# Rational increase of safety: a multi-stakeholder approach to structural design for collision and grounding

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# Motivation for the Study

- Design for safety
  - Safety is an objective not a constraint
  - But, are we designing only for safety???
- Passive protection
  - How can we decrease consequences once accident already occurs
  - Ship should remain floating and capable of returning to nearest port for immediate repair
- Safety by design
  - Design should successfully enhance safety as well as profitability of a ship

# Design environment

- Ship owner
- Shipyard
- Operator
- End-user
- Int. organizations (IMO)
- Passenger
- Insurer
- Financier
- …

**Control the design process**

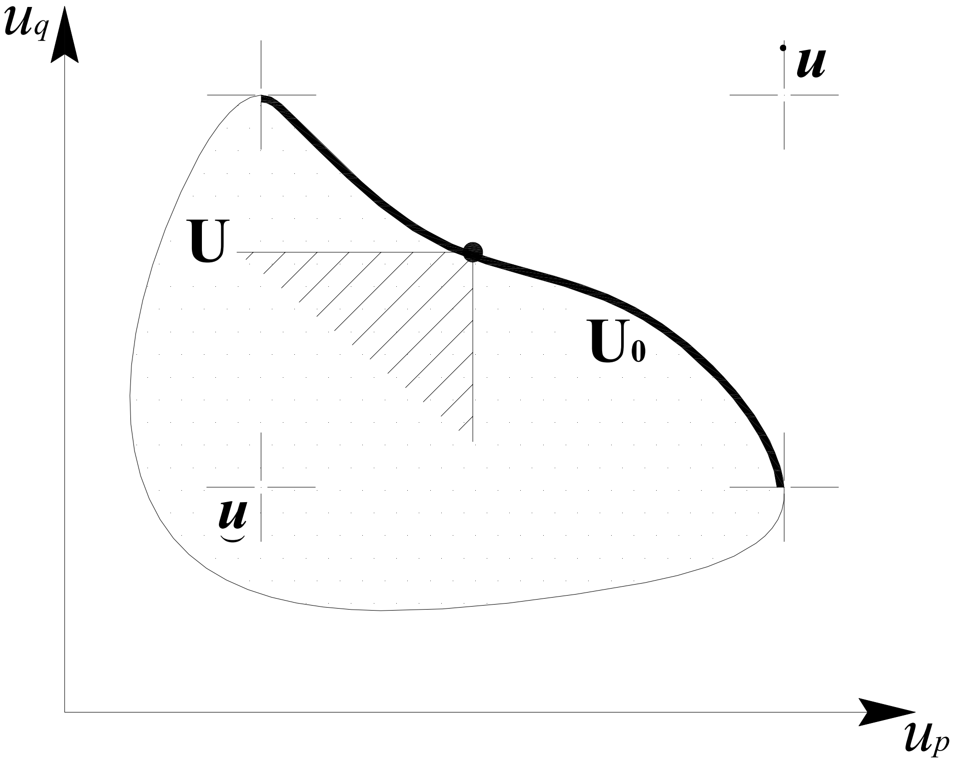
**Do not control the design process, but influence on it**

# Stakeholders are…

- …decision makers,
- …which might value a design alternative differently over multiple attributes
- …competitive
  - Willing to gain on expense of another ☺ ☹

# Design…

- …is a <u>multi-attribute</u> and <u>group decision-making</u> problem
- Multi-stakeholder design



# Example: Crashworthy structures

- Application is ‘difficult’, un-tested, unproven, but…
- Indications are strongly positive
  - Decrease of risk
  - Minor addition to production costs
  - Operability
  - Maintenance

# How to approach the problem

- Assess the problem in its completeness
  - Give ‘voice’ to stakeholders – involve them into process!
  - Let them express demands, wishes, requirements
  - Ask for their agreement
  - Satisfy the minimal levels set by class and intern. org. rules

**RATIONAL INCREASE OF SAFETY**

# Rational increase of safety

- How to reduce risks without significantly harming operations and possibility for profits
- Understanding overall design objectives, e.g.
  - Ship owner wishes to increase safety but is limited with finances
  - Shipyard wants to make a “good” ship but has to reduce the production costs as much as possible
  - Passenger wants significant reduction of risks but is still not willing to pay
- Balance then the needs of all stakeholders
  - The simultaneous satisfaction of stakeholders is then the rational answer how much safety should be increased

# Preference model

- Stakeholders need to decide between different design alternatives
- Ranking…
  - …directly of design alternatives
  - …of design attributes
    - **Analytic hierarchy process**
    - Hypothetical equivalence/inequivalence method
    - …

# Group of decision makers

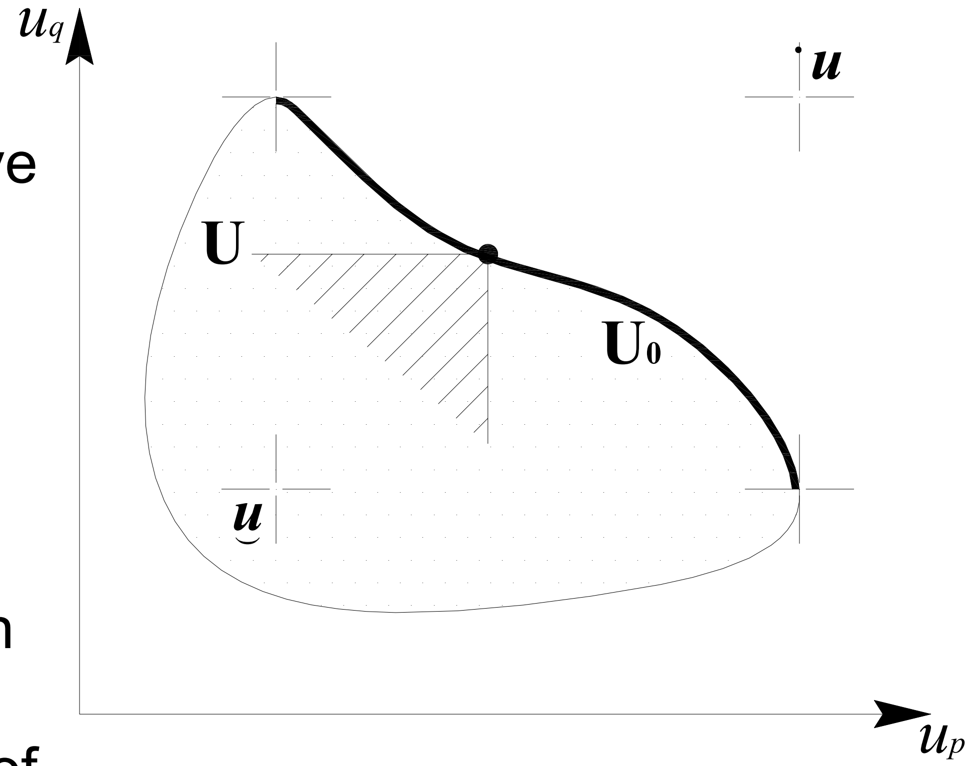
- Arrow's Impossibility theorem for group decision-making
  - A group of rational decision makers with transitive ordering of alternatives will jointly yield intransitive ordering
- It is impossible then to build a joint stakeholder function which models such intransitive behaviour

