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SERBIA

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- Most recent research interests: decision-making methodologies and supporting tools, evolution inspired intelligent algorithms, and natural resources planning and management.
- Author of 240 scientific papers, most in peer-reviewed international and national journals and conference proceedings.
- Led more than 50 professional, scientific and educational projects and programs
- Referee for Elsevier, Springer, IWA, IEEE and ASCE international journals.





4th VALUE Training School:
Validating Regional Climate
Projections



VALUE: COST Action ES1102 (2012-2015)

26 - 30 October 2015 ICTP, Trieste, Italy

Decision Making in a Climate Context

October 26, 2015

Lecture by Bojan Srdjevic ©2015



LESSON TODAY

PART 1: /morning/

- **INTRODUCTION (brief)**
- MULTI-CRITERIA DECISION MAKING (MCDM)
 (APPROACHES, METHODS, MODELS, TOOLS)
- **EXAMPLE USES OF MCDM METHODS AND TOOLS**
- MCDM & SCT (SOCIAL CHOICE THEORY) TOOLS

PART 2: /afternoon/

- **ANALYTIC HIERARCHY PROCESS**
- EXERCISE (individual and group d-m)







D-m in a climate context

- Most decisions balance multiple criteria
- A structured approach is required
- No right answer in a mathematical sense
- Information can be complex, changing and conflicting



D-m in a climate context

- Requirements
 - Organise information
 - Synthesis of the result
 - Justify and explain decision
- Methods lie between hard and soft systems
- Hard = Phenomena obey physical laws, represented by mathematics
- Soft = Processes can be represented by concept of a human activity system



Characteristics / Requirements

- Adaptation framework must be established.
- There are different parts of the adaptation process, and it may differ for different decision-makers in different places.
- Adaptation is an internally generated response of a system to external forces. Though it is a continuous process, it is convenient to break it down into four components or stages:
 - (1) signal detection /after signal and noise are defined/
 - (2) evaluation
 - (3) decision and response
 - (4) feedback.



Signal detection

- For any decision-maker, the manner and form of adaptation will depend on how signal and noise are defined. That is, what is adapted to (signal) and what is ignored (noise).
- Decision-makers with an operational focus on different temporal and spatial scales will tend to define signal in terms of processes they can observe at their characteristic scales of attention.
- Adaptation is conditional on detecting a recognizable signal: no detected signal, no response for different decision-makers in different places.



Evaluation

- Follows the detection.
- The detected signal is interpreted and the foreseeable consequences or impacts of it are evaluated within the d-m process.
- Evaluation can also be performed by individual farmers or larger bodies such as wheat boards and government agencies.



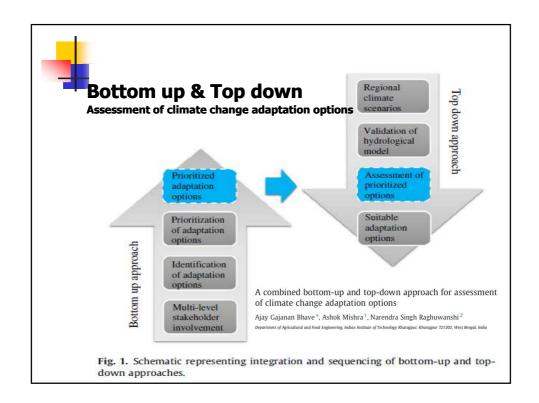
Decision and Response

- The third stage is the response: an observable change in the behavior or performance of the system.
- The response is the result of a decision.
- A variety of different decision making styles (e.g. risk aversion, satisfying; negotiations, consensu building) have been observed among farming communities, systems analysts, polititians, etc.



Feedback

- The final stage is feedback: a monitoring of the outcomes of decisions to assess whether they are as expected.
- If the adaptation is effective, it can be added to a repertoire of adaptive options.
- If it doesn't work, one needs to evaluate what went wrong and why.





