Scheduling and Materials Execution

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Announcement

- Special Modules this year
  - Theory of ERP systems: 1 cr
  - ERP systems exercise with SAP: 1 cr
  - At the lecture 10.3. modules are presented.

Lecture Outline

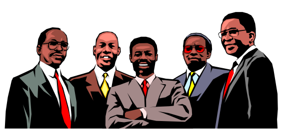
- Scheduling
- Classical job-shop scheduling
  - Sequencing/heuristics
- Queuing theory
- Scheduling Optimisation: Case from steel industry
- Materials Excution

Shop-floor Scheduling & Control
(later in my lecture just Scheduling Vollman uses SCF)

The scheduling problem

Orders

Materials



Labor

Problem: When and where should we do the jobs?

Machines

Concepts

- **Product Structure**: a tree that lists required parts (and their lead times)
- **Routing**: part’s (or product’s) routing through all the necessary processing steps and their planned times in order to complete item
- **Resources**: the machines and other resources needed to complete the item (that is, the ones that are planned). What are the resources and their availability.

Defition of Scheduling

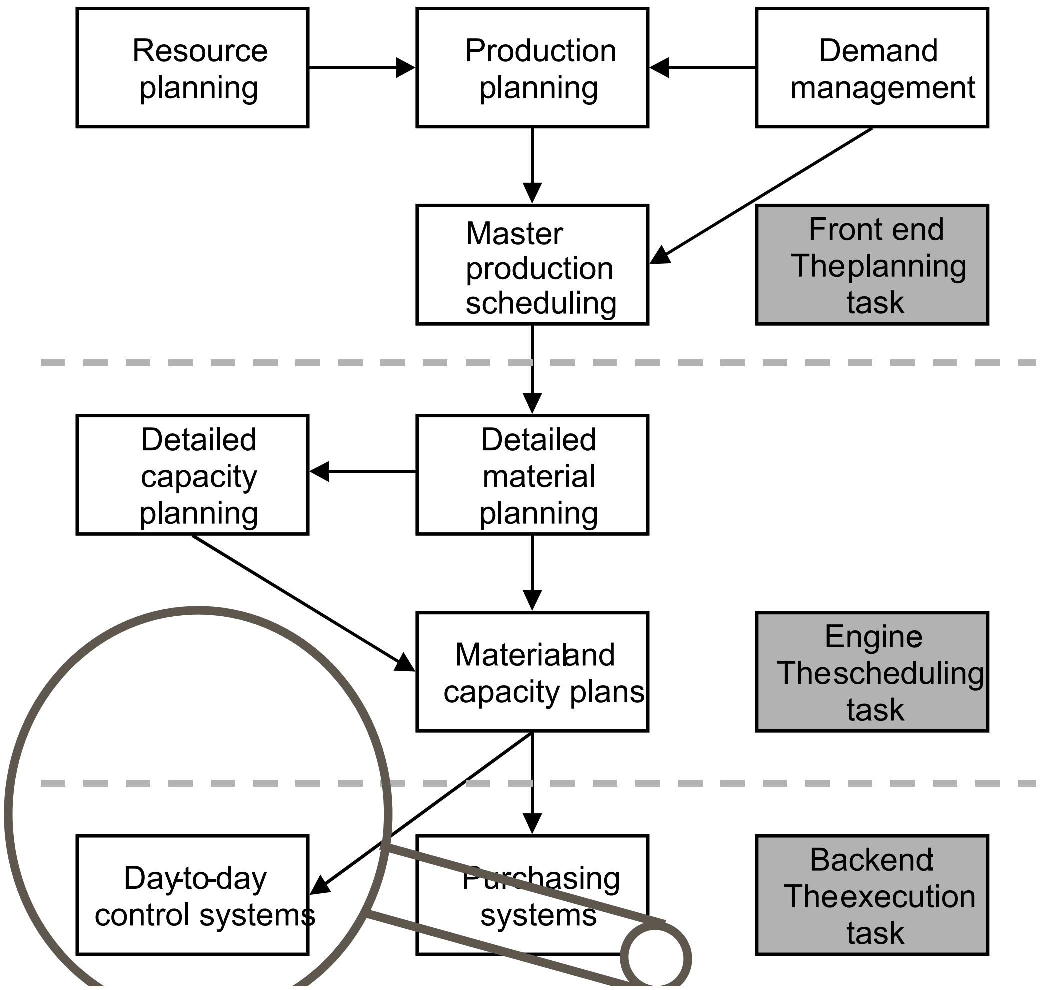
A schedule is a plan with reference to the *sequence* of and *time allocated* for each item or operation necessary for completing the item.