# Group decision-making

- Interactive group decision-making
  - Single negotiation text
  - Impractical if dealing with large number of variables as in structural design
- Axiomatic group decision-making
  - What kind of solution is needed?

# Characteristics of the solution

- Collective stability
  - There does not exist another design alternative which can improve benefits for all stakeholders
- Individual stability
  - Every stakeholder is satisfied with the solution as much as possible considering satisfaction of others

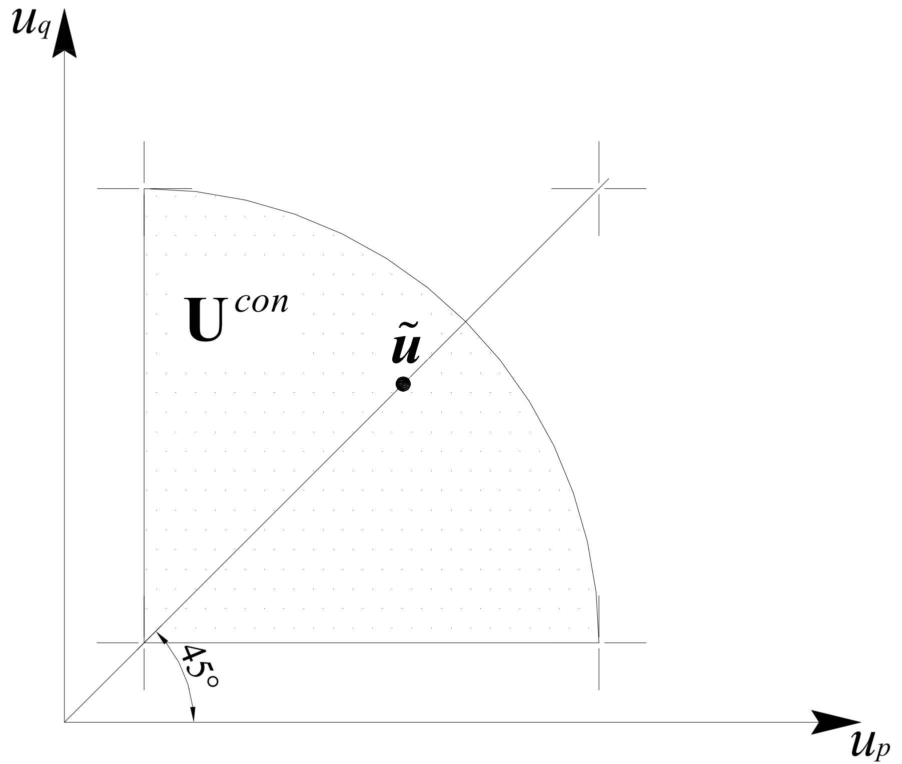


# Three conditions

- Compromise
  - Weak Pareto optimality
  - Strong individual rationality
    - All stakeholders should strictly gain from the solution
- Efficiency
  - Strong Pareto optimality
- Maximal stakeholders' satisfaction in the competitive relationships (MaSSCoR)
  - Anonymity
  - Nash Equilibrium