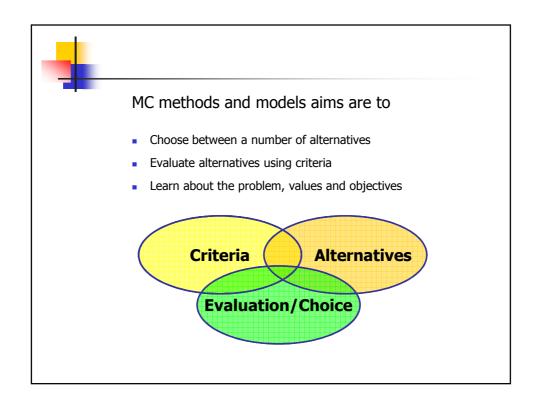
Multiple Criteria Approaches, Methods & Decision Making Models

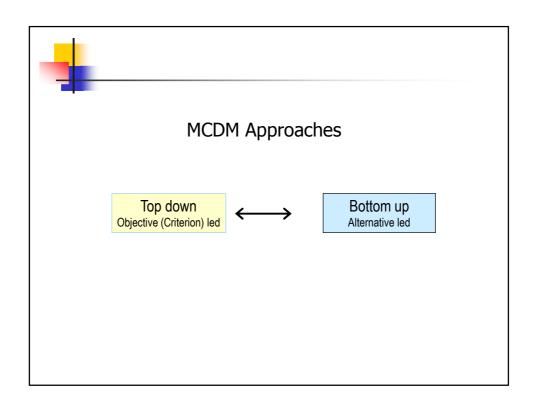


Multiple Criteria Methods and Decision Making Models serve as instruments for resolving conflicts, managing risks, to include multiple actors, and to attack interlocking crises related to

- Climatic shifts
- Megaruptures
- Metabolism
- Socio-political context
- Transboundary dependencies
- Fast pace of technological development

C. Karavitis







TOP DOWN (identify criteria)

BOTTOM UP (alternative led brainstorming)

Plus-Minus-Interesting analysis

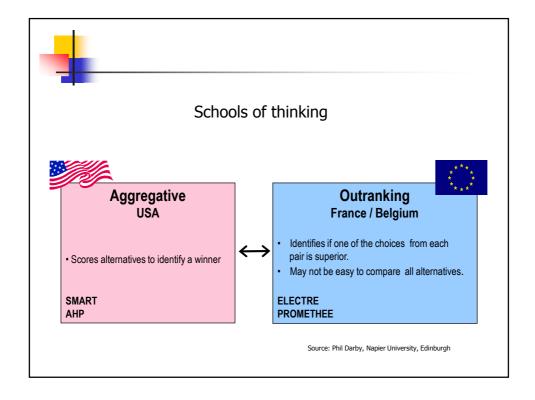
Participants should list strengths, weaknesses and interesting points about each alternative.

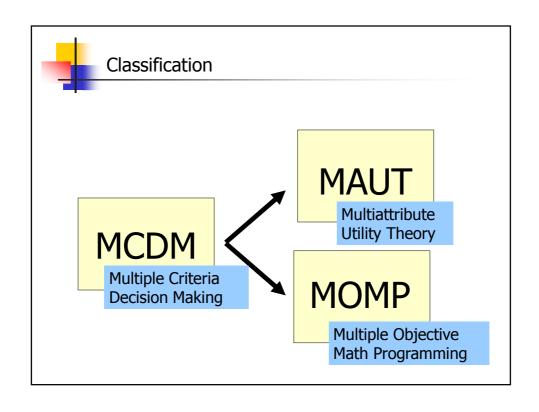
Eliminate alternatives obviously dominated by others.

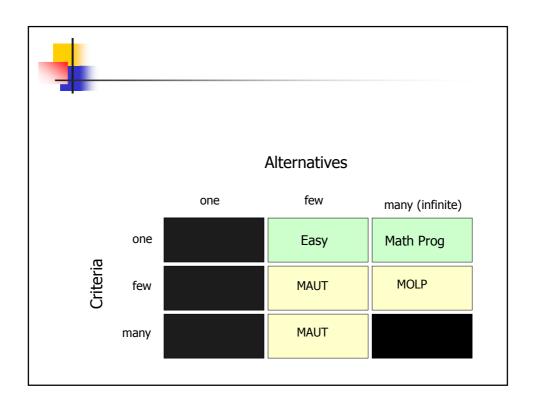
Apply appropriate discrimination mechanism to identify similar alternatives and avoid inferior ones.

