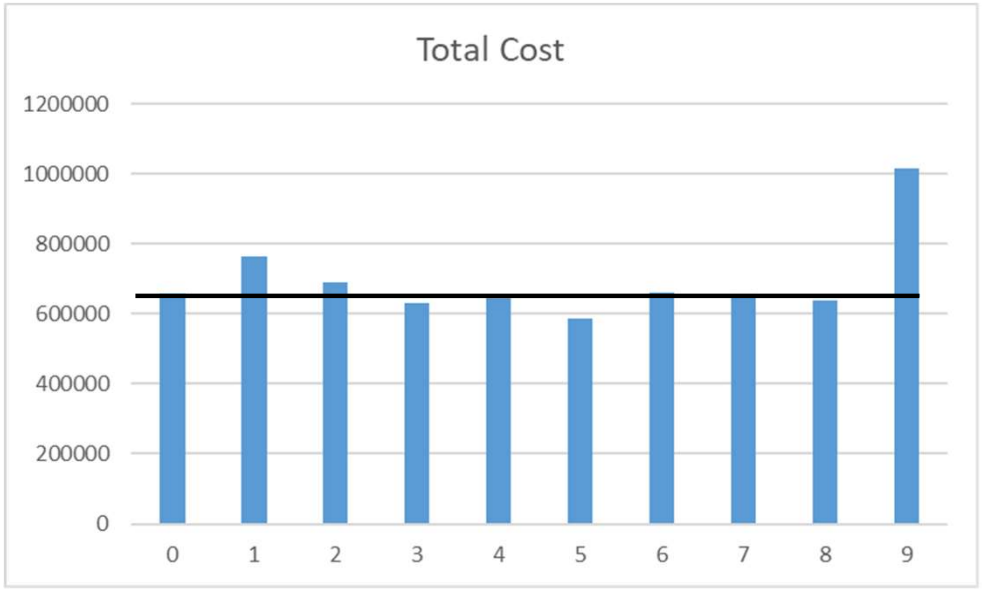
Capacity

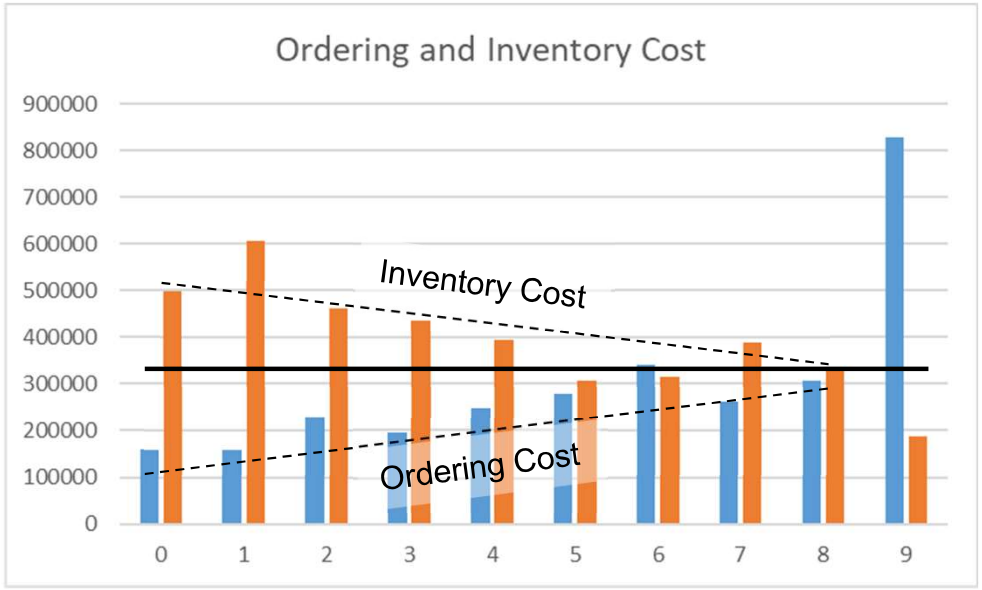
	A1	A2	A3	A4	A5	Sum
P1	4.60	4.09	12.10	5.60	13.60	39.98
P2	7.60	5.59	0.00	5.60	13.60	32.39
P3	0.00	0.00	9.89	8.40	14.40	32.69
P4	0.00	4.88	0.00	6.40	26.40	37.68
P5	11.80	3.79	15.80	0.00	0.00	31.39

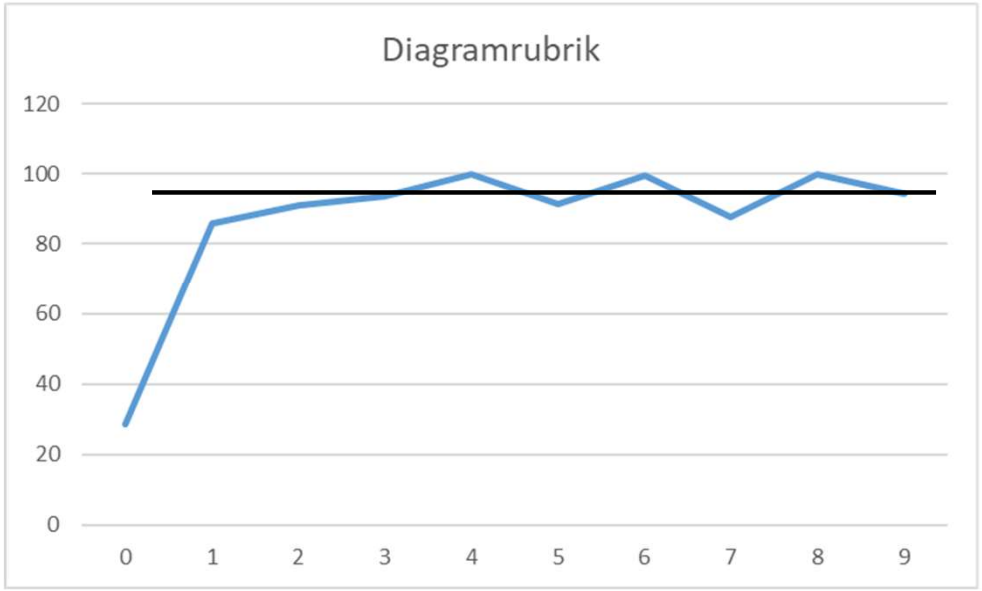
PICSIM: Lean 1 - Run#9

Simulation Results				Simulation Results					
Group No.	1								
Run No.	9								
Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	2.6	1.2	2.8	1.8	4.4	3	3	3	3
Order quantity	125	63	188	250	375	875	63	750	563
Safety stock	238	119	355	0	0	0	0	0	0
Costs									
Ordering cost	827800		Total Ordering Cost			827800			
Inventory of raw materials	12867		Total Inventory Cost			187986			
Work in process	96562								
Semi-finished and finished goods inventory	78557								
Total	1015786								
Service levels (%)									
Product 1	91.8								
Product 2	75.2								
Product 3	100.0								
Overall	94.5								
Statistics									
Stockouts of finished products	412.50	619.50	0.00						
Average inventory level A1-A9	176.50	26.00	380.00	195.00	746.50	221.00	0.00	775.00	512.50
Average actual lead time A1-A5 (weeks)	2.10	3.11	2.87	3.49	3.78				
Average queueing time P1-P5 (hours)	38.27	9.34	10.92	24.37	10.15				
Average load P1-P5 (%)	100.00	80.50	82.17	94.73	77.50				
Inventory turnover rates									
Raw material inventory	62.76								
Work in process	21.18								
Semi-finished and finished goods inventory	26.03								
Total	15.17								

PICSIM : Evaluation







System “optimization”

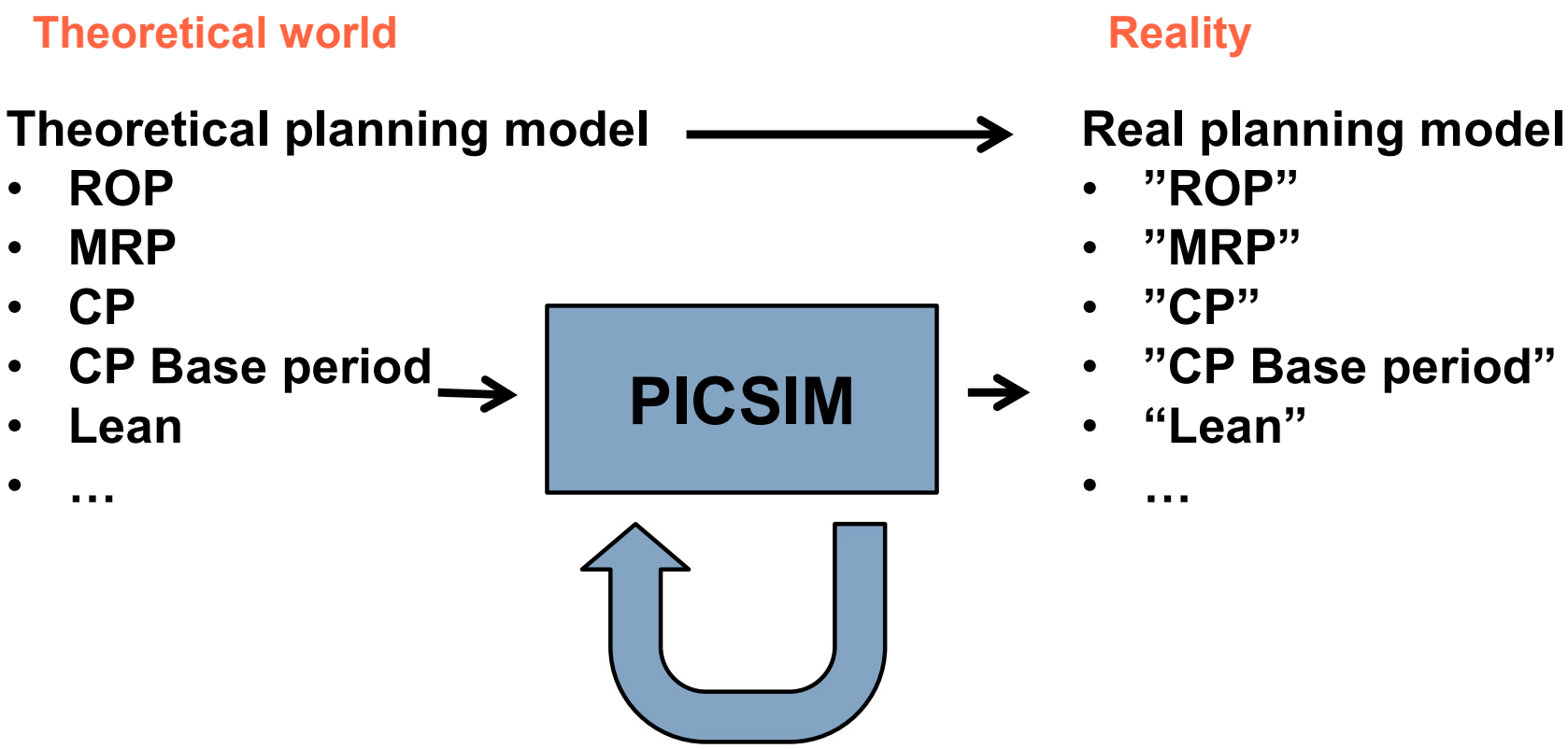
CP and CPB

compared to

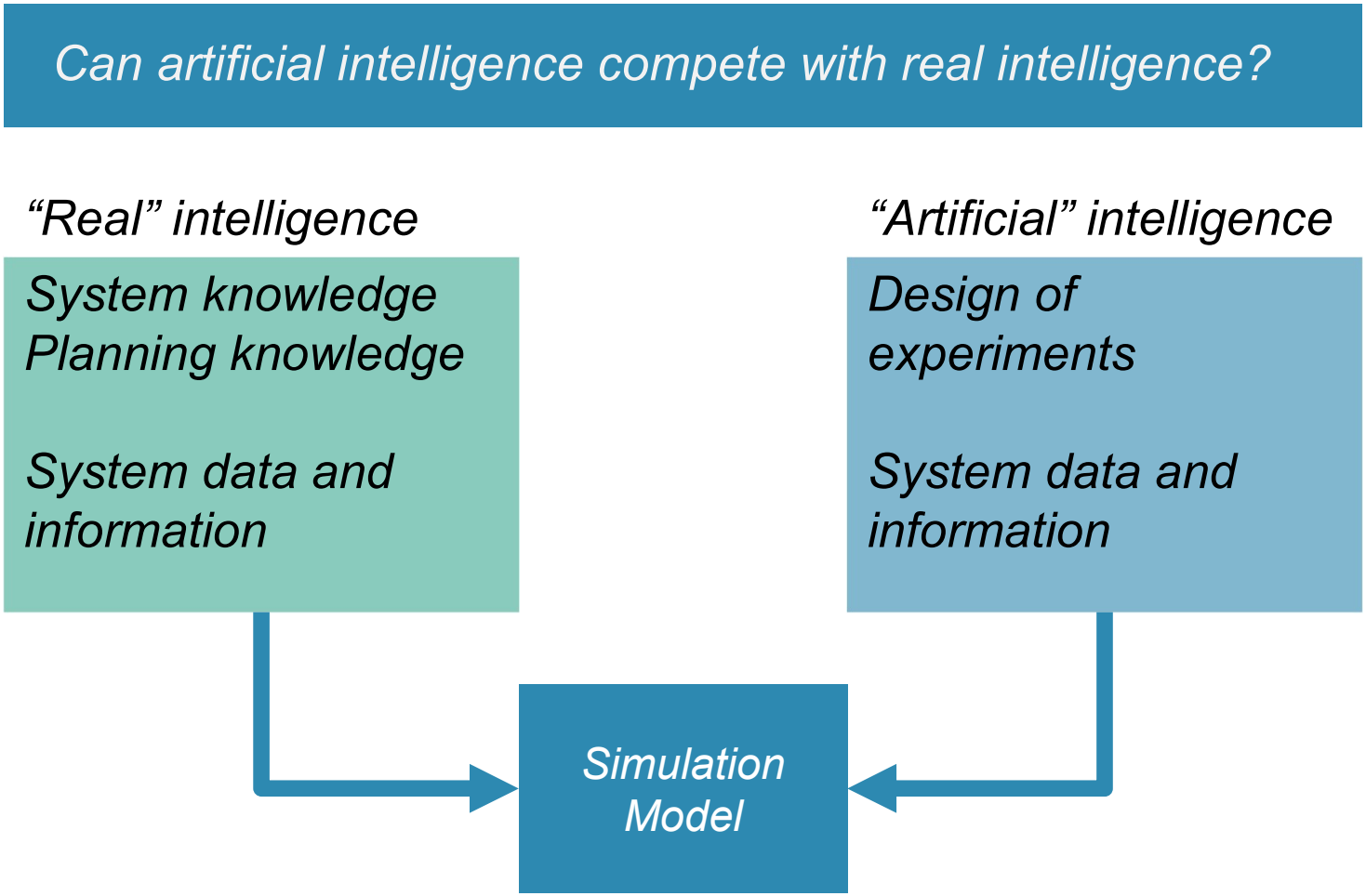
Individual “optimization”

ROP

Pedagogical idea with PICSIM



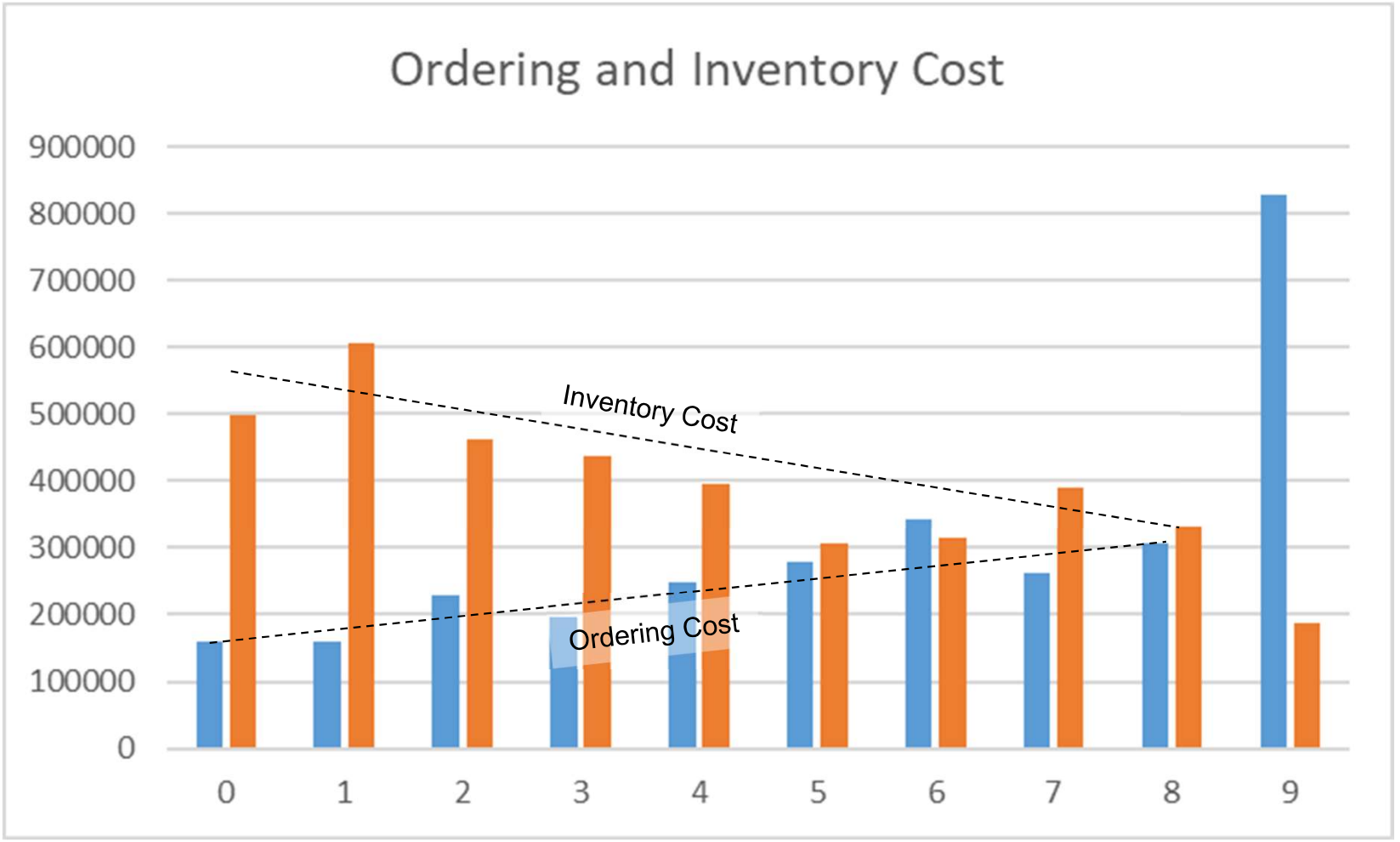
Open Box and Closed Box



The Open Box Solution

- For one Planning Method:
- Calculate the *Theoretical Solution*
  - Order Quantity
  - Planned Lead Time
  - Safety Stock
- Run a simulation and use the simulation result to improve the *Theoretical Solution*
- Run a simulation to control the *Improved Solution*
- Go to next Planning Method…

