Aalto University
School of Engineering

MEC-E1070 Selection of Engineering Materials

Prof. Junhe Lian
Prof. Sven Bossuyt
Zinan Li (Course assistant)

Learning objectives for this Lecture

Knowledge and Understanding

Knowledge on graphical **trade-off methods** and **penalty functions**

Skills and Abilities

Ability to select systematically when **design objectives conflict**

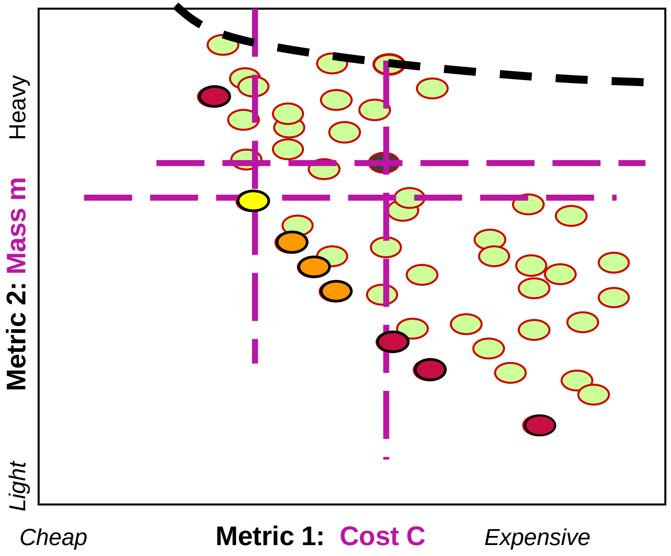
Values and Attitudes

Appreciation of the value of compromise in engineering design

Resources

- Text: "***Materials: engineering, science, processing and design***" 4th edition by M.F. Ashby, H.R. Shercliff and D. Cebon, Butterworth Heinemann, Oxford, 2011, Chapters 7-8.
- Text: "**Materials and the Environment**", 2nd Edition by M.F. Ashby, Butterworth-Heinemann, Oxford 2012, UK. Chapters 9-10

Outline



- The selection strategy when **2+ objectives** – they conflict
- **Trade-off methods**
- **Penalty functions** and exchange constants
- **Examples**

The selection strategy: materials

Design requirements:
expressed as
Constraints *and*
Objectives

- Able to be molded
- Water and UV resistant
- Stiff enough
- Strong enough
- *As cheap as possible*
- *As light as possible*

Comparison engine
- Screening
- Ranking
- Documentation

Final selection

Data:
Material attributes
Process attributes
Documentation

- Density
- Price
- Modulus
- Strength
- Durability
- Process compatibility
- More…….

Multiple constraints and objectives

Design requirements set **constraints** – criteria for screening

objectives – criteria for optimising

Typical constraints

The material must be

- Electrically conducting
- Optically transparent.....

And meet target values of

- Stiffness
- Strength…..

And be able to be

- Die cast
- Welded ......