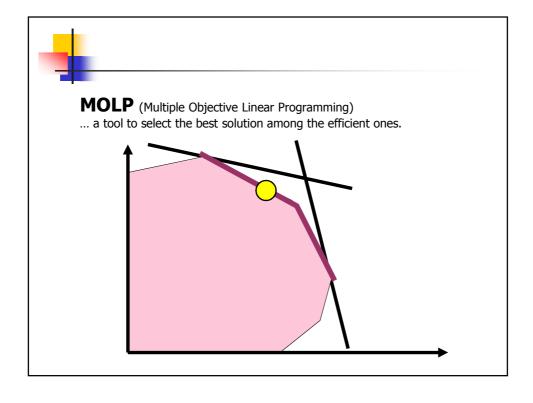
There could be a very large number or pairs.

Both approaches need creative thinking. Both need to reduce number of decision element to an appropriate or manageable set.











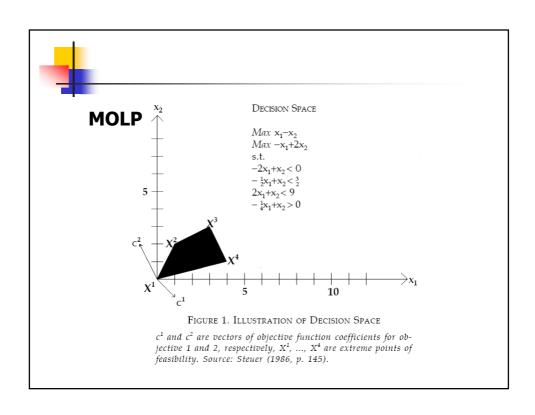
MOLP

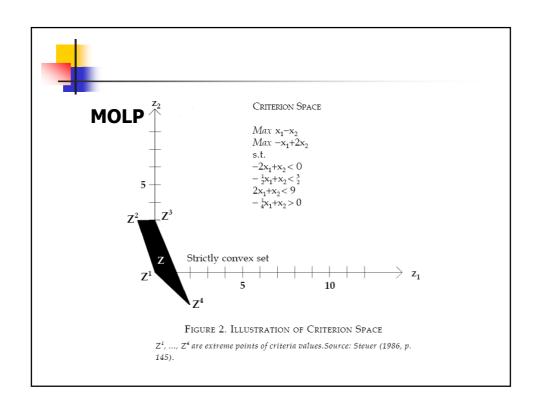
Multiple objective LP is distinct from (single objective) LP by having more than one objective function. Mathematically:

$$\begin{aligned} & \textit{Max } c^1 x = z_1 \\ & \cdot \\ & \cdot \\ & \cdot \\ & \text{Max } c^k x = z_k \\ & \text{s.t.} \end{aligned}$$

$$& \textit{Ax} \leq b$$

$$& \textit{x} \geq 0 ,$$







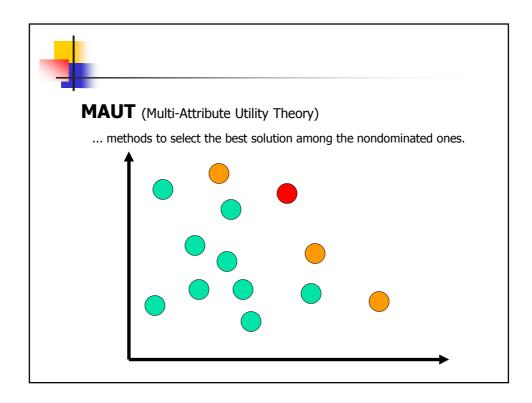
MOLP (Multiple Objective Linear Programming)

- A number of different *MOLP* procedures have been reported, of which *GP* is best known.
- The weighted-sum technique and vector-maximum algorithms are regarded as members of the more frequently applied MOLP approaches



MOMP (Multiple Objective Mathematical Programming)

- Problem types
 - MOLP (multiple objective linear programming)
 - MOILP (multiple objective integer programming)
 - NMOO (nonlinear multiple objective optimization)
- Methods for solving
 - GP (goal programming)





