Unit 12: Risk Management in a Multi-objective Framework

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Structure

- Objectives
- Introduction/background
- Multi-objective approaches (methodology)
- Application
- Summary
- Conclusion

Objectives

- Risk management tries to identify options to reduce the risk
- Secondly: Options are evaluated by a set of criteria
- Choose the options where you have the best result

Risk management

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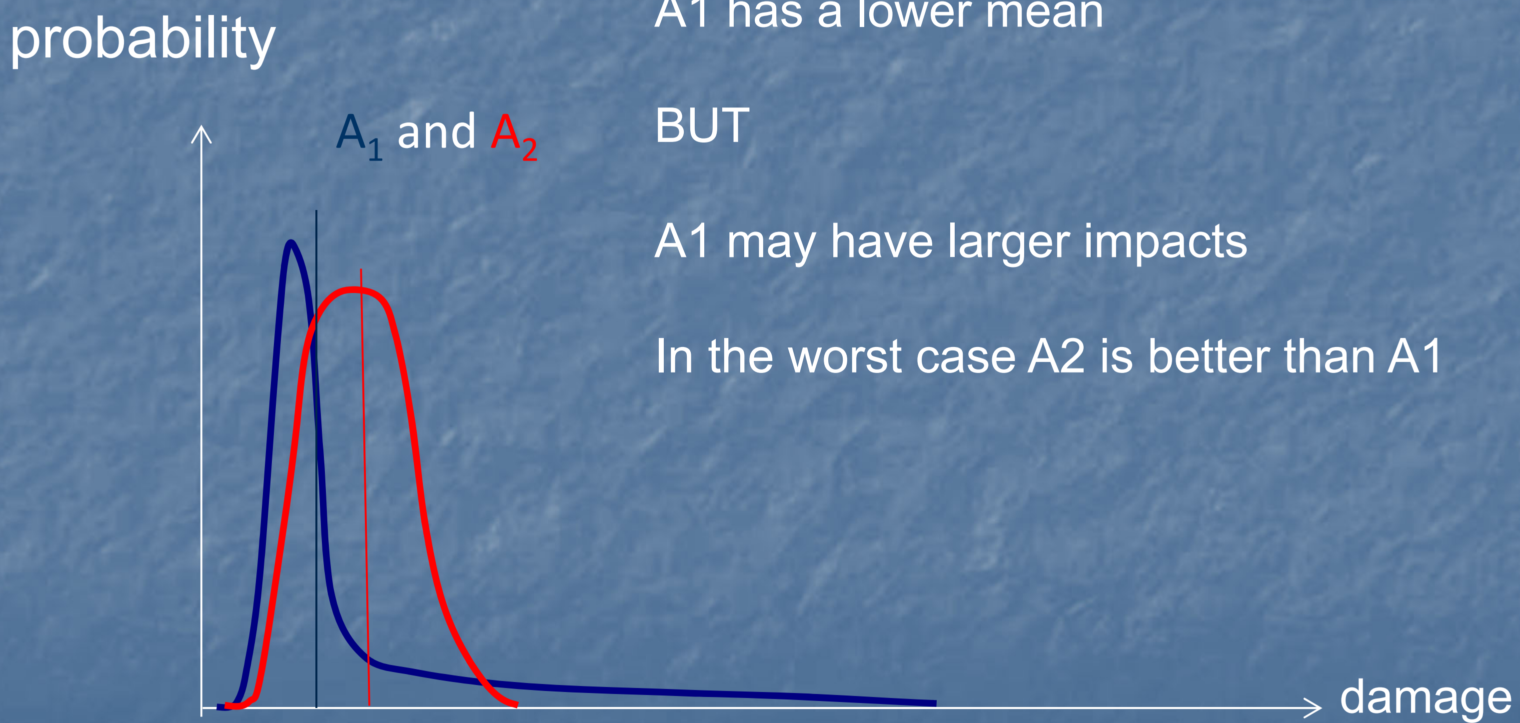
- Origin of uncertainties
  - Data are limited (in time and space)
  - Data are contaminated by measurement errors
  - Models describe only part of reality
  - Social preferences are not perfectly known
- Therefore we have to trade-off different objectives (outcomes) with uncertanties

Comparison of two uncertain alternatives

- e.g A1 (nuclear power plant) and A2 (thermal power plant)



A1 has a lower mean

BUT

A1 may have larger impacts

In the worst case A2 is better than A1

Decision under risk

2 alternatives with uncertain outcomes

Net benefits (k€) and probabilities

	A_1	A_2
w_1=33%	6 400	4 900
w_2=33%	4 100	4 300
w_3=33%	2 500	3 600

Which alternative is better ?