(Vollman et.al)

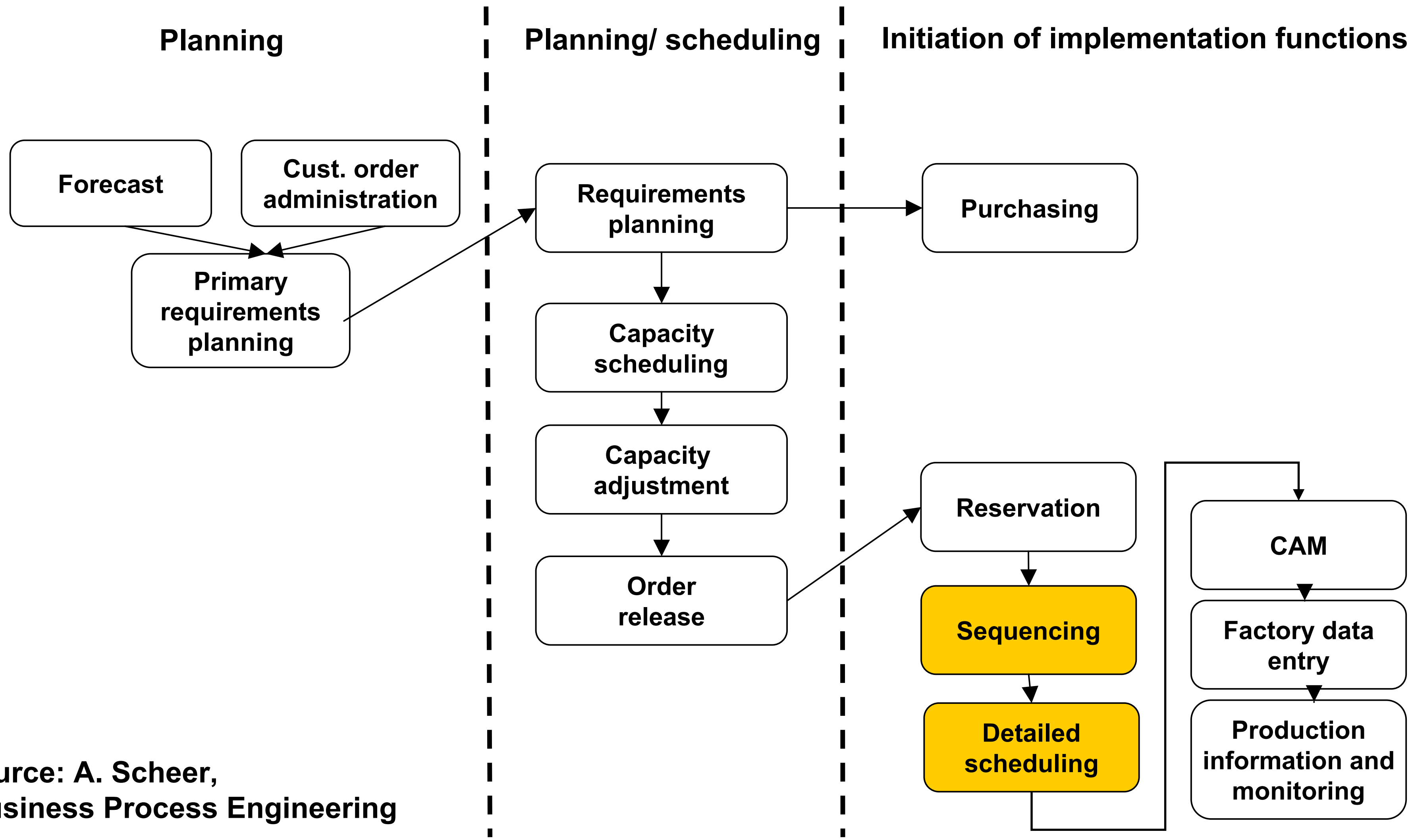
Features of a good schedule

- Reliability: Orders delivered on time (lateness, earliness, tardiness)
- Speed: Short flow times
  - waiting time, total waiting time, flow time
  - minimised inventory
- Throughput: Resource utilisation
  - minimum idle time
  - smart set-ups
- ”Fair”
- Average, max and variance of above values
- One can use these to values to form a cost function. The most usual performance measure is makespan.

