System Physics

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Keypoints of the lecture

- Production Capacity in terms of Volume and Mix
- Decoupled Serial System
- Coupled Serial System

Production Capacity

- It's possible to measure it in different ways and to focus on different levels (single resource, department, company)
- At single resource level, the fondamental element is theoric capacity (eg. Unit/hour). Theoric capacity refers to the conditions when everything goes well.

Cycle time (C/T) = 6 min/pc

Theoric capacity (C_t) = $\frac{1}{C/T}$ = 10 pc/hour

- To determine the actual capacity, it's necessary to also take into account other factors…

Availability

- A resource may be not available to produce.
- Part of working time during which the resource is available for working is named Availability. Its symbol is A.
- Causes for unavailability can be:
  - Breakdowns
  - Interruptions (for problems, or for calls)

Availability (A) = 80%

C_t = 10 pc/hour

Actual capacity (C) = C_t * A = 8 pc/hour

Serial System

Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc

What is the capacity of the system?

Serial System

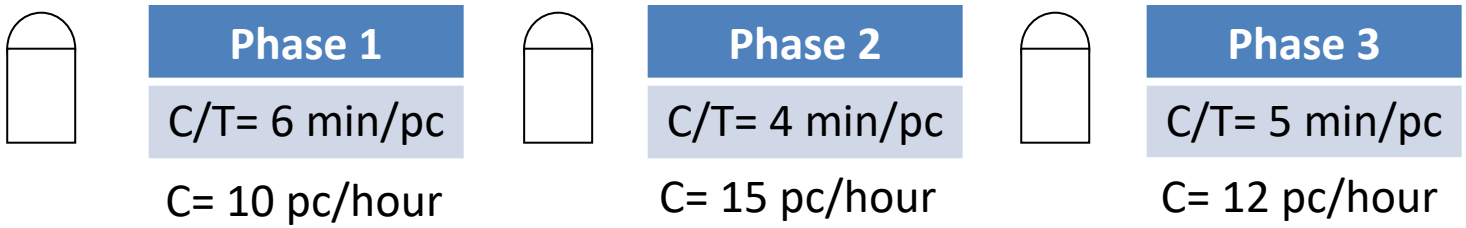
Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
C= 10 pc/hour	C= 15 pc/hour	C= 12 pc/hour

C/T= 6 min/pc

C = 10pc/hour

Capacity is limited by the **slowest phase** (medium-term viewpoint)

Decoupled Serial System

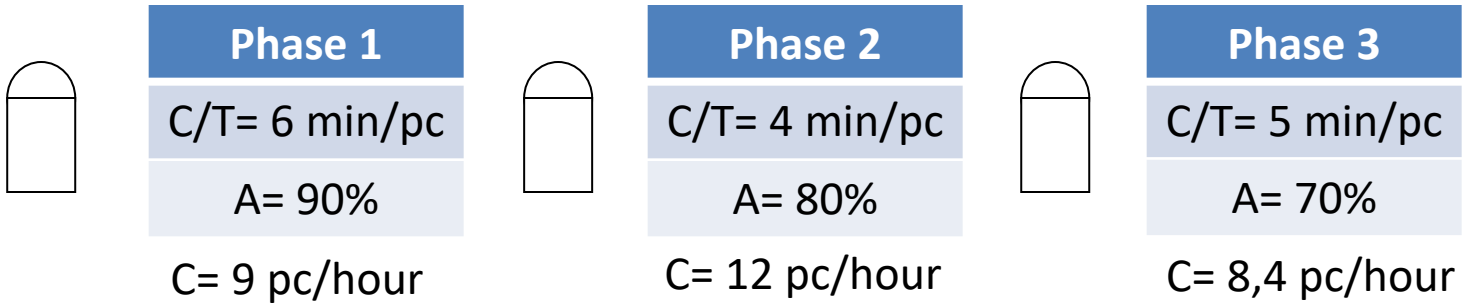


C/T= 6 min/pc
C = 10 pc/hour

Queues between each phase **do not balance** out different C/T

Decoupled Serial System

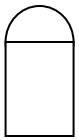
Actual capacity (C) = C_t * A



Availability can change system capacity. Now it's 8,4 pc/h

Availability can change the bottleneck

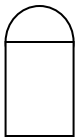
Coupled Serial System (line)



Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
A= 90%	A= 80%	A= 70%

Queues disappear

Coupled Serial System (line)

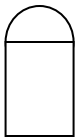


Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
A= 90%	A= 80%	A= 70%

C/T= 6 min/pc

System C/T is the largest C/T

Coupled Serial System (line)



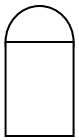
Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
A= 90%	A= 80%	A= 70%

C/T= 6 min/pc
A= 50%

System availablity is the product of the single availabilities

$$A = A_1 * A_2 * A_3 = 0{,}5$$

Coupled Serial System (line)



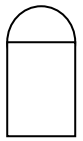
Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
A= 90%	A= 80%	A= 70%

C/T= 6 min/pc
A= 50%

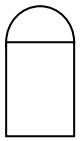
$$C = 60 * 0{,}5 / 6 = 5 \text{ pc/h}$$

Low waiting time but also low production rate

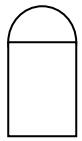
Decoupled VS Coupled serial system



Phase 1
C/T= 6 min/pc
A= 90%

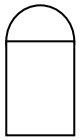


Phase 2
C/T= 4 min/pc
A= 80%



Phase 3
C/T= 5 min/pc
A= 70%

C= 8,4 pc/h



Phase 1
C/T= 6 min/pc
A= 90%

Phase 2
C/T= 4 min/pc
A= 80%

Phase 3
C/T= 5 min/pc
A= 70%

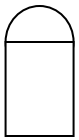
C= 5pc/h

Production changes from 8,4 pc/h to 5 pc/h

It seems like queues/stocks bring an improvement, but it's not true:
They are just an increase of waste

Ideal Coupled Serial System

The **real solution** is to remove wastes



Phase 1	Phase 2	Phase 3
C/T= 5 min/pc	C/T= 5 min/pc	C/T= 5 min/pc
A= 100%	A= 100%	A= 100%

C/T= 5 min/pc
A= 100%

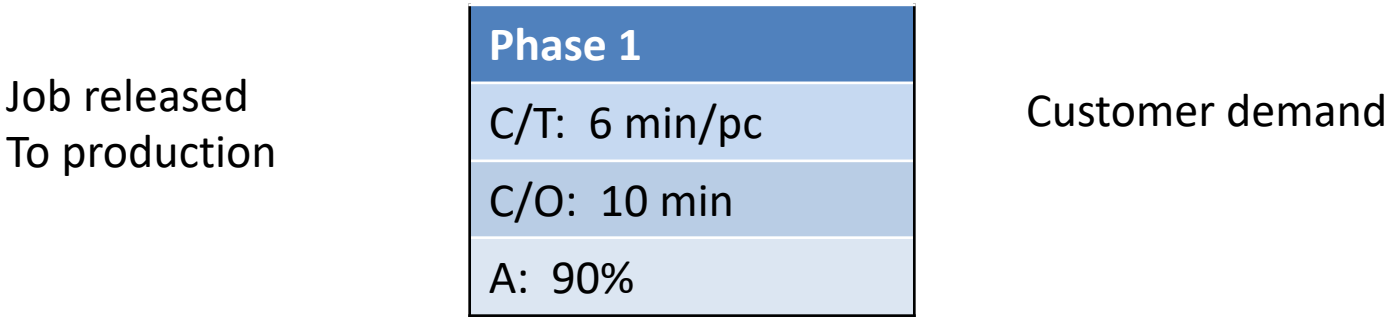
Capacity = 60/5 = 12 u/h → +43% on queue system

Low waiting time and High production

Setup and system flexibilty – EX1

- The system works 8 hours/day and daily demand is 60 products (constant in volume).
- The system has a range variety of **10 products**, and they are all requested every day.

Is the company able to deliver the requested quantities within 1 day?



