Progettazione di Materiali e Processi

Modulo 1 – Lezione 6
Progettazione e selezione di materiali e processi
A.A. 2021-22
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Selecting Processes:

shaping, joining and
surface treatment

Outline

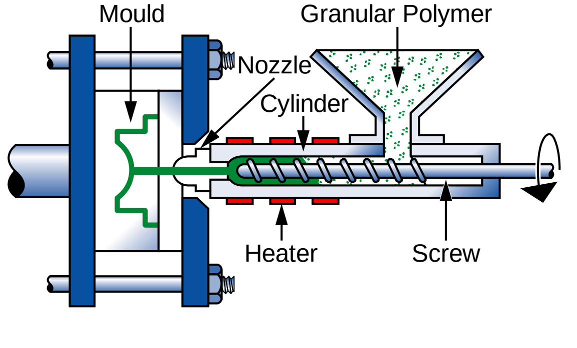
- **Processes and their attributes**
- **Screening by attributes**
- **Selecting shape-forming processes**
- **Selecting joining processes**
- **Selecting surface-treatment processes**
- *Hands-on session with exercises*

Resources

- **"Materials: engineering, science, processing and design**", 2nd Edition, Chapter 18 and 19
- **"Materials Selection in Mechanical Design",** 4th edition Chapters 13 and 14

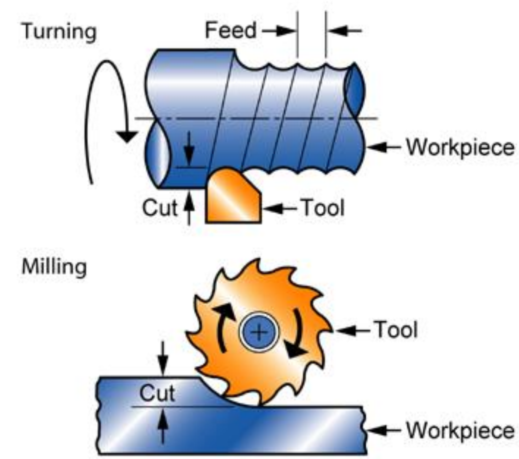
Organizing info: manufacturing processes