Typical objectives

Minimize

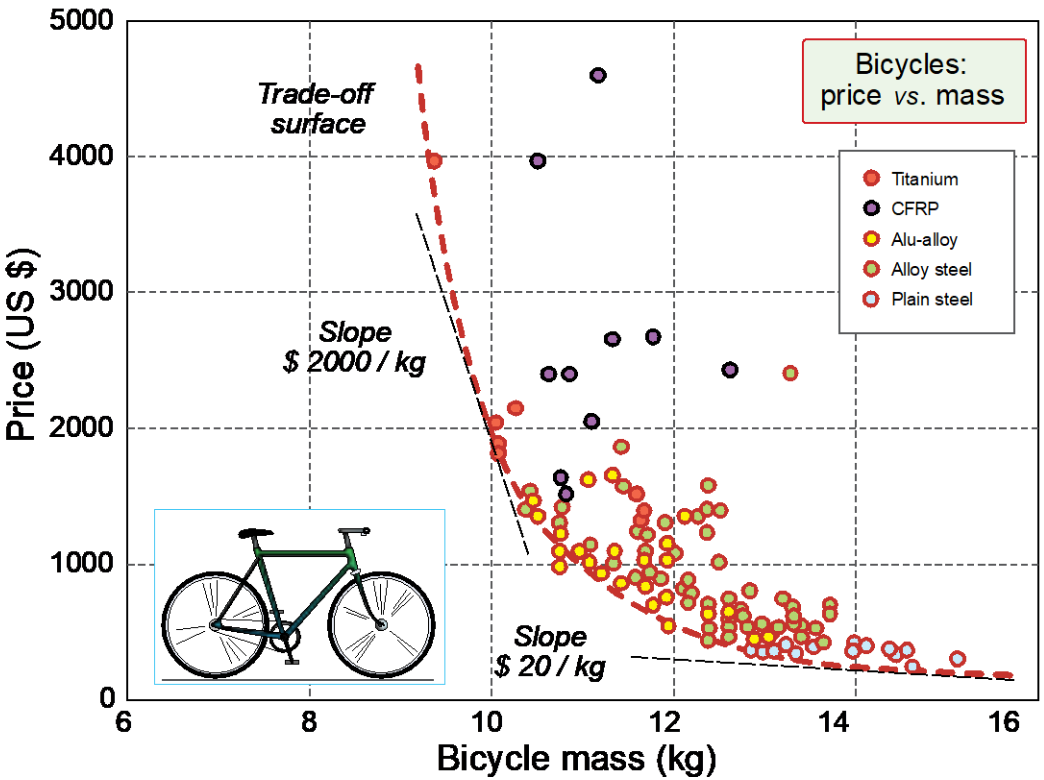
- **Mass m** *(satellite components)*
- **Volume** *(mobile phones)*
- **Energy consumption** *(fridges)*
- **Carbon footprint** *(cars)*
- **Embodied energy** *(materials)*
- **Cost C** *(everything)*

Dealing with multiple constraints is straightforward

Dealing with multiple objectives needs **trade-off methods**

Take, as example, simultaneously minimizing **mass m** and **cost C**

Example: Conflicts between multiple objectives



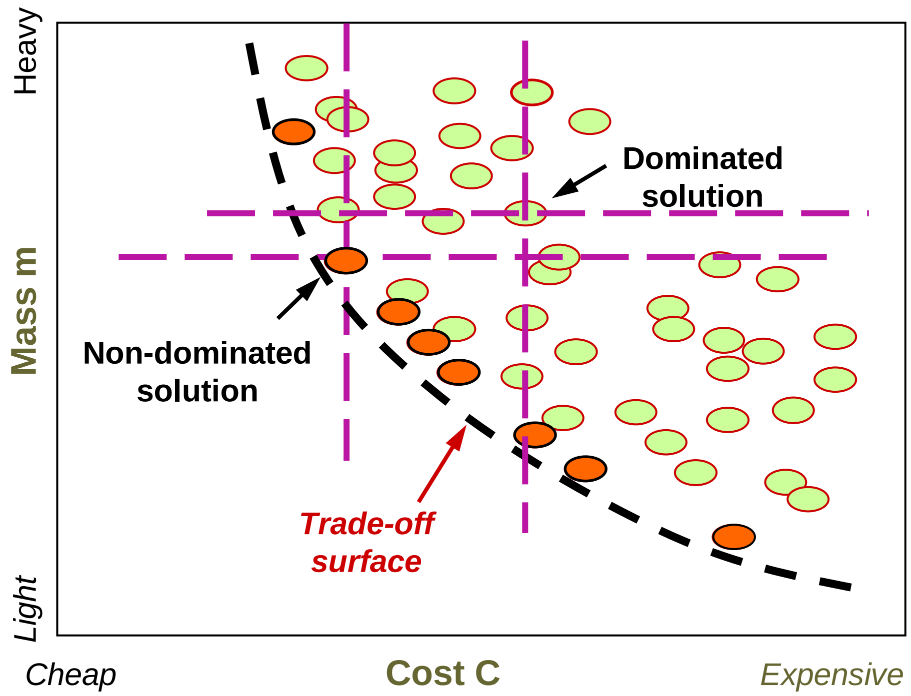
Multi-objective optimization: Trade-off

- **“*Solution”:*** a candidate that meets the constraints, but not necessarily optimum by either objective