Setup and system flexibilty

- **Tp**: Time to produce (only to process)

$$\mathbf{Tp} = \frac{\boldsymbol{Average\ demand}\left(\frac{\boldsymbol{pc}}{\boldsymbol{day}}\right)*\boldsymbol{C/T}}{\boldsymbol{A}}$$

- **Tsu**: Time to Setup

$$\mathbf{Tsu} = \boldsymbol{Number\ of\ setups\ per\ day}\left(\frac{\boldsymbol{setup}}{\boldsymbol{day}}\right) * \boldsymbol{C/O}$$

- **Ta**: Available time (daily)

Productivity's feasibility analysis

$$Tp + Tsu \leq Ta$$

Tp + Tsu = 60pc/day *6 min/pc /0,9 + 10 setup/day*10 min/setup = 500 minutes

Ta= 480 minutes

$$Tp + Tsu > Ta$$

The company cannot satisfy market demand in make to order, thus it must intervene on the production process in order not to lose profits!

What can the company do?

Batching

In order to have more time to produce, companies usually **batch production** of each single product.

Consequencies:

- Advance of unrequested production
- Having interoperantional/finished products stocks
- Increase of system response times
- Increase of throughput time variability, system congestion and coordination needs

Batching

Quantity Batching = for each product, defining the exact (sometimes minimum) quantity that must be produced every time.

Time Batching = for each product, defintion of the time horizon over which a product must be produced (e.g. once/week).

Time batching example

D = 60 pc/day

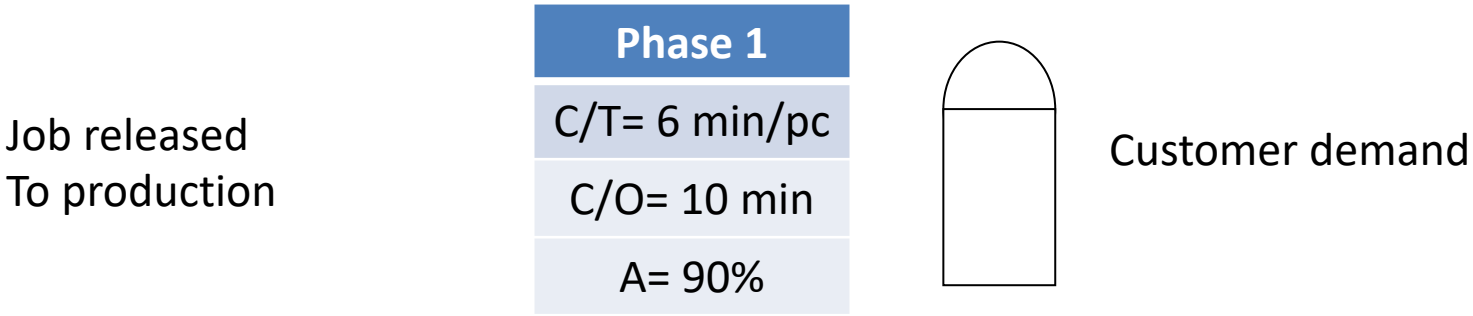
Each product is realised every two days (5 different pc/day)

Tp + Tsu: 6/0,9*60 + 5*10 = 450 minutes

Ta = 480 minutes

Batching creates problems

- There are stocks (need for space, costs increase..).
- Production in advance of demand not yet requested!
- Risk to keep stocks of not requested units! (for example, when demand has variability)
- Flexibility decreases (if today code F is requested and it is not in stock nor scheduled for today's production, it could be produced only adding a rush order that creates inefficiency).
- Increase coordination and supervision needs in production process.



Batching vs reducing set up times

Batching is the way companies follow, even if it entails some disadvantages and it's not for free!

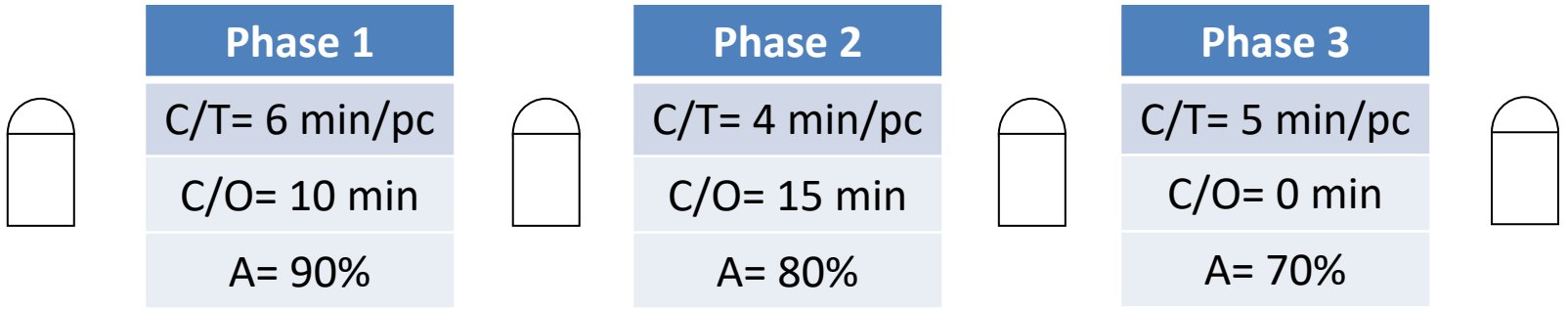
It's much better to pursue the reduction of set up times!