Primary shaping



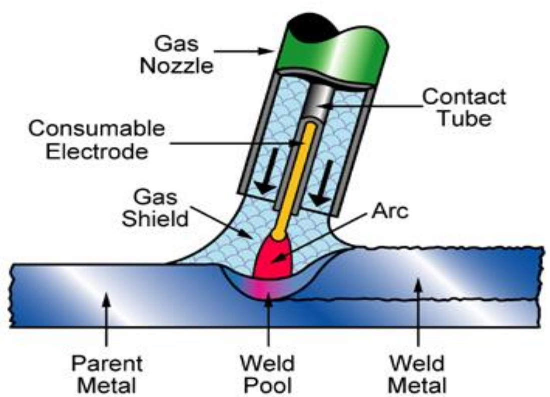
Injection moulding

Secondary shaping



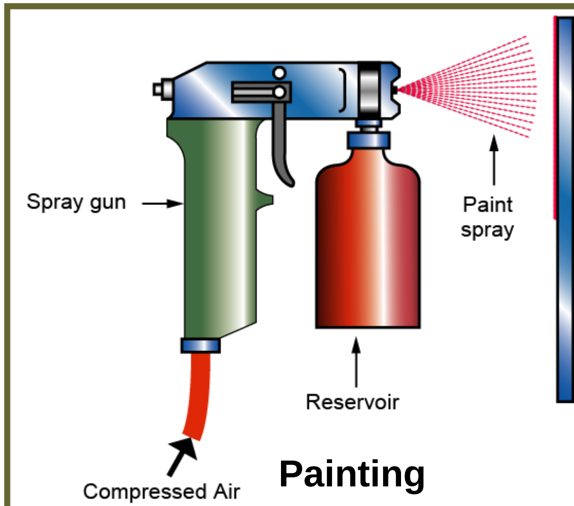
Machining

Joining



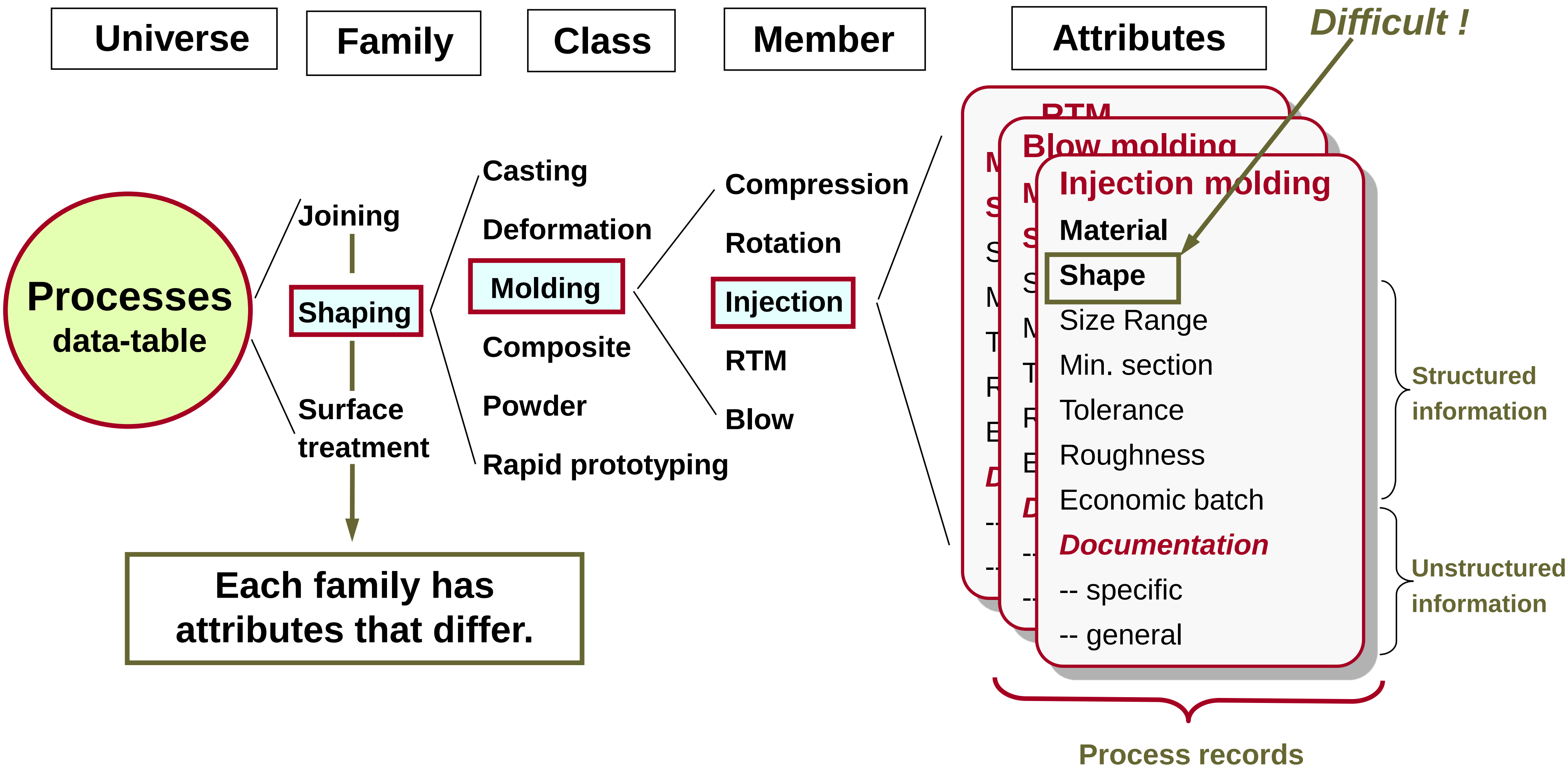
Welding

Surface treating



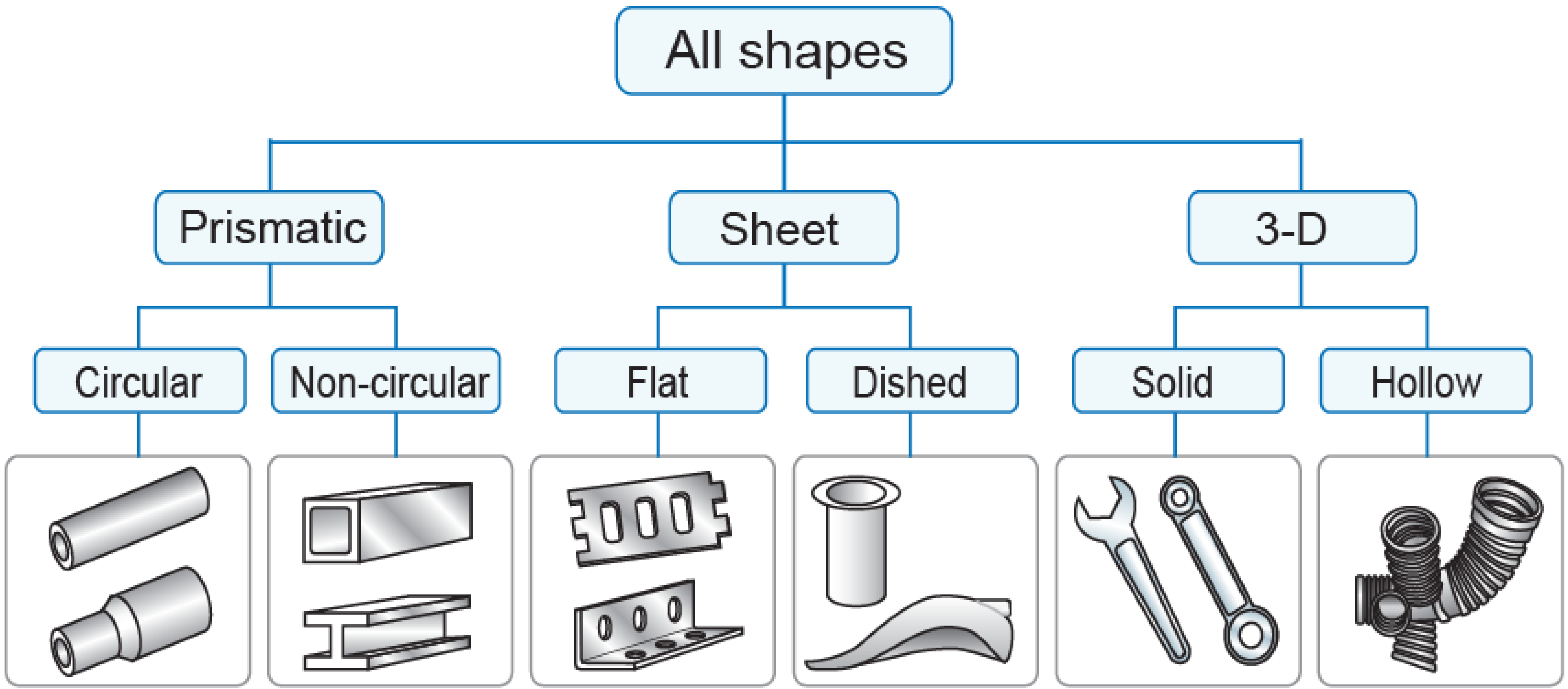
Painting

Organizing information: the PROCESS TREE



Shape classification

Some processes can make only simple shapes, others, complex shapes.



- Wire drawing, extrusion, rolling, shape rolling: **prismatic shapes**

- Stamping, folding, spinning, deep drawing: **sheet shapes**

- Casting, molding, powder methods: **3-D shapes**

Structured data for injection moulding*

Injection moulding (Thermoplastics)

- INJECTION MOULDING of thermoplastics is the equivalent of pressure die casting of metals. Molten polymer is injected under high pressure into a cold steel mould. The polymer solidifies under pressure and the moulding is then ejected.

Shape

Circular Prism	True
Non-circular Prism	True
Solid 3-D	True
Hollow 3-D	True

Physical attributes

Mass range	0.01-	25	kg
Roughness	0.2 -	1.6	µm
Section thickness	0.4 -	6.3	mm
Tolerance	0.1 -	1	mm

Process characteristics

Discrete	True
Prototyping	False

Typical uses

Injection molding is used ……….

Economic attributes

Economic batch size	1e+004 - 1e+006
Relative tooling cost	high
Relative equipment cost	high

Cost modeling

Relative cost index

+ Links to materials

Key constraints in choosing a shaping process

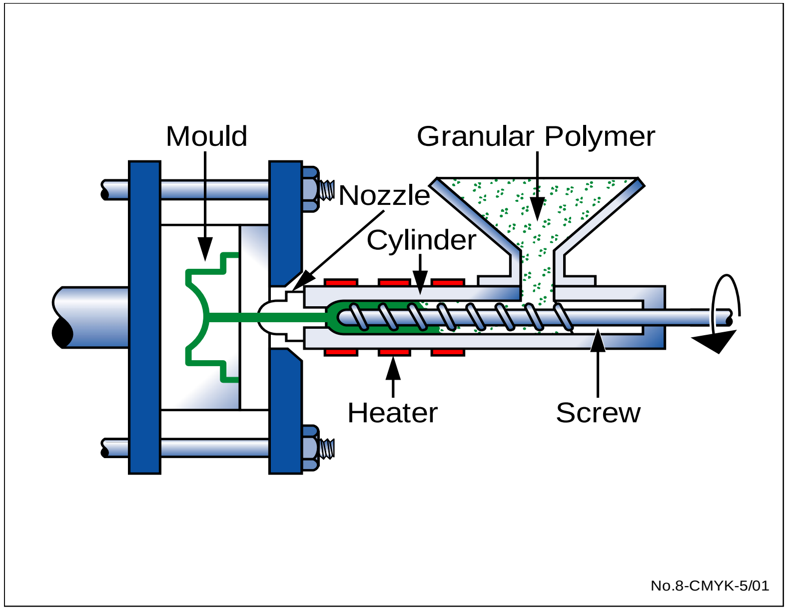
(*economics always important*)

*Using the *CES* EduPack Level 2 DB

Unstructured data for injection moulding*

The process. Most small, complex plastic parts you pick up – children's toys, CD cases, telephones – are injection moulded. Injection moulding of thermoplastics is the equivalent of pressure die casting of metals. Molten polymer is injected under high pressure into a cold steel mould. The polymer solidifies under pressure and the moulding is then ejected.