The decision depends on the perception of risk

mean	4 333	4 266
Max	6 400	4 900
Min	2 500	3 600

Comparing two uncertain outcomes

- Possible Decision Criteria

  $\text{Max}\ \{\Sigma\ w_i\ NB_{ik}\}$
  $\text{Max}\ \{\text{Max}(NB_{ik})\}$
  $\text{Max}\ \{\text{Min}\ (NB_{ik})\}$

Decision criteria

- Bernoulli criterion: choose the one where K_1 is better:

$$K_1 = \max \{K_{1,i}\} = \max \{ \Sigma w_k A_{ik}\}$$

$K_{1,1}$ = 4 333 k€/a
$K_{1,2}$ = 4 266 k€/a

Decisoin criteria

- Risk friendly decision: given a certain risk probability (with e.g. 33% you will win) choose the alternative with the higher outcome
- K_2 = Max $\{K_{2,i}\}$ =Max $\{Max(NB_{ik}$ with $P>p_{crit})\}$
- $K_2 = 6400 = Max\{K_{2,1}= 6400 , K_{2,2}= 4900\}$

- Gambler‘s attitude

Decision criteria

- Neumann-Morgenstern criterion: try to avoid losses or take a risk averse position

- $K_3 = \max\{K_{3,i}\} = \max\{\min(A_{ik}) \text{ for } w_k > p_0\}$

- Choose A_2 because the worst outcome is 3 600 k€/a which is better than the outcome of A_1
- Is a useful criterion for public investments, safe decision

Some examples

- Quantifying risk is associated with economic losses, human impacts, environmental impacts, social disruptions
- Risk management tries to minimize economic losses, to preserve environmental quality, to reduce social disruptions,……

Example of objectives and sub-objectives

Improve regional and national economy

minimize total losses

(direct and indirect losses, costs of protection measures,..)

- Reduce disparity among regions

(income, job opportunities, infrastructure,…)

Example of objectives and Sub-objectives

- Preserve/improve environmental conditions
  preserve/extend aquatic wetlands
  (area (ha), natural diversity (index)…)
  preserve/improve groundwater quality
  (nitrate conc. (mg/l), dissolved iron (mg/l), heavy metals (mg/l), recharge (m3/a)
  preserve/stabilise endangered species
  (number (#), reproduction rate (%)…)
  ……………

Example of objectives and sub-objectives

- Minimize human losses

  (# of fatalities, number of injured people…)

- Improve/preserve living conditions

  (reduce disruptions of social life, ensure basis supply functions, preserve job opportunities (#/a), recreational opportunities (# people/day)……

- Improve equity within society

  benefits and adverse project impacts should be balanced within the region

Example of objectives and sub-objectives

- Preserve cultural heritage

  (number of monuments exposed, age, quality, importance and uniqueness of monuments,…)

Multi-objective decision making

- Overview of the concepts applied in MCDM
  One decision maker
  quantitative (Compromise Programming) and qualitative criteria (ELECTRE I-IV)
- Analysis of pro's and con's
- Applicability

Techniques

- Distance-based techniques
- Outranking techniques (for discrete alternatives only)
- Value- or utility-based techniques
- Graph model
- Alternative Dispute Resolution

Distance based techniques

- Require quantitatively expressed criteria
- Require preferences (weigths and scales)
- Number of alternatives may be infinite (optimisation)

- Yield a full ranking of alternatives
- Might be iteratively applied

Procedure

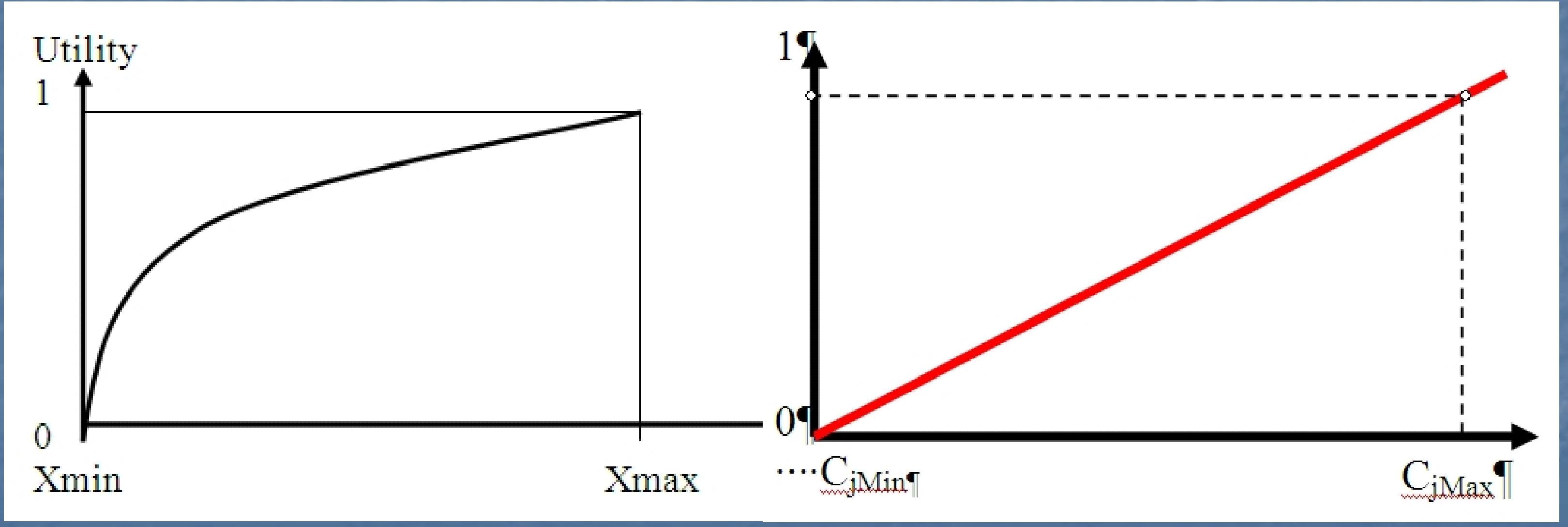
- Impact table:
  expresses the consequences of each alternative with respect to each criterion in measureable units
- Efficiency or payoff table
  transformation of impacts into efficiency measures (scaling)
- Estimation of the overall efficiency („best solutions“)

