Introduction

- Production planning and control
- Types of production
- Hierarchical production planning
- Industrial internet and production control
- Cost functions and economies of scale
- Optimization models and production

Production planning and control

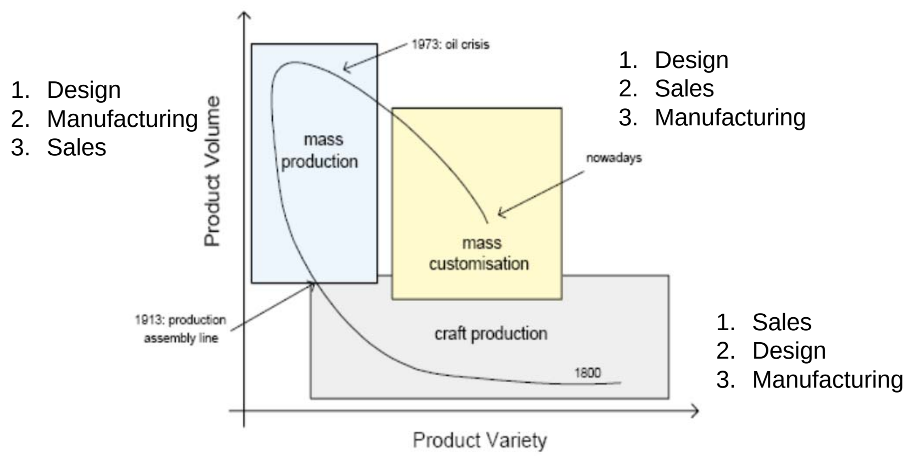
”Production planning is a plan for the future production, in which the facilities needed are determined and arranged”

“The administrative process that takes place within a manufacturing business and which involves making sure that sufficient raw materials, staff and other necessary items are procured and ready to create finished products according to the schedule specified.”

Production planning tasks, from weeks to months and years:
- Supply chain planning
- Warehouse planning
- Production capacity planning
- Schedule generation and deviation control and reporting

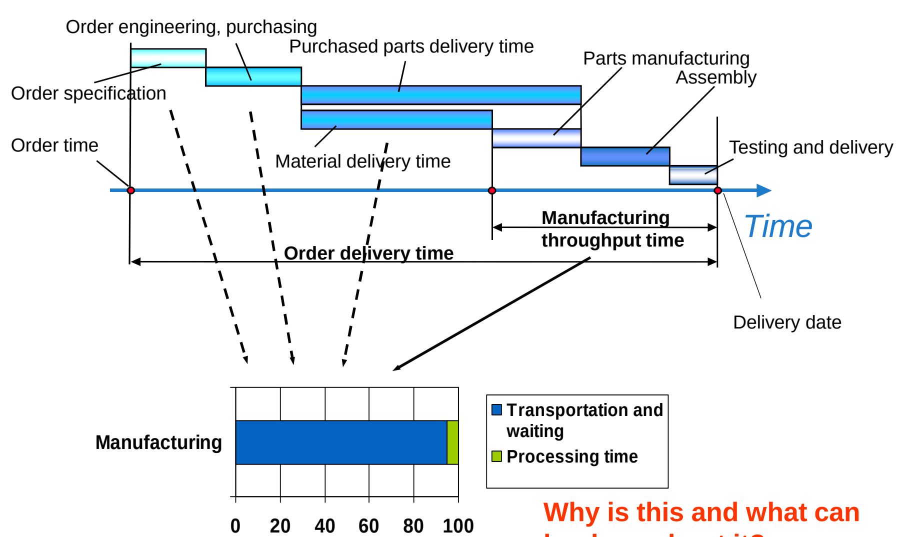
Control tasks, from hours to weeks and months:
- Production scheduling and control
- Stock control
- Efficient resource allocation

From volume to variation



Source: Leitao

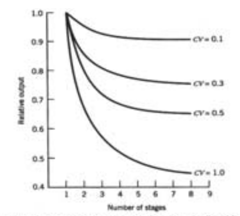
Order-to-delivery process of a mechanical engineering product



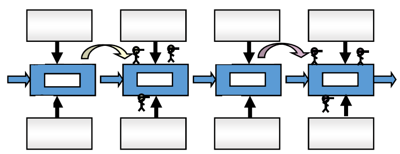
Why is this and what can be done about it?