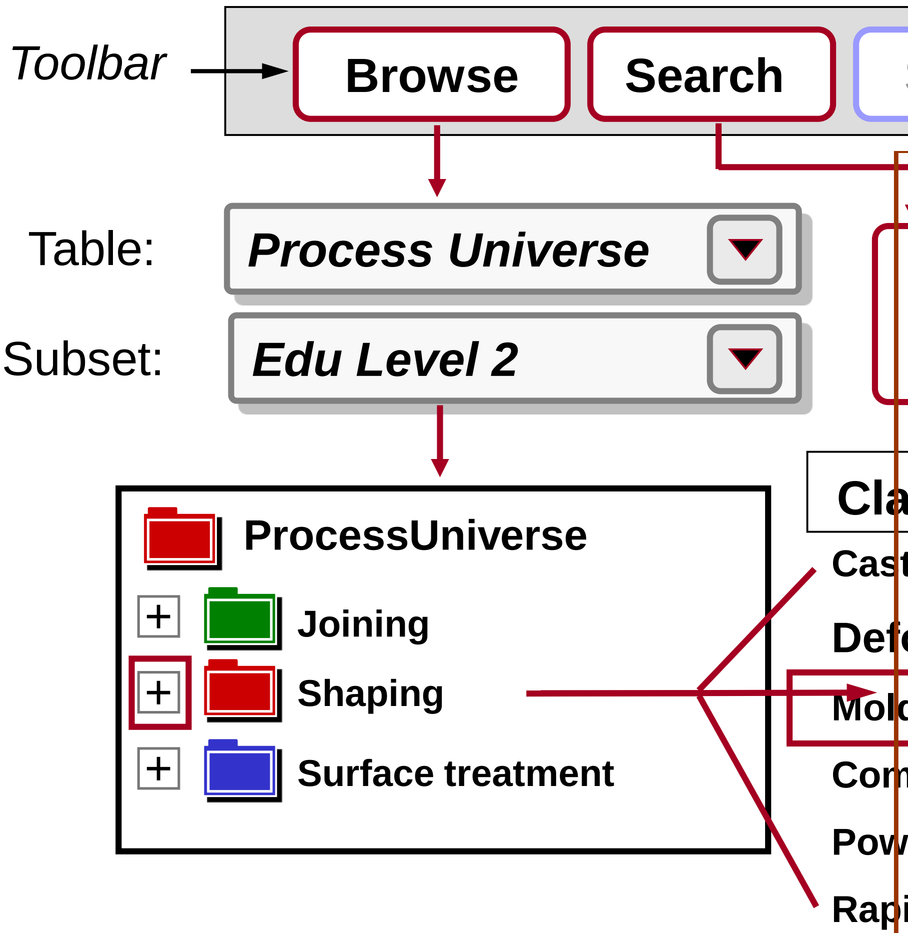
Various types of injection moulding machines exist, but the most common in use today is the reciprocating screw machine, shown schematically here. Polymer granules are fed into a spiral press like a heated meat-mincer where they mix and soften to a putty-like goo that can be forced through one or more feed-channels ("sprues") into the die.



- **Design guidelines.** Injection moulding is the best way to mass-produce small, precise, plastic parts with complex shapes. The surface finish is good; texture and pattern can be moulded in, and fine detail reproduces well. The only finishing operation is the removal of the sprue.
- **The economics.** Capital cost are medium to high; tooling costs are high, making injection moulding economic only for large batch-sizes (typically 5000 to 1 million). Production rate can be high particularly for small mouldings. Multi-cavity moulds are often used. The process is used almost exclusively for large volume production. Prototype mouldings can be made using cheaper single cavity moulds of cheaper materials. Quality can be high but may be traded off against production rate. Process may also be used with thermosets and rubbers.
- **Typical uses.** The applications, of great variety, include: housings, containers, covers, knobs, tool handles, plumbing fittings, lenses, etc.
- **The environment.** Thermoplastic sprues can be recycled. Extraction may be required for volatile fumes. Significant dust exposures may occur in the formulation of the resins. Thermostatic controller malfunctions can be extremely hazardous.

*Using the *CES* EduPack Level 2 DB

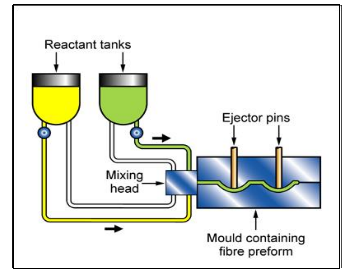
Finding information with CES EduPack



Resin transfer molding (RTM)

The process

RESIN TRANSFER MOLDING (RTM) allows manufacture of complex shapes in fiber-reinforced composites without high tooling costs. It uses a closed mold, in two or more parts, usually made of glass-reinforced polymers or light metal alloys, with injection points and vents to allow air to escape. Reinforcement is cut to shape and placed in the mold, together with any inserts or fittings. The mold is closed and a low viscosity thermosetting resin (usually polyester) is injected under low pressure (roughly 2MPa) through a mixing head in which hardener is blended with the resin.



Shape

Circular prismatic	True
Non-circular prismatic	True
Flat sheet	True
Dished sheet	True
Solid 3-D	True
Hollow 3-D	True

Physical attributes

Mass range	0.8	-	50	kg
Range of section thickness	2	-	6	mm
Tolerance	0.25	-	1	mm
Roughness	* 0.25	-	1.6	µm
Surface roughness (A=v. smooth)	A			

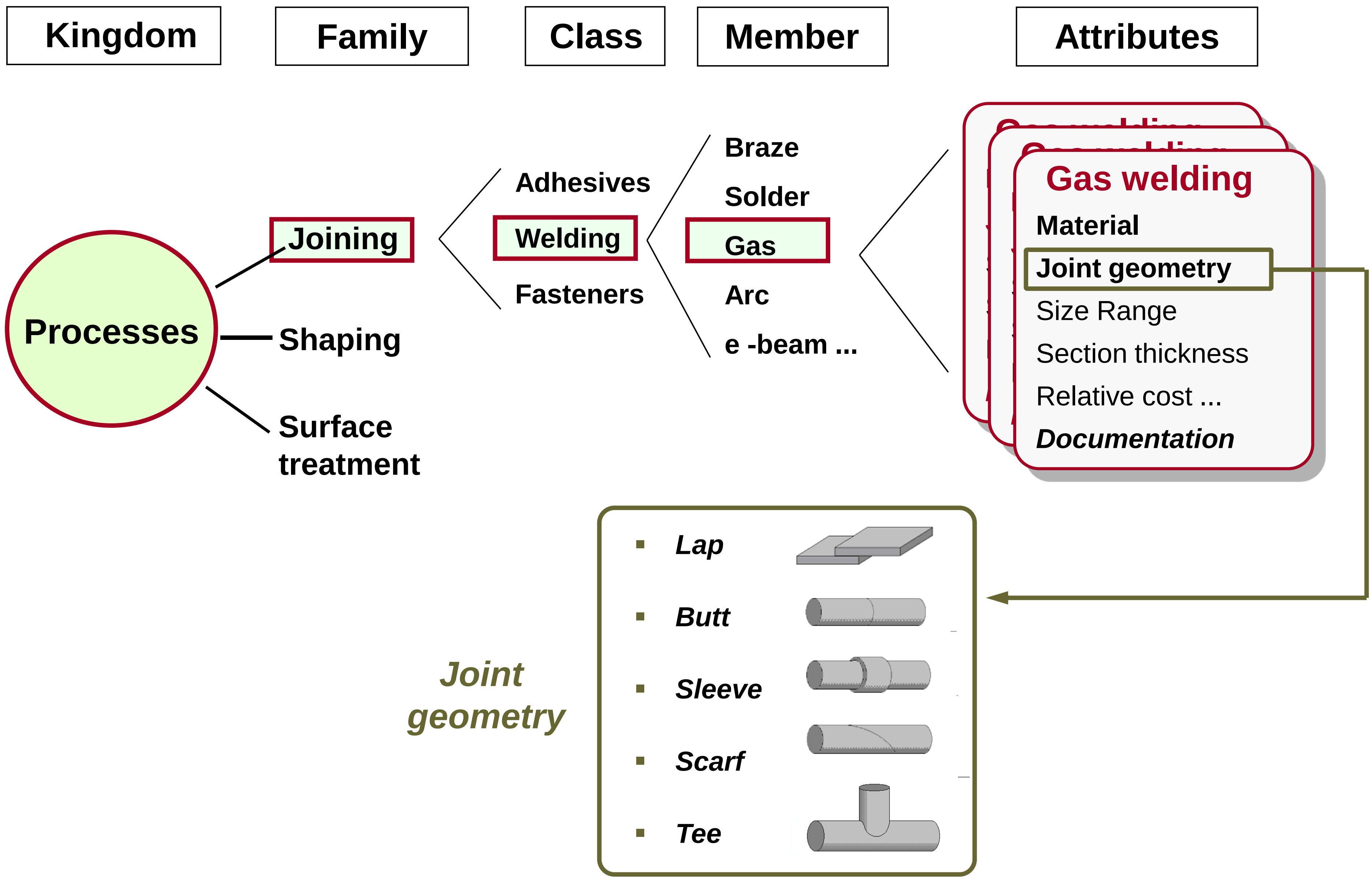
Economic attributes

Relative tooling cost	high		
Relative equipment cost	medium		
Labor intensity	high		
Economic batch size (units)	1000	-	1e6

Typical uses

RTM is used to make large composite structures such as manhole covers, compress soil casings, car doors and side panels, propeller blades, boat building, hulls, canoe paddles, water tanks, bath tubs, roof sections, airplane escape doors.

