Discrete control concepts

Chapter 5

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Goals

- Goal: you should
  - Understand how industrial production is organized and the reasons why
  - Be able to calculate a suitable production rate and inventory for a certain product with production disturbances
  - Be able to schedule the production of a number of products in several machines
- Some calculations on Monday Feb. 7

History

First decades of 20th century - 1970

- Production driven - *push* systems
  - Customer demand “infinite”
- Organized as mass production
- The manager had the responsibility for all critical decisions
- Worker only a production unit

Frederick Taylor:

"*All possible brain work should be removed from the shop floor and centred in the planning or laying-out department.*

In my system the worker is told minutely what he is to do and how he is to do it, and any improvement he makes upon the instructions given to him is fatal to success."

Taylorism

- The man limits the machines
- Divide work into unit operations
- The productivity can increase by controlling the man
- Man = machine
- Man not appreciated
  – See Charlie Chaplin's "Modern Times"
- A change in attitude needed

Henry Ford

- Took over Taylor's ideas
- However, he raised the workers salaries
  – People queuing to be employed by Ford
- Problems:
  – Workers turnover in 1913: 380%
  – In 1970: half of those recruited to work on Chrysler's production line had left within 90 days
- Man still not fully appreciated
  – Brain power of workers not utilized

History

After 1970s

- Global perspective
- The customers market - *pull* systems
  – Customer demand limited => competition
- Diversified and flexible production
  – Initiatives from the shop floor
- Decisions much more decentralized
  – Decisions taken on the shop floor
- Japanese philosophy

Konosuke Matsushita (Japan)

"We are going to win and the industrial west is going to lose; there's nothing much you can do about it because the reasons for your failure are within yourselves. Your firms are built on the Taylor model; even worse, so are your heads. With your bosses doing the thinking while the workers wield the screwdrivers, you're convinced deep down that this is the right way to run a business. …..

Matsushita (con'd)

For you, the essence of management is getting the ideas out of the heads of the bosses and into the hands of the labour. We are beyond the Taylor model; business, we know, is now so complex and difficult, the survival of firms so hazardous in an environment increasingly competitive and fraught with danger, that their continued existence depends on the day-to-day mobilization of every ounce of intelligence."

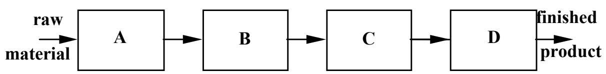
The Japanese philosophy

- Simplify
- Integrate – processes as well as decisions
- Maximize the adequate technology
- Appreciate the worker and his/her brainpower

Fundamental concepts

Chapter 5

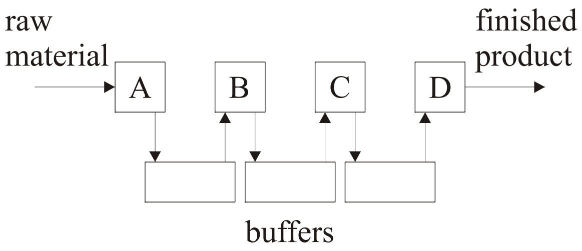
The classical transfer line



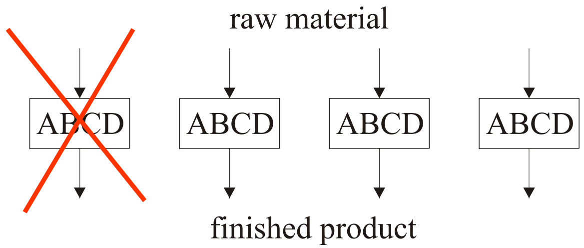
Starving - no input product

Blocking - can not deliver finished product

Introducing buffers

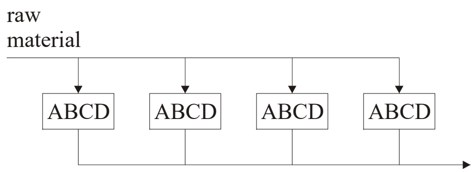


Parallel operations – machine center



Production can still continue!