- Plot solutions.
(***Convention***: express objectives to be ***minimized***)

- “***Dominated solution”:*** one that is definitely non-optimal

- **“*Non-dominated solution”:*** one that is optimal by one metric (but not usually by both)



- **“*Trade-off surface”:*** the surface on which the non-dominated solutions lie (Pareto Front). In our case a 2-dimensional curve

Finding a compromise: Penalty function

Define locally-linear
Penalty function Z
$$Z = C + \alpha\, m$$
Seek solution with smallest Z

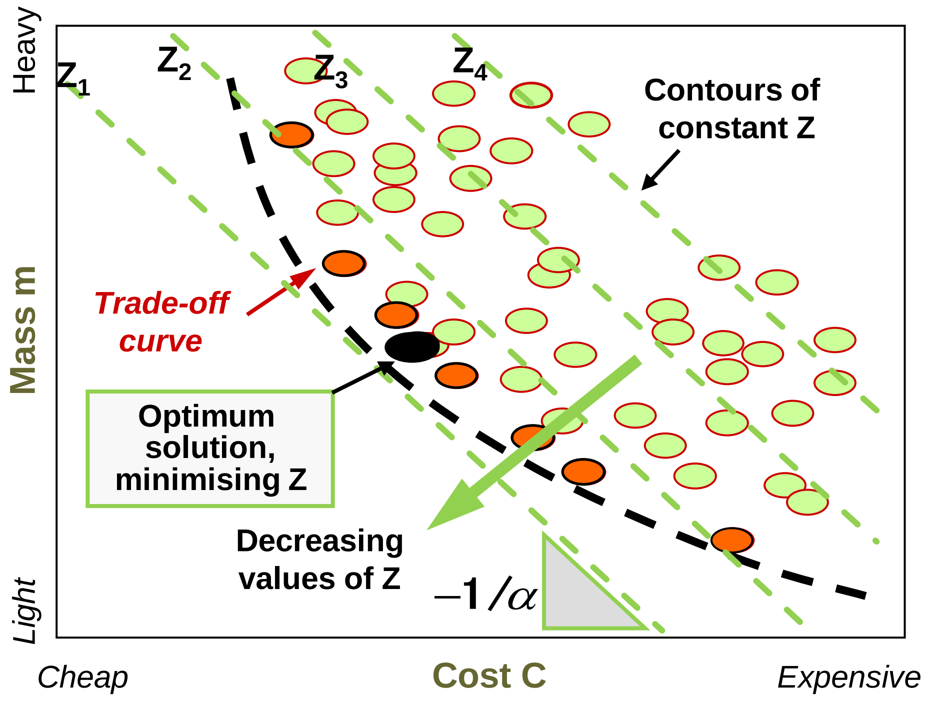
- Make **trade-off plot**

Plot on it contours of Z

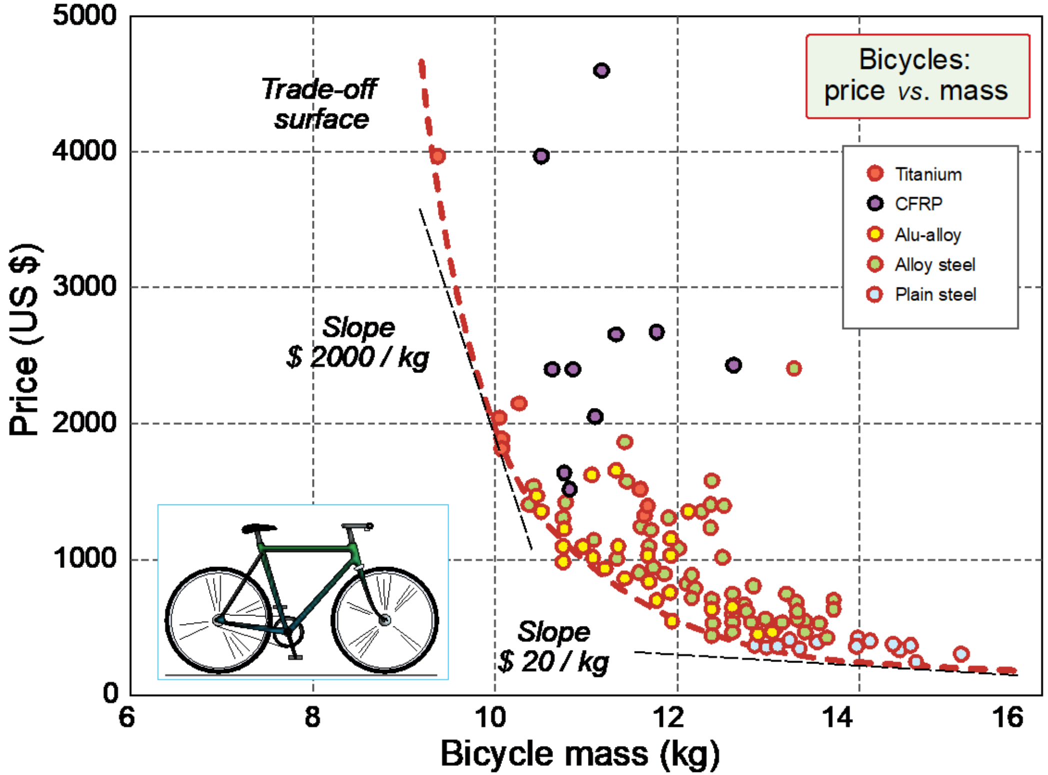
$$m = \boxed{-\frac{1}{\alpha}} C + \frac{1}{\alpha} Z$$

Lines of Z have slope -1/α
(needs linear scales)

- **Read off** solution with lowest Z



Example of graphical solution