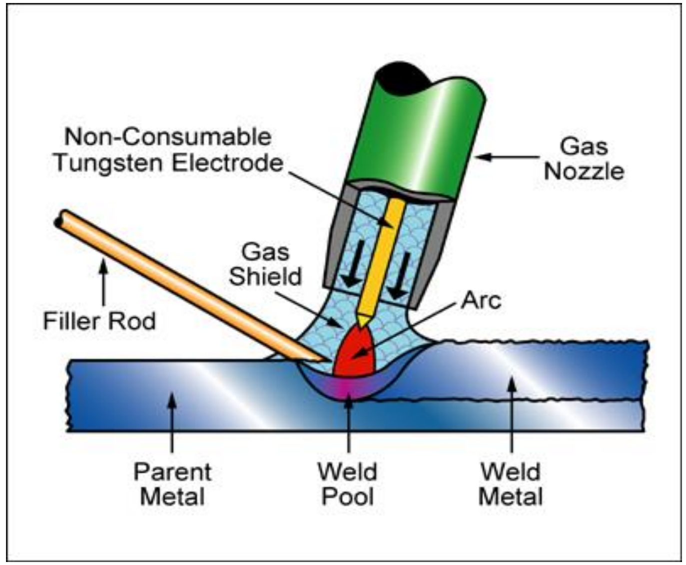
Data organization: joining processes



A joining record*

Gas Tungsten Arc (TIG)

Tungsten inert-gas (TIG) welding, the third of the Big Three (the others are MMA and MIG) is the cleanest and most precise, but also the most expensive. In one regard it is very like MIG welding: an arc is struck between a non-consumable tungsten electrode and the work piece, shielded by inert gas (argon, helium, carbon dioxide) to protect the molten metal from contamination. But, in this case, the tungsten electrode is not consumed because of its extremely high melting temperature. Filler material is supplied separately as wire or rod. TIG welding works well with thin sheet and can be used manually, but is easily automated.



Joint geometry

Lap	True
Butt	True
Sleeve	True
Scarf	True
Tee	True

Materials

Ferrous metals

Physical attributes

Component size	non-restricted
Watertight/airtight	True
Demountable	False
Section thickness	0.7 - 8 mm

Economic attributes

Relative tooling cost	low
Relative equipment cost	medium
Labor intensity	low

+ Links to materials

Typical uses

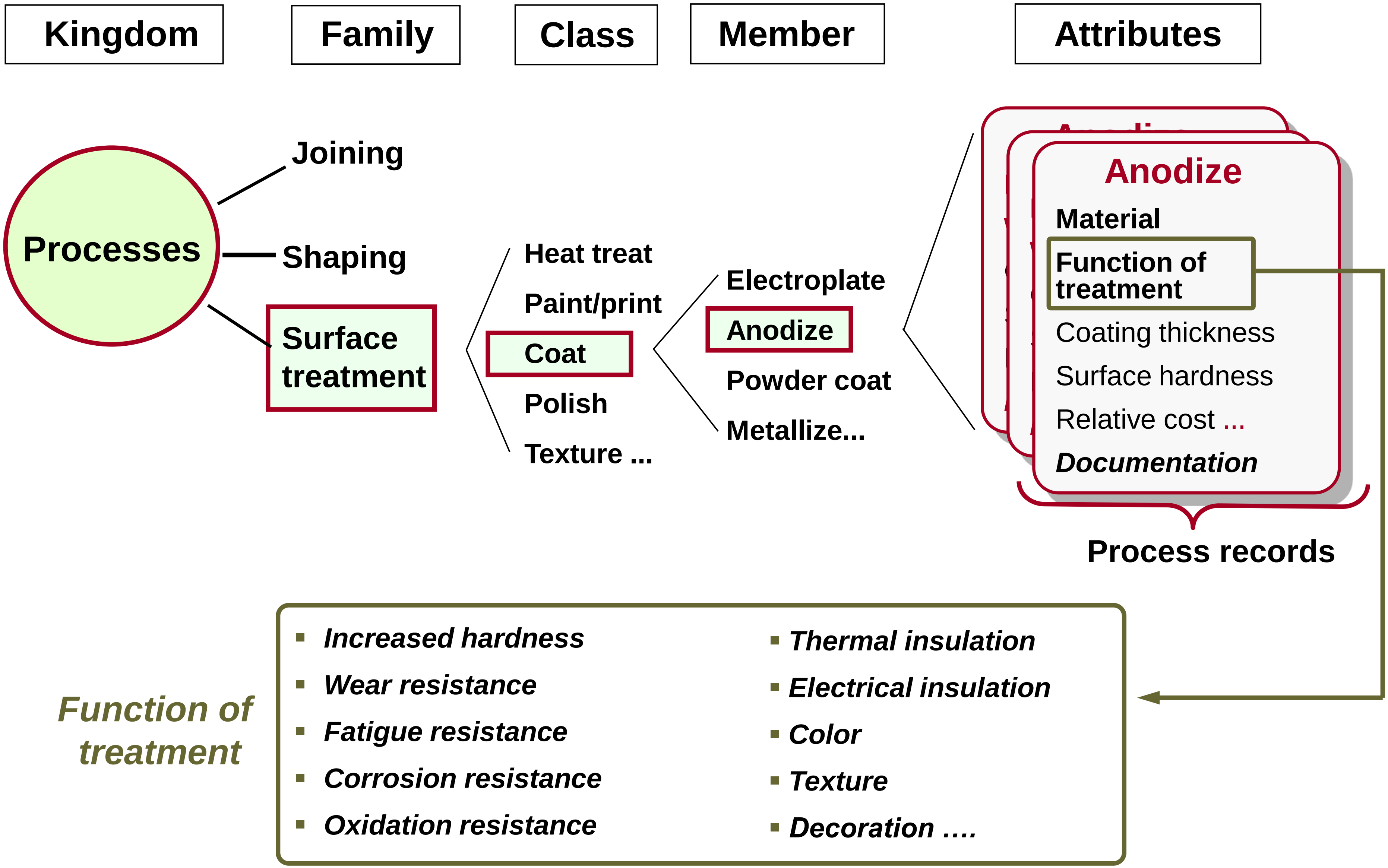
TIG welding is used ……….