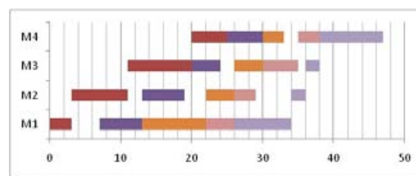
Why are throughput times long compared to processing time?

1. Usually only a small share of calendar time is used for production. One shift covers some 1600 of the annual 8760 hours – ca. 18 %
2. Batch manufacturing: Manufacturing involves one-off starting (set-up) costs. It is economically sensible to distribute these over a larger number of products.
3. Without *variation* throughput time could be calculated as the sum of processing times: for example 4 steps x 1 h = 4 h. Variation causes queuing and waiting.



Effect of random processing time in balanced, unbuffered lines.





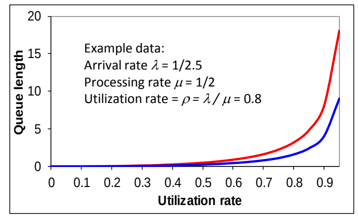
Where does variation originate?

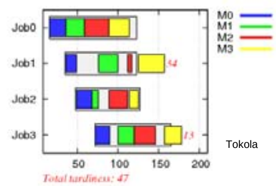
- Demand variation
  - Customers have their own independent needs concerning delivery time, amount and quality
- Different types and sizes of products
  - Processes and processing times are different and resource loading varies
- Manufacturing in lots
  - Lot sizes vary
  - Set-up times vary depending on product and previous product
  - Batch processes
- Process variation
  - Technical variation
  - Human labor variation
  - Absenteeism
  - Machine breakdowns
  - Poor quality
  - Other disruptions

What can be done?

- Increase daily running time by automation or shift work
- Increase capacity to lower utilization rate, which reduces waiting, but is expensive
- Shorten set-up times and decrease lot sizes
- Decrease variation
  - Standardize and modularize products
  - Change set-ups from ”internal” to ”external”
  - Develop process for better flow – utilize Lean tools etc.
  - Increase flexibility of capacity – use flexible technology, cross training, subcontracting
- Plan and control production
  - Organize planning to a hierarchical system
  - Solve in an organized manner piece by piece
  - However, this may be difficult…

Fastems





Tokola

$4!^4$ v= 331 776 alternative permutations

Production types in relation to variation

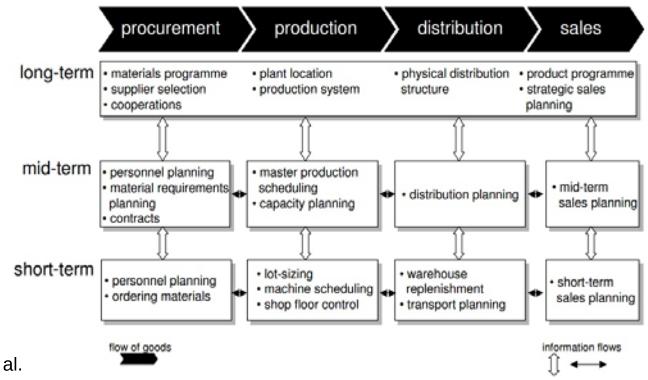
- Mass production
- Serial production, Batch production, production in lots
- Batch production – the whole batch is processed simultaneously
- Mixed production, job shop production
- One of a kind production, one-off production
- Project based production
- ETO (Engineer-To-Order), MTO (Make-To-Order), ATO (Assemble-To-Order), MTS (Make-To-Stock) production

…and to system

- Production line
- Flow shop
- Cellular production
- Functional production layout, job shop
- FMS (Flexible Manufacturing System)

Hierarchical production planning and control

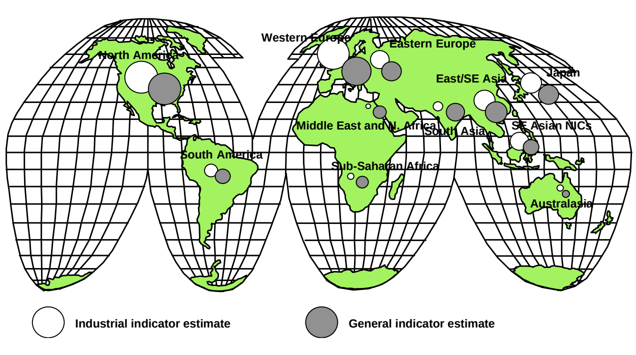
- In production planning the detail and accuracy of information increase as the time horizon shortens
- The controlled system usually is not economical and possible to be treated as a monolith and it is dealt to parts, usually as a hierarchical system in the following way:



Stadtler et al.