The Open Box Solution



The Closed Box Solution

- No (little) knowledge of the system is used
- Goal: Same target range as before, priority on **Servcie Level**
- Two-level full factorial design

	Factors																				
	A	B	C	D	E	F	AB	AC	AD	AE	AF	BC	BD	BE	BF	CD	CE	CF	DE	DF	EF
1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1	1	1
3	-1	1	-1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1
4	1	1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1
5	-1	-1	1	-1	-1	-1	1	-1	1	1	1	-1	1	1	1	-1	-1	-1	1	1	1
6	1	-1	1	-1	-1	-1	-1	1	-1	-1	-1	-1	1	1	1	-1	-1	-1	1	1	1
7	-1	1	1	-1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	-1	-1	1	1	1
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9	-1	-1	-1	1	-1	-1	1	1	-1	1	1	1	-1	1	1	-1	1	1	-1	-1	1
10	1	-1	-1	1	-1	-1	-1	-1	1	-1	-1	1	-1	1	1	-1	1	1	-1	-1	1
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19	-1	1	-1	-1	1	-1	-1	1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	-1
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50	1	-1	-1	-1	1	1	-1	-1	-1	1	1	1	1	-1	-1	1	-1	-1	-1	-1	1
51	-1	1	-1	-1	1	1	-1	1	1	-1	-1	-1	-1	1	1	1	-1	-1	-1	-1	1
52	1	1	-1	-1	1	1	1	-1	-1	1	1	-1	-1	1	1	1	-1	-1	-1	-1	1
53	-1	-1	1	-1	1	1	1	-1	1	-1	-1	-1	1	-1	-1	-1	1	1	-1	1	1
54	1	-1	1	-1	1	1	-1	1	-1	1	1	-1	1	-1	-1	-1	1	1	-1	-1	1
55	-1	1	1	-1	1	1	-1	-1	1	-1	-1	1	-1	1	1	-1	1	1	-1	-1	1
56	1	1	1	-1	1	1	1	1	-1	1	1	1	-1	1	1	-1	1	1	-1	-1	1
57	-1	-1	-1	1	1	1	1	1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	1	1	1
58	1	-1	-1	1	1	1	-1	-1	1	1	1	1	-1	-1	-1	-1	-1	-1	1	1	1
59	-1	1	-1	1	1	1	-1	1	-1	-1	-1	1	1	1	-1	-1	-1	-1	1	1	1
60	1	1	-1	1	1	1	1	-1	1	1	1	-1	1	1	1	-1	-1	-1	1	1	1
61	-1	-1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1
62	1	-1	1	1	1	1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1
63	-1	1	1	1	1	1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1	1	1
64	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

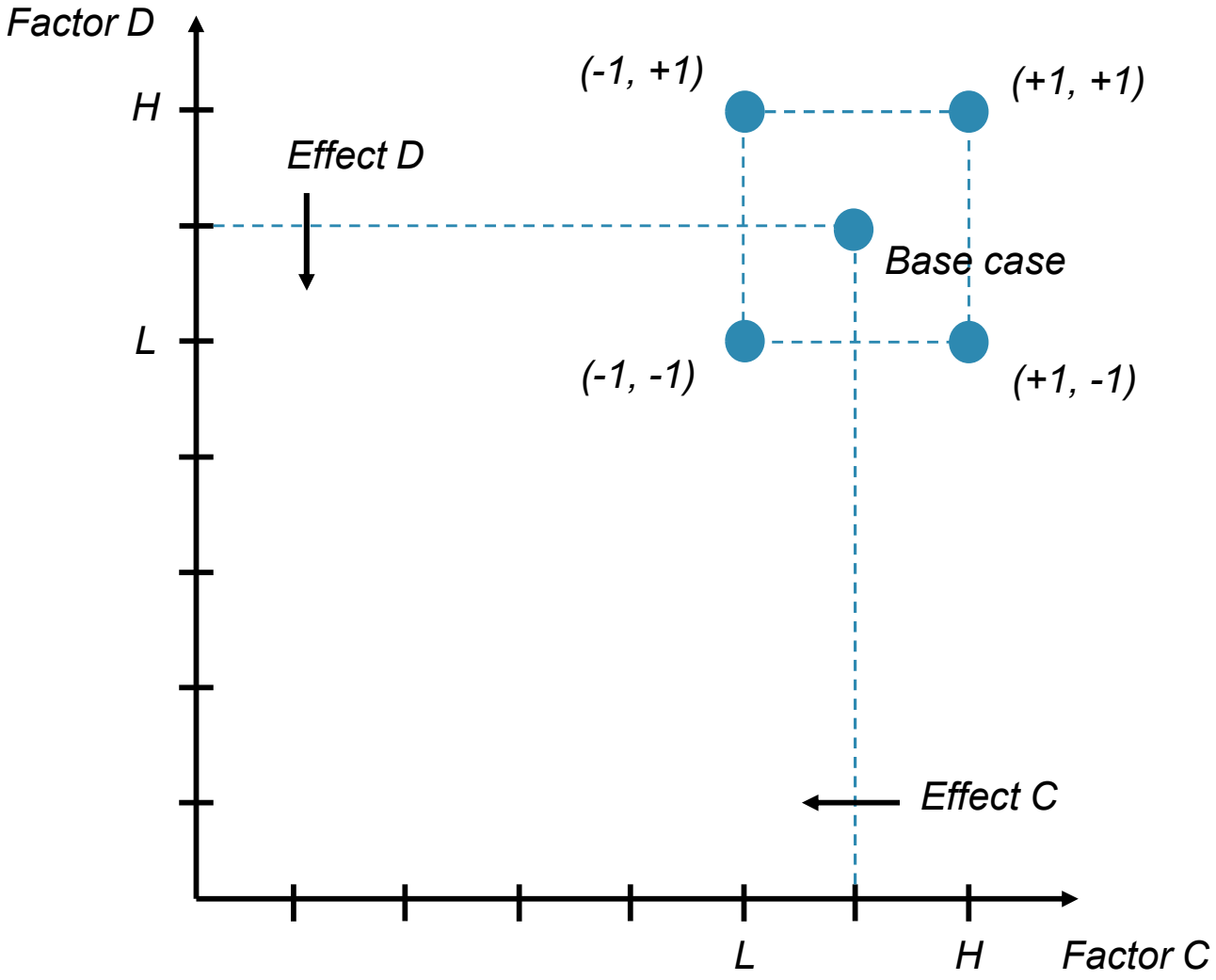
- Why **Servcie Level?** Hardest to get at a good level…

Group Factor Design

- Two-level full factorial design
- Factor A and B
  - + 1 week for high, -1 week for low
- Factor C to F
  - + 25% for high level, -25% for low level

Group factor	Design parameters	Product
Factor A	Planned Lead time	A1
		A2
		A3
Factor B	Planned Lead time	A4
		A5
Factor C	Order Quantity	A1
		A2
		A3
Factor D	Order Quantity	A4
		A5
Factor E	Order Quantity	A6
		A7
		A8
		A9
Factor F	Safety Stock	A1
		A2
		A3

The Closed Box Solution

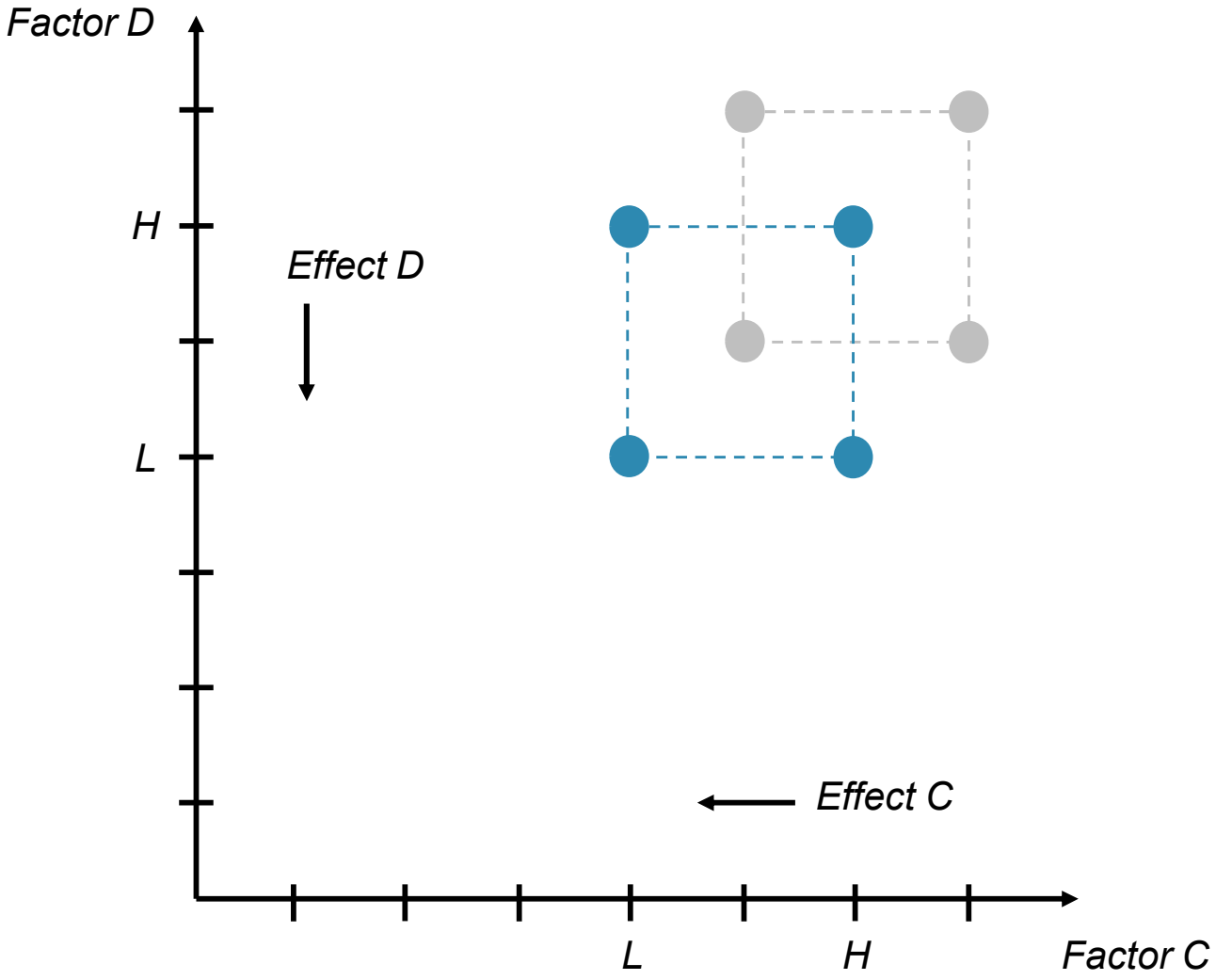


First 2^6 experiment

- 6 factors
- 64 experiments
- Effects suggest to continue with low levels

	Ordering	Inventory	Total	Service
Best run	196 200	365 503	561 703	32.0%
Average run	167 881	489 841	657 722	26.4%

The Closed Box Solution

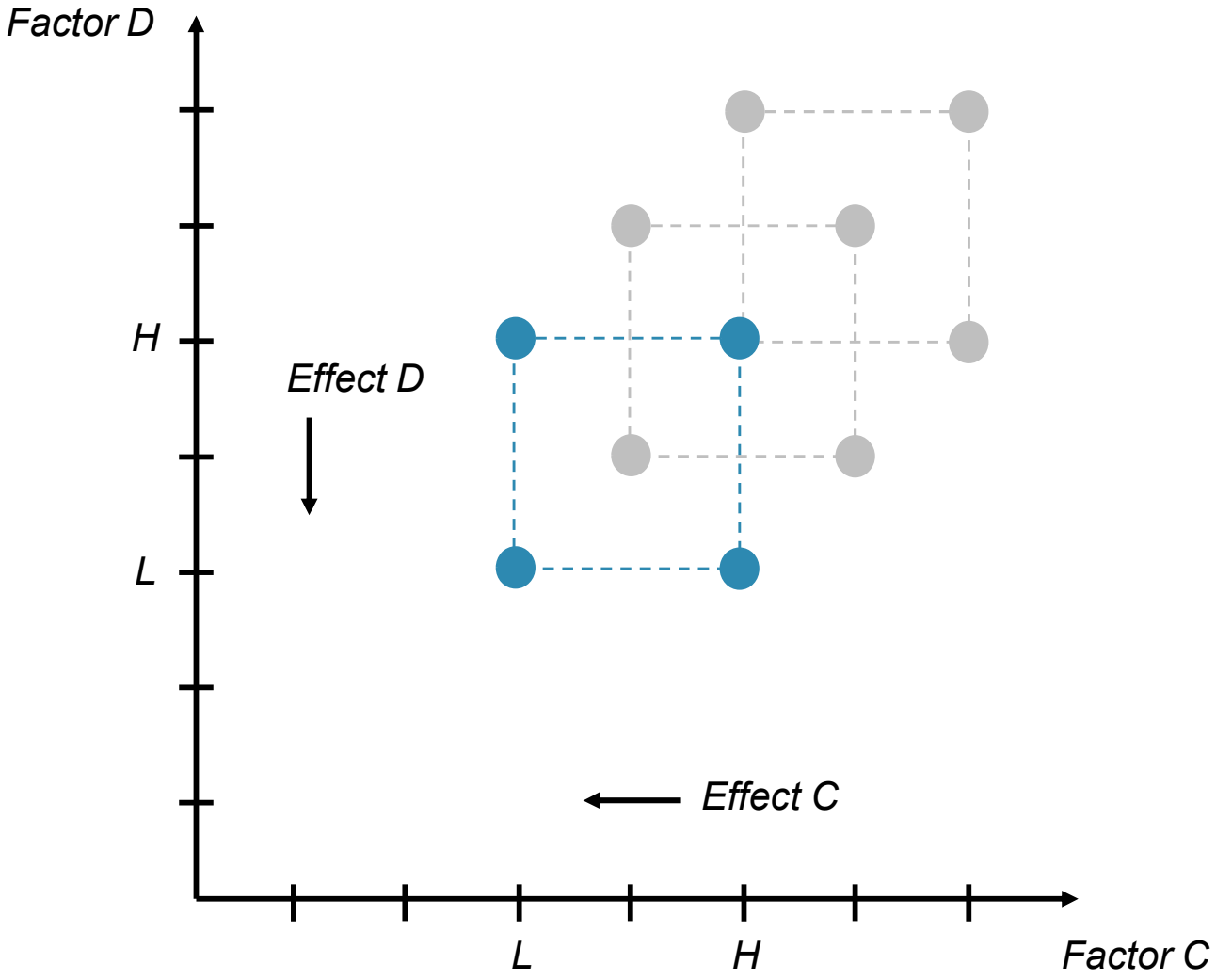


Second 2^6 experiment

- 6 factors
- 64 experiments
- Effects suggest to continue with low levels

	Ordering	Inventory	Total	Service
Best run	265 200	301 302	566 502	43.7%
Average run	211 597	392 166	603 763	47.6%

The Closed Box Solution

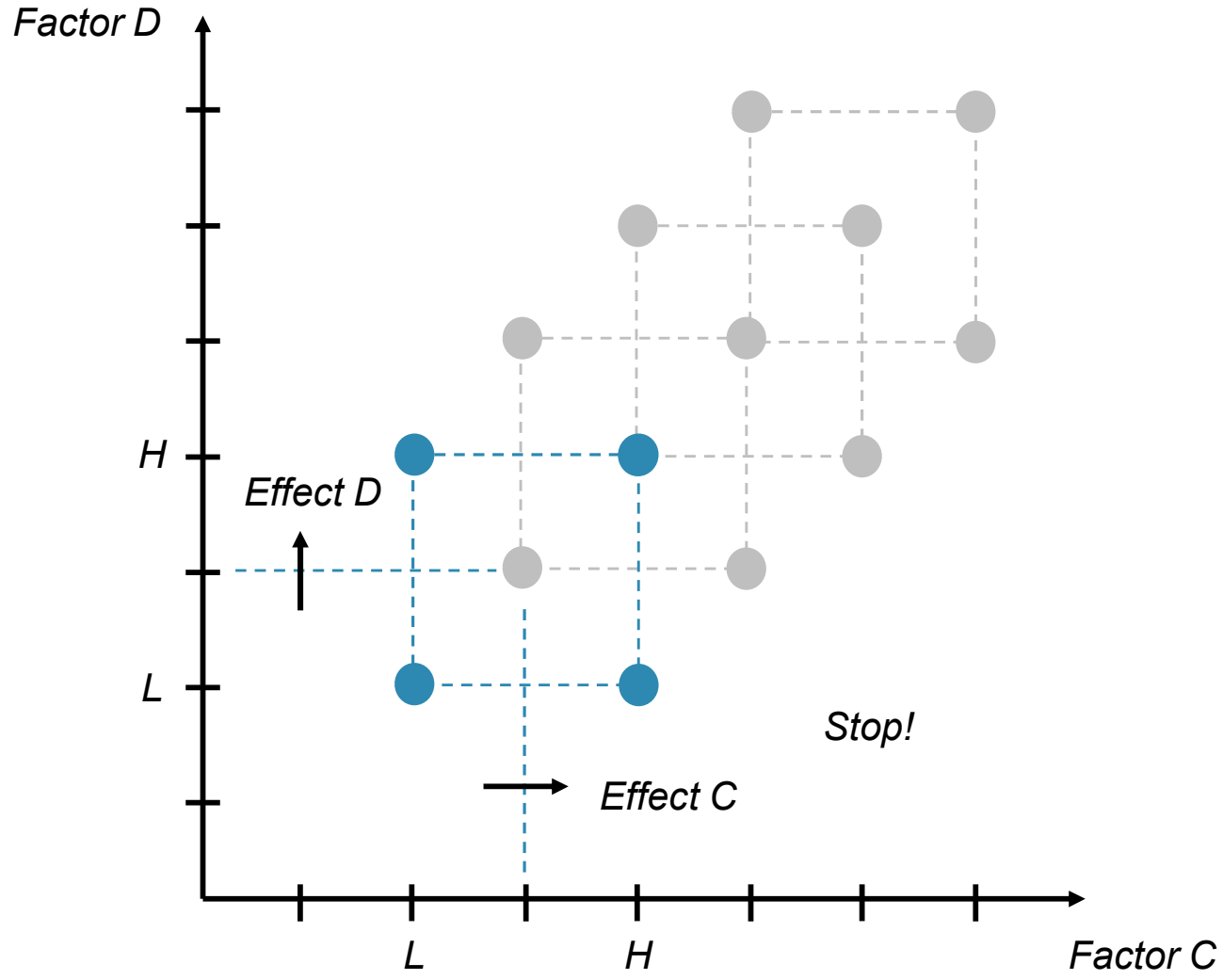


Third 2^6 experiment

- 6 factors
- 64 experiments
- Effects suggest to continue with low levels

	Ordering	Inventory	Total	Service
Best run	267 500	313 144	580 644	80.4%
Average run	270 494	392 121	662 615	86.3%

The Closed Box Solution



Fourth 2^6 experiment

- 6 factors
- 64 experiments
- Effects suggest to move back to high levels
- Stop!