Shop-floor Scheduling & Control



Production Planning & Control

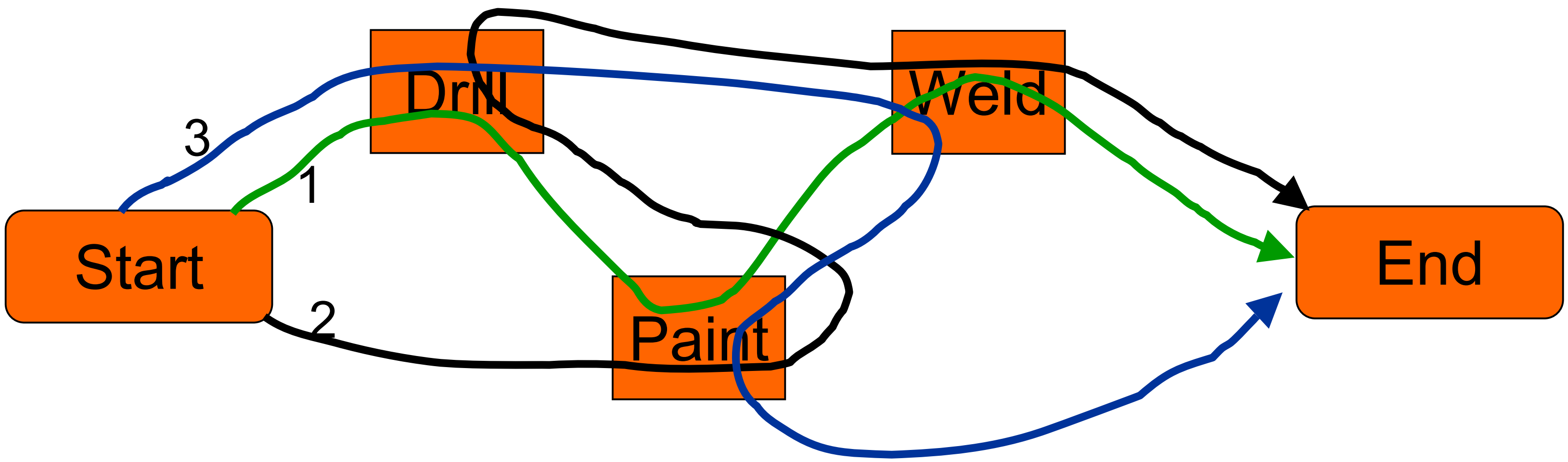


Source: A. Scheer,
Business Process Engineering

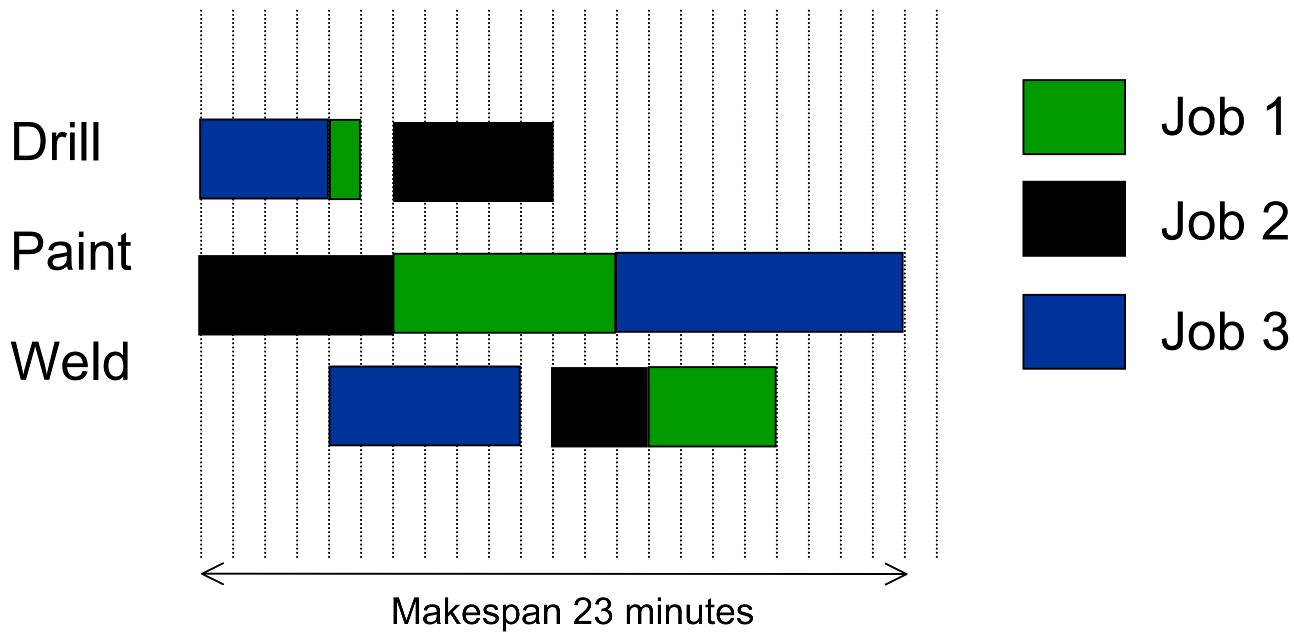
A Scheduling Problem Example

A scheduling example

- 3 machines: Drill, paint shop and weld (welding = hitsaus)
- 3 jobs
  - Job 1 needs drill (1 min) -> paint (8 min) -> weld (4 min)
  - Job 2 needs paint (6 min) -> drill (5 min) -> weld (3 min)
  - Job 3 need drill (4 min) -> weld (7 min) -> paint (9 min)