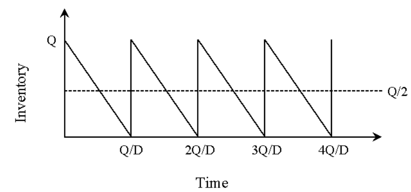
Hierarchical production planning and control

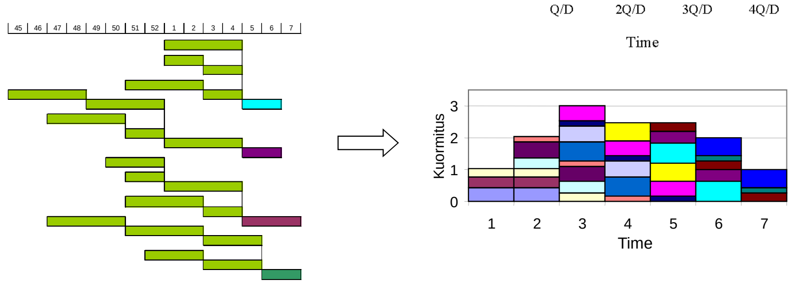
- **In the long run** (strategic) planning types of operation and resources, facilities location and product and service allocation to various markets are defined
  - Factories are built
  - Production system types are specified
  - Investments in machinery are made



Hierarchical production planning and control

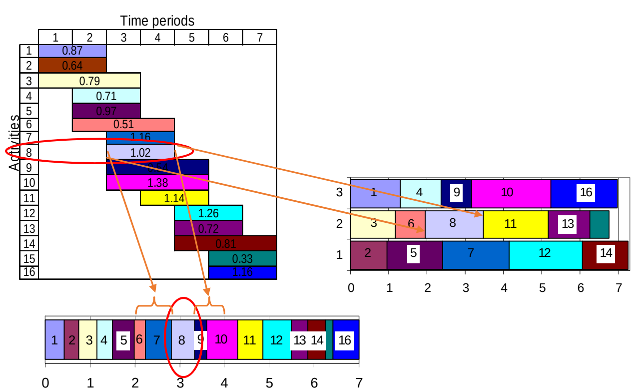
- **In the medium run** (tactical) resource capacity is matched with forecasted demand and the orders are roughly scheduled for processing so that the resource load is levelled
  - Labor is hired
  - Supply contracts are made
  - Stocks are used for load levelling
  - Aggregate planning is made



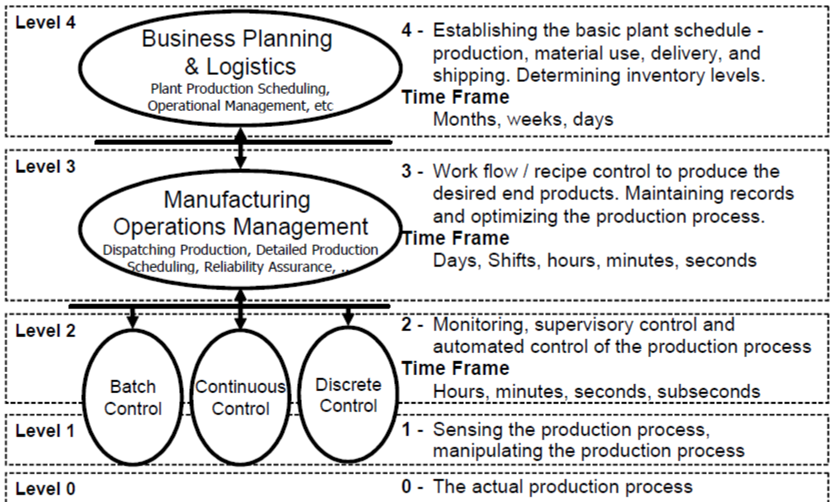


Hierarchical production planning and control

- **In the short run** (operational) scheduling of existing orders and labor allocation is done
  - Exact timing of jobs and lot sizes are determined
  - Labor is moved
  - Overtime work and subcontracting are used



ANSI/ISA—95.00.03—2005 Enterprise Control System Integration Part 3: Activity Models of Manufacturing Operations Management