	Ordering	Inventory	Total	Service
Best run	275 000	383 582	658 582	98.5%
Average run	349 996	452 617	802 614	99.9%

Single Factor Design

- Back to Third experiment

Effects	A	B	C	D	E	F
Service L	10.6	10.9	-6.8	-24.6	1.4	8.1
Setting	1	1	-1	-1	1	1

- Factor A and C are end products – Keep them at the recommended levels
- Factor F is on a good level – Experiment 4 gives service level = 100%
- Factor E is kept on recommended levels

Effects	A	B	C	D	E	F
Single	-	Yes	-	Yes	-	-
# Factors	3	2	3	2	4	3

Single Factor Design

- Factor A and B
  - + 1 week for high, -1 week for low
- Factor C and D
  - + 25% for high level, -25% for low level

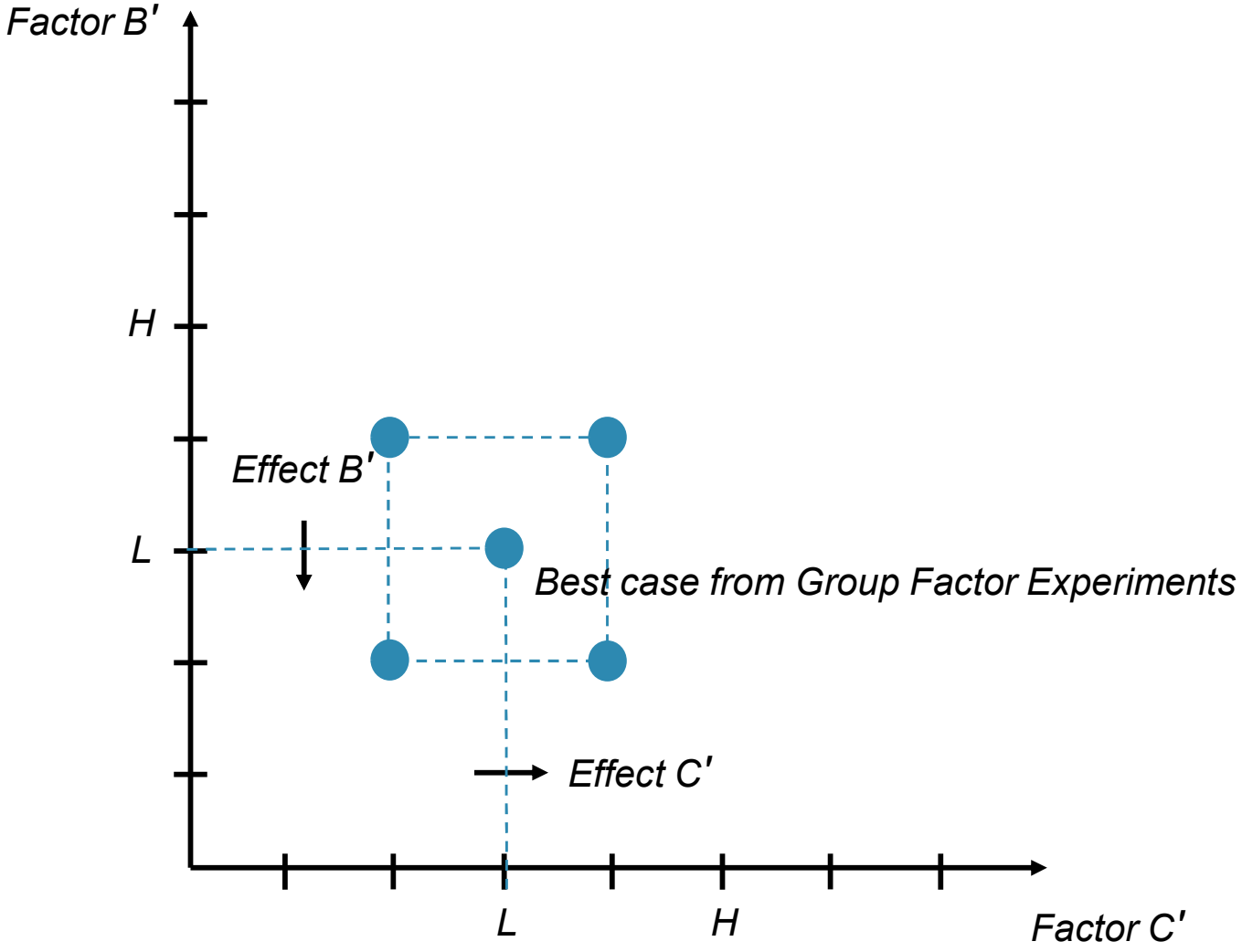
Factor	Design parameters	Product
Factor A'	Planned Lead Time	A4
Factor B'	Planned Lead Time	A5
Factor C'	Order Quantity	A4
Factor D'	Order Quantity	A5

- Follow factors B' and C'

The Closed Box Solution

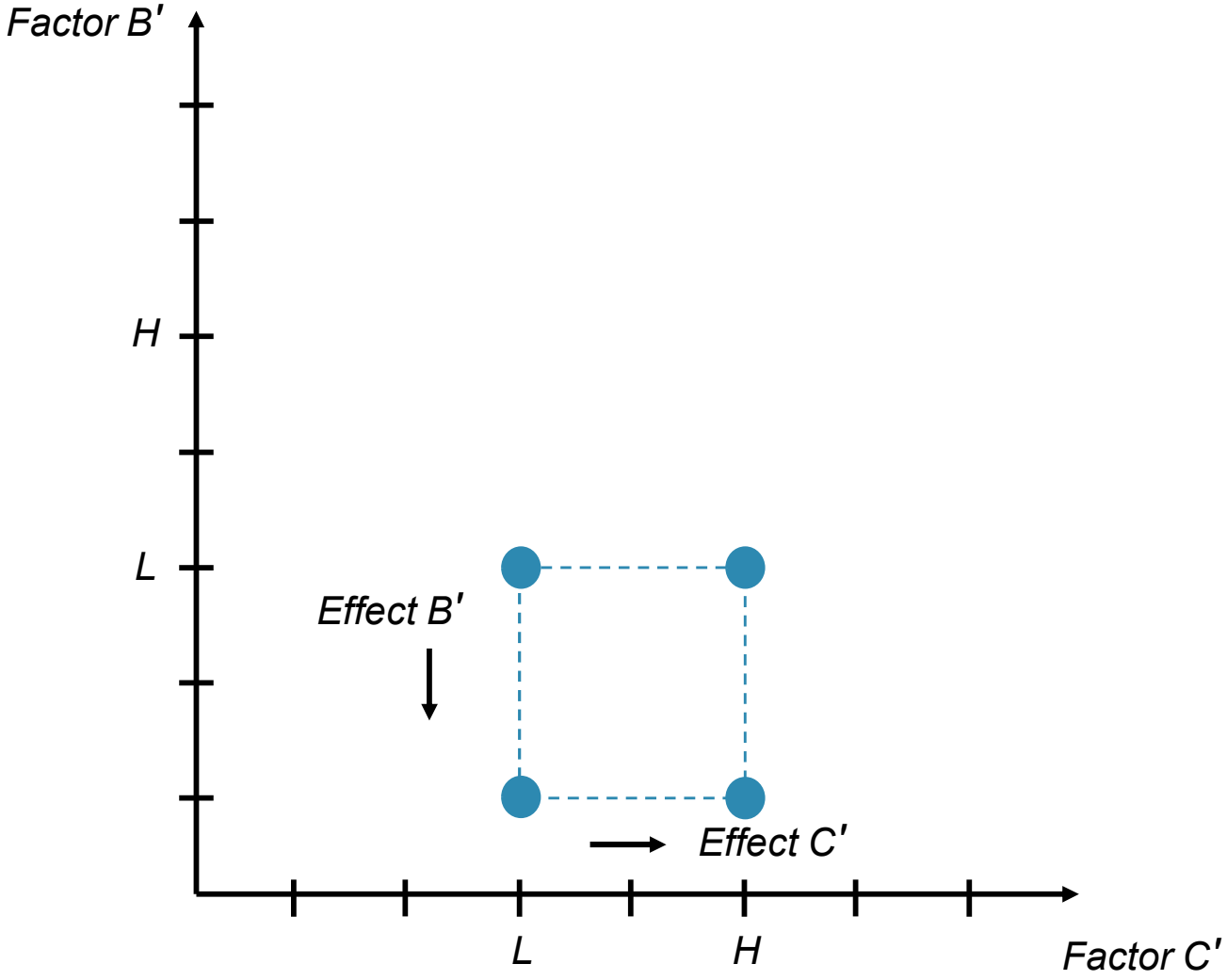
First 2^4 experiment

- 4 factors
- 16 experiments



	Ordering	Inventory	Total	Service
Best run	298 300	387 574	685 874	99.9%
Average run	338 112	399 878	737 990	100.0%

The Closed Box Solution

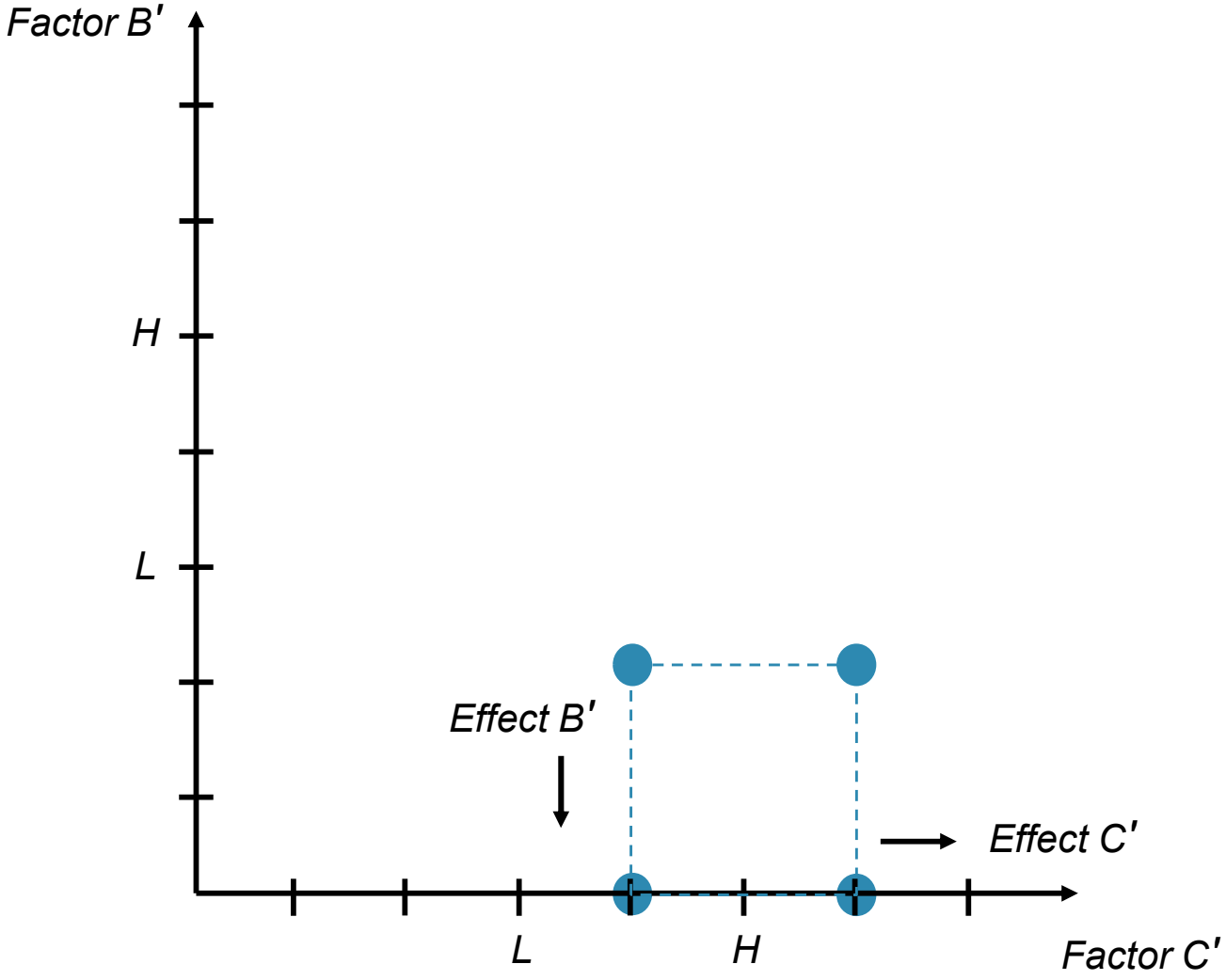


Second 2^4 experiment

- 4 factors
- 16 experiments

	Ordering	Inventory	Total	Service
Best run	284 300	378 192	662 492	99.4%
Average run	287 250	395 636	682 886	81.2%

The Closed Box Solution



Third 2^4 experiment

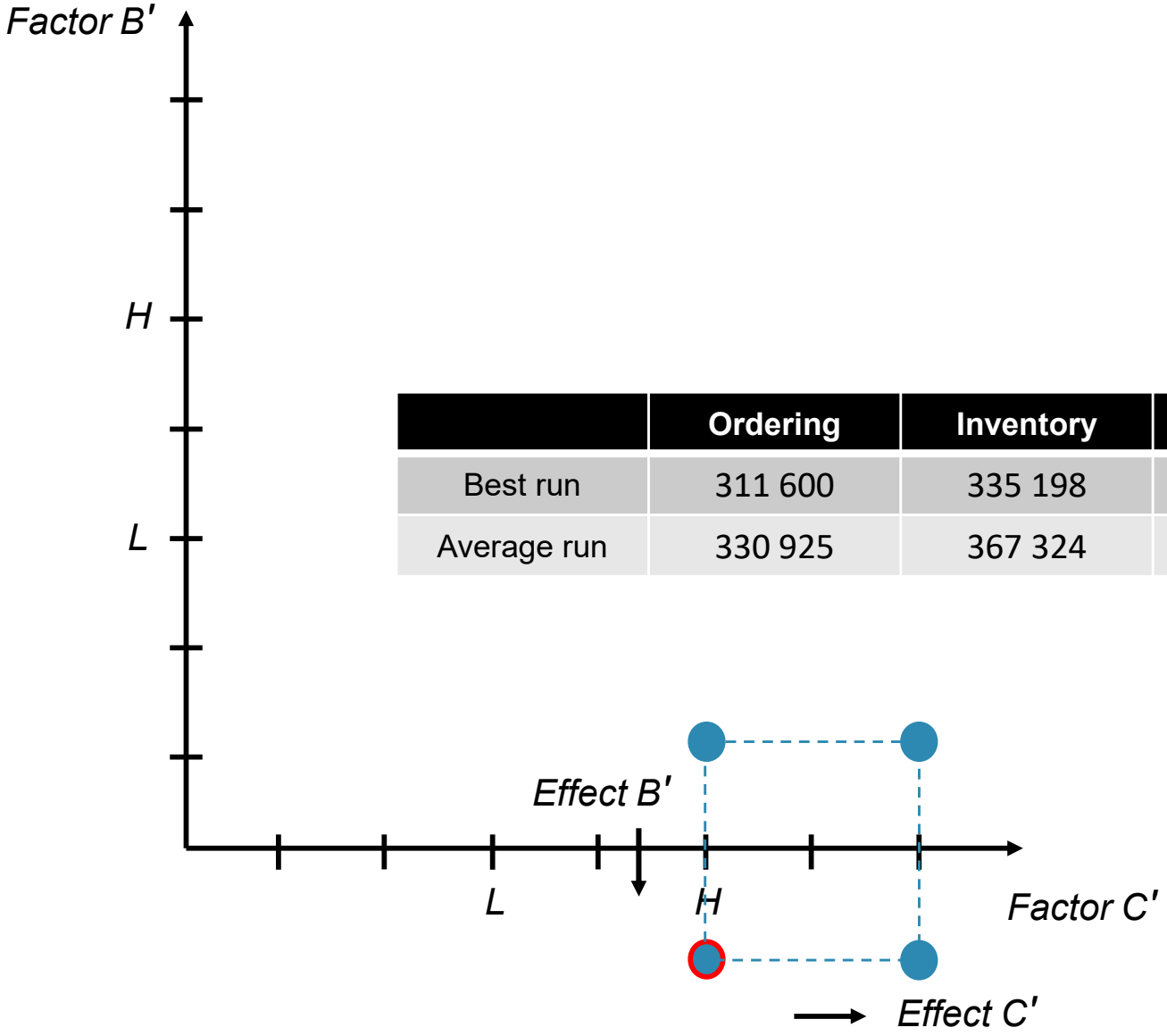
- 4 factors
- 16 experiments

	Ordering	Inventory	Total	Service
Best run	281 300	379 165	660 465	99.7%
Average run	315 562	374 464	690 027	98.8%

The Closed Box Solution

Fourth 2^4 experiment

- 4 factors
- 16 experiments



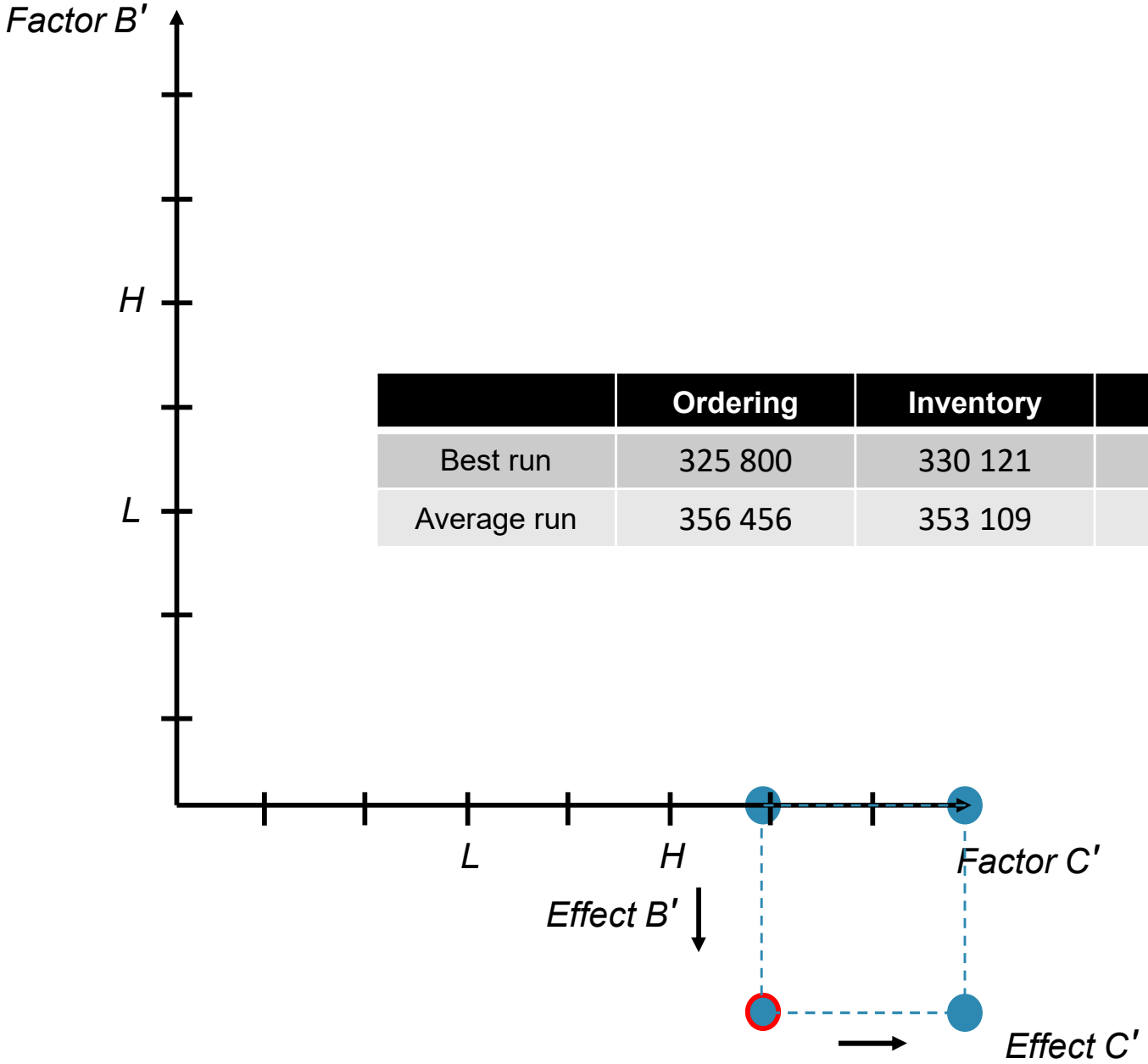
	Ordering	Inventory	Total	Service
Best run	311 600	335 198	646 798	97.3%
Average run	330 925	367 324	698 249	99.4%