Impact table

	full set of alternatives A				
Criteria	A1	A2	A3	Ai	AN
C1 (€)	c11	c12	c13	c1i	c1N
C2 …	c21	c22	c23	c2i	c2N
C3 (mg/l)	c31	c32	c33	c3i	c3N
Cj …	cj1	cj2	cj3	cji	cjN
CJ (ha)	cJ1	cJ2	cJ3	cJi	cJN

Payoff table

- The physical outcomes have to be transferred into appreciation values (often the efficiency in reaching an objective is used)



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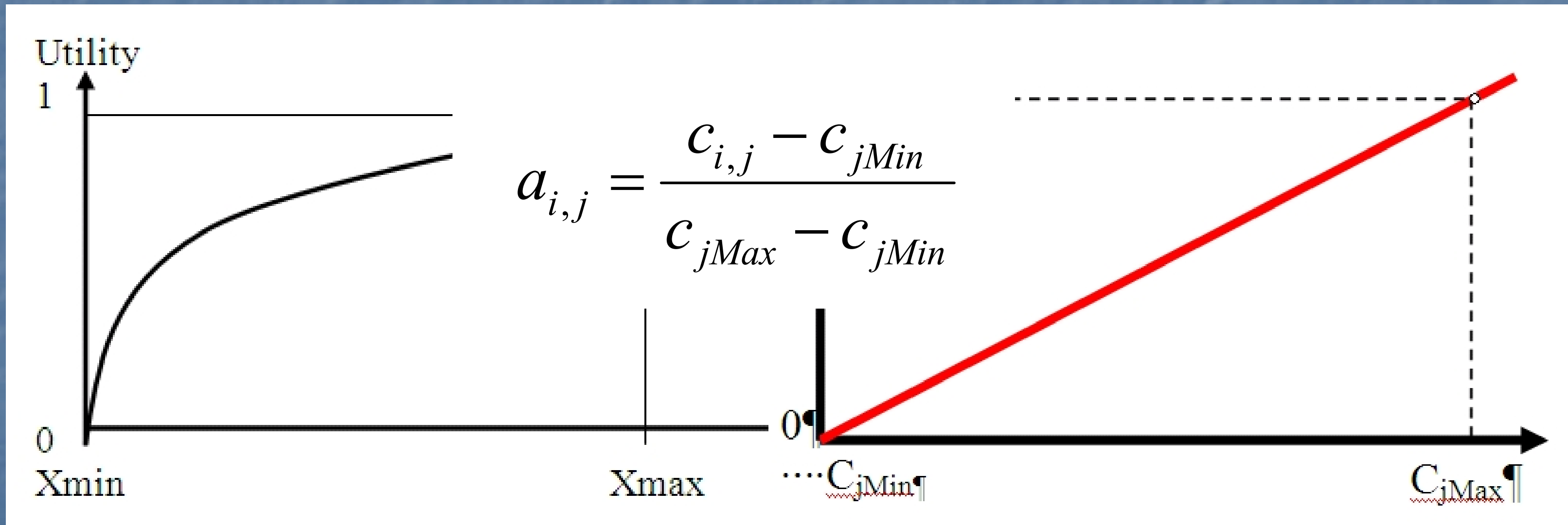
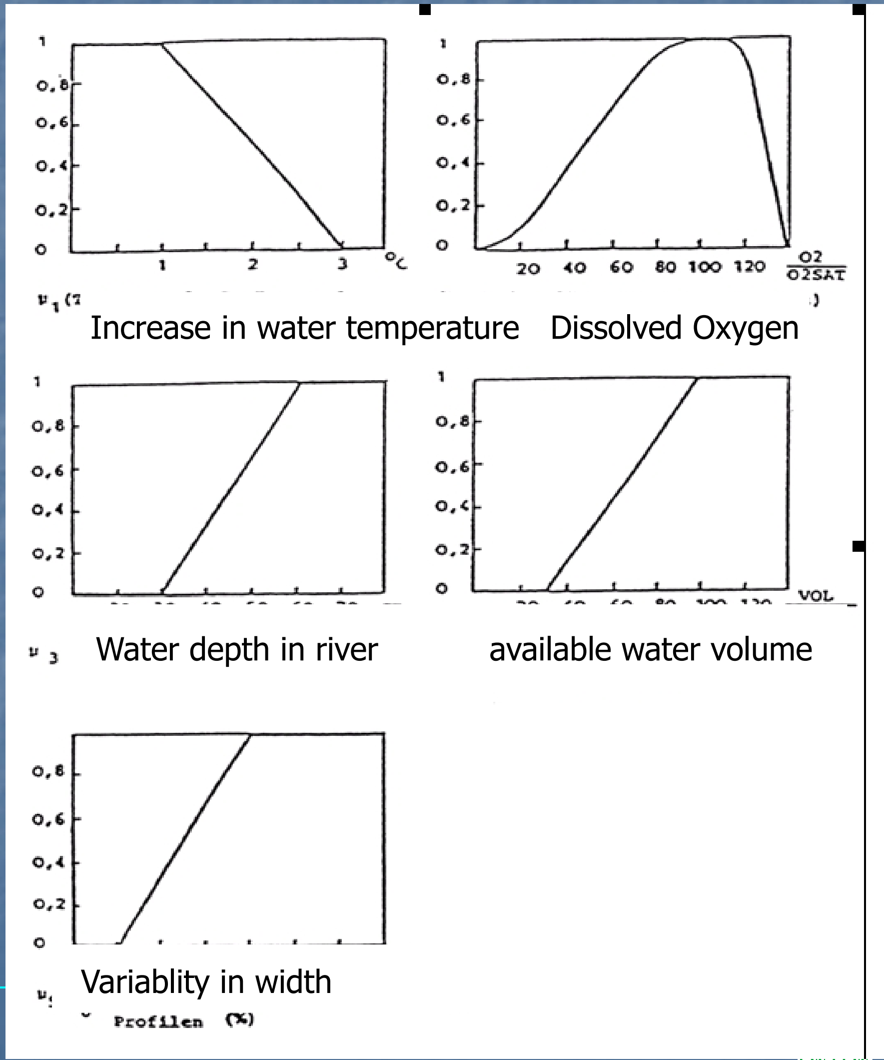