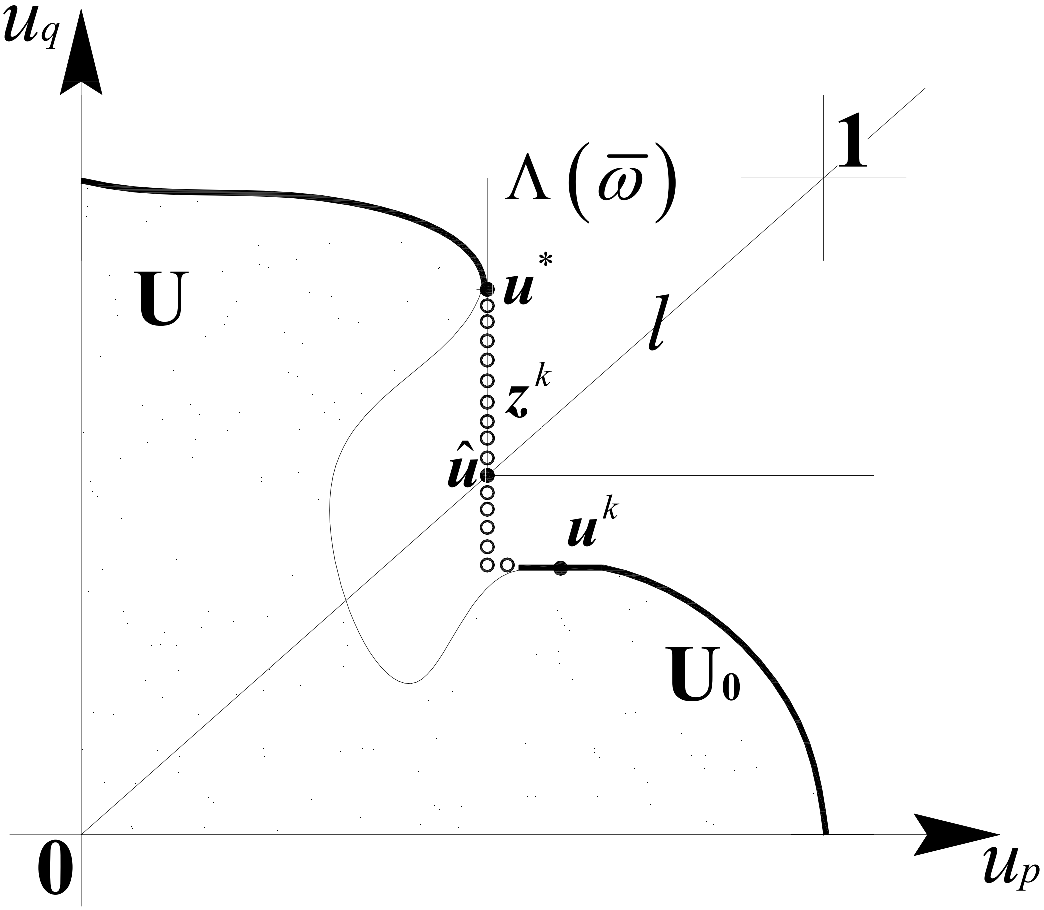
# MaSSCoR

- Anonymity
  - If the overall wealth can be separated equally to individuals than it should be as such given in equal amounts
- Symmetry
  - For symmetric problems solution should have equal payoffs to stakeholders



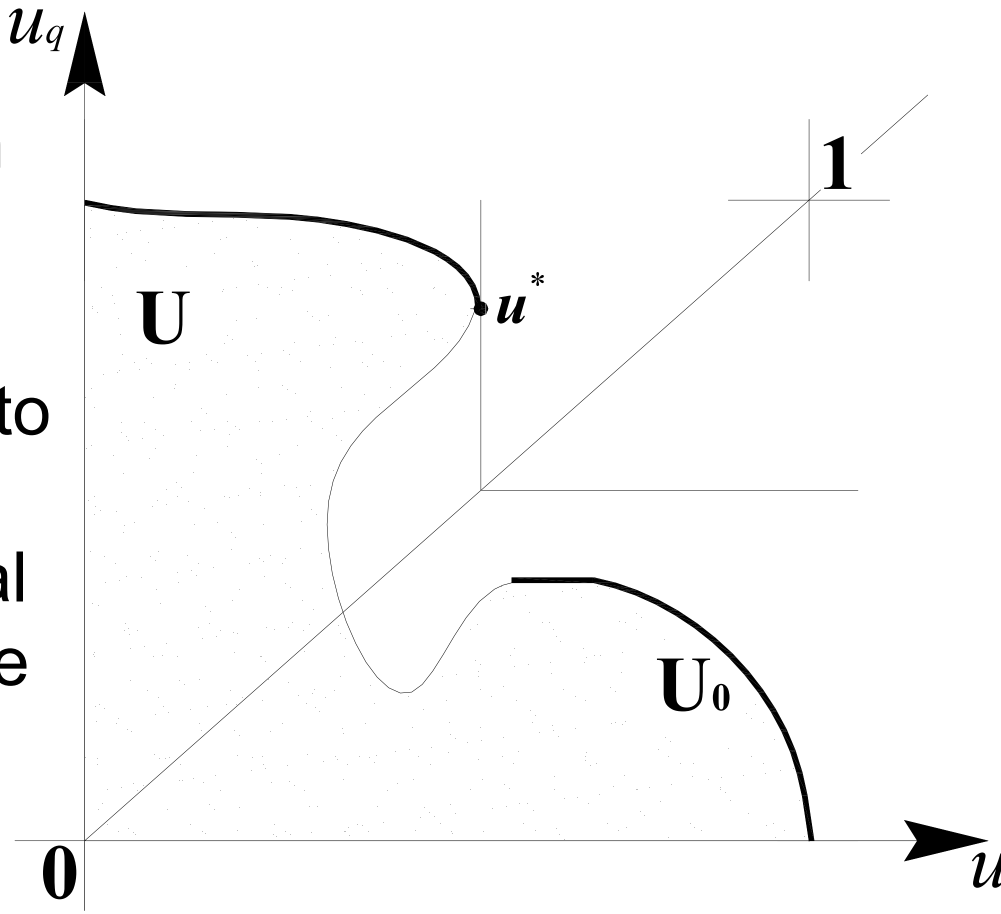
# Nash Equilibrium…

- …maximizes a pay-off of a player while keeping the strategies of others fixed; and
- If considering all the Pareto optimal DAs, members of the *Chebyshev* isometric cone within unit space, then NE is the DA with equal pay-off to stakeholder



# The competitive optimum

- …an alternative which satisfies all three conditions
- …it is a Strongly Pareto optimal alternative, member of the minimal isometric cone Λ of the uniformly weighted *Chebyshev* metrics




$$\boldsymbol{u}^* = \boldsymbol{u} \in \Lambda\left(\overline{\varpi}\right) \mid \text{ó}\ \boldsymbol{u}' \in \mathbf{U}, \boldsymbol{u}' \geq \boldsymbol{u}$$

# Case study - grounding

- Rational increase of safety of a generic 30000 GT RO-PAX in powered hard grounding, by
- Changing the structure of the double bottom
  - A: The initial double bottom with the height of 1.6 m and 12 mm outer shell thickness
  - B: Double bottom height increased by 50 % from A to 2.4 m
  - C: Bottom plate thickness increased by 50 % from A
  - D: The stiffness of double bottom longitudinals increased by about 90 % from A by changing the profiles from HP260x10 to HP300x13
  - E: Intercostal girders instead of longitudinal stiffeners