α determines a location on the trade-off curve and reflects priorities (price per kilo)

Example: materials for transport systems

Choice of material depends on system

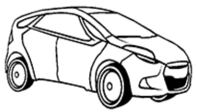
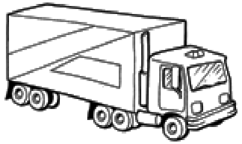
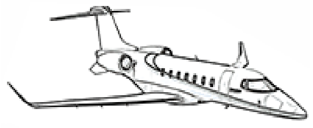
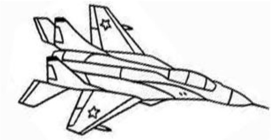
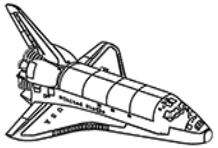
- **Mass**, in transport systems, means **fuel**
- **Life cost** = Initial cost, **C** + Fuel cost over life, scaling with mass **m**

€ kg

- **Penalty function** $Z = \mathbf{C} + \alpha m$

€/kg

- Must establish **exchange constant,** α

	Steel	Steel / Alu	Alu / (composite)	Alu / Ti / composites	Composites
α (€/kg)	3 – 6	6 – 20	100 – 600	600 – 2,000 (?)	5,000 – 10,000

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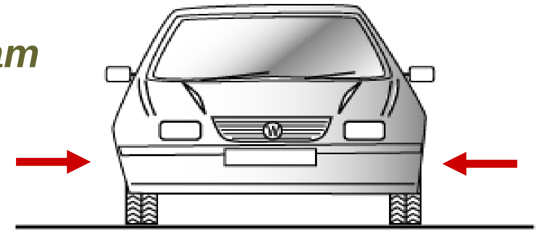
Example: materials for auto bumpers