Minimum-makespan solution

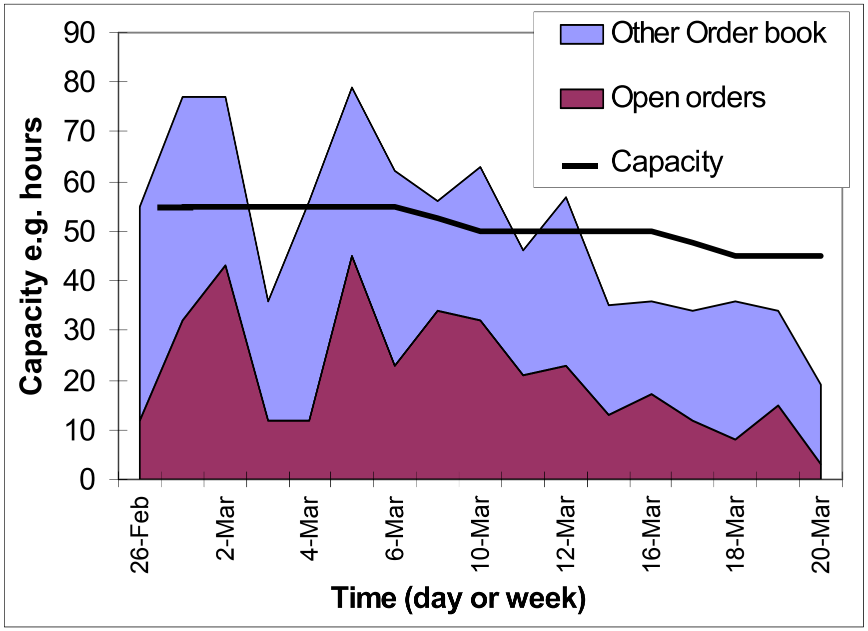


Scheduling strategies

Infinite scheduling

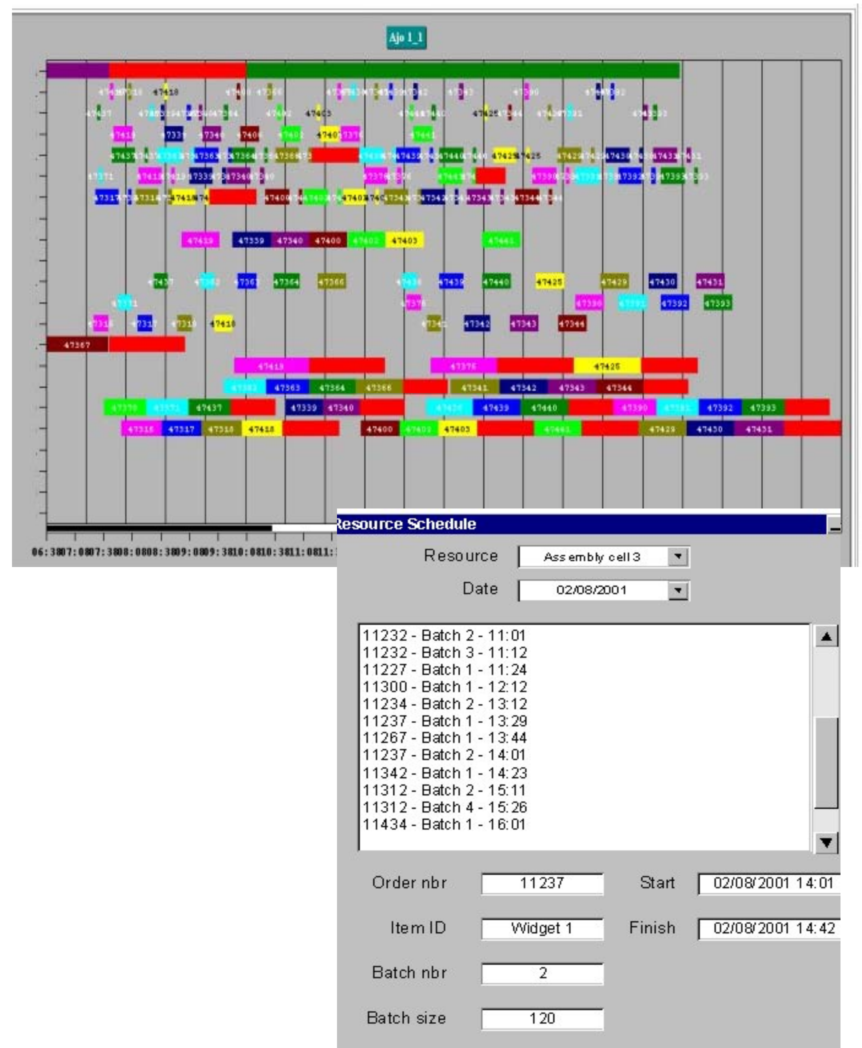
– MRP-type with no capacity constraints, just the materials constraints.