# Design environment

- Contractual situation
  - Possibility to change main dimensions
  - Main dimensions are fixed
- Stakeholders
  - Shipyard
  - Ship owner
- Attributes
  - Risk of loss of life
  - Risk of environmental damage
  - Risk of material damage
  - Costs for the shipyard
  - Costs for the owner

# Model of stakeholders preferences - AHP

- Shipyard wishes to reduce the added production costs while significantly accounting for the risks
- Ship owner wishes to significantly decrease the risk of loss of life, but considers the increase in costs, mostly of operational loss

Life Costs

$$\mathbf{a}_{\mathbf{SY,I}} = (0.252\ 0.037\ 0.076\ 0.636)^T,$$

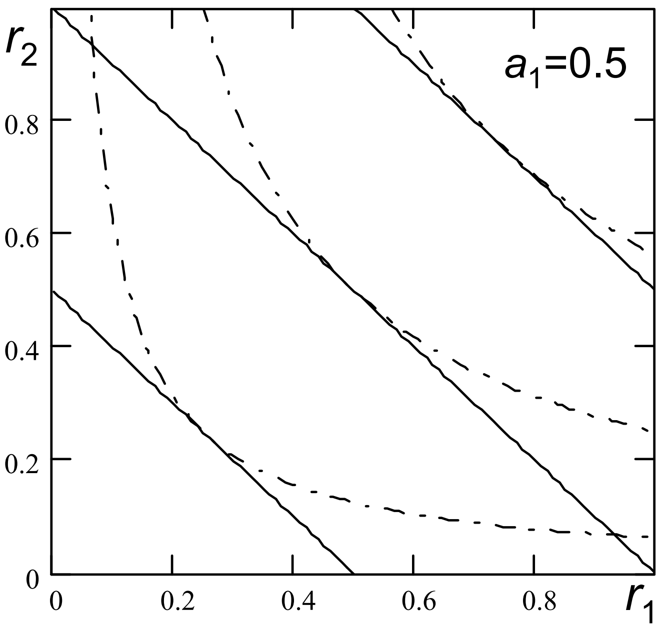
$$\mathbf{a}_{\mathbf{SO,I}} = (0.631\ 0.042\ 0.191\ 0.191)^T,$$

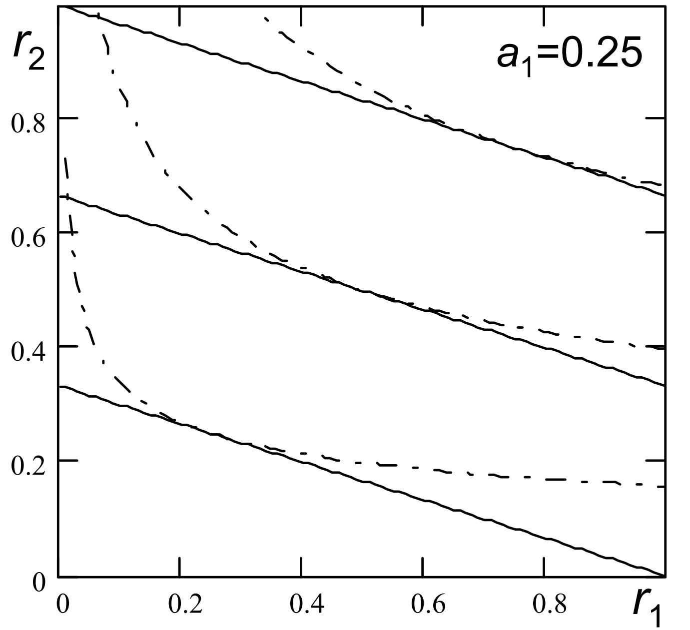
$$\mathbf{a}_{\mathbf{SY,II}} = (0.365\ 0.046\ 0.098\ 0.491)^T,$$

$$\mathbf{a}_{\mathbf{SO,II}} = (0.469\ 0.042\ 0.151\ 0.339)^T,$$

# Stakeholders utility functions

- Additive $$u_j^+ = \sum_i a_{ij} r_{ij} ,$$
- Product $$u_j^\bullet = \prod_i r_{ij}^{a_{ij}} .$$