Key constraints in choosing a joining process

Documentation

*Using the *CES* EduPack Level 1 DB

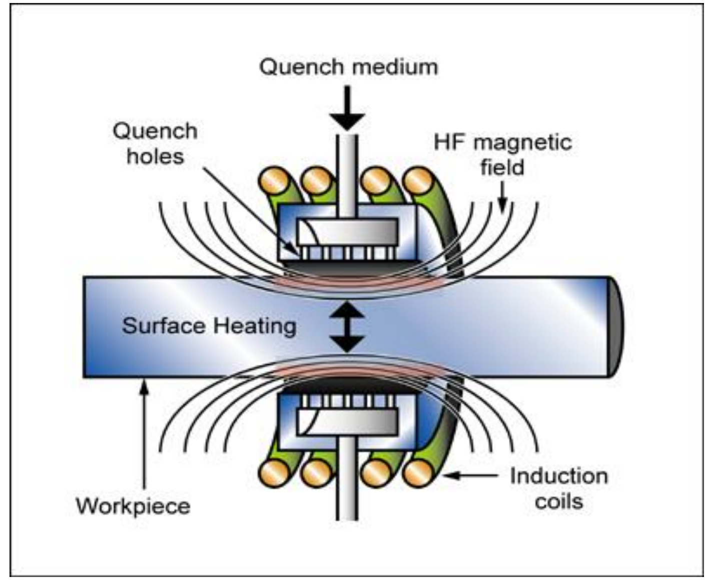
Data organization: joining and surface treatment



A surface-treatment record*

Induction and flame hardening

Take a medium or high carbon steel -- cheap, easily formed and machined -- and flash its surface temperature up into the austenitic phase-region, from which it is rapidly cooled from a gas or liquid jet, giving a martensitic surface layer. The result is a tough body with a hard, wear and fatigue resistant, surface skin. Both processes allow the surface of carbon steels to be hardened with minimum distortion or oxidation. In induction hardening, a high frequency (up to 50kHz) electromagnetic field induces eddy-currents in the surface of the work-piece, locally heating it; the depth of hardening depends on the frequency. In flame hardening, heat is applied instead by high-temperature gas burners, followed, as before, by rapid cooling.



Function of treatment

Fatigue resistance
Friction control
Wear resistance
Hardness

Physical attributes

Curved surface coverage	Very good			
Coating thickness	300	-	3e+003	µm
Processing temperature	727	-	794	K
Surface hardness	420	-	720	Vickers

Typical uses

Induction hardening is used …..

Economic attributes

Relative tooling cost	low
Relative equipment cost	medium
Labor intensity	low

Documentation

+ Links to materials

Key constraints in choosing a surface treatment

*Using the *CES* EduPack Level 2 DB

So what?

- Processes can be organised into a tree structure containing records for structured data and supporting information

- The structure allows easy searching for process data

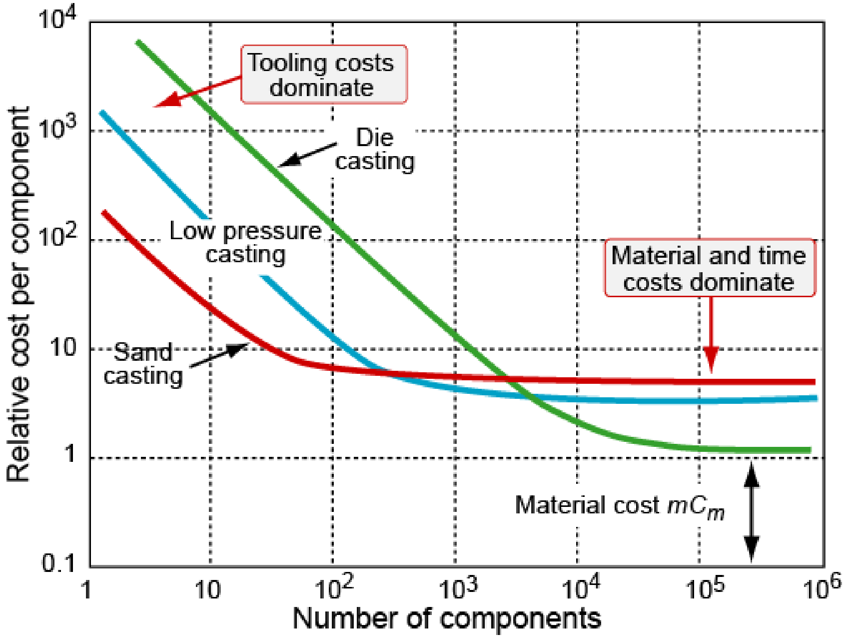
- **Links** connect processes to materials

- **Screening** based on primary constraints
  - **Shaping:** *material, shape and batch size*
  - **Joining:** *material(s) and joint geometry*
  - **Surface treatment:** *material and function of treatment*

- **Ranking** is usually based on **cost analysis** (see following section)

- **Documentation** in CES, and http://matdata.net

Cost Modeling for Materials Selection



- **Assessing potential: cost and value**
- **Inputs to a cost model for selection**
- **The model and its implementation**
- **Cost drivers, batch size, assembly**

Cost, price and value

- **Cost** = what it actually costs to make the part or product
- **Price** = the sum you sell it for
- **Value** = the worth the consumer puts on the product

The real requirement is

Cost < Price < Value

C < P < V

To maximize profit, P - C we seek to minimize C

"Not worth the price" **means P > V**

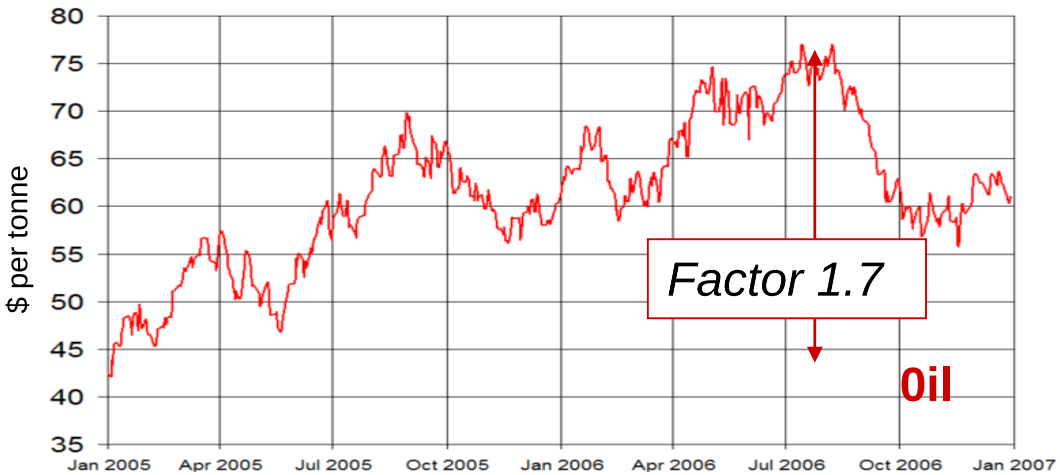
"Good value for money" means **P < V**

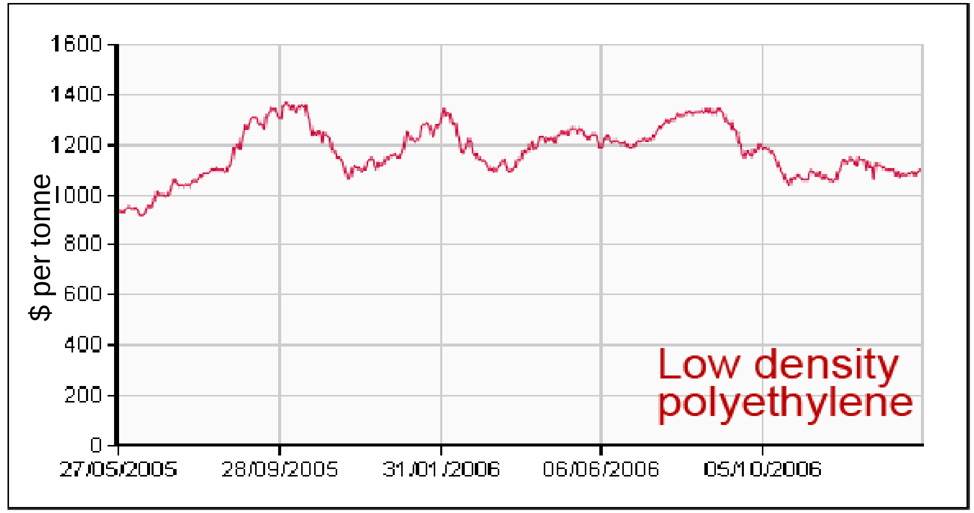
The cost of producing a component or product is made up of