The Closed Box Solution

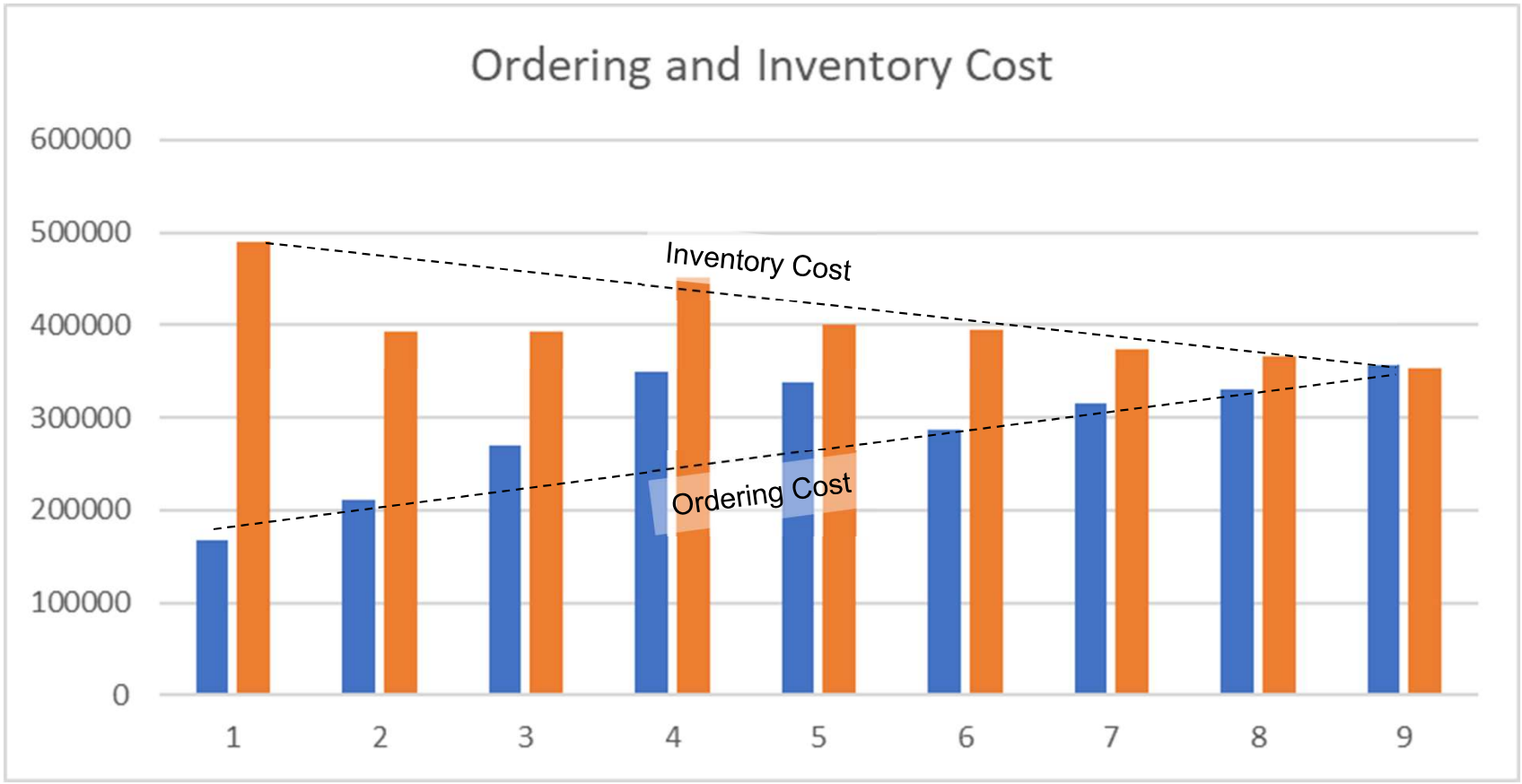
Fifth 2^4 experiment

- 4 factors
- 16 experiments

	Ordering	Inventory	Total	Service
Best run	325 800	330 121	655 921	99.5%
Average run	356 456	353 109	709 566	97.5%



The Closed Box Solution



Comparison

- The Open Box
  - Result in the target range
  - Reasoning and knowledge in planning and system

	Ordering	Inventory	Total	Service
Best run	307 000	333 008	640 008	99.9%

8 runs

- The Closed Box
  - Result in the target range
  - Knowledge in experimental design

	Ordering	Inventory	Total	Service
Best run	311 600	335 198	646 798	97.3%

336 runs

Simple Regression Analysis

- After the Closed Box and additional test runs, a data base of total 784 runs is available
- This opens for Regression Analysis
- For simplicity:
  Linear Regression of Output: Overall Service Level (Total Cost implied)
- Limitations:
  MS Excel maximum of 16 input variables (skip Q A7)

Simple Regression Analysis

- Using the Regression Analysis to find a design

Variable	Value	Medel	Min	Max	Run
Constant	230.5				
LT A1	0.0	3.8	3	6	4
LT A2	-2.4	3.6	3	6	6
LT A3	-5.1	3.8	3	6	4
LT A4	-2.6	5.9	3	8	6
LT A5	-1.9	5.9	3	8	6
Q A1	64.3	250.7	209	408	408
Q A2	6.0	319.3	266	520	319
Q A3	-51.6	350.0	292	570	292
Q A4	0.0	880.2	510	1661	880
Q A5	0.0	1346.0	583	2301	1346
Q A6	-48.4	3184.0	1875	4883	1875
Q A8	55.9	2757.3	1624	4229	4229
Q A9	0.0	2135.4	1258	3275	2135
SS A1	-108.4	318.0	187	488	187
SS A2	-85.1	158.9	94	244	94
SS A3	100.6	477.9	281	733	733

Simple Regression Analysis

Simulation Results									
			Simulation Results						
Group No.	0								
Run No.	1								
Input data									
Product/Item	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lead time	4	6	4	6	6	3	3	3	3
Order quantity	408	319	292	880	1346	1875	319	4229	2135
Safety stock	187	94	733	0	0	0	0	0	0
Costs									
Ordering cost	269600		Total Ordering Cost			269600			
Inventory of raw materials	41277		Total Inventory Cost			364542			
Work in process	183524								
Semi-finished and finished goods inventory	139741								
Total	634142								
Service levels (%)									
Product 1	87.7								
Product 2	100.0								
Product 3	99.5								
Overall	94.9								
Statistics									
Stockouts of finished products	614.50	0.00	40.00						
Average inventory level A1-A9	257.50	292.50	657.50	630.00	611.50	987.00	0.00	2166.00	1704.50
Average actual lead time A1-A5 (weeks)	4.14	4.96	3.58	6.54	8.35				
Average queueing time P1-P5 (hours)	31.57	21.67	23.88	51.55	24.95				
Average load P1-P5 (%)	87.61	67.94	70.97	80.35	74.84				
Inventory turnover rates									
Raw material inventory	19.56								
Work in process	11.14								
Semi-finished and finished goods inventory	14.63								
Total	7.82								

Comparison

- The Open Box
  - Result in the target range
  - Reasoning and knowledge in planning and system

	Ordering	Inventory	Total	Service
Best run	307 000	333 008	640 008	99.9%

8 runs

- The Closed Box
  - Result in the target range
  - Knowledge in experimental design

	Ordering	Inventory	Total	Service
Best run	311 600	335 198	646 798	97.3%

336 runs

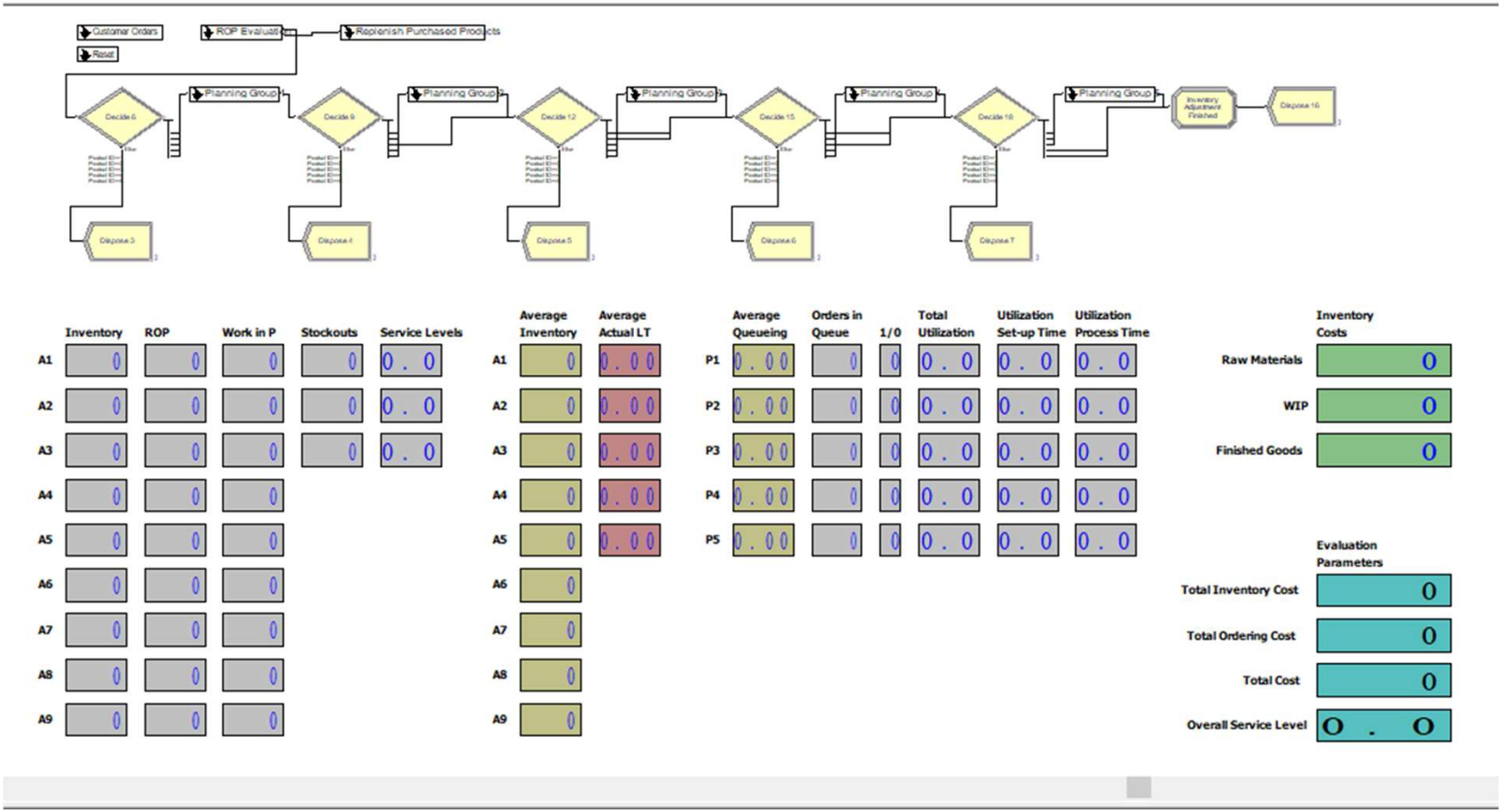
- The Regression Analysis
  - Result close to the target range

	Ordering	Inventory	Total	Service
Best run	269 600	364 542	632 142	94.9%

784 runs

Outlook

- PicSim in Arena 16.0
- All runs with 10 replications
- Animations 2.5D
- Runtime 10 seconds



TPPE74
Design and Development of Manufacturing Operations

Le 7 Part 2

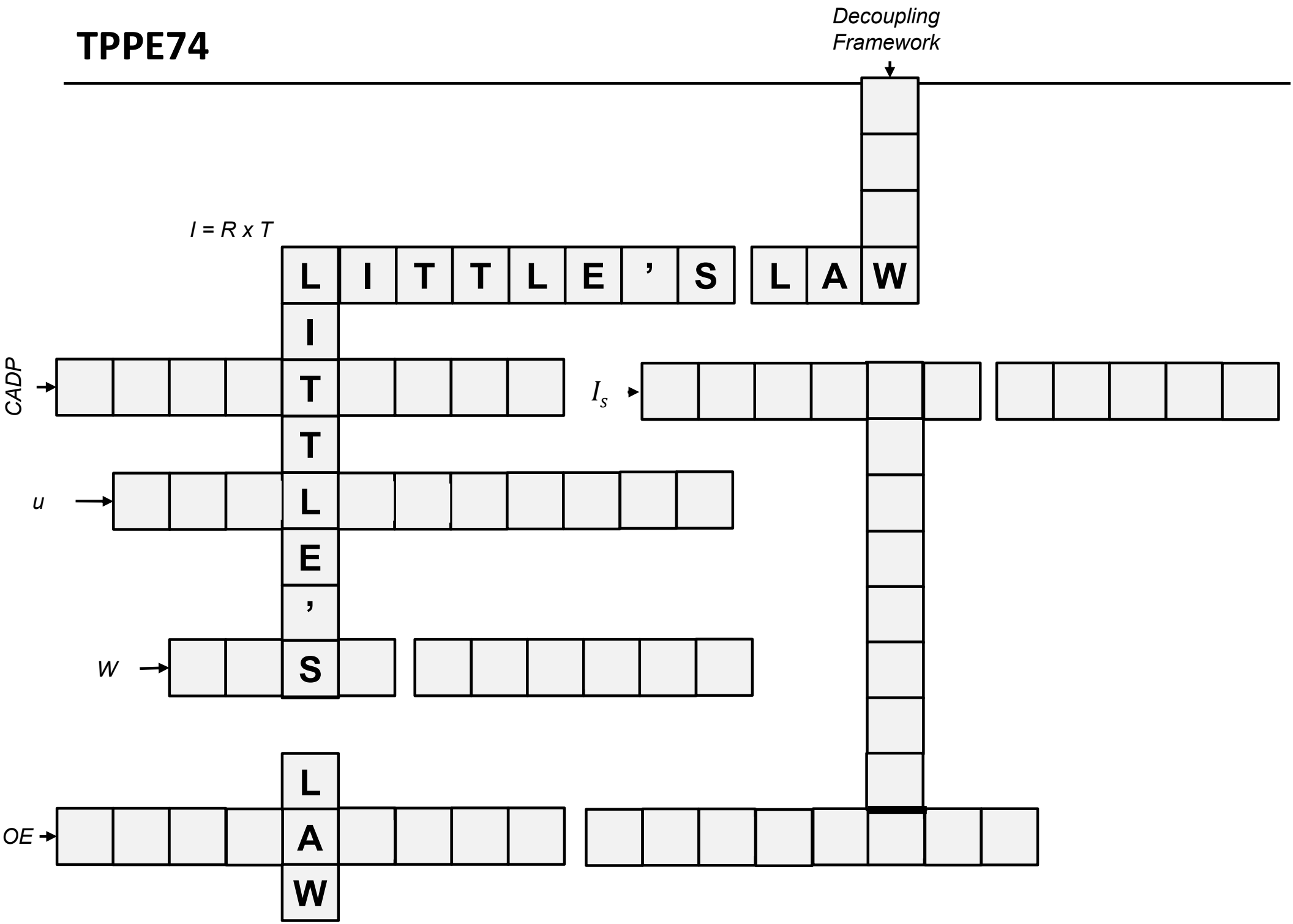
Summary

2021

Content Le 7 Part 2

- Summary of lectures
  - Lecture 1
  - Lecture 3
  - Lecture 4
  - Lecture 5
  - Lecture 6
- Course overview
- Ending

TPPE74

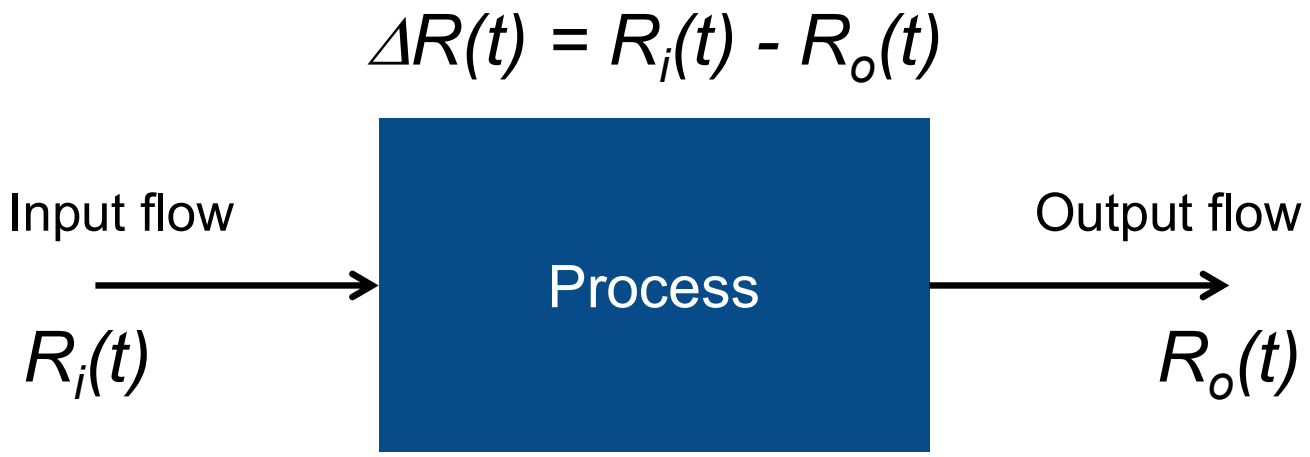

Decoupling Framework
I = R x T
L I T T L E ' S L A W
I
CADP
T
I_s
T
u
L
E
'
W
S
L
OE
A
W

Content Le 1

- Manufacturing strategy as a point of origin
  - Product
  - Process
  - Product-Process Matrix
- Static analysis
  - Flow, time, inventory
  - Little's Law
  - Static analysis using Little's Law
- Introduction to project (PicSim)
  - The Project
  - System analysis
  - Lot size relationships for ROP, MRP, CPS

Flow definitions

- Flow time
  - The total time spent by a flow unit within the process boundaries
  - T = Average Flow Time
- Inventory
  - The total of number of flow units present within the process boundaries
  - I = Average Inventory.
  - $I(t)$ = Inventory at time t
  - $\Delta R(t) = R_i(t) - R_o(t)$ Inventory accumulation rate



Little's Law

Little's Law: $I(t) = R \times T$

Rate $R = I(t) / T$

Takt Time $Takt = 1 / R$

Flow time $T = I(t) / R$

Little's Law (TPPE78)

Little's Law: $L_s = \lambda_{eff} \times W_s$

$L_q = \lambda_{eff} \times W_q$

Rate $\lambda_{eff} = L_q / W_q$

Takt Time $Takt = 1 / \lambda_{eff}$

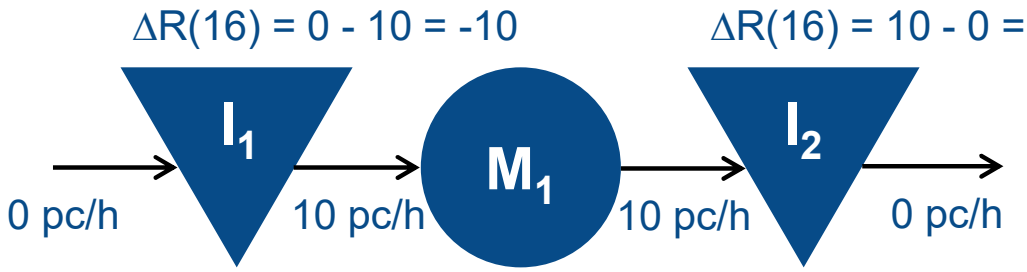
Flow time $W_s = L_s / \lambda_{eff}$

Inventory Turns = R / I(t)

Inventory Turns = 1 / T

Example: Analysis using Little's Law

- Time = 16 h



$\Delta R(0) = R_i(0) - R_o(0)$

$I(t) = I(t-1) + \Delta R(t)$

$T = I(t) / R$

$I_1(0) = 200$
$I_1(1) = 210$
$I_1(8) = 200 + 8 \times 10 = 280$
$I_1(16) = 280 + 8 \times -10 = 200$

$\bar{I}_1 = 200 + 80/2 = 240$

$R_i = (20 + 0) / 2 = 10$ pc/h

$T_1 = 240/10 = 24$ h

$I_2(0) = 200$
$I_2(1) = 190$
$I_2(8) = 200 + 8 \times -10 = 120$
$I_2(16) = 120 + 8 \times 10 = 200$

$\bar{I}_2 = 200 - 80/2 = 160$

$R_o = (20 + 0) / 2 = 10$ pc/h

$T_2 = 160/10 = 16$ h

$R_i = R_o$

Is this a **stable process**?
A stable process is one in which, in the long run, the average inflow rate is the same as the average outflow rate.