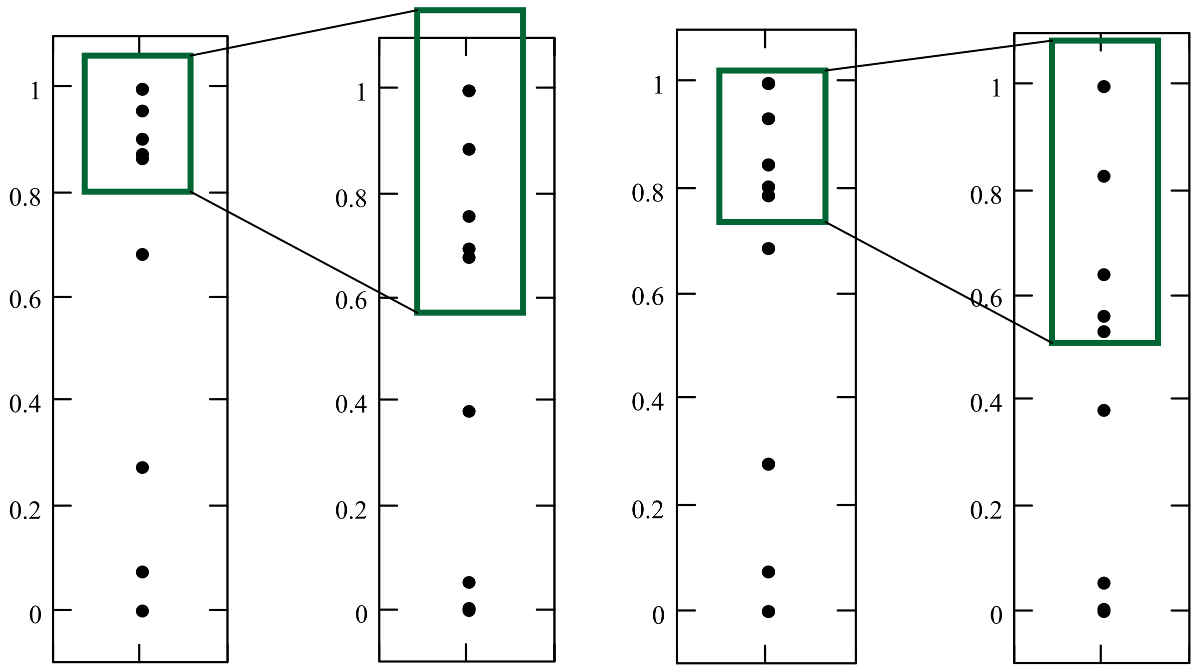



# Marginal (attribute) utilities

- Subjective consideration of attribute values
- Assumptions based on rationality
  - Transitiveness – monotonous function
  - Objectiveness – continuity and validity for both of stakeholders
- Criterion of sufficient distinction between marginal utility values

# Costs

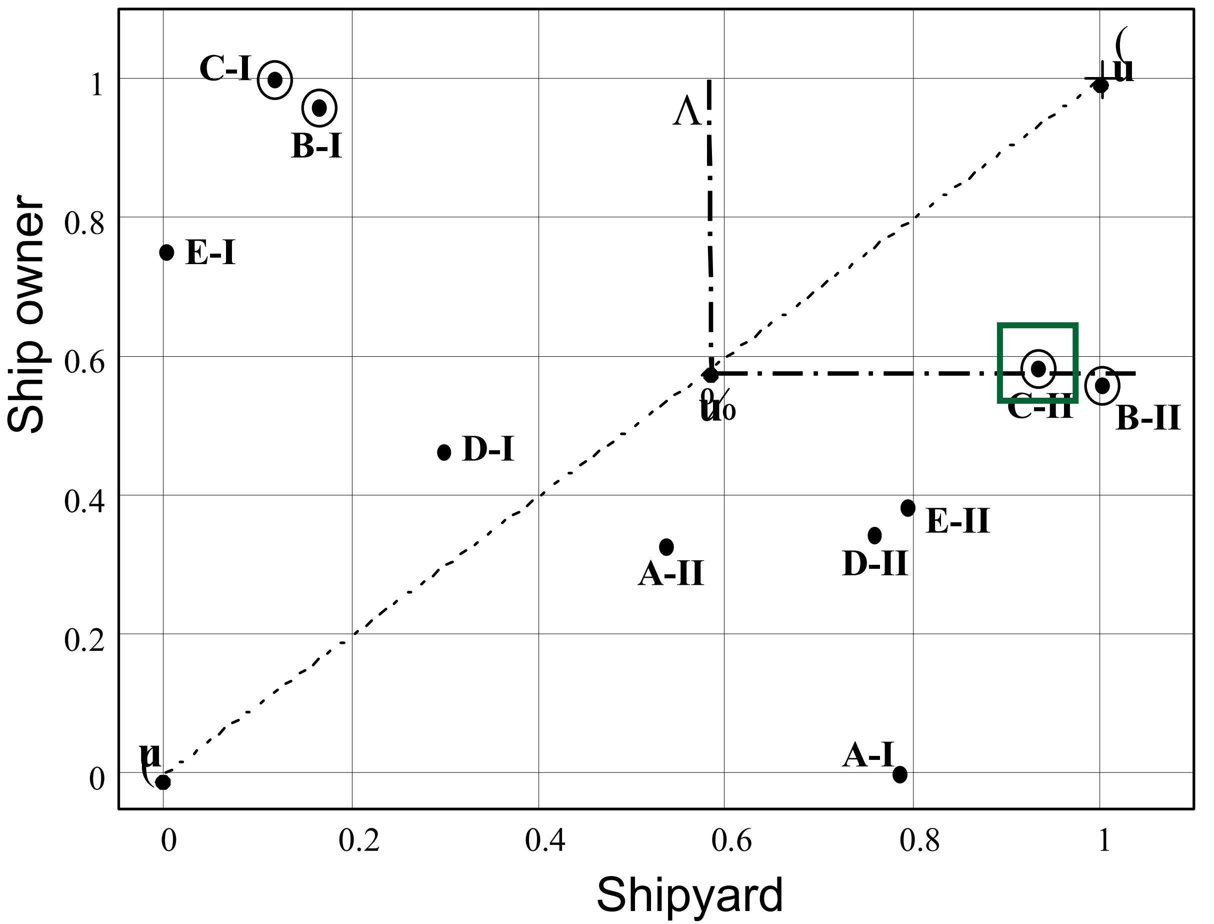
- Joint consideration of costs for both contractual situations
- Grouping of preferred alternatives