- the **material cost**
- the **cost of manufacture**

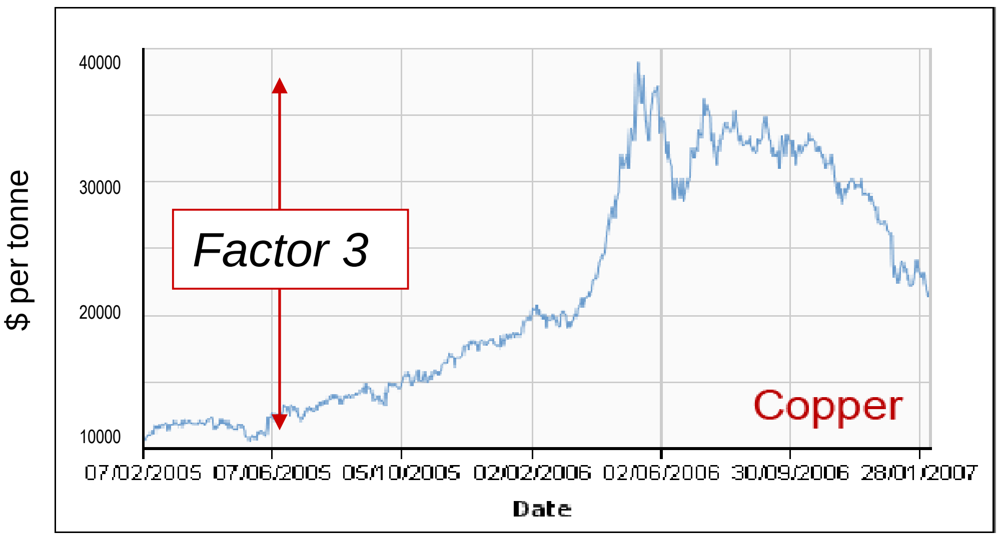
The problem of material price

Changing price of materials 2005 - 2007





The need: Cost modeling for material selection



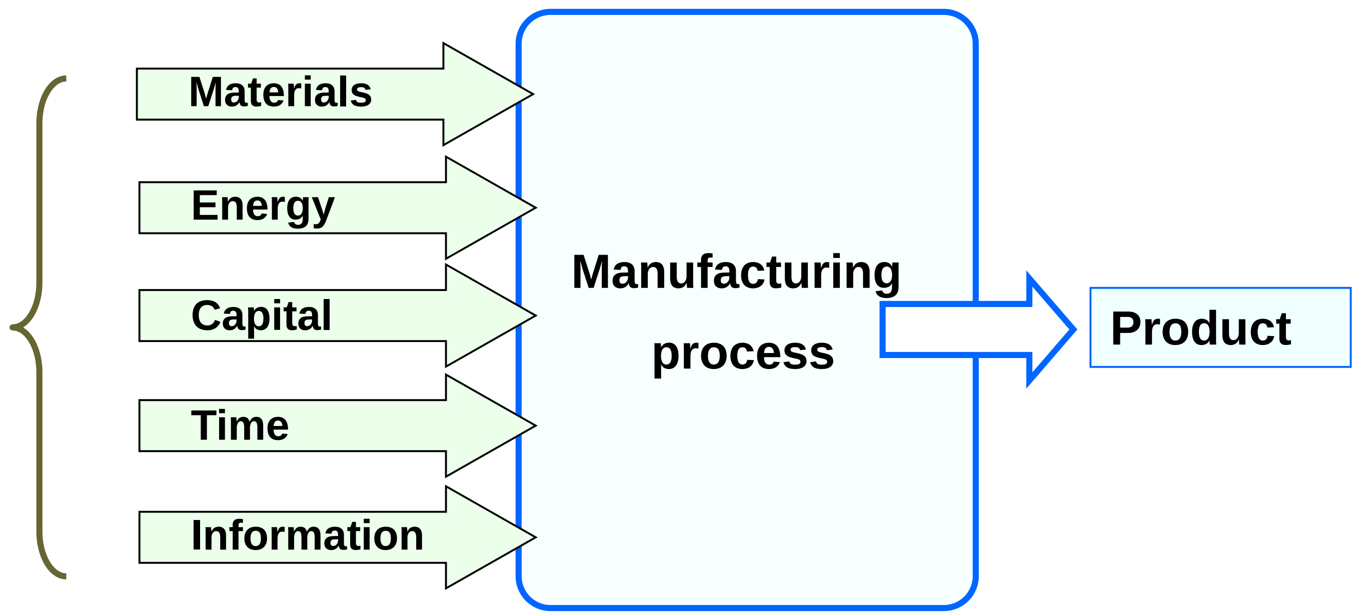
Estimating cost

When alternative material-process combinations meet the constraints, it is logical to rank them by **cost**

- **Cost estimate for competitive bidding** -- *absolute* cost is wanted, to $\pm$ **5%**
- **Cost estimate for ranking** -- a *relative* cost is OK – but need generality

Generic inputs to any manufacturing process:

All have an associated cost



Inputs to a generic cost estimator

Generic = can be applied to any process

Resource		Symbol	Unit
Materials	including consumables	C_m	\$/kg
Capital	cost of equipment cost of tooling	C_c C_t	\$ \$
Time (including labor) overhead rate		$\dot{C}_{oh}$	\$/hr
Energy	cost of energy	C_e	\$/hr
Space, admin.	a cost/hr	$\dot{C}_{s,a}$	\$/hr
Information	R & D royalties, licenses	$\dot{C}_i$	\$/hr

Lump into overhead rate $\dot{C}_{oh}$

The cost per unit of output

Material costs C_m per kg, mass **m** per unit; **f** is the scrap fraction $\Rightarrow \dfrac{m C_m}{1-f}$

Tooling C_t is "dedicated" -- written off against the number of parts made, **n** $\Rightarrow \dfrac{C_t}{n}$

Capital cost C_c of equipment is "non-dedicated" written off against time.

Capital write-off time is t_{wo} .

Rate of production is $\dot{n}$ units/hour.

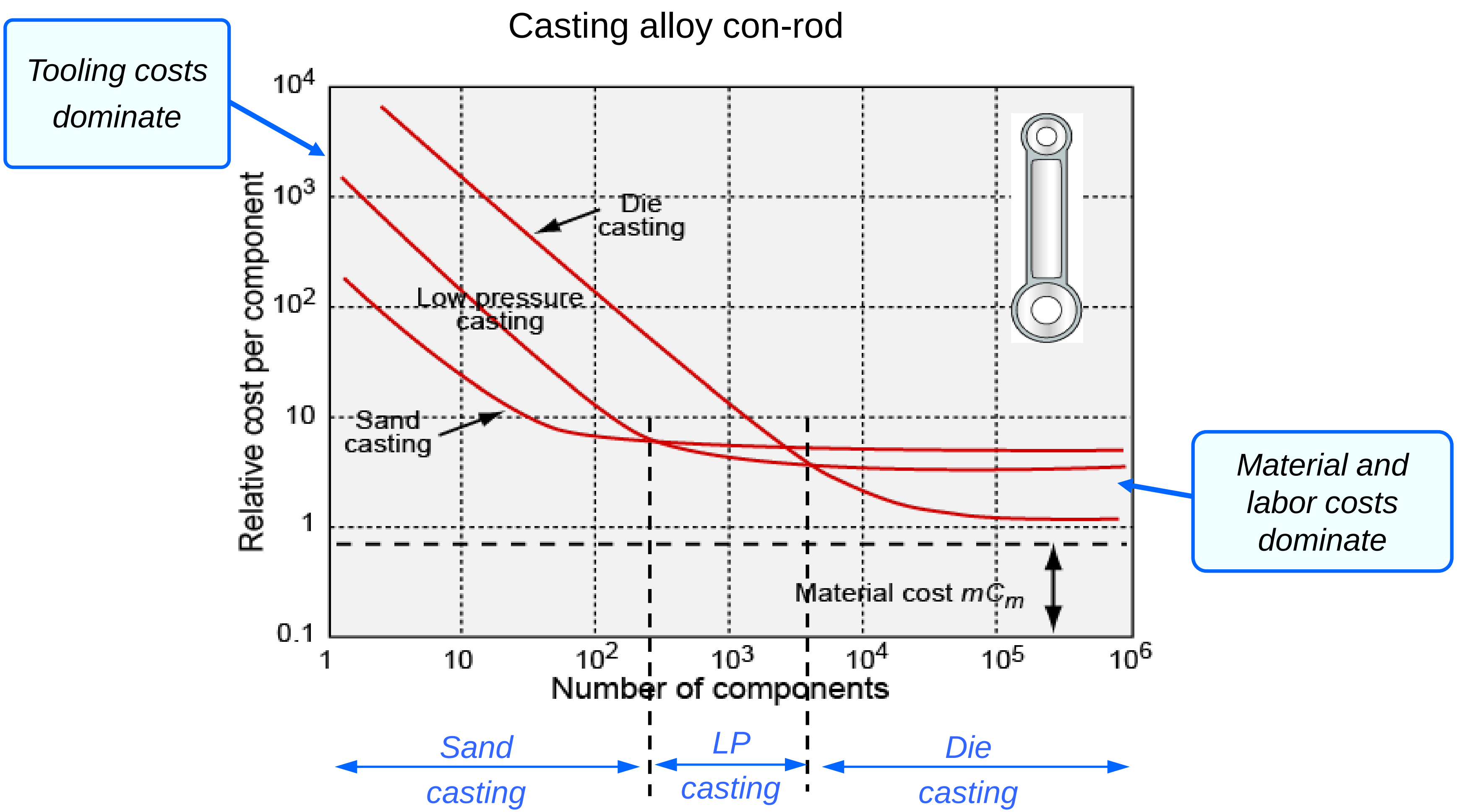
The load factor (fraction of time the equipment is used) is **L.**