$$a_{i,j} = \frac{c_{i,j} - c_{jMin}}{c_{jMax} - c_{jMin}}$$

Sometimes utility and membership functions are used

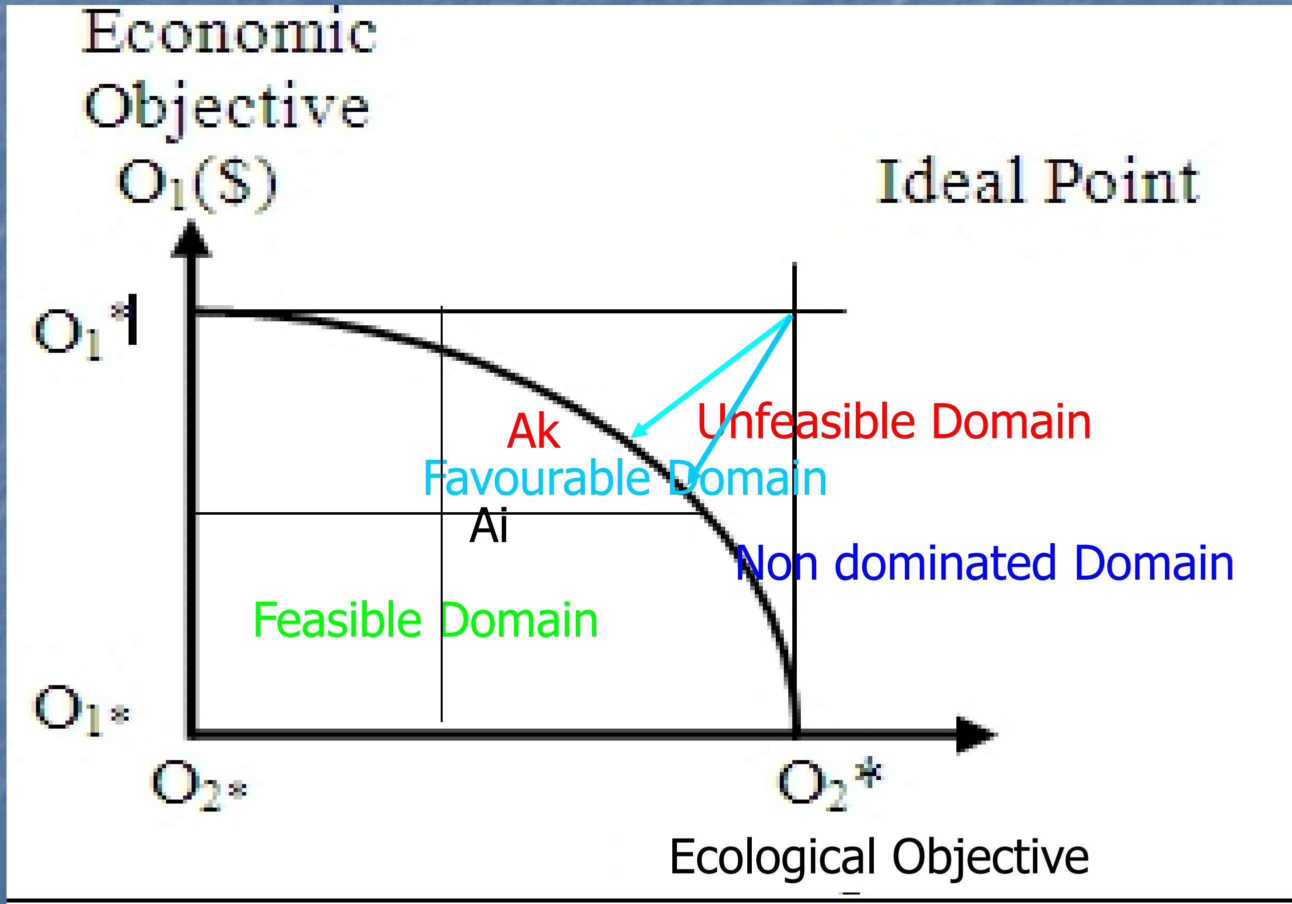


Efficiency or payoff table

full set of alternatives A

Criteria	A_1	A_2	A_3	A_i	A_N
C_1 (€)	a_{11}	a_{12}	a_{13}	a_{1i}	a_{1N}
C_2 …	a_{21}	a_{22}	a_{23}	a_{2i}	a_{2N}
C_3 (mg/l)	a_{31}	a_{32}	a_{33}	a_{3i}	a_{3N}
C_j …	a_{j1}	a_{j2}	a_{j3}	a_{ji}	a_{jN}
C_J (ha)	a_{J1}	a_{J2}	a_{J3}	a_{Ji}	a_{JN}