Flexible manufacturing cell



Need advanced control computers to be fully utilized!

Properties

Structure	Series size	Flexibility	Sensitivity
Transfer line	Medium	Low	High
Transfer line with buffer	High	Low	Medium
Parallel centers	Low	High	Low
FMS	Medium	High	Low

Just-in-time (JIT) production

- Market demands flexibility
  - Fashion, seasons, trends, etc.
- Large inventory
  - Costly, inflexible
- Buffers hide production problems
  - Symptom of bad synchronization
- Solution:
  - *"produce necessary quantity at the right moment"* => JIT

JIT

Goals of JIT:

- Find and eliminate the losses and problems
- Simplify on all levels
- Material handling systems (e.g. Kanban)
  - Information technology

JIT

- No buffers
  - Pull system, meet customer demands
- No waiting time
  - Remove the bottlenecks and set-up time
- No errors
  - Quality control in all operations
- No failures
  - Preventive maintenance
- No paper
  - Administrative simplifications

Production control

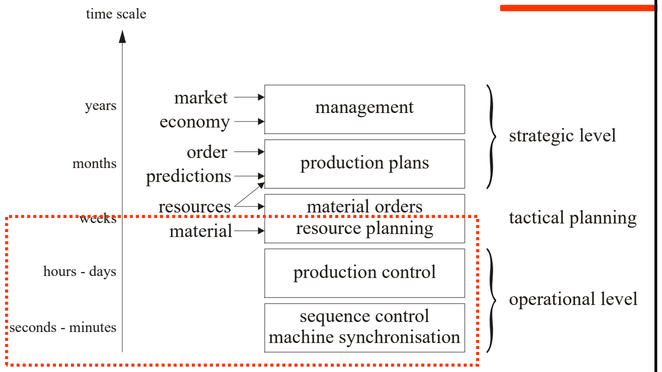
Chapter 14

Criteria for production control

- Minimize the production time
- Minimize the production costs
- Satisfy delivery dates

  – Minimize buffers and inventory
  – Minimize idle time
  – Minimize average waiting time

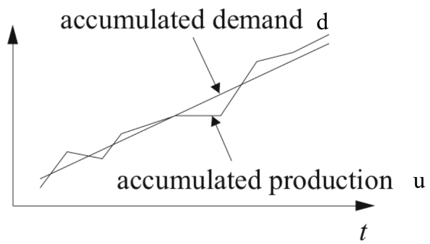
Time scales in production control



Levels of control

- Production level (long term planning)
  – Finding the right production rate
  – Finding an appropriate inventory to meet demand
- Cell level (short term planning)
  – Routing (which way?)
  – Scheduling (in what order?)
- Machine level
  – Control of sequential operations (PLC)
  – Control of continuous processes/movement (e.g. PID)

Long term planning



Hedging point strategy

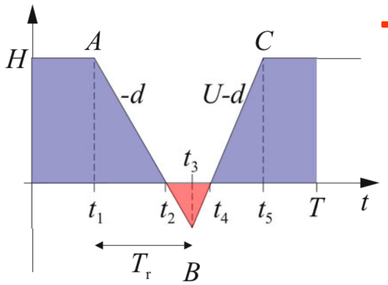
- How to find the “optimal” size of inventory
- Strategy for planning production rate on a hourly and daily (and longer) basis
- Machines will break and production will be disturbed
- Keep the expected average $x_j(t)$ close to zero

Hedging point strategy

- To get the “optimal” buffer size (H) we need to estimate:
  - The demand, *d*
  - The mean time between failures (MTBF), T_f
  - The mean time to repair (MTTR), T_r
- We also need to define the time period for the analysis, *T* and the number of failures, N_f:

$$N_f = \frac{T}{T_f + T_r}$$

One breakdown



$g(H) = c_p \cdot$ (positive area) $+ c_n \cdot$ (negative area)

Minimize $g(H)$!