Average Lead Time = $T_1 + 1/R_s + T_2 = 24 + 1/10 + 16 = 40.1$ h

Content Le 2

- Little's Law
  - Inventory (I) = Flow rate (R) x Flow time (T)
- Flow time (T)
  - Process Flowchart
  - Flowcharts and critical paths
  - Theoretical flow time and waiting
  - Flow time efficiency
  - Value adding and non-value adding activities
- Flow rate (R)
  - Resources and capacity
  - Capacity utilization and Theoretical capacity
  - Throughput and bottlenecks
- Inventory (I)
  - Inventory costs
  - Economic order quantity, special case of production rate
  - Periodic ordering, special case of periodic production - Cyclic planning

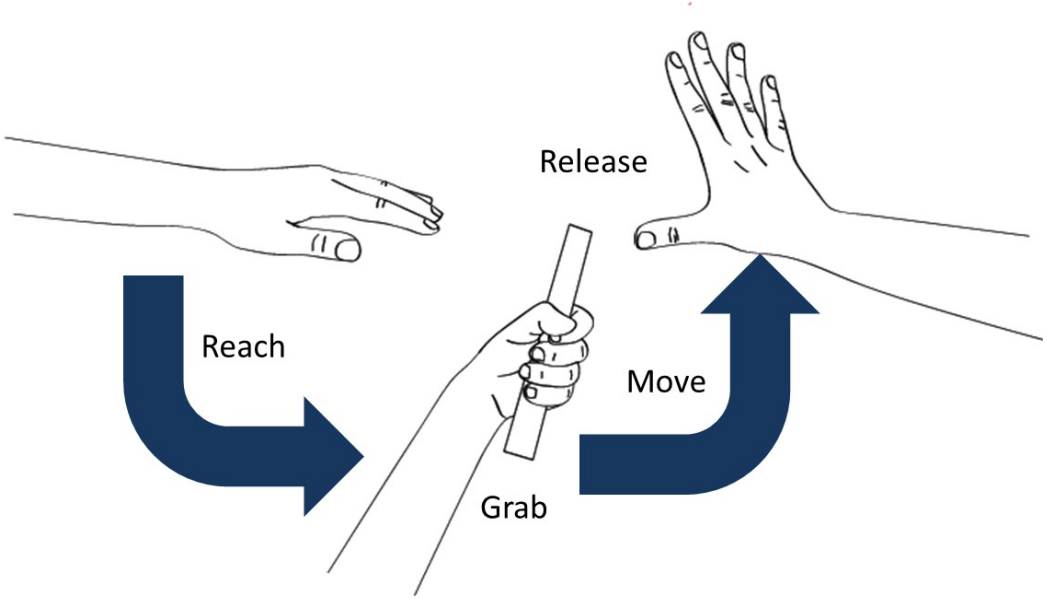
Flow Time Measurements

- Direct observation
  1. Observe the process over a specified, extended period of time
  2. Select a random sample of **Flow Units** over the specified period
  3. Measure the **Flow Time, from entry to exit, of each Flow Unit in the sample**
  4. Compute the average of the **Flow Times measured**
- Application of Little's Law (I = R x T) measure Inventory
  1. Observe the process over a specified, extended period of time
  2. Select a random sample of **points of time** during the specified period
  3. Measure the **actual Inventory within the system boundaries at each point in time in the sample**
  4. Compute the average of the **Inventory values measured**
- Note: The Process must be carefully specified

Other approaches to Flow Time Measures

MTM

- Methods-Time Measurement (MTM)
  - Developed from Elementary time systems (Gilberth)
- A tool to measure work (Flow Time)
  - The dominating time measurement tool in 1950 – 1970
  - Each movement is identified and has a normal time associated
  - Time is measured in Time Measurement Units (TMU)
  - 1 hour = 100,000 TMU, 1 TMU = 36 milliseconds
  - Makes the working time measurable even independent of who is doing the work



Effective capacity (EC)

- Unit Load (T) of Resource Unit
  - The average amount of time required by the resource unit to process one Flow Unit
- Effective capacity (EC)
  - The inverse of Unit Load

$$EC = \frac{1}{T}$$

- Effective capacity of a Resource pool (c number of resources)
  - The sum of all Effective capacities of all resource units in the pool

$$EC\ of\ resource\ pool\ i = EC_i = c_i \frac{1}{T_i}$$

Capacity Utilization (u)

- Bottleneck
  - The “slowest” resource pool in a process
- Effective capacity (EC) of a process
  - The effective capacity of the bottleneck
- Capacity Utilization (u)
  - Indicates to which extent the resources are utilized to generate Throughput (R)

$$u_i = \frac{R}{EC_i}$$

Theoretical Capacity

- Capacity Waste Factor (CWF)
  - CWF is a percentage of how much capacity is wasted in e.g. rework and non-value-adding activities

$$Theoretical\ Capacity = \frac{EC}{(1 - CWF)}$$

$$Throghput \leq Capacity \leq Theoretical\ Capacity$$

- Theoretical Capacity Utilization
  - Throughput (R) compared to Theoretical Capacity

Measuring Capacity Utilization

Work Sampling

- The statistical technique for determining the proportion of time spent by resources in various defined categories of activity (utilization)
- Basic method of Work Sampling
  - Identify and define the categories of activity
  - Sample a set of random points in time where observations are to be made
  - Calculate the occurrence percentage of each activity

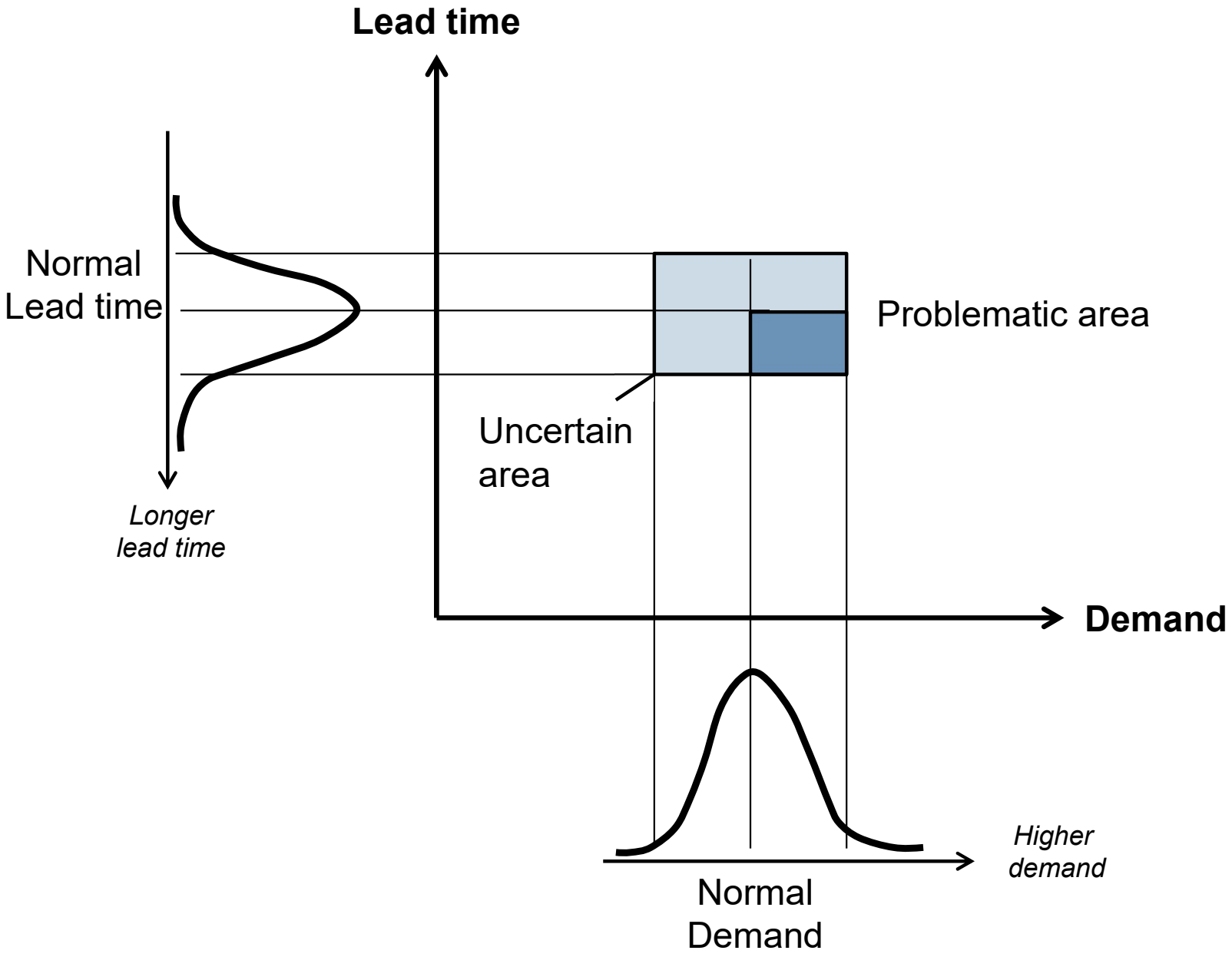
Machine Work Sampling

Activity	*Frequency*	*Percentage*
Processing	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 III	33%
Waiting for operator	𝍸 I	6%
Setup	𝍸 𝍸 𝍸 𝍸 IIII	24%
Waiting for setup	𝍸 III	8%
Waiting for material	𝍸 II	7%
Broken	III	3%
Waiting for repair	𝍸 𝍸 II	12%
Being repaired	𝍸 II	7%
Total	100	100%

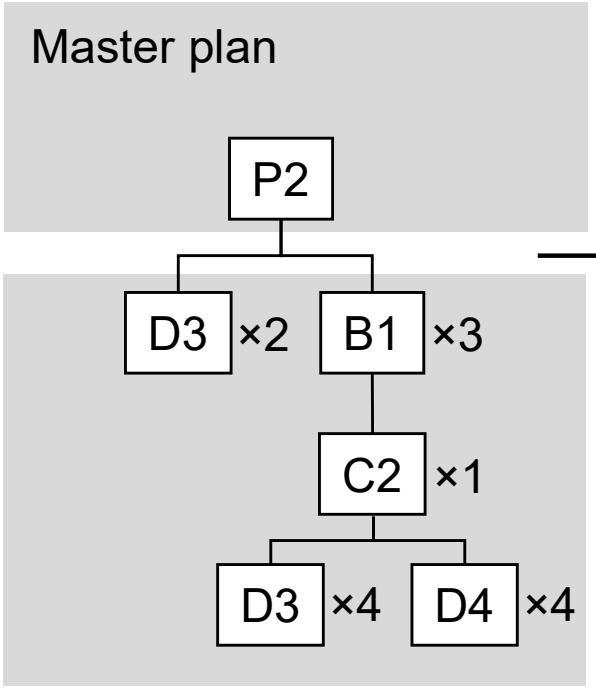
Content Le 3

- Safety Stock (MTS)
  - Definitions of service levels and the ”SERV” concepts
  - Uncertainties in demand and lead time
  - SERV1
  - Usage of Safety Stock
- Safety Capacity (MTO)
  - Uncertainties in capacity
  - Capacity utilization
  - Inventory and capacity

SERV1: Uncertainty in Demand and Lead Time



Usage: Where is Safety Stock used?



Data	Is SS needed?
$Q_{P2} = 100$	Depends on Forecast or Demand
	Depends on BOM and uncertainties
$Q_{B1} = 300$	$SS_{B1} = \{3xQ_{P2}, 0\}$
$Q_{D3} = 900$	$SS_{D3} = \{2xQ_{P2}, 0\}$
$Q_{C2} = 400$	$SS_{C2} = \{Q_{B1}, 0\}$
$Q_{D4} = 900$	$SS_{D4} = \{4xQ_{C2}, 0\}$
$Q_{D3} = 600$	$SS_{D3} = \{4xQ_{C2}, 2xQ_{P2}, 0\}$

Queuing system with single server

$$E(L_q) = \frac{u^2}{1-u} \times \frac{C_i^2 + C_p^2}{2}$$

$$E(W_q) = \frac{u}{1-u} \times \frac{C_i^2 + C_p^2}{2} \times t$$

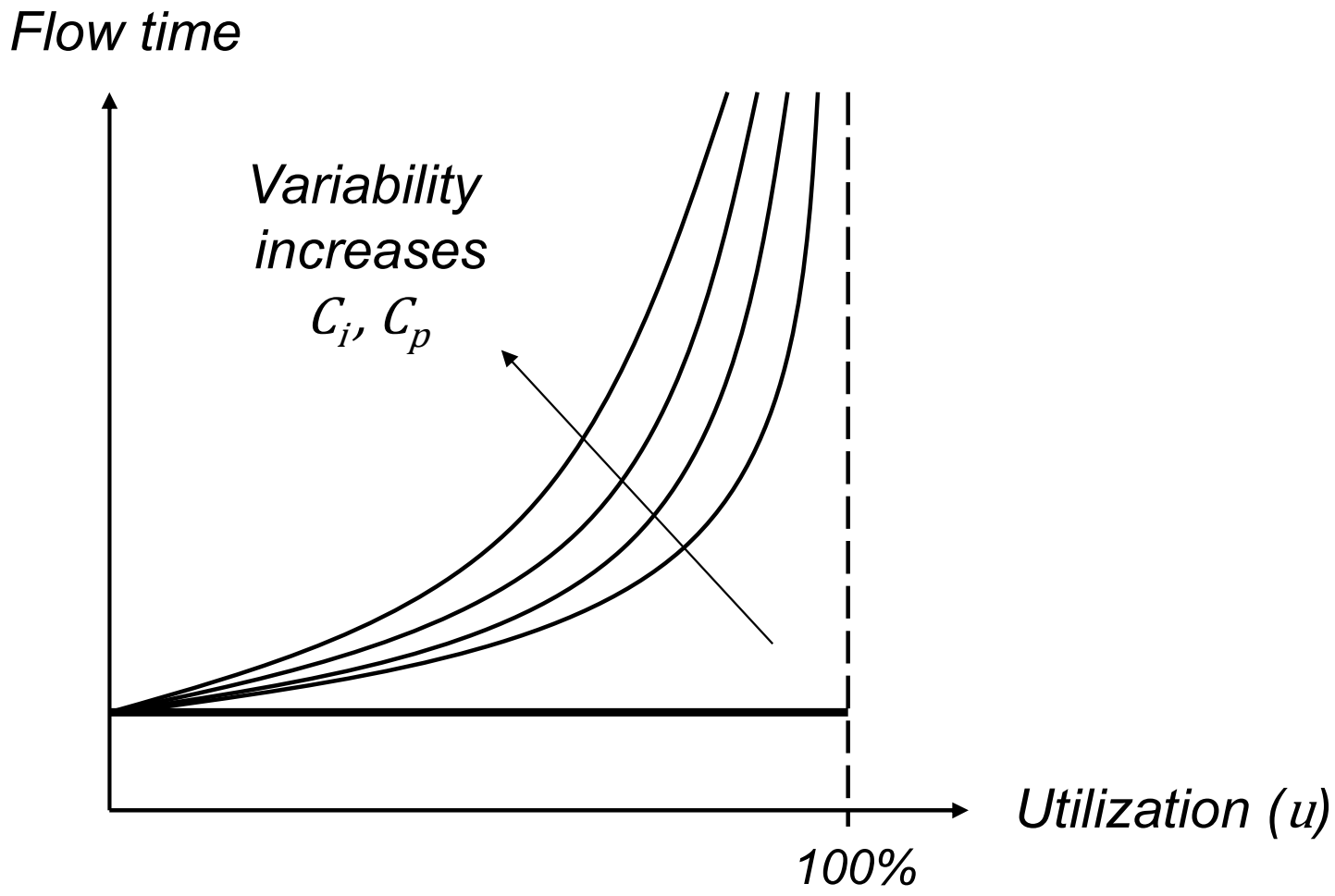
u = utilization

t = average processing time

C_i = coefficient of variation for the time between arrivals

C_p = coefficient of variation for the service time

Relationship between flow time and utilization



Kingman equation and Lean

$$E(W_q) = \frac{u}{1-u} \times \frac{C_i^2 + C_p^2}{2} \times t$$

Capacity utilization (u)

$$u = \frac{R}{EC} = \frac{Demand(real, failure, rework)}{1/(activity\ time + waste)}$$

System variation (C)

Arrival variation, by customers or demand
Process variation, by different processing times