Distance based techniques



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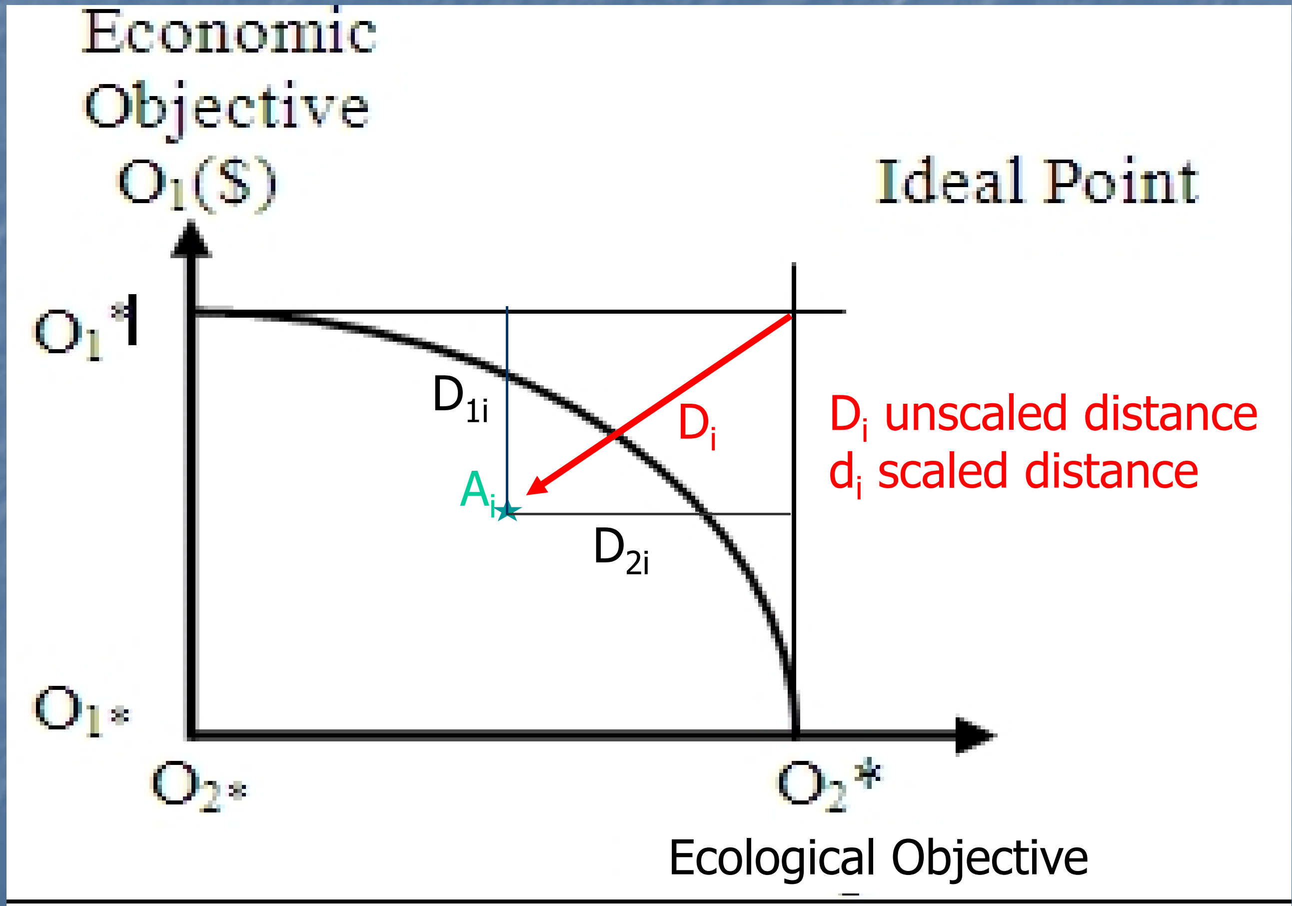
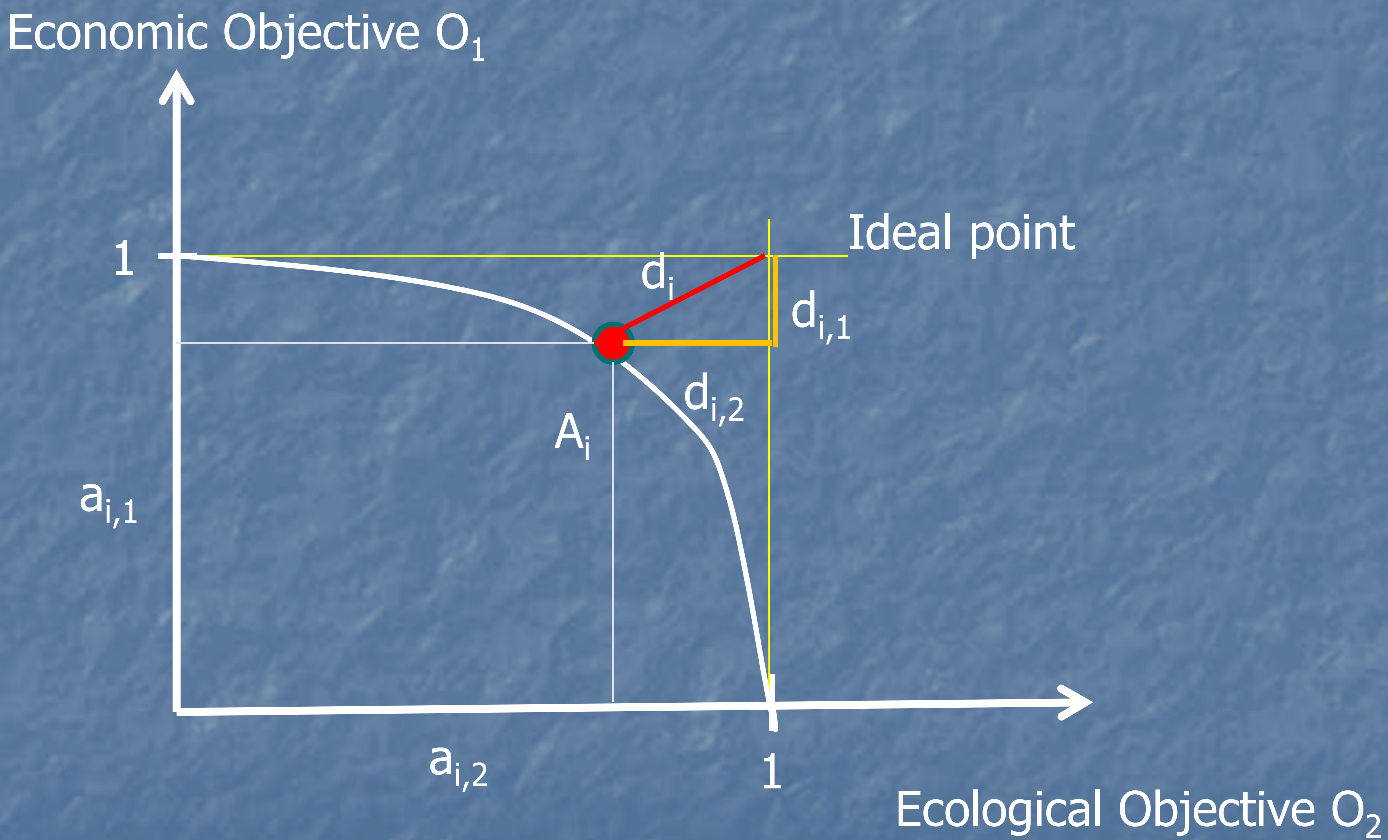