Multi-level functional hierarchy of activities

Industrial Internet and Production Control – "Control room concept"

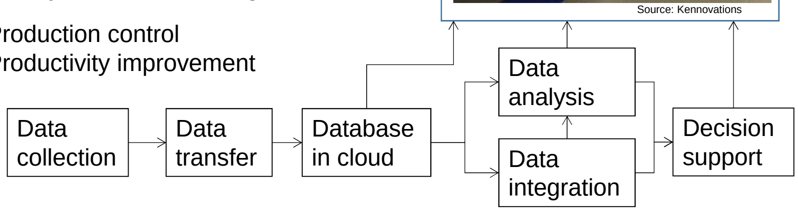
Industrial internet based data collection facilitates unforeseen accuracy and detail in:

- Object location and status monitoring
- Part flow analysis
- Worker follow-up
- Data integration and work analysis
- Flow time analysis
- Quality related monitoring…

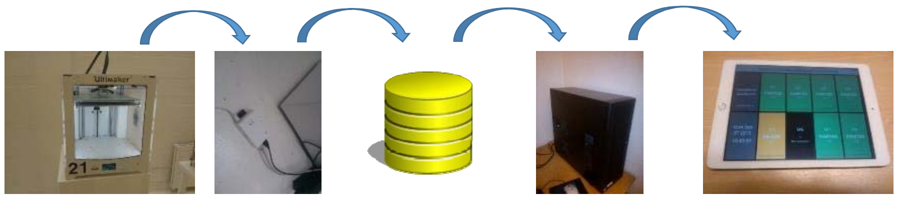
- Production control
- Productivity improvement

Visualization, dashboards

Source: Kennovations



Dashboard demo in production engineering laboratory



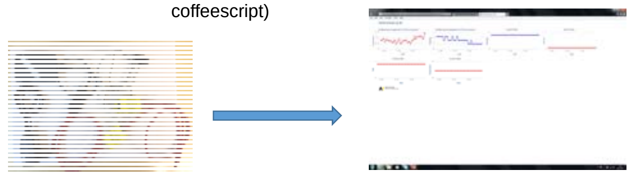
3D Machine Ultimaker (arduino, USB)

Raspberry Pi is used to transfer data from machine to cloud (USB, G-code, REST, http, octoprint, hyprox)

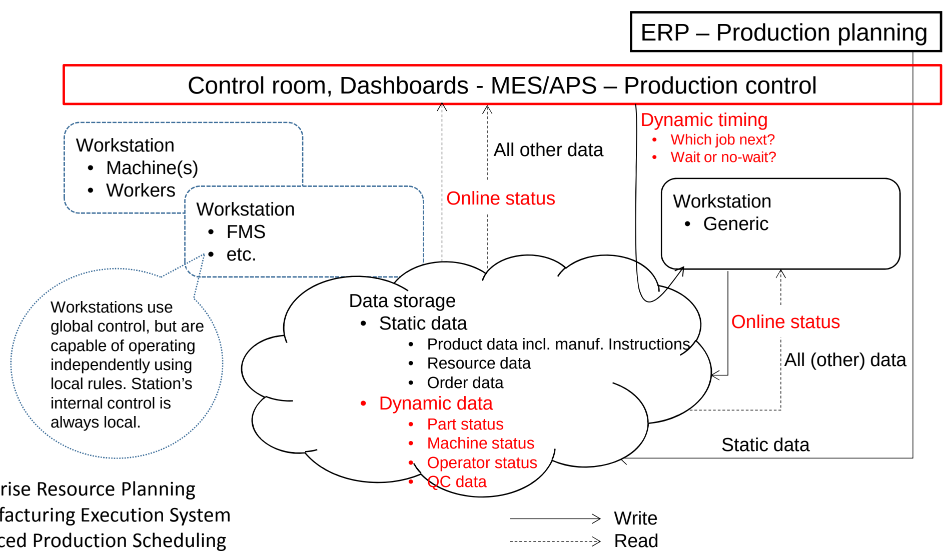
Data is collected in cloud using open messaging interface (OM-I) standard

RedHat server running dashing framework. Generates websites for dashboards (Thin server, dashing, ruby, coffeescript)

iPad shows dashboards in browser



Industrial Internet and Production Control – A De/Centralized Decision Making Architecture