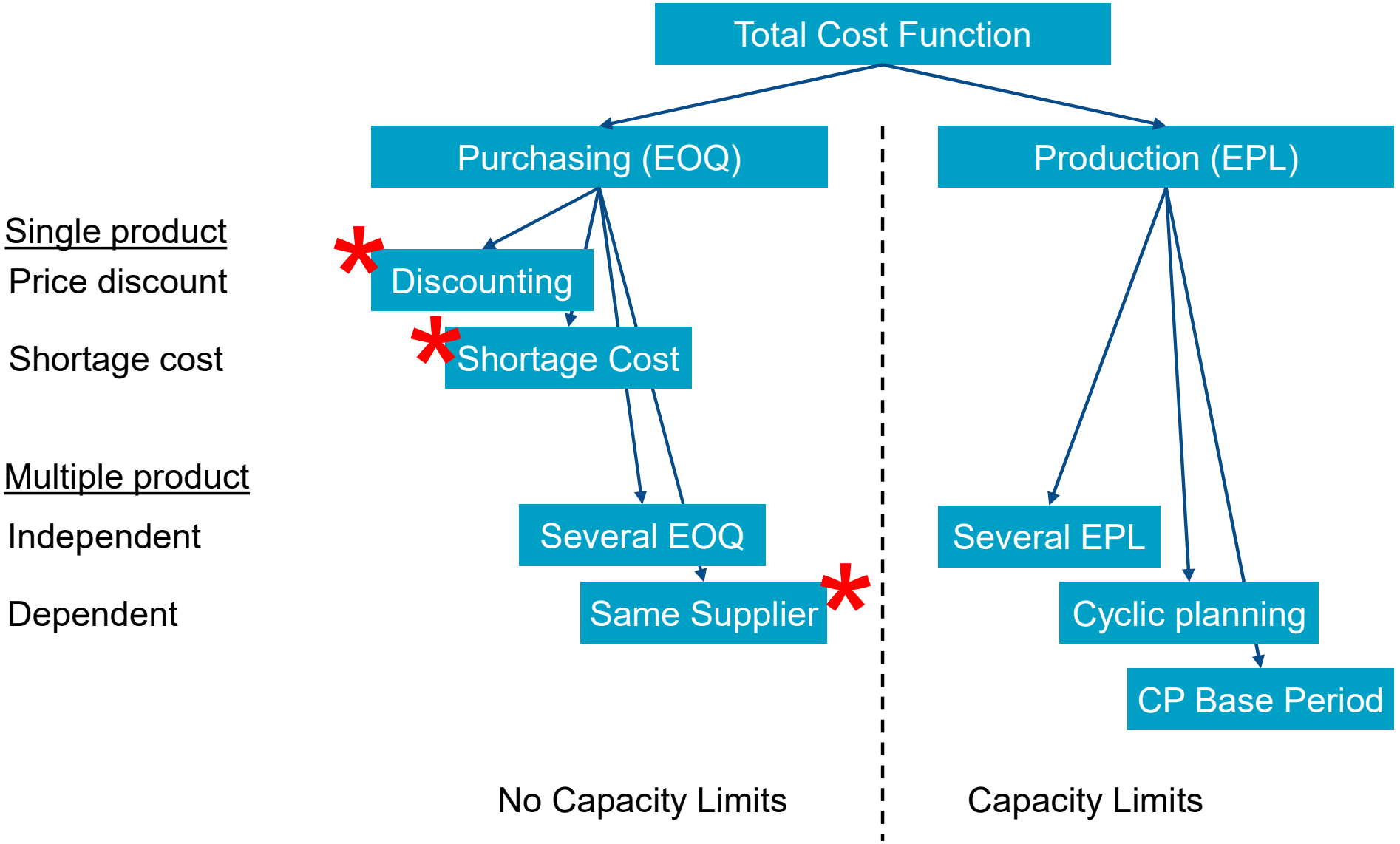
Variation can be related to the customer (value adding) or self-created (non value adding)

Highligths the need for waste and variation reduction: *Muda, Muri, Mura*

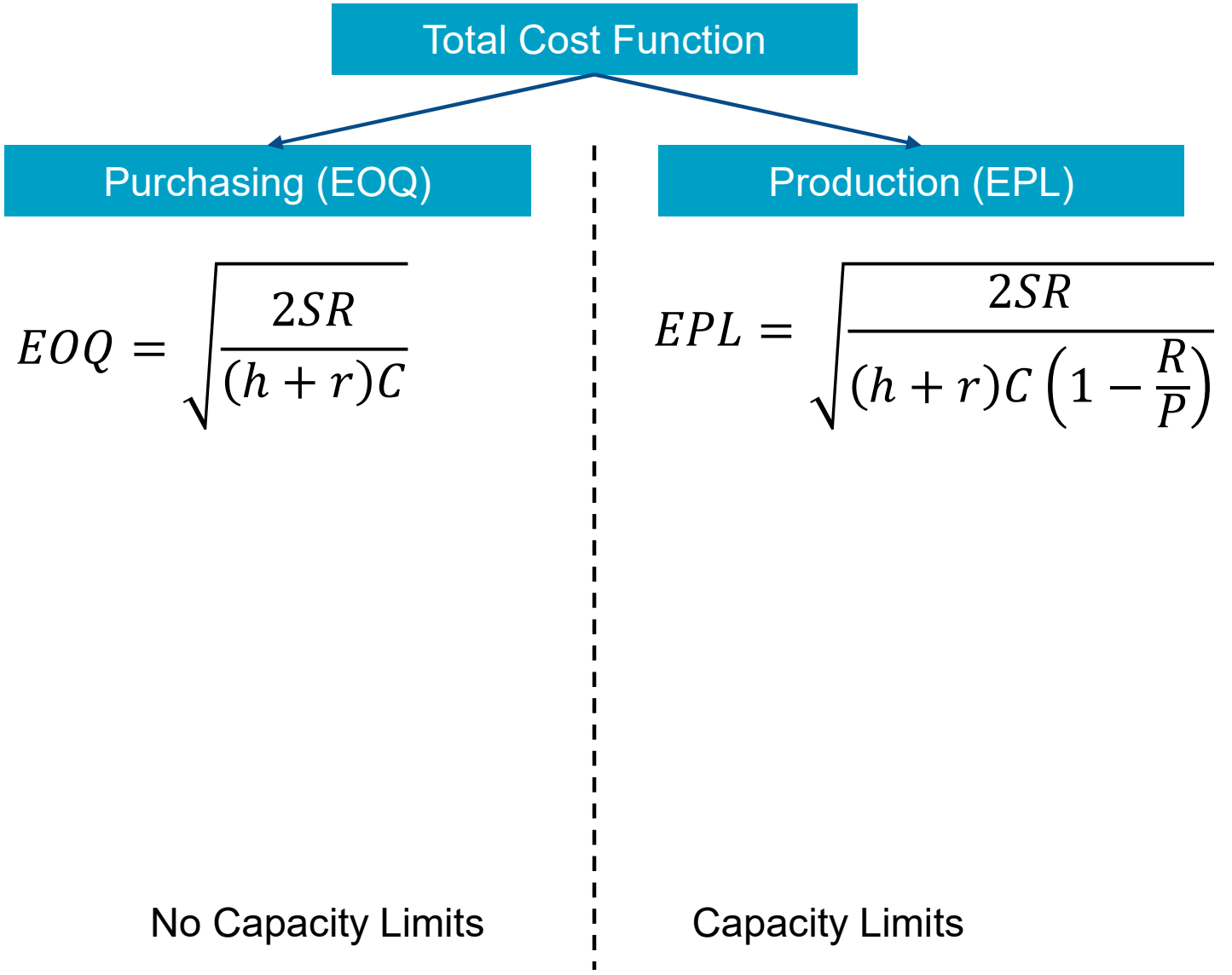
Contents Le 4

- Economic Order Quantity
  - Total Cost Function
  - The EOQ Tree
  - Variants of EOQ
- Flow Thinking Framework
  - System Perspective
  - Strategic Lead Times
  - Decoupling Points
  - Flow Thinking Framework

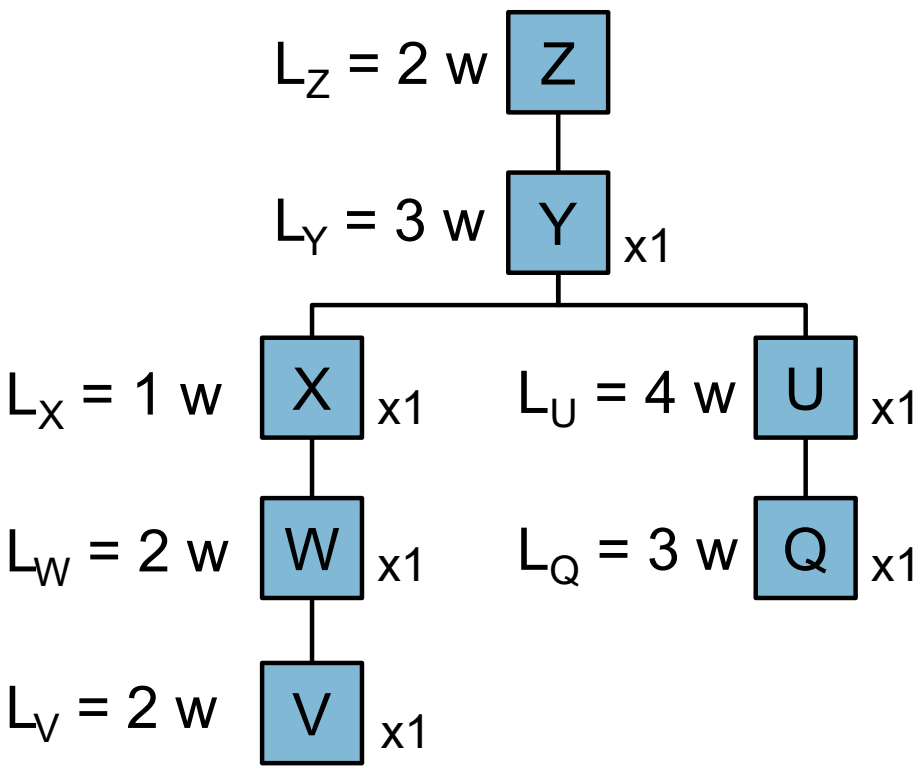
The EOQ tree

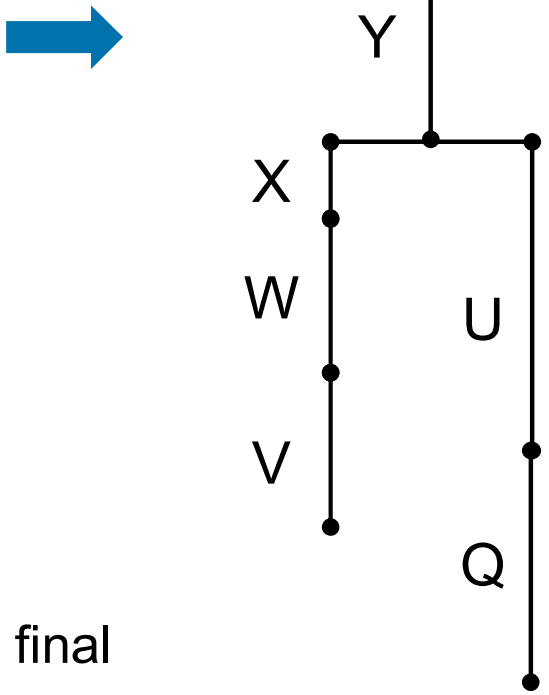

Total Cost Function
Purchasing (EOQ)
Production (EPL)
Single product
Price discount
Discounting
Shortage cost
Shortage Cost
Multiple product
Independent
Several EOQ
Several EPL
Dependent
Same Supplier
Cyclic planning
CP Base Period
No Capacity Limits
Capacity Limits

The EOQ tree


Total Cost Function
Purchasing (EOQ)
Production (EPL)
$EOQ = \sqrt{\frac{2SR}{(h+r)C}}$
$EPL = \sqrt{\frac{2SR}{(h+r)C\left(1-\frac{R}{P}\right)}}$
No Capacity Limits
Capacity Limits

Example: Flow Mapping

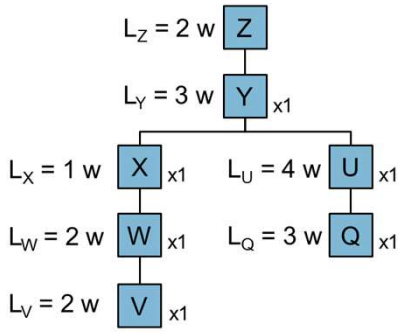


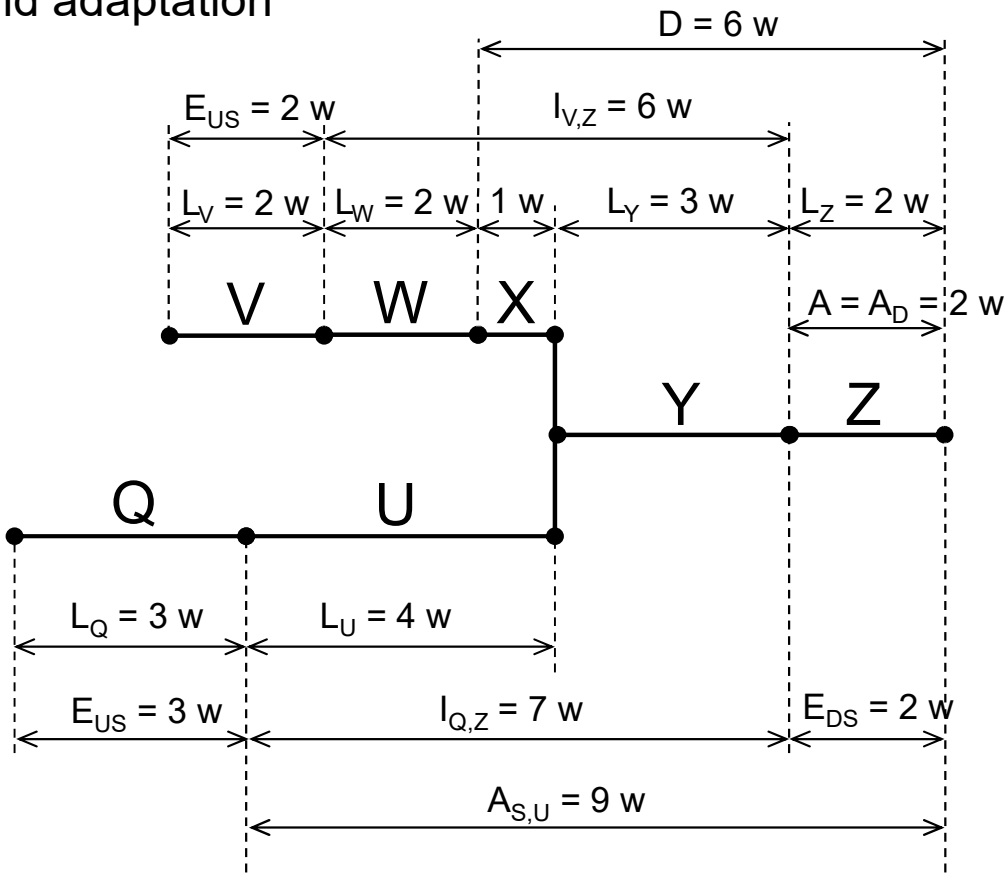


- End product Z is sold MTO/ATO with a final customer adaptation in the last step of processing (from Y to Z)
- End product adaptation is done in a special department
- Components V and Q are purchased from external suppliers

Example: Flow Mapping

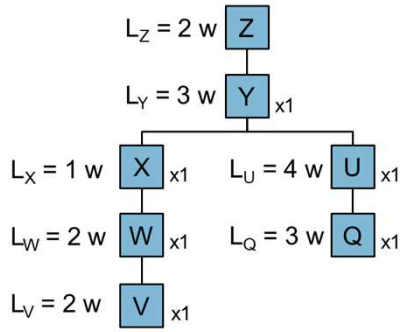
- Step 2: Lead Time mapping …
  - Adapt lead time (A)
    A_S = supply adaptation and
    A_D = demand adaptation

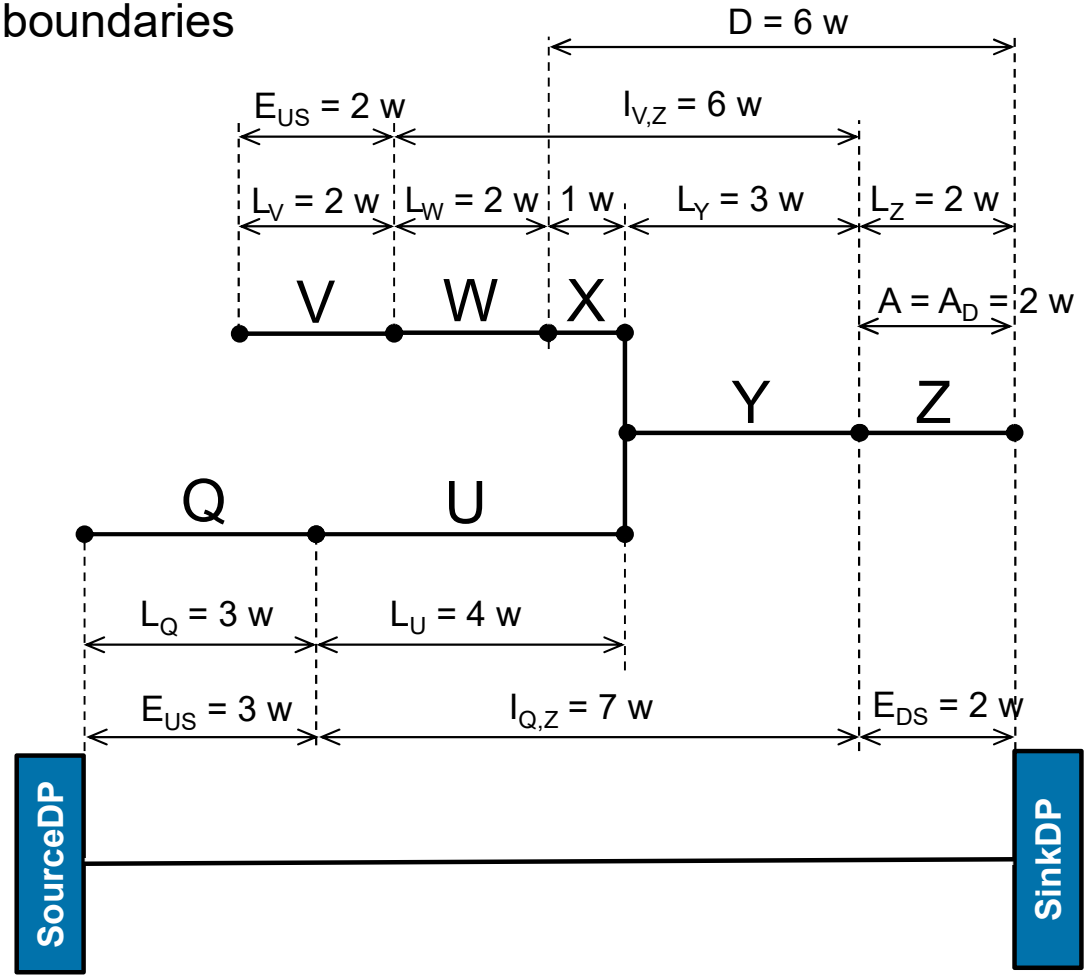




Example: Flow Mapping

- Step 4: External boundaries of a flow system (B1a and B1b)
  - Source Decoupling Point
  - Sink Decoupling Point
  - System boundaries