Function — *Absorb impact, transmit load to energy-absorbing units or supports*

Objectives — *Minimize mass and material cost*

Criteria — ***Mass m** per unit bending strength* — ***Cost C** per unit bending strength*

Beam in bending
Index to minimize:

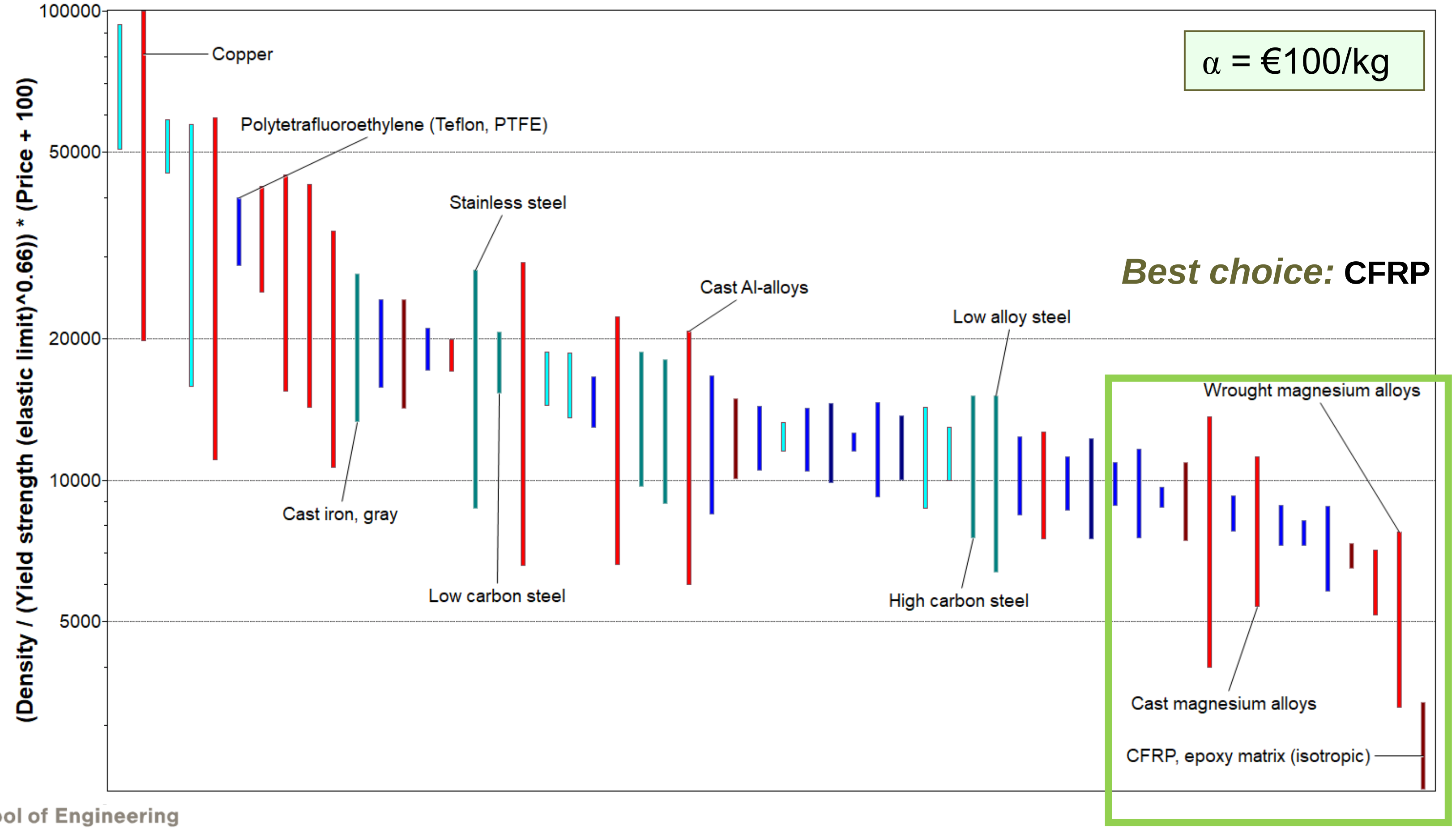
$$m = \frac{\rho}{\sigma_y^{2/3}} \qquad C = \frac{C_m \rho}{\sigma_y^{2/3}}$$