Scaled Representation



Distance based techniques

$$d_{i,j} = 1 - a_{i,j}$$

$$L_i(p) = \left[\Sigma(w_j \cdot d_{i,j}^p)\right]^{1/p}$$

Distance with respect to one criterion

Overall distance

L_i the distance of alternative i from ideal point depends on w_j and p

w_j	weights
p	trade-off factor

Outranking techniques

- Often, a pairwise comparison of alternatives is performed
  e.g. A3>A4, A5>A4, A4>A2, A3>A2

  In ELECTRE (I) only an incomplete ranking can be achieved
  In ELECTRE (IV) a complete ranking is achieved

  Both approaches require weigths and scales for describing the preferences.

ELECTRE I

Govindam et al. (2016) https://doi.org/10.1016/j.ejor.2015.07.019

- Simple example: 2 alternatives A1 and A2,
- 3 criteria: C1, C2 and C3
- Weights: w1, w2, w3
- Scales: s1, s2, s3

	A1	A2	W	S
C1	c11	c12	w1	s1
C2	c21	c22	w2	s2
C3	c31	c32	w3	s3

ELECTRE I

C1 NPV in (Mio €)

C2 (mg/l) water pollution

C3 (# of created jobs)

ELECTRE I

- Impact table

W weight
S scale

	A1	A2	W	S	Best	Worst
C1	1.5	1.8	0.5	10	2.0	1.0
C2	10	20	0.2	10	0	50
C3	100	120	0.3	10	200	0

ELECTRE: concordance and discordance

- Concordance expresses the dominance of Ai>Aj
- Discordance expresses the weakness of Ai<Aj

$$CI(i,j) = \frac{\sum\limits_{A_i > A_j} w_k + \frac{1}{2} \sum\limits_{A_i = A_j} w_k}{\sum w_k}$$

$$DI(i,j) = \underset{k=1,J}{Max} \left\{ \frac{Z_{ki} - Z_{kj}}{Max(Sc)} \right\} for\_all\_A_j > A_i$$

- Definition of threshold values CI* and DI*
- Identification of alternatives with high CI and low DI