ERP = Enterprise Resource Planning
MES = Manufacturing Execution System
APS = Advanced Production Scheduling

Industrial Internet and Production Control – Decentralised Control

- *Decentralised control* distributes decision making and is supposed to be robust against disturbances and changes in system configuration
- Simple local decision making is common in practice
  - Does not require complete status information
  - Easy to implement and often works quite well
  - …But in many cases is far from optimal

Industrial Internet and Production Control – Decentralised Control

- Particularly the following situations can not be efficiently dealt with using only local status information:
  - Disturbances causing bottle necks further downstream
  - Timing of parts for assembled products
  - Control of re-entrant processes
  - … any factors not in the immediate neighbourhood of the decision maker cannot be taken into account
- Using the status information enabled by the Industrial internet better quality local decision making than simple prioritising is possible

Costs and cost functions

In economics cost function gives minimum cost (C), at which a given production quantity ("flow", amount per time unit) can be produced by combining factors of production efficiently with the given factor prices

Simple linear cost function

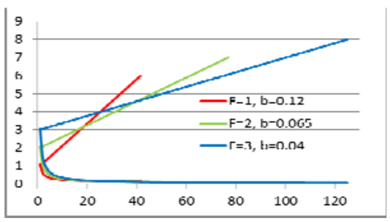
This is often used in short run examination, when the technology does not change. *Total production cost* function consists of fixed and variable costs:

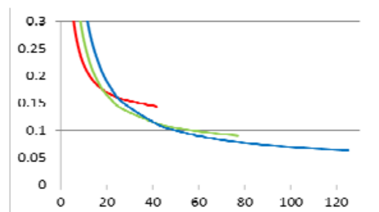
$C_{tot} = F + bx$,

where F = fixed cost and b ($b > 0$) is variable cost.

Average cost is obtained by dividing TPC by production quantity:

$C_{ave} = C_{tot} / x = F / x + b$



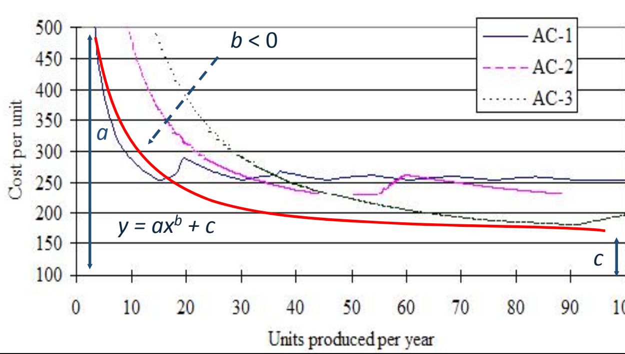


Costs and cost functions

In reality, and especially in the long run, cost functions are nonlinear. If the manufacturing process consists of several steps and/or alternative technologies exist for the process steps, the minimum manufacturing cost can usually be formulated as follows:

$C_{ave} = ax^b + c$ ja $C_{tot} = ax^{b+1} + cx$,

where a ($a > 0$) is a parameter that defines the level of fixed cost; b ($-1 < b < 0$) is a parameter that determines the level of economies of scale and c determines a minimum for the variable cost



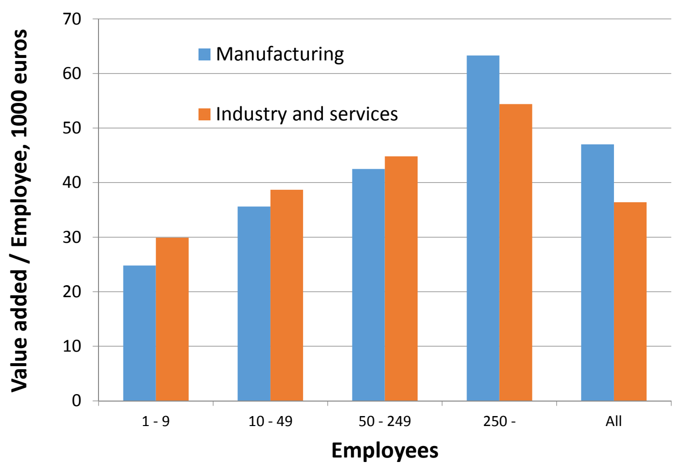
The effect of production volume on costs

Economies of scale are caused by the following:

1. Distribution of one time costs over a large amount of products: machinery, tools, set-ups, supply contracts etc.
2. Specialization: right kind (technology) and size resource (equipment) for each purpose (process)
3. Type of production system: functional – cell – line
4. Large dimensions: for example tank capacity increases cubically in relation to diameter whereas relative area increase is square
5. Sharing of risk: costs related to spare parts, buffer capacity and stocks do not increase linearly in relation to production volume but in a square root relationship
6. Learning: Learning, i.e. experience, increases with accumulated production amount. With larger production volume, this takes place faster
7. Quality: Various quality costs decrease in high volume production for many reasons…

Economies of scale may be utilized through outsourcing without large volume in one's own production

Economies of scale in Europe



Source: Eurostat 2005

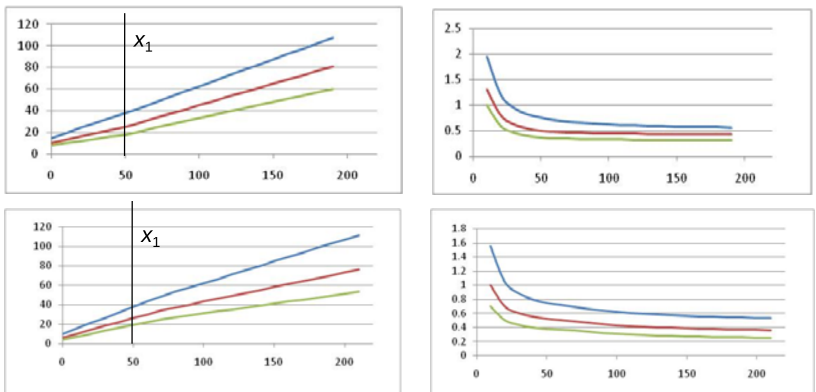
Costs and cost functions

In optimization models cost function (economics' or optimization objective function) is often modelled as piecewise linear:

$C_{tot} = F_1 + b_1 x$, when $x < x_1$

$C_{tot} = F_2 + b_2 x$, when $x > x_1$,

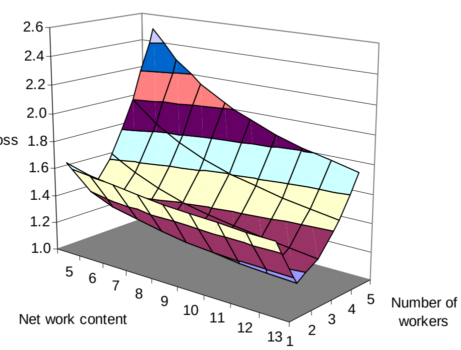
where F = fixed cost and b_1 and b_2 (b_1, $b_2 > 0$) are variable costs



Labor productivity as a function of group size

- Too small a number of workers in a factory decreases specialization
- Too large number causes congestion
- If a job can be done by a variable number of workers, productivity depends on the number of workers. For example in assembly:
  - One worker can not handle large parts
  - Two may be an optimal group size (”dynamic duo”)
  - Several workers obstruct each other and may not find a suitable task
- Starting work involves a ”set-up time” always when a worker starts or restarts a job

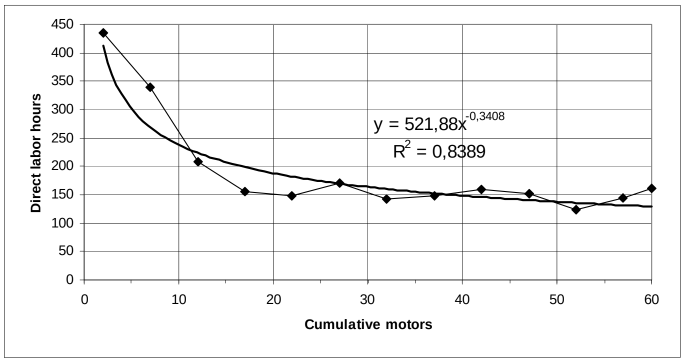
Relative loss



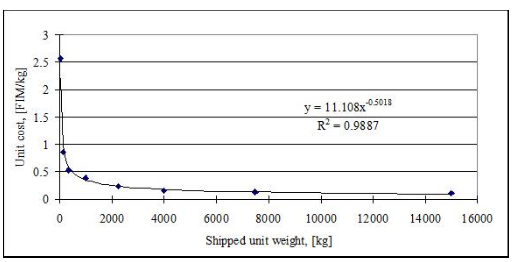
Labor productivity with different group sizes and work content and fixed ”set-up” time. Efficiency function is piecewise linear =>

Other cost functions - learning

Learning as a function of accumulated production amount obeys a simple power curve, especially in the beginning. This is important in small series production. With larger production volume the classical power curve converges to zero, which is not realistic. The afore presented cost function shape $y = ax^b + c$,($b < 0$) is better.