Hedging point calculations

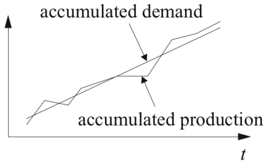
$$g(H) = c_p\left(HT - N_f \frac{UT_r H}{U-d}\right) + c_p N_f \left(\frac{H^2}{2d} + \frac{H^2}{2(U-d)}\right) +$$

$$+ c_n \frac{N_f}{2} \frac{(dT_r - H)^2}{U-d} \frac{U}{d}$$

$$dg(H)/dH = 0$$

$$H = \frac{c_n}{c_p + c_n} T_r d - \frac{c_p}{c_p + c_n} \frac{d}{U} \left(UT_f - d(T_f + T_r)\right)$$

Hedging point control strategy



$$u(t) = U \text{ if } x(t) < H$$
$$u(t) = d \text{ if } x(t) = H$$
$$u(t) = 0 \text{ if } x(t) > H$$

$$\frac{dx}{dt} = u(t) - d(t)$$

In practice, the control law has to be somewhat more sophisticated!

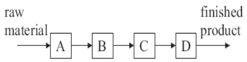
Short term planning

- Routing
  - A products path through the machines
  - Not treated here, assumed to be known
- Scheduling
  - The order in which different products are produced.
  - Sequencing

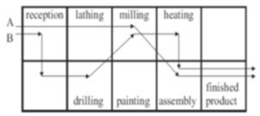
- The book is a bit confusing on this

Complexity

- Type of plant
  - Flow shop, job shop
- Arrival pattern
  - Dynamic, static
- Level of detail
  - Failure rates, uncertainty



Flow shop



Job shop

Criteria for scheduling

- Production time
  - Average time in shop
- Idle time of machines
  - Waiting time
- Average lateness of product
  - How late (or early) is the product in respect to due date
- => minimizing costs (operating, inventory)

The sequencing problem

- Determine the order of operations for a certain family of products
- *n* products to be produced by *m* machines
- Production system (routing) is given and the same for all jobs, i.e. flow shop
- All *n* jobs available at start
- Buffers may be used

One machine and *n* jobs (*n/1*)

- Waiting + processing time for 1 job:

$$P_i = W_i + t_i$$

- Total time for job *k* to be completed:

$$F_k = \sum_{i=1}^{k} P_i$$

- The mean flow time (MFT) in the shop:

$$\overline{F} = \frac{1}{n}\sum_{k=1}^{n} F_k = \frac{1}{n}[P_1 + (P_1 + P_2) + \ldots + (P_1 + \ldots + P_n)]$$

$$\overline{F} = \frac{1}{n}\sum_{i=1}^{n}(n - i + 1)P_i$$

One machine and *n* jobs (*n/1*)

- MFT is minimized if

$$P_1 \leq P_2 \leq \ldots \leq P_n$$

- that is, the shortest job first.

One machine and *n* jobs (*n/1*)

- Lateness, defined as:

$$L_i = F_i - d_i$$

- where d_i is the due date for job i
- Mean lateness:

$$\overline{L} = \frac{1}{n}\sum_{k=1}^{n} L_k = \frac{1}{n}\sum_{k=1}^{n}(F_k - d_k) = MFT - \overline{d}$$

- $\overline{d}$ is the average due date.