– Well, one can also omit material constraints and then Vollman talks about rough-cut capacity planning.



Finite scheduling

- Taking into account capacity constraints (one or several).
- Applied especially in stable resource environments with high capacity utilisation.
- May involve a fair amount of track & trace to get feedback from actual processing times.



Job-Shop Scheduling

Classical job-shop scheduling

- A sizable amount of research since 1960s.
- Concepts
  - Job, machine, processing time and setup time for each job at each machine.
  - In basic scheduling literature only one job can processed in one machine at one time
- An important and counterintuitive finding is that the size of the scheduling problem does not appear important. The findings in small problems are scalable to larger problems - as long as other important problem features like utilisation or layout are similar.
- This means that findings from smaller problems can be applied to real production environments.

Scheduling problem types

- General job shop and flow shop, where the routing is same for all n jobs.
- Static vs. dynamic, ongoing scheduling.
- Problem classification to *n/m/A/B* where
  - *n* is the number of jobs
  - *m* is the number of machines
  - *A*: F=flow shop (same routing), P=permutation flow-shop (A+same order in each machine, like assembly line), G=general
  - *B*: performance measure in question

Sequencing rules/ heuristics

- A well-researched area – 100s of rules invented. No single rule has been found to outperform other rules in all situations
- First In First Out (FIFO) / First come first served (FCFS)
  - The base-case heuristic
  - Minimizes variance of flow time – predicatble
  - ”Fair”

Sequencing rules/ heuristics cont.

- Shortest process time (SPT)
  - Minimises flow times (and inventories)
  - Good resource utilisation
  - Vollman et al (1994): "simulation experiments have consistently demonstrated SPT is a very good dispatching rule for many criteria. This conclusions is robust and supported by a variety of simulation studies."
- Earliest due date (EDD)
  - Minimized lateness
- Benefit of heuristics: Fast and easy

Basic JSSP results (i.e scheduling batches)

- SPT (shortest processing time) is best in $n/1/G/F_{max}$
- EDD (earliest due date) is the best in $n/1/G/T_{max}$
- Johnson's algorithm best in $n/2/G/F_{max}$ (sorts jobs from smallest job time and schedules in the beginning if job time in 1st machine and last if job time in 2nd machine.
- No such (P) rules/algorithms for $n/m \geq 3/G/B$.

Real scheduling is complex

- Unlike the classical JSSP, real factories may have:
  - product structures
  - dynamic scheduling (jobs scheduled during execution)
  - randomness
  - several classes of resources, such as machines + workers + tools
  - machines that can handle several jobs at a time
- Algorithms typically address one or two of these issues, but you will seldom find a ready-made algorithm for your factory.

Optimisation vs. Heuristics

- Heuristic rules are used for choosing the next job of a group of jobs to be processed on a machine (Sellers). Vollman (the textbook) calls them sequencing rules.

- Optimisation techniques use an mathematical description of the problem that is minimised through an algorithm (there are different definitions of *optimisation* out there).

Optimisation

- Unlike heuristics, optimisation considers all jobs for creating an optimal solution.
- In a job shop scheduling problem with is a set of n jobs to be scheduled on m machines, there are $(n!)^m$ possible ways to schedule the jobs.
- No polynomial time, optimal algorithms are known for larger (realistic size) scheduling problems (i.e. NP-hard).
- As considering all possible solutions is often not feasible, algorithms try to limit the search space. Tradeoffs:
  - Constraints / realism
  - CPU time
  - Solution quality – how far from the global optimum?

Production Paradigms/approaches and Scheduling

- Materials Requirements Planning (MRP / MRP II)
  - A algorithm based on BOM.
  - Infinite scheduling determines required, not necessarily installed capacity.
- Just-In-Time (JIT)
  - A ”philosophy”, emphasis on WIP reduction
  - Descriptive, not a scheduling algorithm (although Toyota Algorithm i.e. heuristic for building final assembly sequence is in litterature and Vollman cites a formula for determining KanBan cards)
  - Stresses flexibility & buffer (KanBan) control -> no need for formal scheduling for each and every order.

Production Paradigms/approaches and Scheduling

- Optimised Production Schedules (OPT)
  – Originally a software package based on Eliyahu Goldratt's Theory of Constraints (1980s)
  – Basic idea:
    - Identify bottlenecks and avoid bottleneck being out of work (small buffer)
    - elsewhere, material should move ASAP by pull control.
  – black-box, bottleneck scheduling algorithms unpublished
- ERP/APS
  – Basic ERP:s do not include advanced scheduling approaches, more often MRPII -based. Newer approaches are often referred as advanced planning & scheduling software (APS).