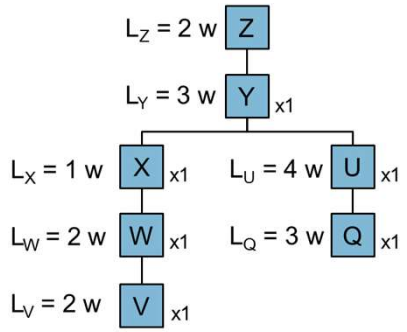


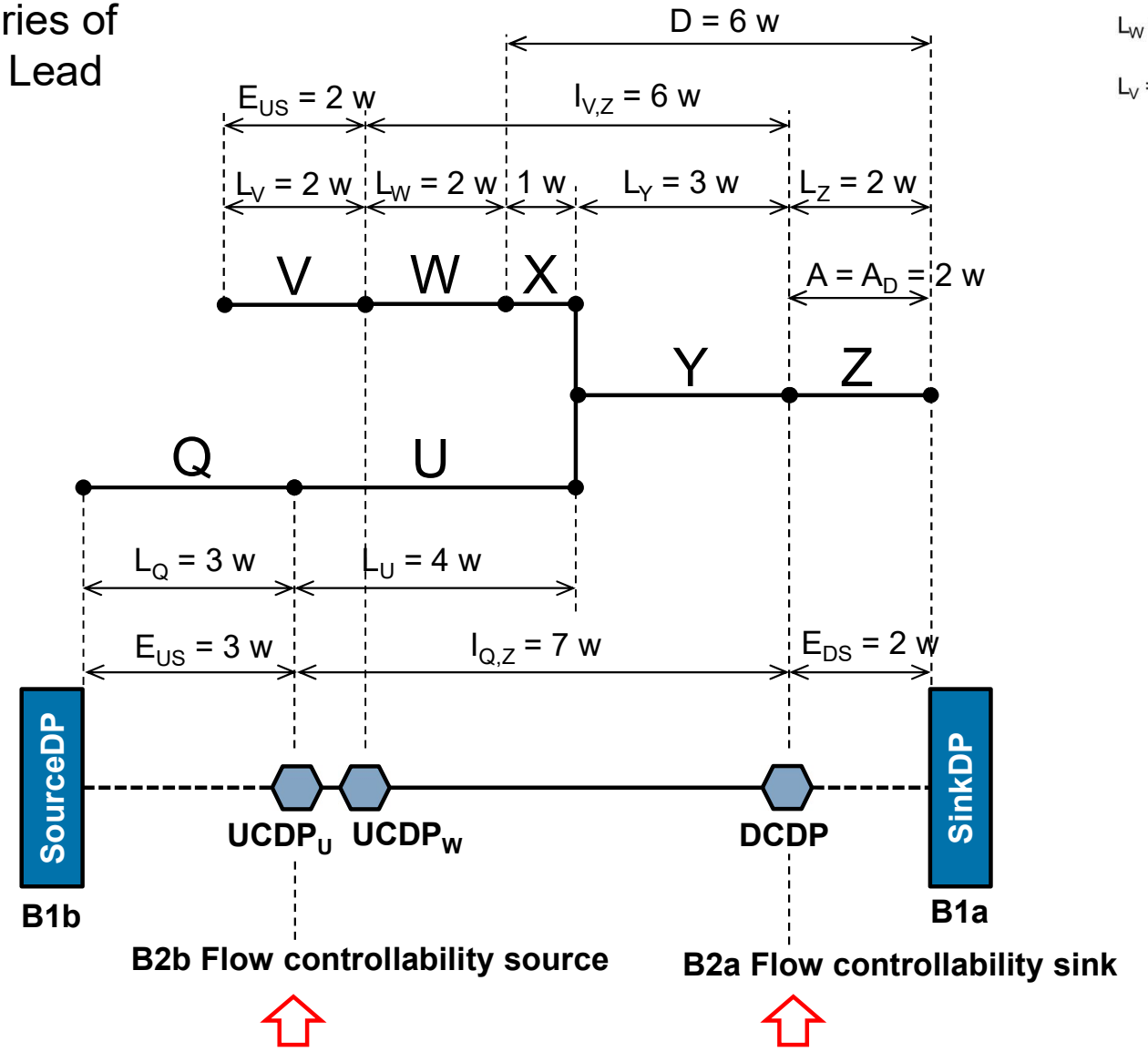
B1b Flow boundary source

B1a Flow boundary sink

Example: Flow Mapping

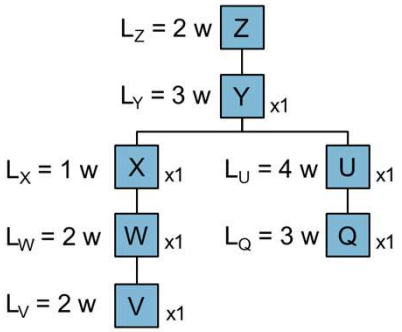
- Step 5: Controllable part of a flow system (B2a and B2b)
  - Upstream Controllability Decoupling Point (UCDP)
  - Downstream Controllability Decoupling Point (DCDP)
  - Boundaries of Internal Lead Times

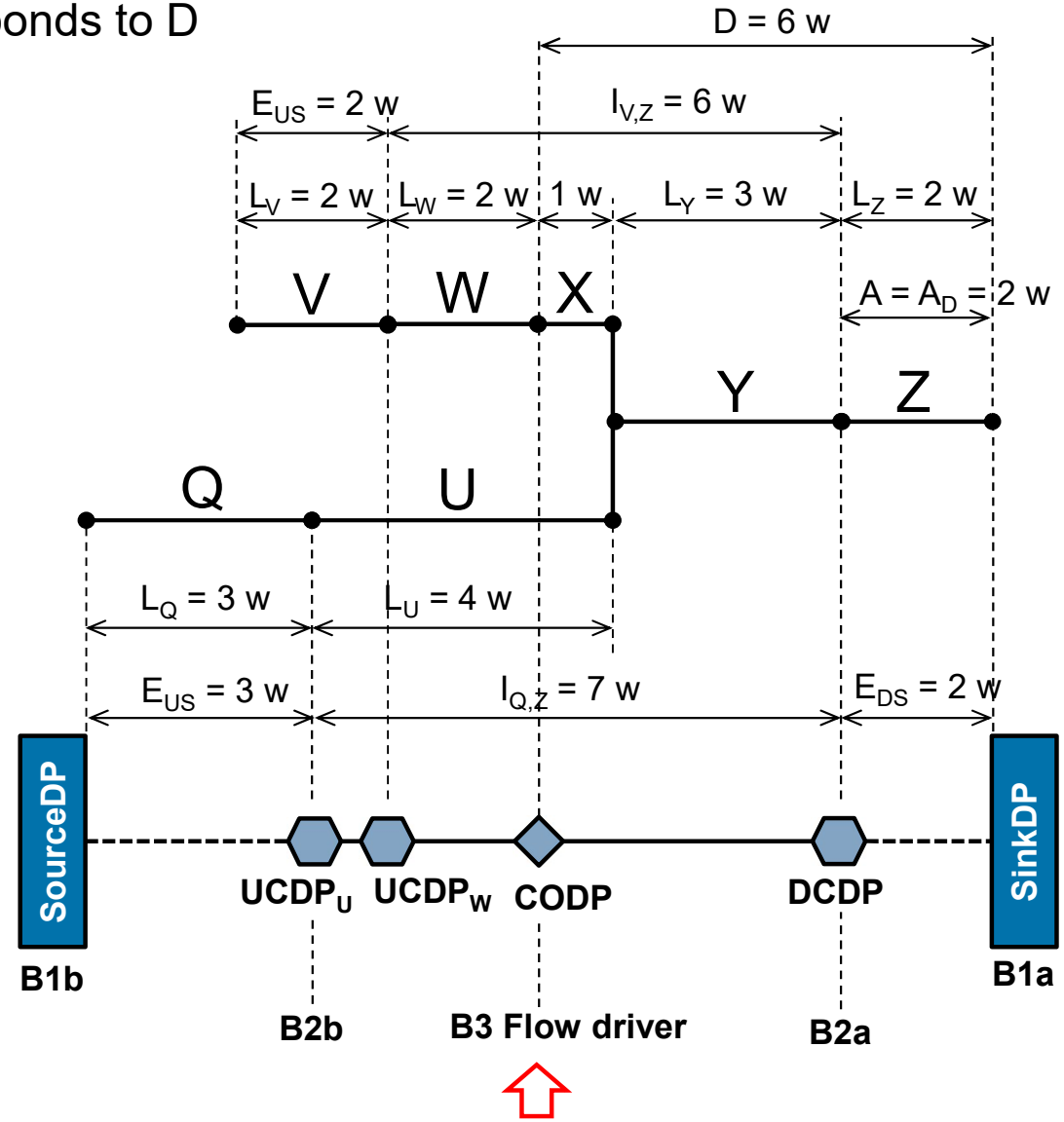




Example: Flow Mapping

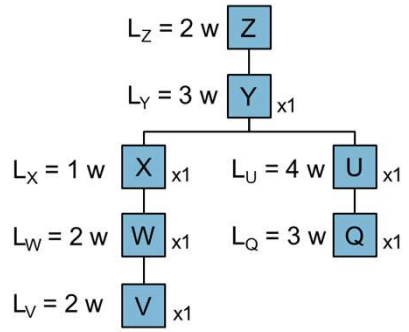
- Step 6: Driver of a flow (B3)
  - Flow driver is what drives the flow (CODP)
  - Speculation or Customer orders
  - Corresponds to D

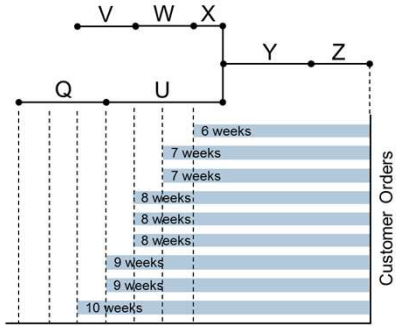


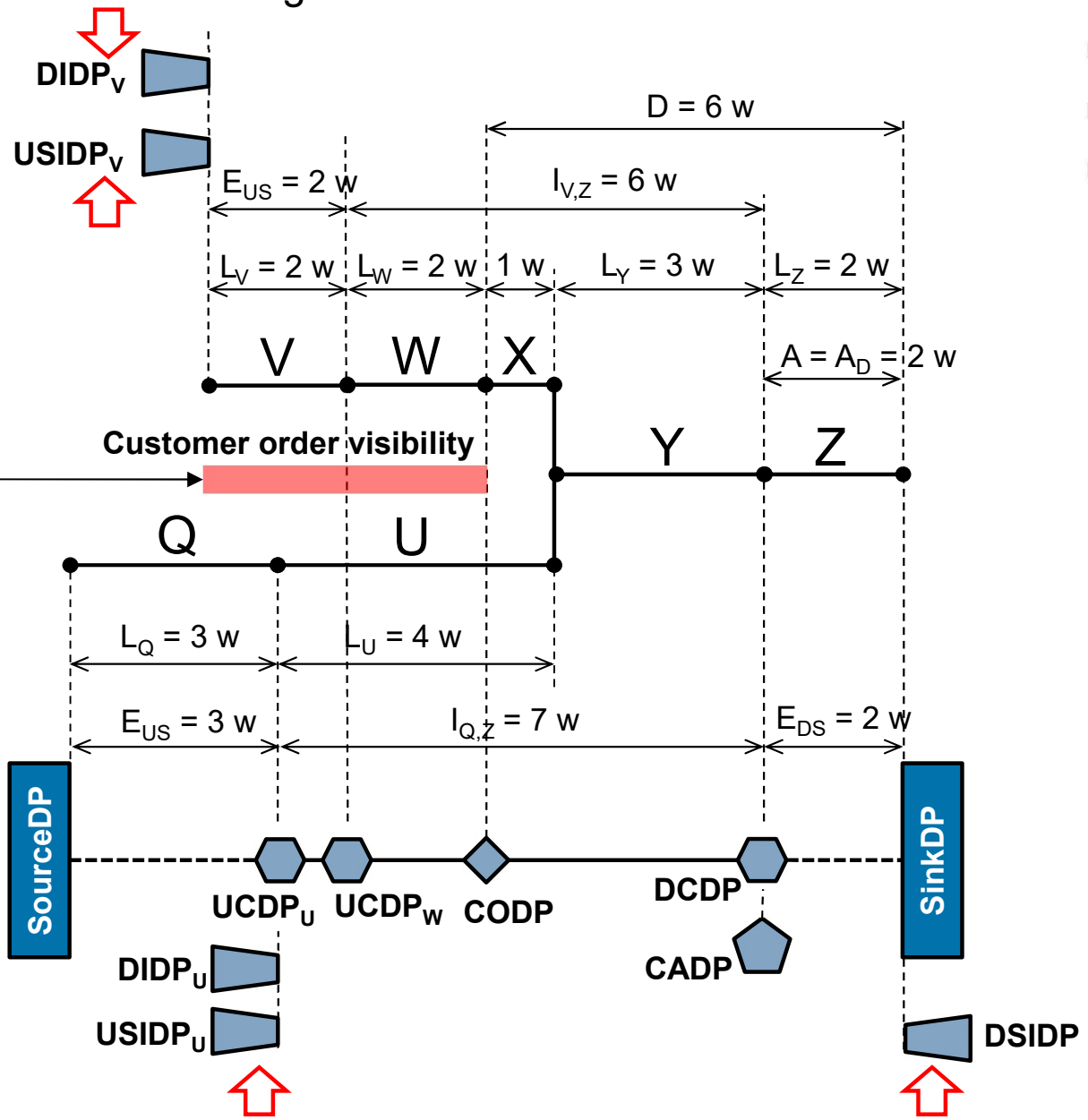


Example: Flow Mapping

- Step 8: Information shared in a flow (B5a, B5b and B5c)
  - Customer orders as long as 10 weeks in advance





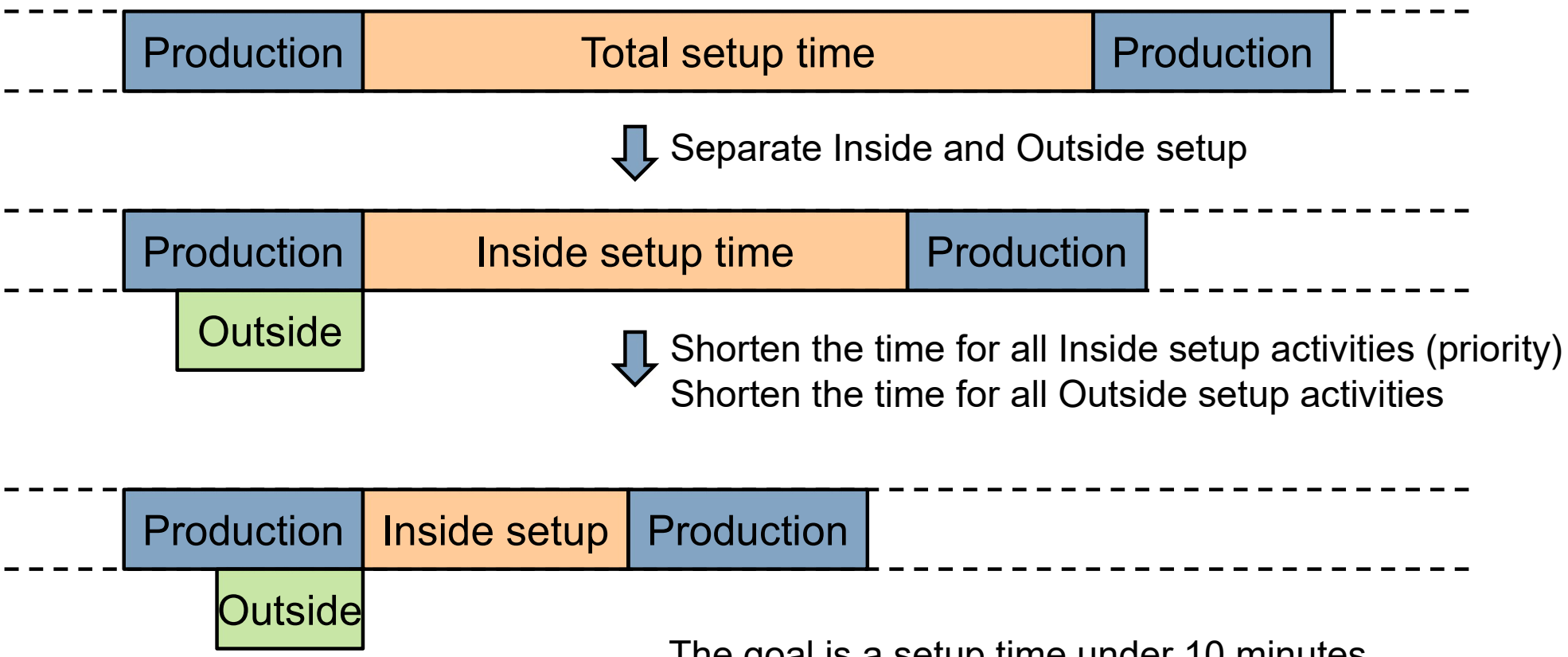


Contents Le 5

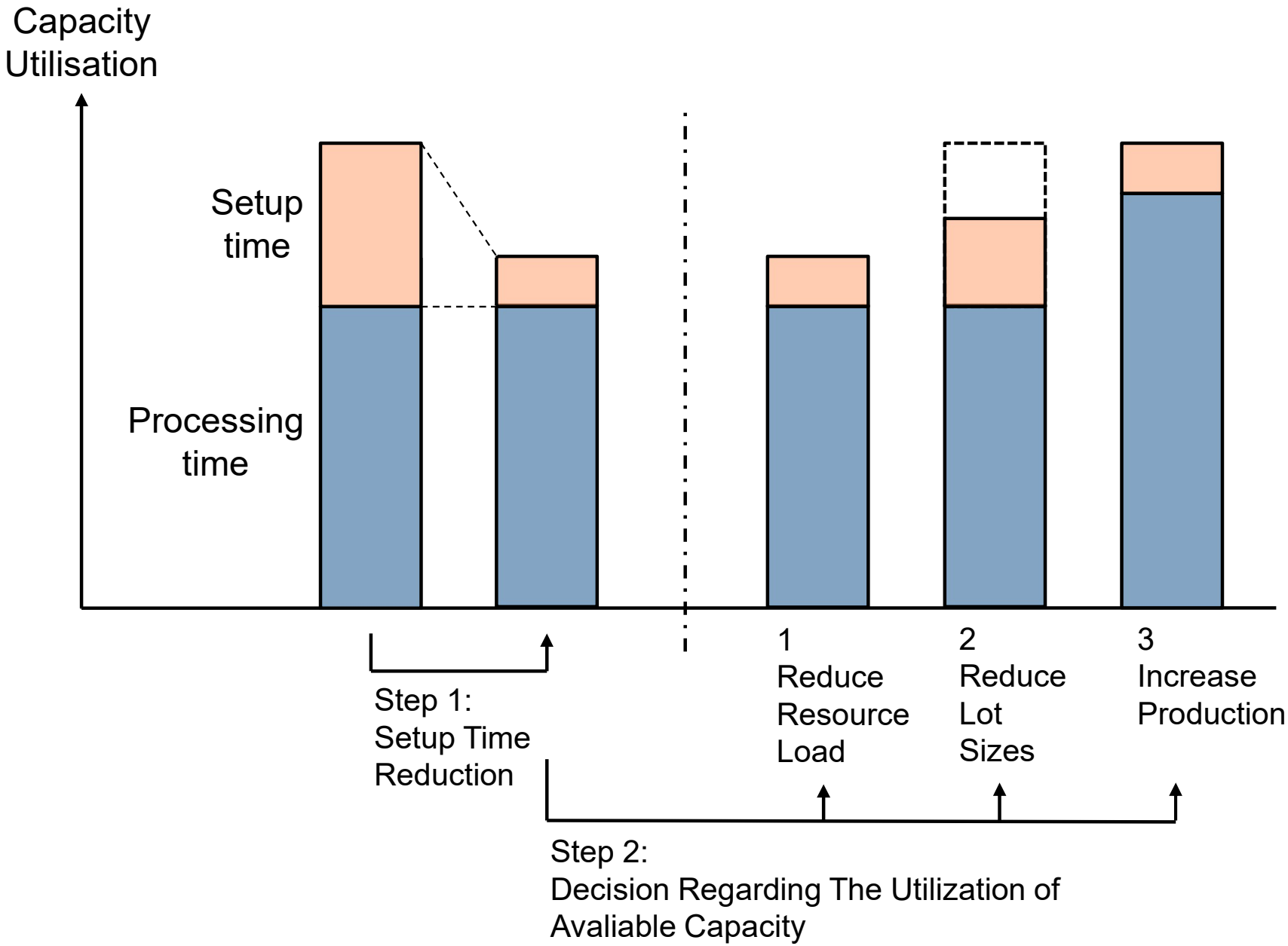
- Setup and Setup Time Definition
- History of setup time
- Setup Time Reduction
  - SMED
  - SMED example
  - OTED
- Effects of Setup Time Reduction
  - Lead times
  - Capacity
  - Order quantities
  - Total cost
- Ordering Cost – Setup Cost
- Setup Time Reduction
  - EOQ model
  - Cyclic Planning Model