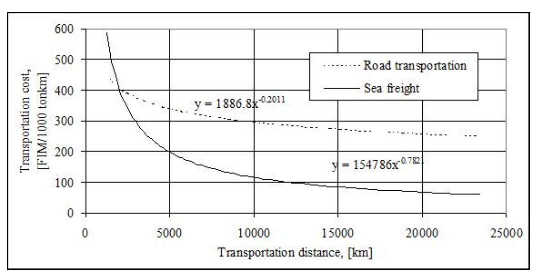


Other cost functions – examples from transportation



Transportation cost as a function of shipment weight. Here an increase beyond 20 tons does not bring any additional benefit. It may be even harmful due to container weight limitations.

Transportation cost as a function of travel distance. The technology used affects transportation time, which may set practical constraints and affect total costs.



About modelling and production planning

- Queuing theory examines production control based on assumptions about distributions concerning variation involved and apply simple priority rules (FIFO), and results are averages and probabilities
- Real production control requires detailed and deliberate decisions about the order in which the jobs are executed
- Because the task is difficult (n! permutations for n jobs already on one machine), control may be based on rules of thumb, trials (simulation, GUI + manual moving etc.), optimization using heuristics or proven algorithms
- General practical arrangement is a hierarchical system, where aggregate planning schedules orders as projects or larger lots
- Floor level control is based on prioritizing
- This means selecting the next job among all available jobs using a simple rule
- Typical rules: SPT Shortest Processing Time, EDD Earlies Due Date, FIFO First In First Out, S/RO Slack per Remaining Operation, Slack per Total Work Remaining, LWKR Least Work Remaining
- Mathematical programming, that is optimization with classical general methods, can nowadays be applied to many problems successfully, to some problems only to a limited extent

Observations and assumptions about optimization in production control

- Jobs (orders) may be available all at once (static situation) or they may become known or arrive over time (dynamic situation)
- It is assumed, unless otherwise stated, that there is no uncertainty: machines do not break down, workers are available, processing times are known etc.
- Usually no pre-emption is allowed. Job is processed continuously until complete once it is started
- Time is usually discrete in static capacity calculations and in aggregate planning and continuous in detailed scheduling
- Aggregate planning events are scheduled to “time buckets” within timing constraints and other, mainly capacity and resource use related constraints are set on the time buckets
- In detailed scheduling the jobs’ starting times and finishing times usually have real values

Typical objectives in production control

- Average or total flow time and WIP
  - Directly related to each other according to Little's law
- Makespan, finishing time of the last job of a number of jobs
  - Minimization maximizes utilization rate of machines
- On-time-delivery
  - Popular in practice, but problematic in reality
- Service rate
  - Availability from stock
- Utilization rate
  - Used capacity in relation to planned capacity; < 1
- Loading rate
  - Planned load in relation to (planned) capacity: may be > 1
- Maximum tardiness
- Total or average tardiness
- Number of tardy jobs
- Total cost, average cost

Models for objectives

- Total flow time $\sum c_i$, c_i = completion time of job i
- Makespan, latest completion time f of set c_i :

$$\begin{aligned} &\text{Min} f \quad \text{so that} \\ &f \geq c_i, \quad \forall i \end{aligned}$$

- Maximum tardiness (D_i are due dates)

$$\begin{aligned} &\text{Min} l \quad \text{s.t.} \\ &l \geq c_i - D_i, \quad \forall i \\ &l \geq 0. \end{aligned}$$

- Total tardiness or average tardiness

$$\begin{aligned} &\text{Min} \sum l_i \quad \text{s.t.} \\ &l_i \geq c_i - D_i, \quad \forall i \\ &l_i \geq 0. \end{aligned}$$

- Number of tardy jobs (M is a large number)

$$\begin{aligned} &\text{Min} \sum z_i \quad \text{s.t.} \\ &M z_i \geq c_i - D_i, \quad \forall i \\ &z_i \in \{0,1\}. \end{aligned}$$