One machine and *n* jobs (*n/1*)

- Minimizing mean lateness is the same as minimizing MFT
- Minimizing the maximum lateness:

$$d_1 \leq d_2 \leq \ldots \leq d_n$$

Prioritizing

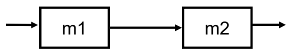
- Sometimes it is necessary to prioritize a job.
- Weight can be used to order the production:

$$\frac{P_1}{w_1} \leq \frac{P_2}{w_2} \leq \cdots \leq \frac{P_n}{w_n}$$

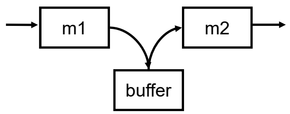
Two machines and *n* jobs (*n/2*)

Two cases:

- Without buffer between machines



- With buffer between machines



Two machines and *n* jobs (*n/2*)

- The maximum total production time for all jobs:

$$F_{\max} \geq \sum_{i=1}^{n} P_{i,1} + P_{n,2}$$

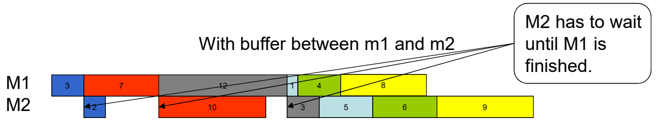
and

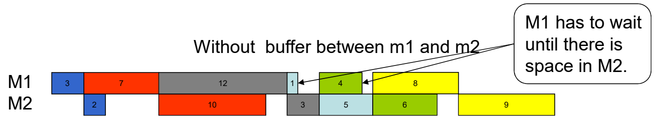
$$F_{\max} \geq P_{1,1} + \sum_{i=1}^{n} P_{i,2}$$

- since $P_{i,2}$ must wait for $P_{i,1}$ to finish.

Processing time - Gantt chart

	J1	J2	J3	J4	J5	J6
M1	3	7	12	1	4	8
M2	2	10	3	5	6	9





Minimizing the processing time

Johnson's procedure

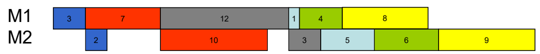
- Choose the shortest time of $P_{i,1}$ and $P_{i,2}$
- If shortest job time is on M1
  put this job first
  else
  put this job last
- Eliminate the job from the list and repeat

Minimizing the processing time

From Johnson's procedure:

	J4	J5	J2	J6	J3	J1
M1	1	4	7	8	12	3
M2	5	6	10	9	3	2

Total time: 37
Idle time M1: 2
Idle time M2: 2



Total time: 45
Idle time M1: 10
Idle time M2: 10

n/3 problem

- Can be solved under certain conditions:
  - Same order for all jobs, i.e. flow shop
  - If M2 (the machine in the middle) is completely dominated by either M1 or M3
  - This is true if:

$$\min P_{i,1} \geq \max P_{i,2}$$

or

$$\min P_{i,3} \geq \max P_{i,2}$$

n/3 problem

- Introduce virtual machines M1' and M2'

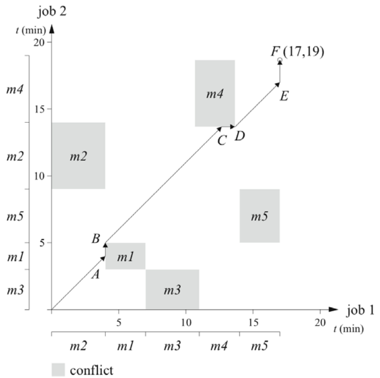
$$P_{i,1}' = P_{i,1} + P_{i,2}$$
and
$$P_{i,2}' = P_{i,2} + P_{i,3}$$

- Apply Johnson's procedure

Flexible manufacturing

- If the order of operations is not the same for all jobs?
- Can be solved in some special cases
- Optimal solution often not possible
- Graphical approaches used

Two jobs and *m* machines (*2/m*)



Two jobs and *m* machines (*2/m*)

- Finding the shortest path
  - 45 degree angle
- Can be extended to 3/m
  - Computer solution

Production control - summary

- Long term planning- hedging point
- Short term scheduling
  - Find minimum mean flow time
- The general *n/m* problem not solved
  - *n*/2 (*n*/3) possible for flow shops
  - *n*/2 (*n*/3) sometimes possible for job shops
  - 2/*m* difficult for job shops