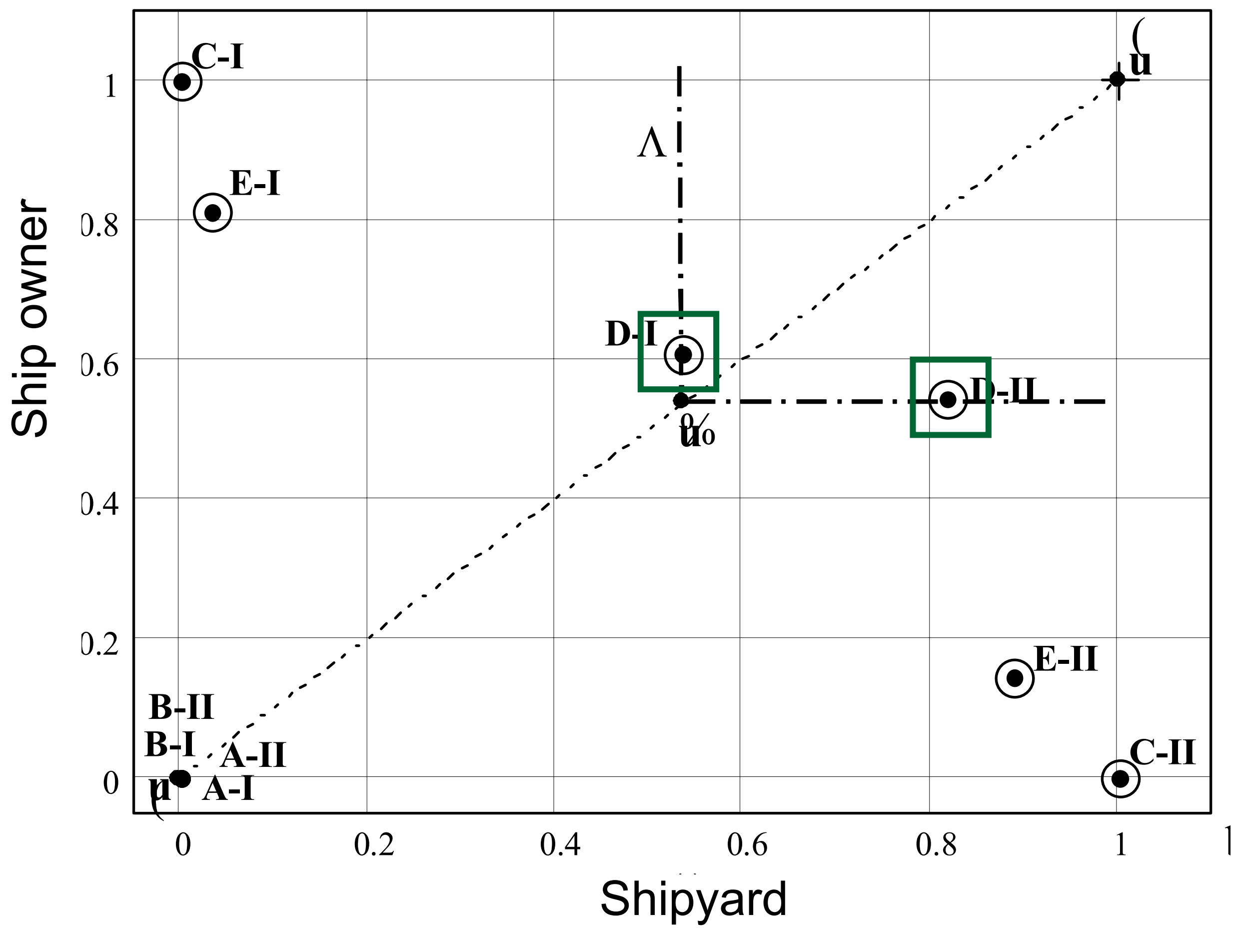

$$r_P = 2^{P_n^2} - 1,$$

$$r_O = 2^{O_n^2} - 1,$$

# Normalized utility space – additive f.



# Normalized utility space – product f.



# The competitive optimums

- Additive f. – DA-C-II
- Product f. – DA-D-I and DA-D-II

| **DA** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| $\text{NC-I} = P_{SHIP} - B \ \left[ € \times 10^3 \right]$ | - | 18.4 | 36.9 | 8.6 | 37.6 |
| $\text{ICAF-I}^* = \text{NC-I}/\Delta \text{AFR} \ \left[ € \times 10^6 \right]$ | - | 0.8 | 2.0 | $\boxed{0.9}$ | 2.2 |
| $\text{NC-II} = P_{DB} + O_{LOSS} - B \ \left[ € \times 10^3 \right]$ | - | 64.5 | 101 | 28.8 | 97.1 |
| $\text{ICAF-II}^* = \text{NC-II}/\Delta \text{AFR} \ \left[ € \times 10^6 \right]$ | - | 2.9 | $\boxed{6.1}$ | $\boxed{3.2}$ | 5.9 |

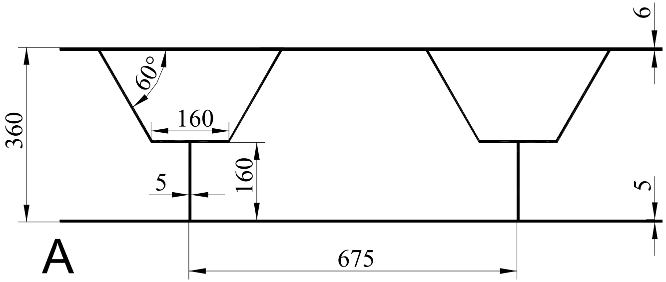
# Results

- Main dimensions should be increased if ever possible
- DA-C-II is not preferable if observing ICAF due to extremely high operational costs
  - The most expensive alternative
  - Additive function does not penalize such alternatives
- DA-D-I and –II (increase of stiffener size by 90%) are much more reasonable solutions then
- Such solution is regularly used in practice, hence confirming sensibleness of the proposed decision approach

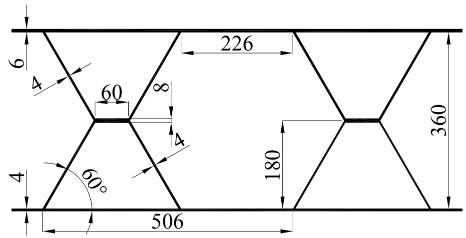
# Case study - collision (IMDC 2006)

- Design selection of a crashworthy structure considering
  - Capacity to absorb energy before the tearing of the inner hull shell plating
  - Production costs
  - Maintenance
  - Operability
- Design objectives of two stakeholders
  - Shipyard
  - Ship owner