In our example, reducing set up time from 10 to 8 minutes will enable the every day production of the requested quantities!

Minimum batching (decoupled system) – EX2

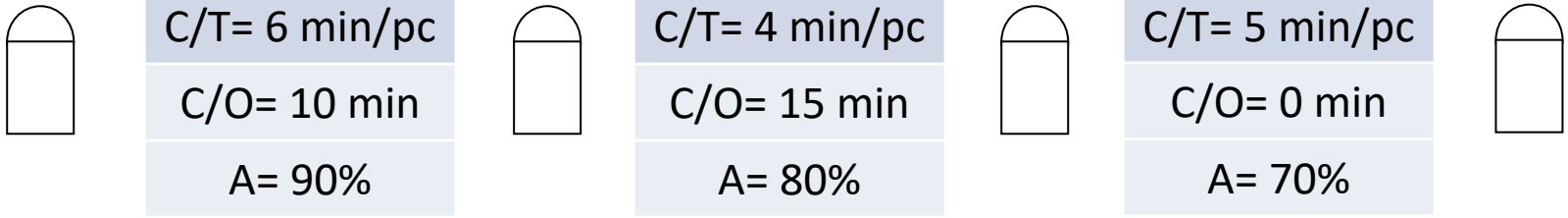
- The system works 8 hours/day and daily demand is 60 units (constant in volume).
- The following stocks decoupled the different phases.
- The system has a range variety of **10 products**, and they are all requested every day. Each machine produces 10 different products (with set up at every product change).

What is the minimum batching for each of the 3 phases?



Minimum batching (decoupled system) – EX2

To calculate the minimum batching, it's necessary to understand how many sets up can be done in each phase every day.



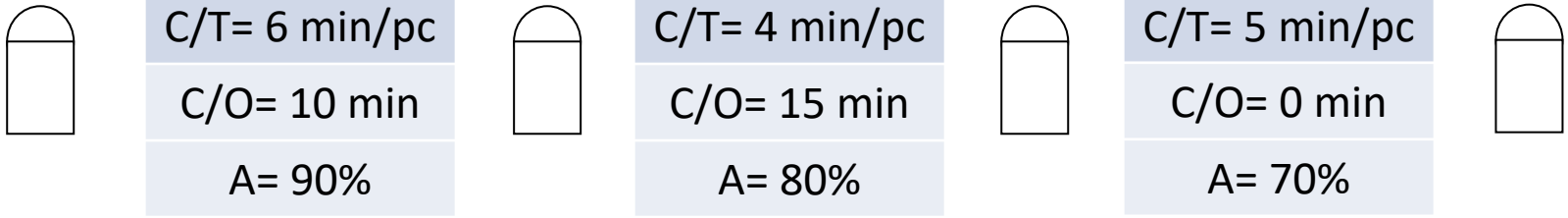
Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
C/O= 10 min	C/O= 15 min	C/O= 0 min
A= 90%	A= 80%	A= 70%

Phase 1:
How many sets up may we do per day?
6/0,9*60 + X*10 = 480 min → **8 set-up per day**

The average batch quantity for each product is:
Total demand/number of setup per day -> 60/8 = **7,5 pc/batch**

Minimum batching (decoupled system) – EX2

To calculate the minimum batching, it's necessary to understand how many sets up can be done in each phase every day.