A little queueing theory

Concepts & Techniques

Lead Time Elements (from Vollman):

1. **Run time**: (time per piece x production lot size)
2. **Setup time**: (time to prepare the work center -> independent of lot size)
3. **Move time**: (time to move from work center to another -> depends on actual moving time and the transport size)
4. **Queueing/waiting time**: (time spent waiting to be processed at a work center -> depends on capacity utilisation and schedule)

Queueing system

- A queueing system consists of a queue and a server or multiple combinations of these elements
- Jobs/tasks arrive to the system, wait in the queues, are processed in servers and exit.
- Arrival time distribution, processing time distribution and number of servers define a queue-server system.
- For manufacturing systems, job can be a job and server a machine.

Pollaczek-Kyntch formula

(for M/G/1 queuing system steady-state)

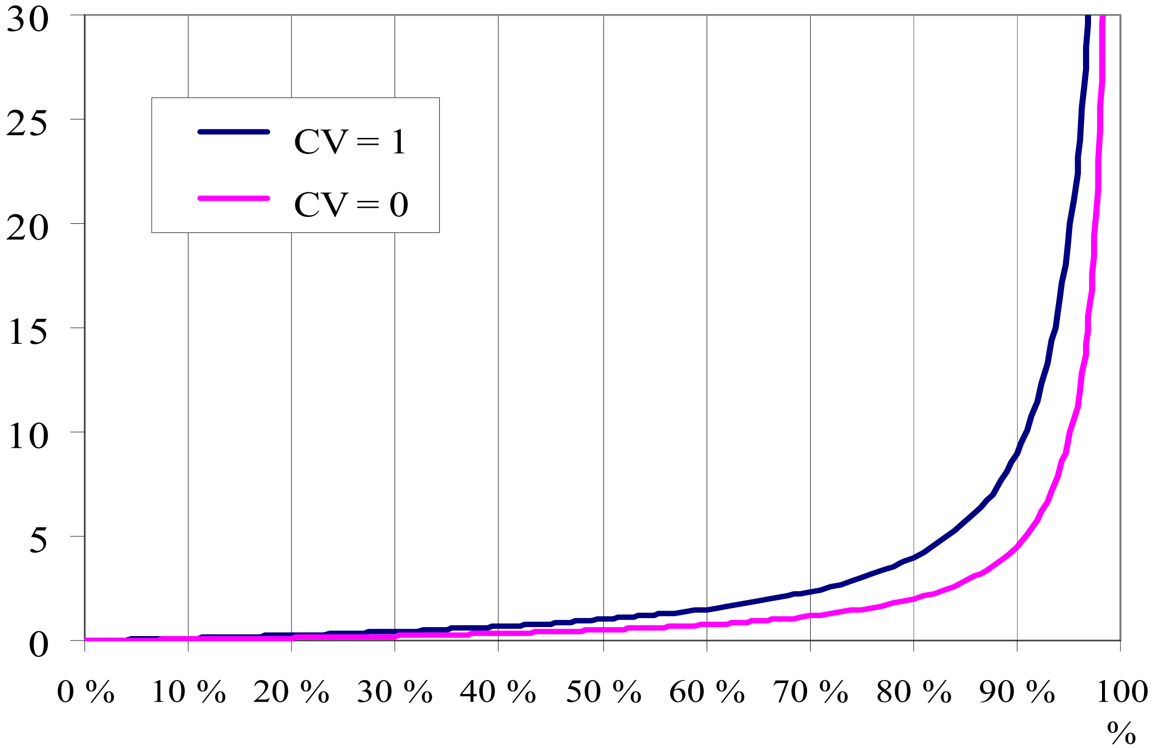
$$WT=1/2(1+CV)(\rho/(1-\rho))(PT)$$

Where

WT	=	average waiting time
ρ	=	utilisation
PT	=	average processing time
CV	=	δ/μ (coefficient of variation)

Waiting time as a function of utilisation

(Using Pollaczek-Kyntch steady-state approximation formula)



Utili-sation	WT	PT	WT % of total
50 %	1	1	50 %
60 %	1,5	1	60 %
70 %	2,3	1	70 %
80 %	4	1	80 %
90 %	9	1	90 %
95 %	19	1	95 %
99 %	99	1	99 %

in table CV = 1

CV = 1 (exponential distribution in arrivals)
CV = 0 (constant time between arrivals)
PT = 1 (average processing time, distribution general)

Queing theory insights for operations

- High utilisation leads to high WIP.
- Lead time is a function of utilisation.
- Variability in arrivals as well as processing increase WIP – but WIP is also often viewed as a buffer against those problems.
- Pull control limits WIP, achieves controlled lead times
- Push systems try to plan lead times, do not necessarily achieve controlled WIP due to variation (i.e. operative problems).
- In the MRP logic, lead times are constant. In fact, lead times are planned as a part of operations.