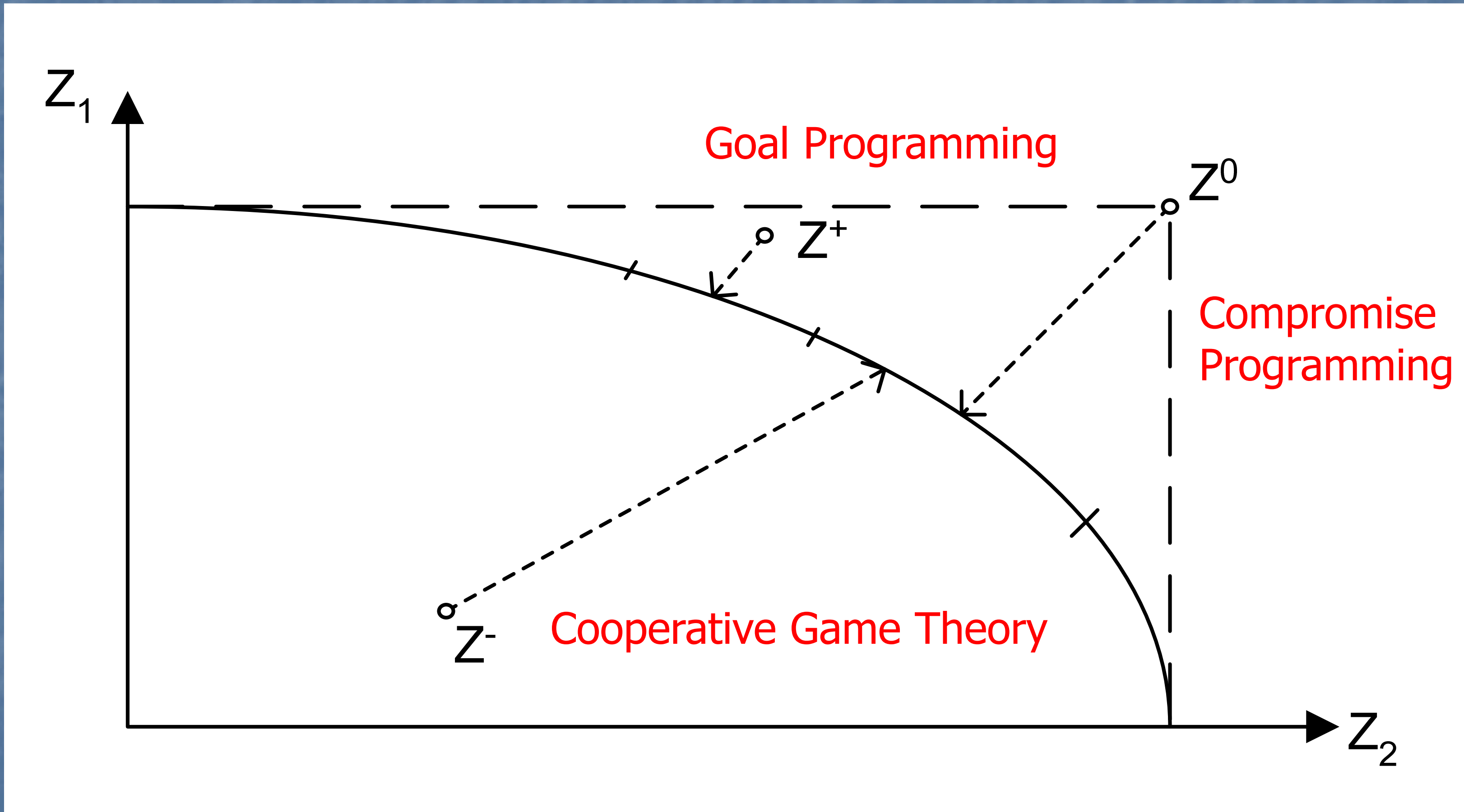
ELECTRE I

- CI(1,2)=0.2, CI(2,1)= 0.8
- DI(1,2)= Max (0.3, 0,1)=0.3
- DI(2,1)=Max(10/50)=0.2
- Finally two matrices CI(,) and DI(,) are obtained
- A threshold level CI* and DI* is introduced (e.g. CI* = 0.75, DI*=0.2 then A2>A1
- The lower CI* and the higher DI* the more alternatives are considered in pairwise comparison

Conclusions

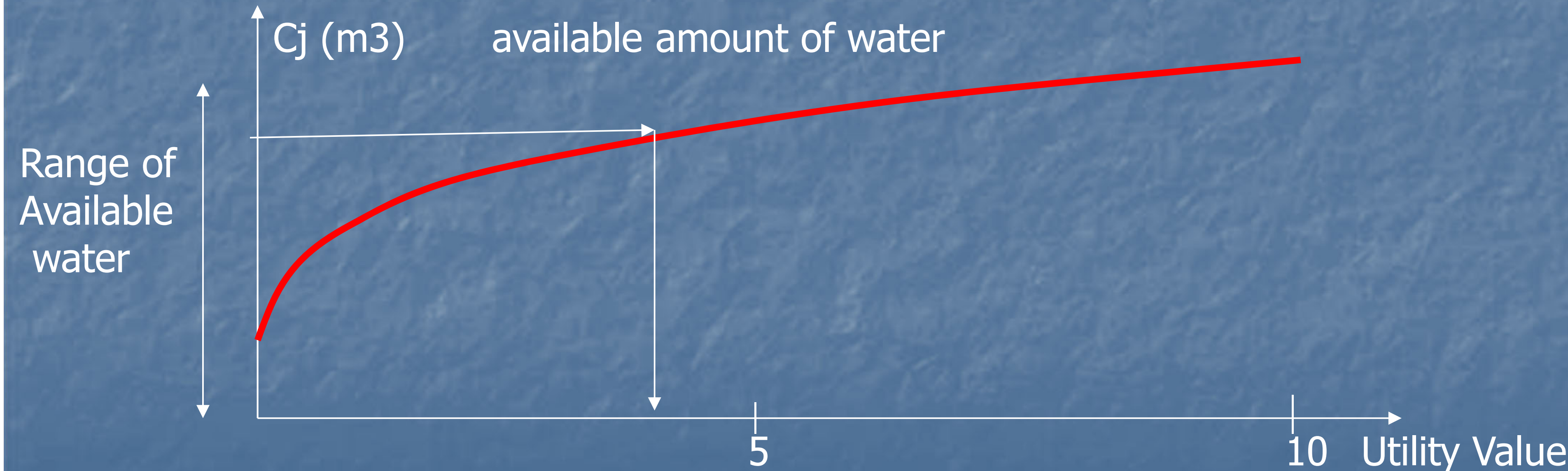
- Numerous methods exist for conflict analysis and resolution
- Multi-objective decision making is a daily problem
- The concepts of multiple objectives is found in many international/national documents
- The major steps are in the problem definition
  in the impact assessment
  in knowing about the preferences
- The numerical methods are helpful in improving the understanding of the problem and the exploring the feasible domain

Distance based techniques



Utility based techniques

- Often single attribute utility theory is applied
- If possible, MAUT (Multi-Attribute-Utiliy Theory) should be applied



Utility theory

- Impact matrix
- Transformation of impacts into utilities
- Definition of weigths for each criterion
- Overall utility value UV_i of alternative A_i is

$$UV_i = \sum_j w_j \cdot uv_{ij}$$

1-D and 2-D Utility Functions