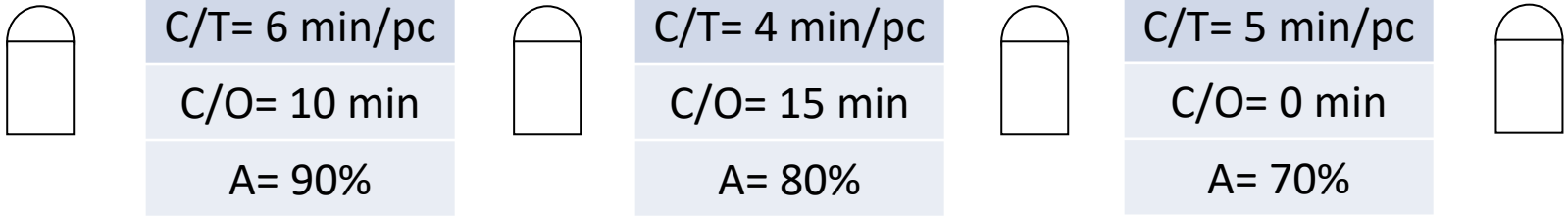
Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
C/O= 10 min	C/O= 15 min	C/O= 0 min
A= 90%	A= 80%	A= 70%

Phase 2:
How many sets up may we do per day?
4/0,8*60 + X*15 = 480 min → **12 set-up per day**

The average batch quantity for each product is:
Total demand/number of setup per day -> 60/12 = **5 pc/batch**
NB: if orders are grouped per day, there is no need to produce more than the ordered quantity

Minimum batching (decoupled system) – EX2

To calculate the minimum batching, it's necessary to understand how many sets up can be done in each phase every day.



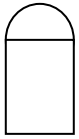
Phase 3:
no constraints on the batch

C/O is 0

Minimum batching (coupled system) – EX3

- The system works 8 hours/day and daily demand is 60 units (constant in volume).
- The system is coupled (no stocks between stages)
- The system has a range variety of **10 products**, and they are all requested every day. Each machine produces 10 different products (with set up at every product change).

What is the minimum batching for each of the 3 phases?



Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
C/O= 10 min	C/O= 15 min	C/O= 0 min
A= 90%	A= 100%	A= 95%

Minimum batching (coupled system) – EX3

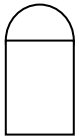
What does it mean that the system is coupled?

If one phase stops for setup, so do the others!

It is therefore important to understand how much time the line is stopped to make setups:

total time of stop for the line is the total time of stop for setups

Minimum batching (coupled system) – EX3



Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
C/O= 10 min	C/O= 15 min	C/O= 0 min
A= 90%	A= 100%	A= 95%

C/T= 6 min/pc
C/O= 15 min*
A= 0,9*1*0,95= 85,5%

*longest set up time, if setups are performed in parallel. It is the sum of setup time if setups are performed sequentially. E.g. by one single person

System:

How many sets up may we do per day?

6/0,855*60 + X*15 = 480 min → **4 set-up per day**

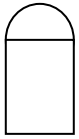
The average batch quantity for each product is:

Total demand/number of setup per day -> 60/4 = **15 pc/batch**

Minimum batching (coupled system) – EX4

- The system works 8 hours/day and daily demand is 60 units (constant in volume).
- The system is coupled (no stocks between stages)
- The system has a variety range of **10 products**, and they are all requested every day.
- There are 5 different product types at phase 1.
- At phase 2 there is a further differentiation leading to 10 different product types.

What is the minimum batching for each of the 3 phases?