Materials Execution

Materials execution

- The logic behind managing the material flow: four examples:
  - visual control
  - lot-for-lot & purchase / make to order
  - order point method
  - VMI

Visual control

- The replenishment trigger is based on a visual impulse
  - Two-bin control
  - Kan-Ban
  - “Visual order point”
- Pros: happens on the spot, simplicity, participation of workers instead of computer systems, fast reaction to temporary problems
- Cons: is based on past consumption

Visual control (2)

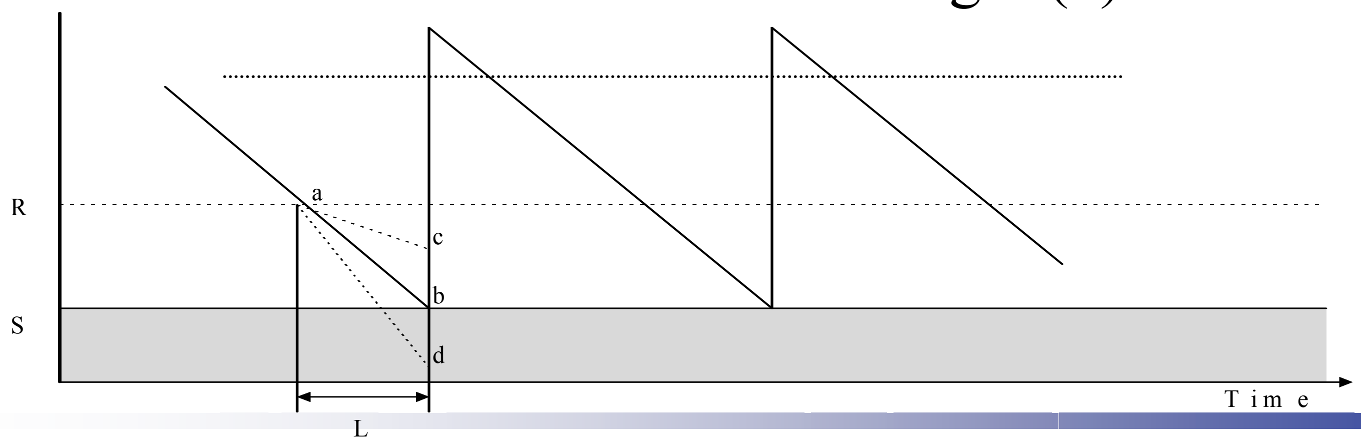
- Slow reaction to permanent changes and trends -> sets limitations to production mix variability
  - Origins in the Japanese car industry: production is smoothed and KanBan-system can take only variations of about 10%.
  - Not readily applicable in an environment where
    - demand variations big: short life cycles (frequent ramp-ups and -downs), changes in demand, cyclical / seasonal demand or big changes in production mix, large number of products/components)
    - the replenishment lead times of critical components are long.
  - Good tool to control bulk parts with low prices and steady consumption

Lot-for-lot /replenish to order

- Items are manufactured / replenished to customer order (lot-for-lot)
- Expensive parts, rare parts, large parts
- Pros: small inventories, flexibility
- Cons: length of customer lead time defined by purchasing lead times if no safety stock allowed

Order point method

- R = order point, S = safety stock, L = replenishment lead time
- a is the point, where inventory goes below the order point. If the demand stays as expected (average), the limit of safety stock is reach exactly when the replenishment arrives (point b).
- The actual/realised demand can be larger (d) or smaller (c).