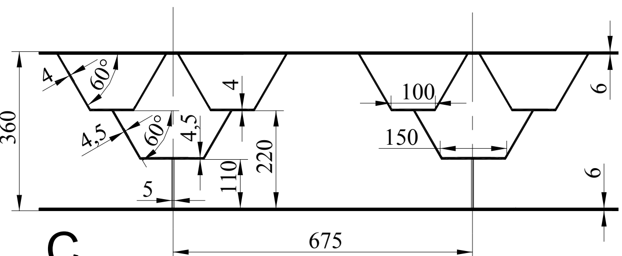
# Design Alternatives



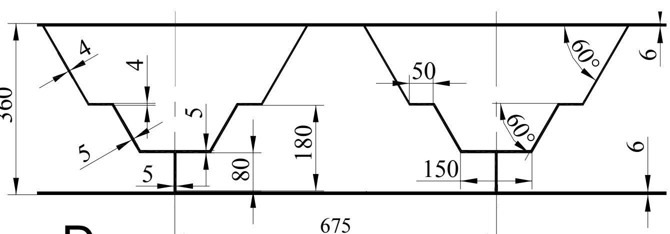

A



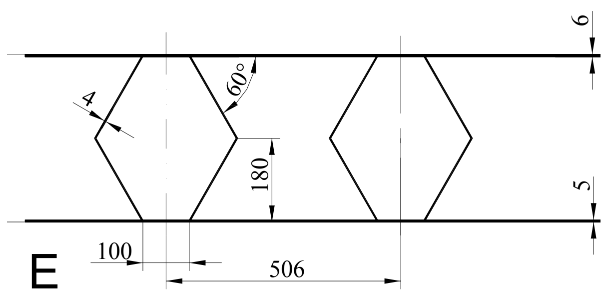

B




C

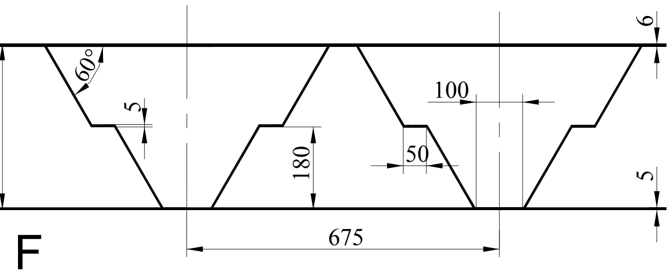


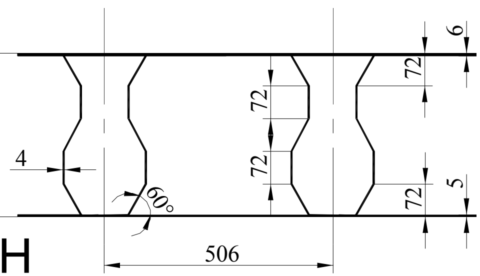

D

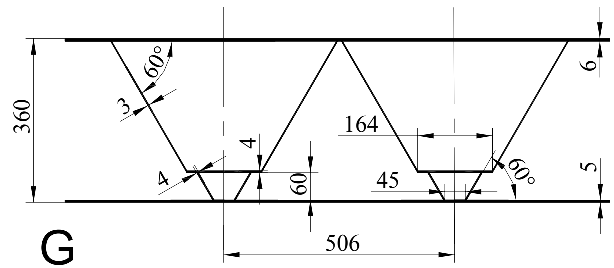


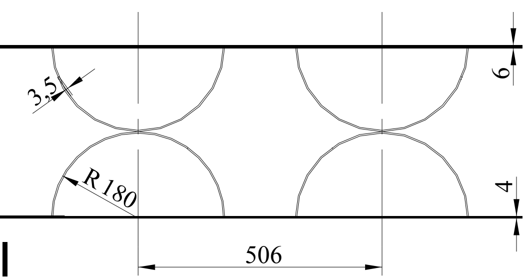

E

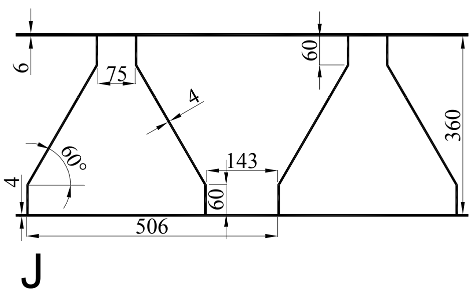
# Design Alternatives

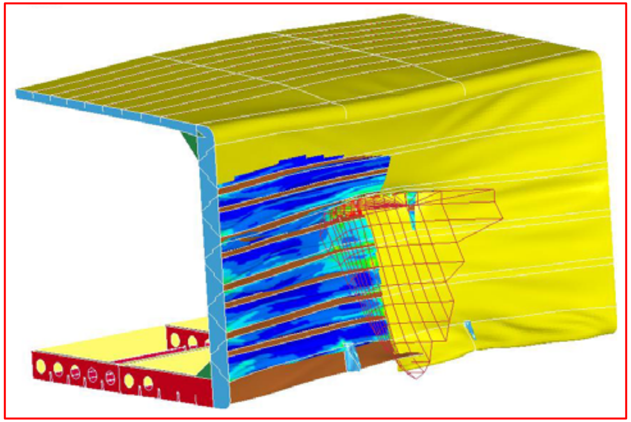


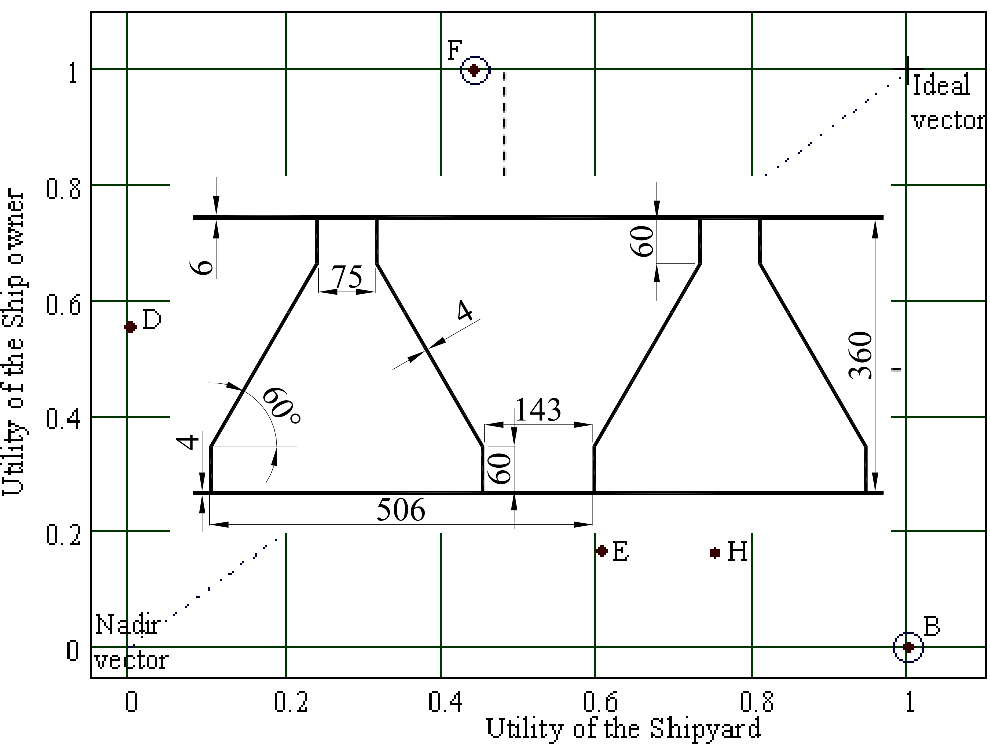
# Model of Stakeholders Preferences

- Final price of the ship is fixed – the contract is signed
- Shipyard wishes to minimize the production costs while significantly considering structures with good operability and crashworthiness
- Ship owner wishes to significantly increase the crashworthiness for the reasons of lower insurance fees, better safety record and improved image, but also considers the maintainability of the structure to reduce the overall life cycle costs

$$\mathbf{w}_{\mathbf{SY}} = \left(0.136\ 0.598\ 0.051\ 0.214\right)^{\mathrm{T}},$$

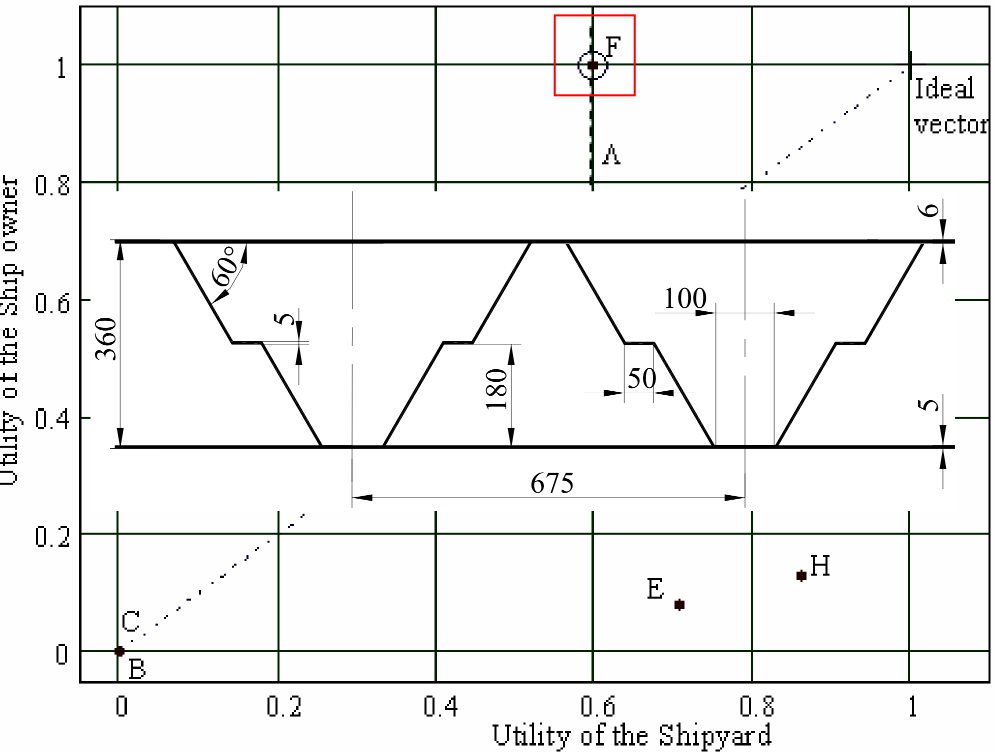
$$\mathbf{w}_{\mathbf{SO}} = \left(0.875\ 0.125\right)^{\mathrm{T}}.$$

# Normalized Utility Space – Additive F.




- DA-F
  - Preferred by the ship owner
  - The best in crashworthiness and good in maintenance, but
  - Suffers due to higher production costs and low operability
- DA-B
  - Preferred by the shipyard
  - The cheapest and the best in operability
  - The worst in crashworthiness – negative effect for the ship owner
- DA-J
  - Favorable for the shipyard
  - Cheap to produce
  - Good overall performance – acceptable for the owner
- DA-J is the competitive optimum

# Normalized Utility Space – Product F.




- Designs that perform worst over any attribute are reduced to nadir vector
- Other designs generally improve
- DA-F becomes now the competitive optimum

# Results

- Design selection has yielded two DA which are rather similar
  - Corrugated core differing only in the position of knuckles
- Corrugated panels generally exert good crashworthiness and allow for good maintenance
  - Good transfer of shear forces (involves the whole panel in deformations)
  - Larger enclosed spaces (someone can squeeze in)
  - Low amount of discontinuities
  - No welding in the middle of core elements
- Low or demanding operability
  - Large unsupported plate spans
  - Low critical buckling stresses
  - Need for additional stiffening of applied on ocean going vessels

# Conclusion

- Rational increase of safety demands fundamental consideration of design environment
- A new approach to multi-stakeholder decision-making is proposed based on axiomatization of a desired outcome – <u>The Competitive Optimum</u>
- The proposed decision function can be then directly applied for design optimization