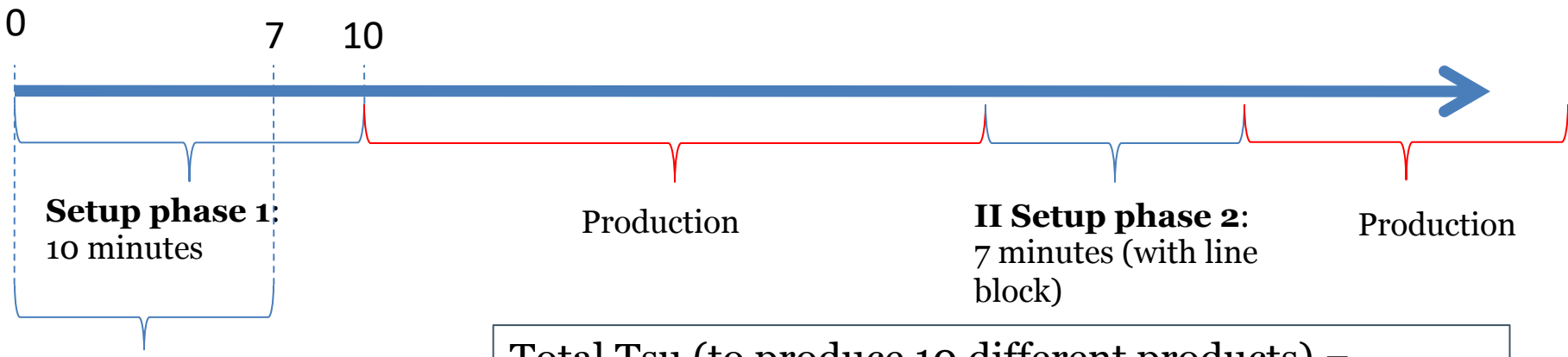


Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
C/O= 10 min	C/O= 7 min	C/O= 0 min
A= 90%	A= 100%	A= 95%

Minimum batching (coupled system) – EX4

At system level:

- 5 setups at phase 1
- 10 setups at phase 2
- How much is the stop time for the line because of sets up?

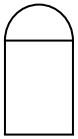


Total Tsu (to produce 10 different products) =
5*10+5*7 = 85 minutes

Average time to setup*: **85/ 10 = 8,5 minutes**

*time to change form one version to another

Minimum batching (serial coupled system) – EX4



Phase 1	Phase 2	Phase 3
C/T= 6 min/pc	C/T= 4 min/pc	C/T= 5 min/pc
C/O= 10 min	C/O= 7 min	C/O= 0 min
A= 90%	A= 100%	A= 95%

C/T= 6 min/pc
C/O= 8,5 min
A= 85,5%

System:
How many sets up may we do per day?
6/0,855*60 + X*8,5 = 480 min → **7 set-up per day**

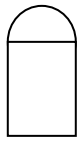
The minimum average batch quantity for each product is:
Total demand/number of setup per day -> 60/7 = **8,6 pc/batch***

*It corrisponds to the average demand of 1.43 days for each type of finished products

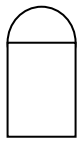
Minimum batching (decoupled system) – EX5

- The system works 8 hours/day and daily demand is 60 products (constant in volume).
- The system is decoupled (stocks between stages)
- The system has a range variety of **10 products**, and they are all requested every day.
- There are 5 different product types at phase 1.
- At phase 2 there is a further differentiation leading to 10 different product types.

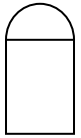
What is the minimum batching for each of the 3 phases?



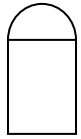
Phase 1
C/T= 6 min/pc
C/O= 10 min
A= 90%



Phase 2
C/T= 4 min/pc
C/O= 7 min
A= 100%



Phase 3
C/T= 5 min/pc
C/O= 0 min
A= 95%



Setup and system flexibilty

- Production change requires setups.
- The longer the set up time is, the less frequent the production changes will be.
- The longer the set up time is, the greater the risk of producing something that is not requested.
- Setups have obviously impacts on performances, increases costs (stocks, necessity of coordination..), increases throughput times variability and decreases system flexibility.

Production capacity

- Theoric production capacity indicates the number of products realized in the time unit that the resource is able to produce under optimal conditions.
- Availability takes into consideration resource's stops that decreases the theoric production capacity.
- Sets up decreases the time available for production and system flexibilty. Batching is used to increase single reasource's efficiency but it creates problems at a system level.

Decoupled VS Coupled serial system

- A system decoupled by stocks allows to make production phases more independent, but it's a system that requires stocks to work, thus showing that is a system with problems.
- A serial coupled system links the production phases. This highlights problems and allows to see them and address them.
- The objective is to remove problems (remove the causes of the problems), so that the system improves.

Take Aways from the lecture

1. How to do a Production Feasibility Analysis for both a
- Decoupled System
- Coupled Serial System (line)

2. Considering C/O, C/T and A of different stages composing the system.

3. How to interpret and see stocks and design the batching policy if it is necessary.

4. How to interpret system's flexibility and how to improve it.

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