C_m = Material cost / kg
ρ = Density, kg/m^3
σ_y = Yield strength, MPa
α = exchange constant , €/kg

Penalty function

$$Z = C + \alpha m = \frac{\rho}{\sigma_y^{2/3}}\left(C_m + \alpha\right)$$

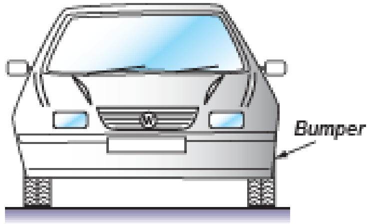
Bar chart selection using the penalty function



Best choice: **CFRP**

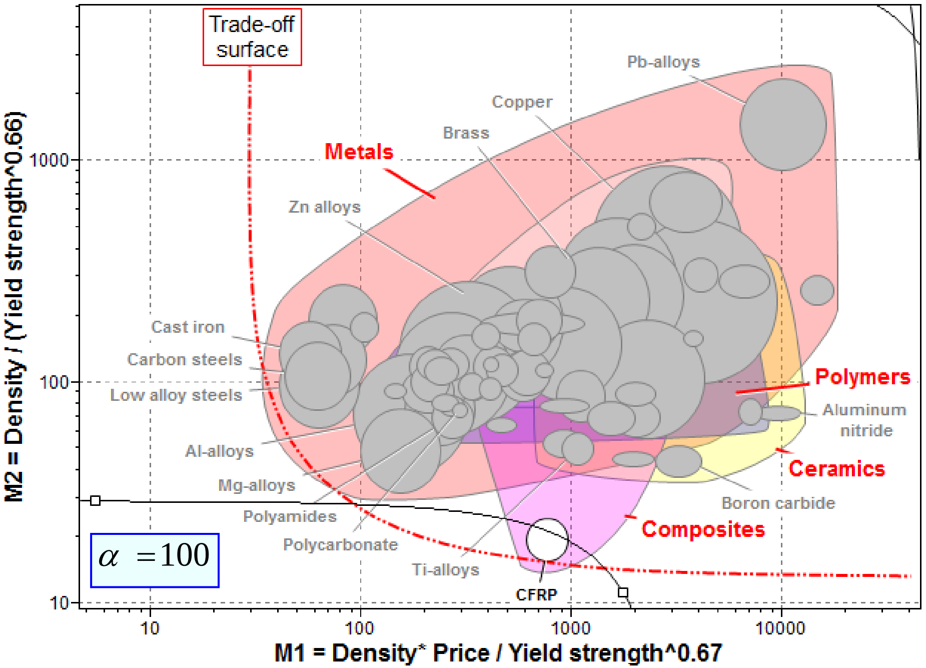
Bubble chart selection using penalty function

Strong bumper, minimum weight and cost



Minimize weight ⇨ $M_2 = \dfrac{\rho}{\sigma_y^{2/3}}$

Minimize cost ⇨ $M_1 = \dfrac{C_m \rho}{\sigma_y^{2/3}}$



Penalty function $Z = M_1 + \alpha M_2$

α = 1 €/kg ⇨ *Low alloy steels, Carbon steels,*

α = 10 €/kg ⇨ *Aluminum alloys, Magnesium alloys*

α = 100 €/kg ⇨ *Carbon-fiber reinforced composites*