$\Rightarrow \dfrac{1}{\dot{n}}\left(\dfrac{C_c}{L.t_{wo}}\right)$

Gross overhead rate $\dot{C}_{oh}$ contributes a cost per unit of time that, like capital, depends on production rate $\dot{n}$ $\Rightarrow \dfrac{\dot{C}_{oh}}{\dot{n}}$

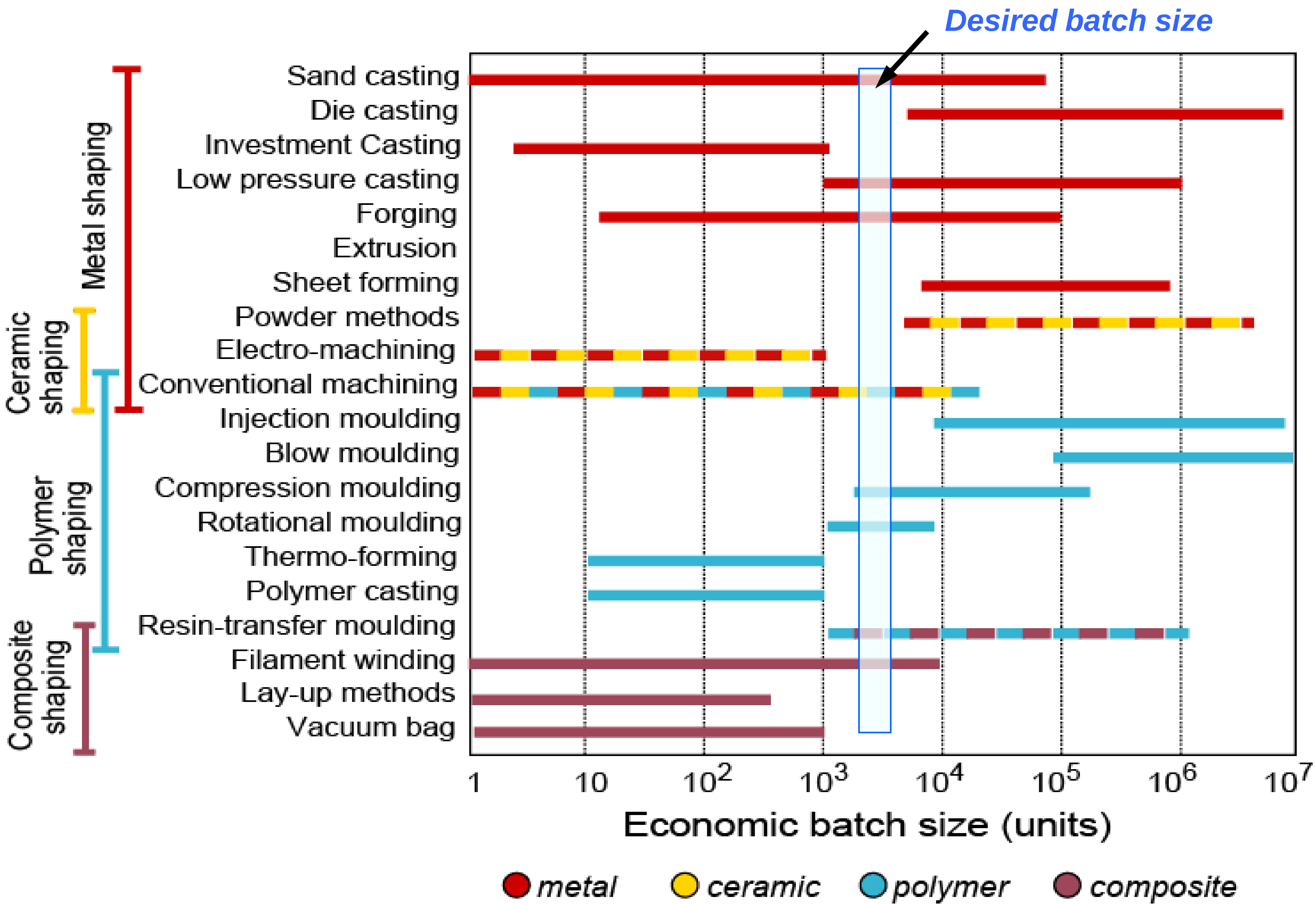
$$C = \left[\frac{m\,\overset{\text{Materials}}{C_m}}{1-f}\right] + \left[\frac{\sum\left(\overset{\text{Tooling}}{C_t}\right)}{\underset{\text{Batch size}}{n}}\right] + \frac{1}{\underset{\text{Rate of production}}{\dot{n}}}\left[\sum\left(\frac{\overset{\text{Capital, Labor, Information, Energy...}}{C_c}}{L.t_{wo}}\right) + \dot{C}_{oh}\right]$$

Features of a cost model



- Identify most economic process
- Examine materials-cost sensitivity
- Explore alternative materials and processes

Economic batch size



Where do you get the input information?

- **Material and process costs** vary with time and depend on the quantity you order

- CES EduPack has approximate cost for 3800 materials, regularly updated
- Web helps with commodity material prices
  - American Metal Market On-line, www.amm.com
  - Iron & Steel Statistics Bureau, www.issb.co.uk
  - Kitco Metals Inc Gold & Precious Metal Prices. www.kitco.com/charts/livegold.html
  - London Metal Exchange, www.lme.co.uk
  - Metal Bulletin, www.metalbulletin.com
  - Mineral-Resource, www.minerals.usgs.gov
  - The Precious Metal and Gem Connection, www.thebulliondesk.com
- Ask suppliers: but how find them?
  - Thomas Register of European Manufacturers, TREM
  - Thomas Register of North American Manufacturers
  - Kelly’s register, www.kellysearch.com

Cost modelling in CES

$$C = \left[\frac{m\,C_m}{1-f}\right] + \left[\frac{C_t}{n}\right] + \frac{1}{\dot{n}}\left[\frac{C_c}{L.t_{wo}} + \dot{C}_{oh}\right]$$