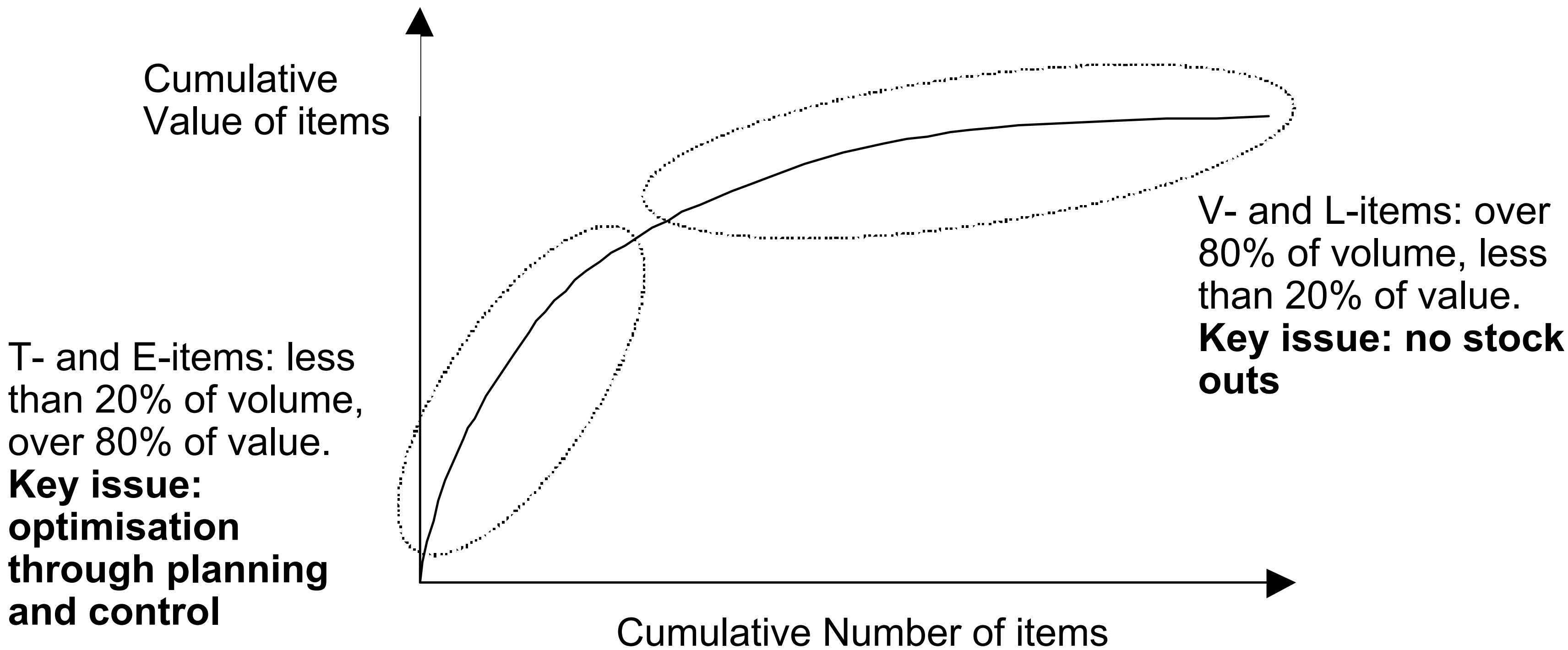


VMI: vendor managed inventory

- The manufacturer does not necessarily need to take care of inventories themselves, vendor may wish to take care of them.
- A well-known, old ”story”: Würth where applied to low volume, low cost items (screws).
- Like any inventory replenishment, requires accurate inventory counts but also automatic instead of visual transmitting of the counts.
- For process industries, large containers/vessels can have fluid level measurement which is transmitted to supplier like Fortum.
- Pros: allows supplier more room for minimising total costs
- Cons: accuracy in inventory counts, arrangement information flow.

Case: materials management at Tamrock

Four item classes :
E-, T-, V- and L-items

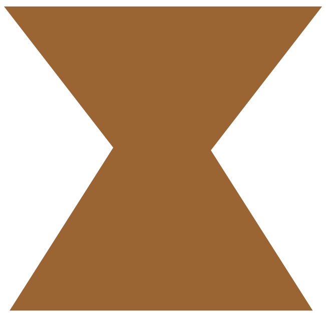


Tamrock

- L-items: two-bin control; suppliers replenish directly to factory floor. Low price items, high consumption. No material allocations no quantity on hand in the IT system. Turnover target >10.
- V-items: pure order point: an order is generated when the qty on hand goes below the order point. Qty on hand and allocations in the system.
- E-items: material profile with allocation. An order suggestion (which is accepted by the system user) is generated when the qty on hand will go below the order point in the future, with regard to the lead time.
  - New item is always first E-item, when the criteria for another group are fulfilled, the item is removed to another class.
- T-items: Lot-for-lot to customer orders. Includes bulky materials.

Implications of Product Structure

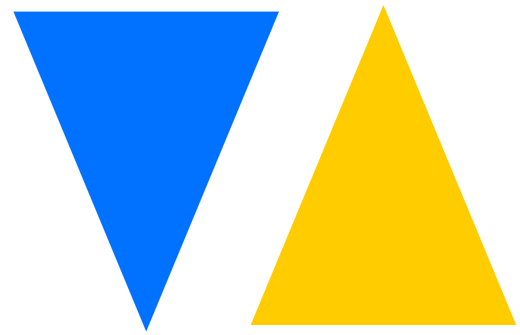
Modular product structure



Amount of end products

Amount of modules

Amount of components



- In many industries the production management can be simplified in product development through modular product structures.
  - Products are divided into different control classes, such as ATO-, MTO- and ETO-products.
  - Product groups have different pricing and delivery time policies.
- Mass customisation, T-structure!

The materials impact of modularity

- Situation in for example electronics industry
  - components expensive,price erosion high and the industry cost structure very material intensive
  - the lead time for critical purchased components considerably longer than the factory lead time
  - product life cycles short

  => inventories should be avoided.
- Need to forecast the materials requirements as precisely as possible.
- Advantage of modular product structure: small amount of modules yield a large amount of end products.
- Instead of end products, modules (options) are forecasted and controlled. Through this, better forecast accuracy is achieved.

Thank You for Your Attention!

Juha-Matti Lehtonen