SMED

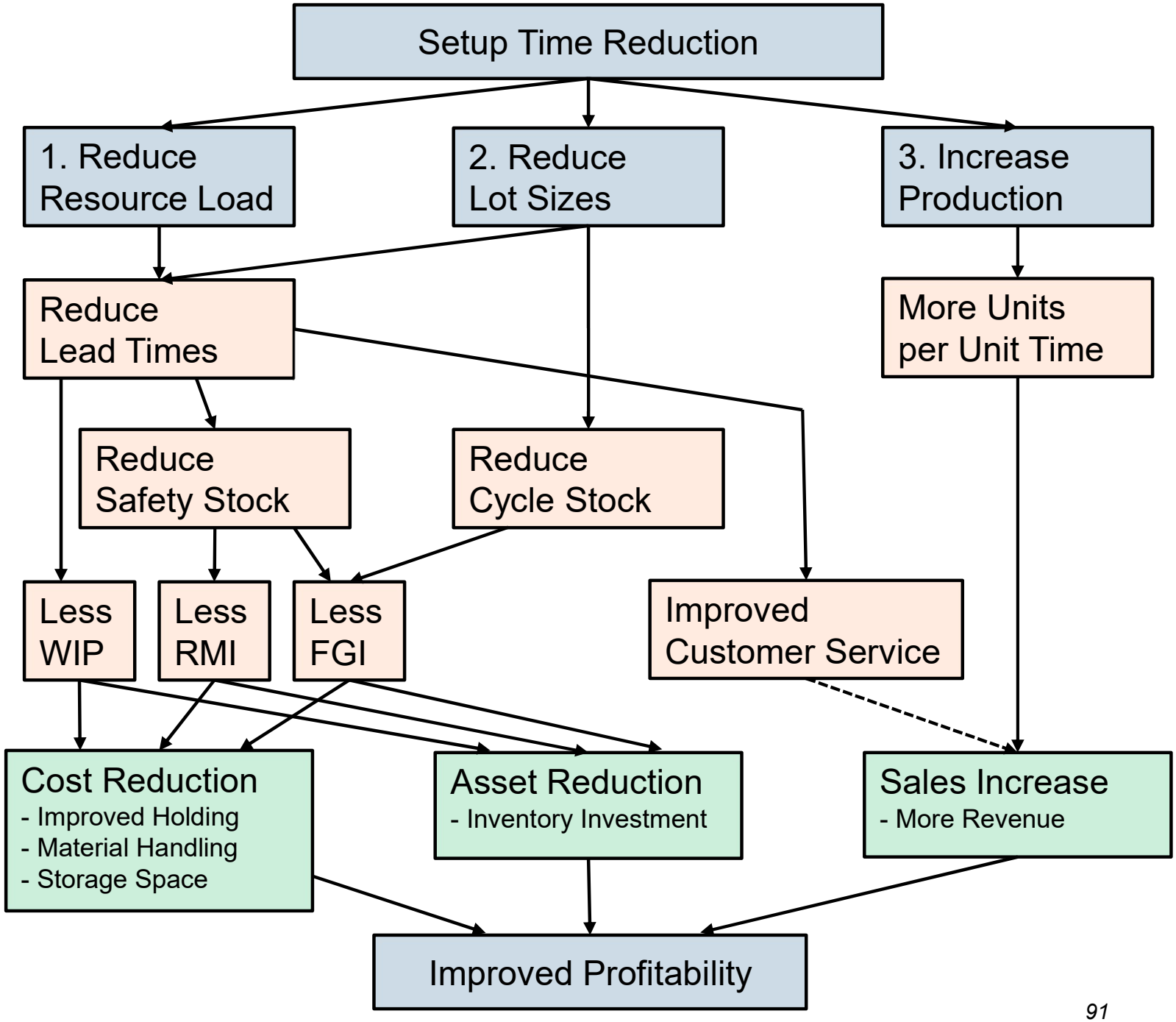
- A method to shorten the time to change a resource in order to manufacturing a different product (setup time)



Effects of Setup Time Reduction



Effects of Setup Time Reduction



Setup Time Reduction in EOQ Model

Setup cost evaluation	$S = c \cdot s$
Order quantity adjustment	$\frac{EOQ_N}{EOQ} = \sqrt{\frac{s_N}{s}}$
Freed capacity	$\frac{R}{EOQ} s \left(1 - \sqrt{\frac{s_N}{s}}\right)$

Setup Time Reduction in Cyclic Planning Model

Setup cost evaluation	$S = c \cdot s$	
Case	$T^* \rightarrow T_N^*$	$T_{min} \rightarrow T_{N,min}$
Order quantity adjustment	T^* $\frac{Q_{Ni}}{Q_i} = \sqrt{\frac{\sum s_{Ni}}{\sum s_i}}$	T_{min} $\frac{Q_{Ni}}{Q_i} = \frac{\sum s_{Ni}}{\sum s_i}$
Freed capacity	T^* $\frac{R_i}{Q_i} s_i \left(1 - \sqrt{\frac{\sum s_{Ni}}{\sum s_i}}\right)$	T_{min} 0

Capacity is not freed since T_{min} is defined as full capacity utilization regardless setup time

Course Goals

- After this course the student should be able to:
  - design and develop manufacturing operations using static analysis models
  - design and develop manufacturing operations using dynamic analysis models
  - understand cause-and-effect relationships within manufacturing operations relating to rate, inventory, and time
  - use and evaluate appropriate planning and control methods in operations management
  - use and evaluate contemporary development methods in operations management

TPPE74 Design and development of Man. Op.

Examination

- The course consists of two examinating activities:
  - UPG2: Seminar (project) task (U, G) – Project, 3 hp
  - TEN1: Written examination (U, 3, 4, 5) – 3 hp
- Project
  - The project is a larger task where a manufacturing system is depicted in a simulation model and the model is used in order to design and develop the manufacturing operations
  - Grading criteria is used to determine if the project should pass or fail (rework)
  - Maximum of 4 students in each group.
  - Final submission **no later than 7 June, kl. 09:00.**

Course Evaluation 2020

- Course Evaluation 2020
  - 84 students were registered on the course
  - 36 answered the course evaluation (42.9 %)
- Some Key questions
  - Question 4. The educational methods used in the course supported my learning.
    5: Yes, completely – 4.47
  - Question 9. What is your overall evaluation of the course?
    5: Highest – 4.58
  - Question 11: The course was relevant to my education.
    5: Yes, absolutely – 4.72
- Comments
  - “If distance mode is continued, make both live and recorded classes.”
  - “More supervision time or the possibility to book a supervision time in advance.”
  - “There should have been more feedback during the simulations in the project.”
- Other sources for change
  - EU financed project that focus on digitalization in OM
  - Research article that use DOE for design and development of a manufacturing system

TPPE74 Design and development of Man. Op.

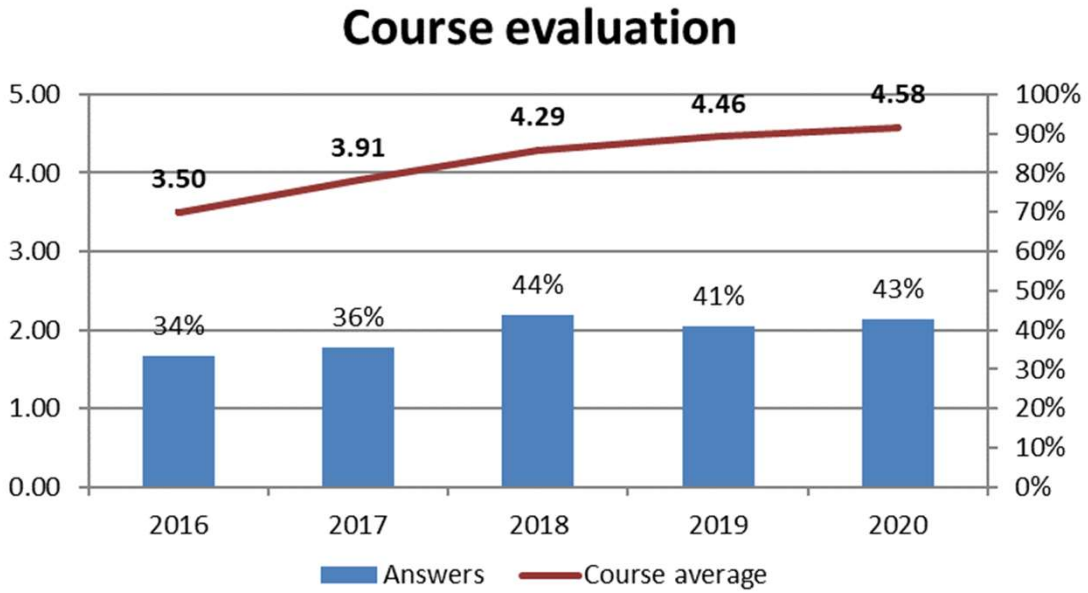
Course Development

- Changes in the course
  - Updated Project, 3 more seminars and new tasks
  - Task A, new – Quiz
  - Task D, new
  - Supervision each week, book between 08:30 – 10:00, 10:15 – 11:30 free.
  - All seminars are live.
  - Possibility to free supervision after each seminar (not seminar 6).
  - New Lecture 6 and Seminar 6 in AI (by Implema AB)
  - Black-Box approach to design and development in Lecture 7
  - Distance Mode

Course Development

TPPE74

- Course evaluation in Evaliuate
  - 2018: 4.29 (44%)
  - 2019: 4.46 (41%)
  - 2020: 4.58 (43%)



TPMM06

- Course evaluation in Kurt
  - 2016: 3.00 (22%)
  - 2017: 4.31 (25%)

TPPE19

- Course evaluation in Kurt
  - 2016: 4.00 (45%)
  - 2017: 3.50 (46%)

2021
Evaliuate
Opens May 31
Closes June 20

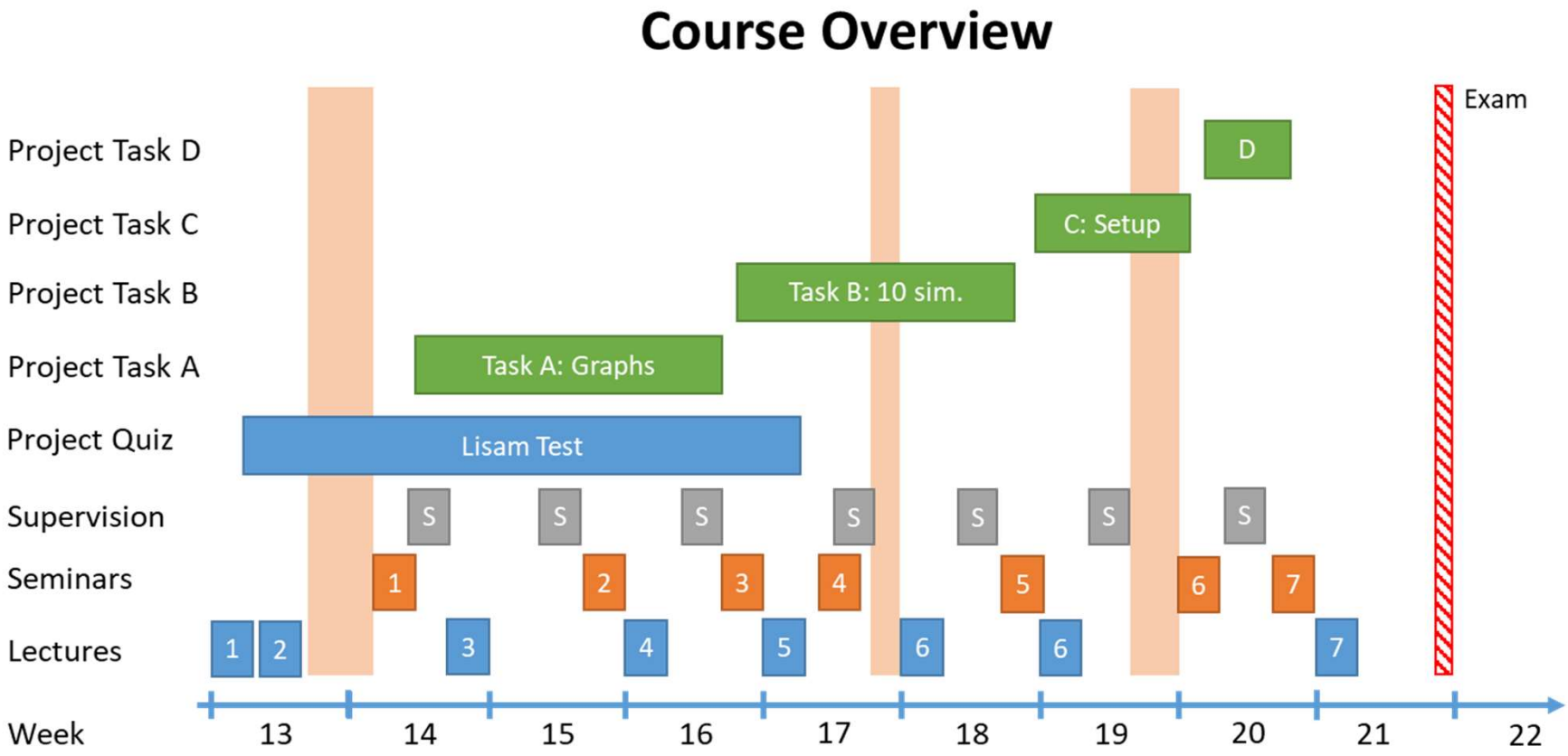
TPPE74 Design and development of Man. Op.

Prohibited Aids and Plagiarism

In this course, the following aids are allowed at the examination:

- TEN1 (3 hp) Written examination
  - Printed dictionary and calculator can be used during the exam. If the calculator is programmable, it is NOT allowed to have any code written in the calculator before the exam. Other tools or aids are not allowed during the exam. No collaboration between students is allowed.
  - In distance mode: see Lisam.
- UPG1 (3 hp) Seminar Project
  - No collaboration between groups is allowed. No collaboration between students is allowed except for in the own group. Urkund is used for all handed in tasks. Plagiarism and/or self-plagiarism is not allowed. Use proper references according to the Harvard system.
- The use of unlawful tools or aids, or attempt to mislead otherwise, during examination for both TEN1 and UPG1 will lead to disciplinary actions

Course Overview



TPPE74 Design and development of Man. Op.

TPPE74
Design and Development of Manufacturing Operations

Le 7

Closing

2021

Exam instructions

Regarding content (exam questions)

- In the exams from 2019 and previous, the first question has been to define five key terms in the course. This question has been removed and replaced with another type of question, focusing more on understanding key terms.
- You will recognize the structure of the exam from older exams. Out of the 100 points, approximately 50 points will be questions where you fully or partially calculate the answer. The reminder of the exam are theoretical questions where understanding is tested.
- The level for passing is still 50 points (out of 100) and grade 4; 65p, grade 5; 80p.

Exam instructions

Instructions for the exam

- The exam is 4 hours, and the exam questions are downloaded from Lisam and the answers are uploaded in Lisam, in the course room of TPPE74.
- You can register for the exam until May 18. Then the exam is closed. In the distance mode, you have to be registered for the exam before the exam takes place to be able to do the exam. There is no exception from this.
- The exam starts on May 28, at 14:00. At that time, the exam questions will be made available on Lisam under a certain folder called “07 Home examination”. The exam is a PDF file that you can download or read online. Any additional files are uploaded for your convenience.
- The exam ends at 18:00 but submission of answers is done before 18:15 in a submission in Lisam called “07 Home exam submission”.

Exam instructions

Instructions for the exam

- You can answer in an electronic document or on paper. See the question itself what options are available. The electronic document (in MS Word) is uploaded as usual in Lisam. If you answer on paper, you need to photograph or scan the paper to convert it to a format that can be uploaded. Include the photos in the document or save them in JPG-format. Scans should be done in PDF. Make sure you have found suitable ways to convert all your answers on paper to an electronic format before the exam and that you have tested that it works. Note that there is a limit of 135 MB per upload in Lisam.
- All files that you submit must contain your name and LiU-ID in text and in filename.
- If you are unable to submit your answers in Lisam, you can email your answers to me at the end of the exam, no later than 18:15.
- You are yourself responsible for the quality of the submission, that it is readable, complete, and do not refer to other digital sources such as links to other uploaded documents or photographs.
- I will be available during the whole exam to answer questions, see the exam cover page, on telephone or on email.

Exam instructions

After the exam

- Corrections are made and commented in Lisam. When all exams are corrected, the results are made available in Ladok. After that, the corrections and comments are made available in Lisam.
- You can request a correction of the grading decision (omprövning) as usual. You fill out the form "Request for correction or review (amendment) of grading decisions" that can be picked up at the student office at IEI or downloaded here: https://www.iei.liu.se/student/studexp/rattelse-och-omprovning-av-betyg?l=sv
- The section below contains what is stated on the cover page of the exam, for your information.

Closing

- Thanks for your attention!
- Distance mode is hard for all… Thanks for trying to do the best of the situation!
- Answer the Course Evaluation!
- Good Luck on the exam!
  - Corrected on May 18 (latest)
- Have a nice summer and welcome back to the university in August!

/ Fredrik