Characteristics of the process

Cost of equipment	C_c
Cost of tooling	C_t
Production rate	$\dot{n}$

The database has approximate value-ranges for these

Site-specific, user defined parameters

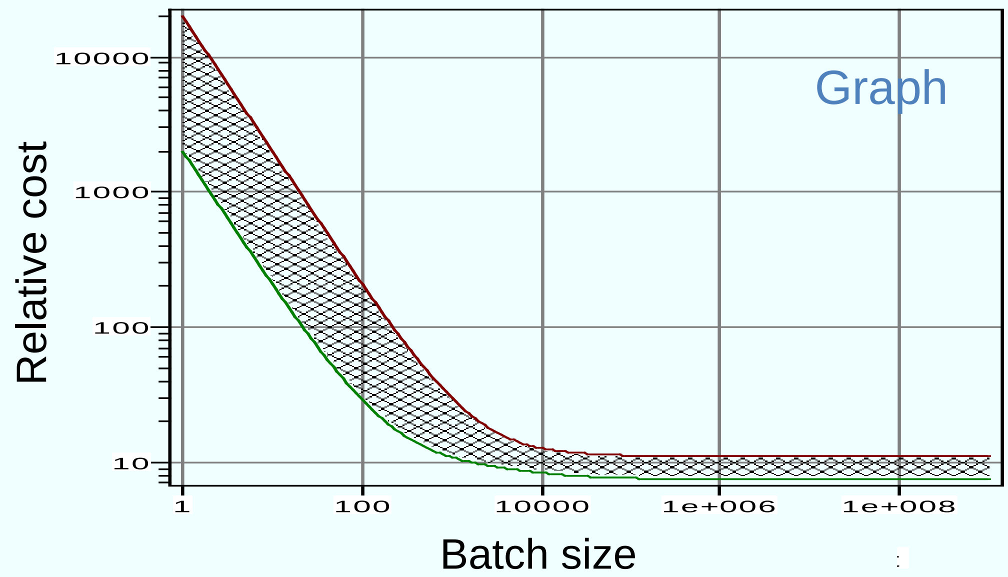
Batch size	n
Mass of component	m
Capital write-off time	t_{wo}
Load factor	L
Overhead rate	$\dot{C}_{oh}$

These are entered by the user via a dialog box

Cost model

Cost modeling

Relative cost index (per unit)	5	-	6	
Capital cost	2000	-	5000	GBP
Material utilisation factor	0.7	-	0.75	
Production rate (units)	20	-	30	per hr.
Tooling cost	300	-	450	GBP
Tooling life	5000	-	10000	units



Dialog box

Capital write-off time t_{wo} = ...

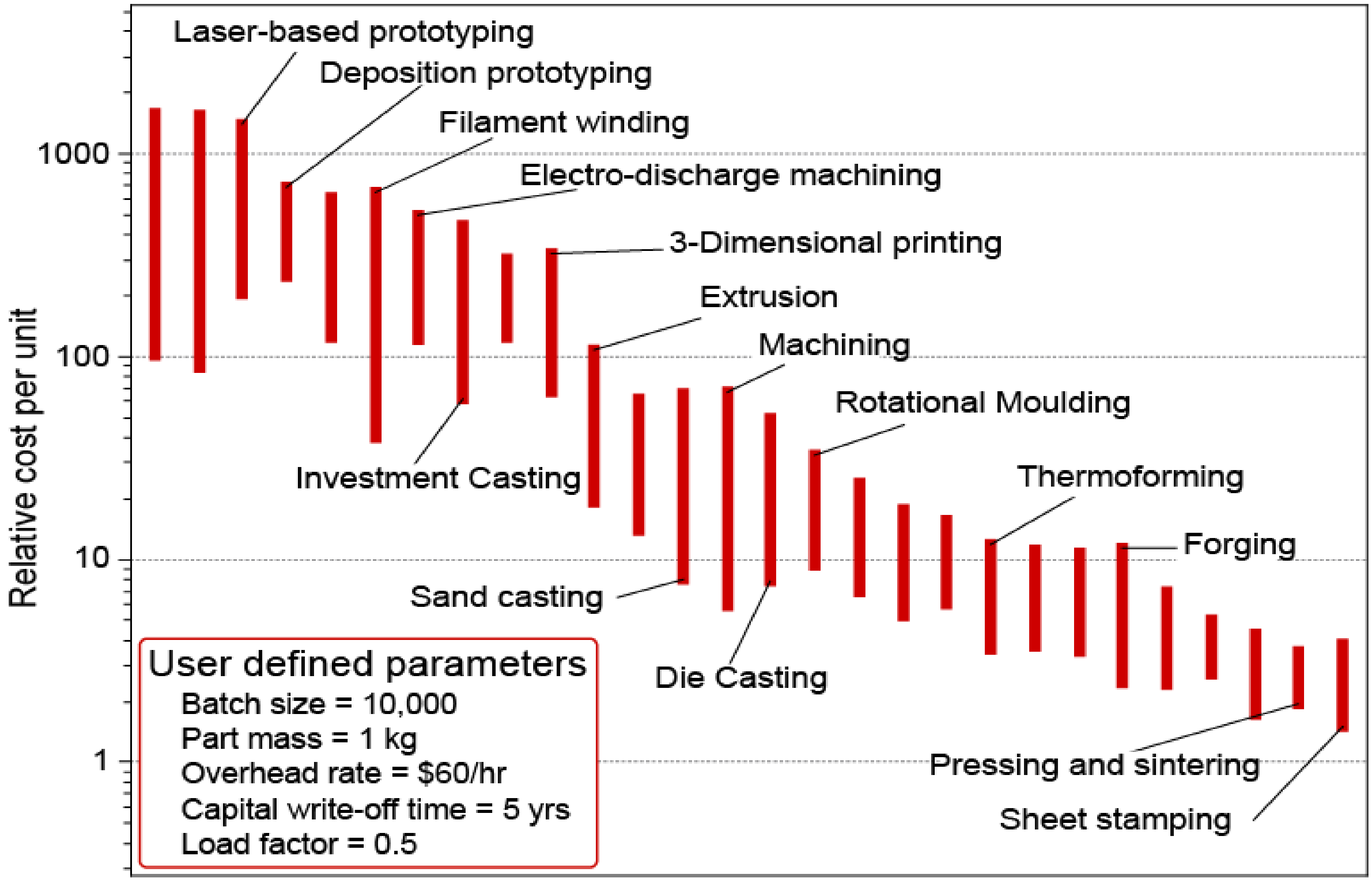
Component mass m = ...

Load factor L = ...

Material cost C_m =

Overhead rate $\dot{C}_{oh}$ = ...

Cost model


Relative cost per unit
1000
100
10
1
Laser-based prototyping
Deposition prototyping
Filament winding
Electro-discharge machining
3-Dimensional printing
Extrusion
Machining
Rotational Moulding
Thermoforming
Forging
Investment Casting
Sand casting
Die Casting
Pressing and sintering
Sheet stamping
User defined parameters
Batch size = 10,000
Part mass = 1 kg
Overhead rate = $60/hr
Capital write-off time = 5 yrs
Load factor = 0.5

So what?

- To maximize profit: minimize cost C (economics of manufacture) and maximize value V (technical performance and product image)
- Cost can be modeled at several levels -- depends on purpose
- To rank process options, approximate modeling is adequate
- A cost-model for this uses “generic” inputs: material, time, capital etc
- More precise analysis must be based on information from suppliers or (if out-sourcing) contractors.

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www.grantadesign.com

www.eng.cam.ac.uk

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GRANTA TEACHING RESOURCES

Granta's Teaching Resources website aims to support teaching of materials-related courses in Engineering, Science and Design. The resources come in various formats and are aimed at different levels of student.

This resource is part of a set created by Mike Ashby to help introduce materials and materials selection to students.

The website also contains other resources contributed by faculty at the 800+ universities and colleges worldwide using Granta's CES EduPack.

The teaching resource website contains both resources that require the use of CES EduPack and those that don't.

www.grantadesign.com/education/resources