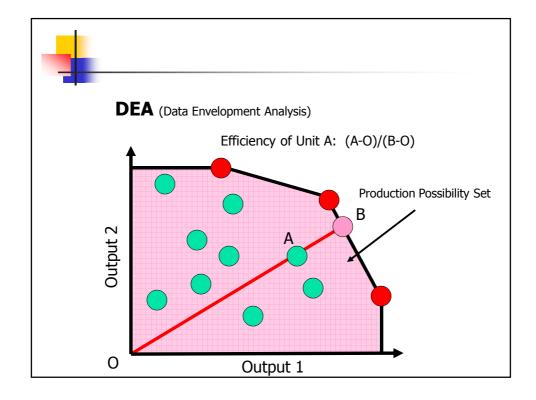
Methods for solving MAUT problems

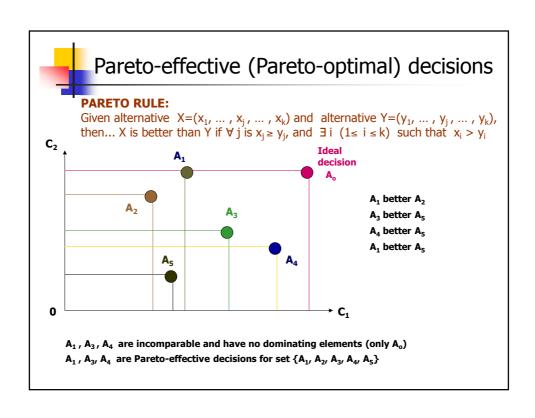
- MAUT (Multi-attribute Utility Theory)
 - Utility function is constructed and used to evaluate alternatives (usually concave)
- AHP (Analytic Hierarchy Process)
 - Pair wise comparisons
 - Assumes linear additive utility function
- Outranking methods (Promethee, Electre)
 - Produce a (weak) ordering of alternatives

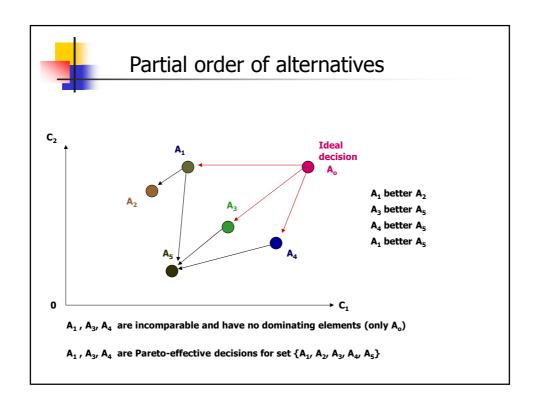


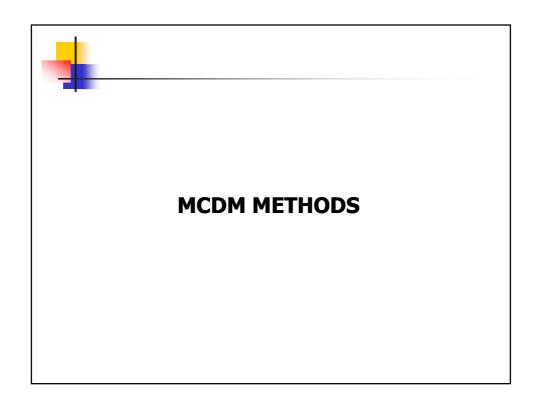
DEA (Data Envelopment Analysis)

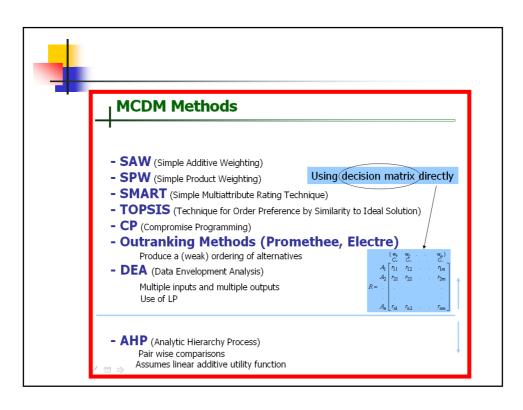
- MCDM tools are used to select a best alternative
- DEA evaluates the efficiency of a group of alternatives
 - ... but does not indicate a clear winner
- DEA has a multicriteria flavor: minimize all inputs, maximize all outputs
- Standard version of DEA does not use DM's preferences over inputs and outputs
- However, this can be done
 - ... there are weight restrictions







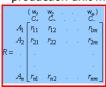






Performance matrix

- ... as a tool for modeling real-world multi-criteria situations
- Many real-world situations can be modelled by performance matrix.
- In some cases it is an easy task and the matrix is obtained immediately.
- In other cases it can be a hard problem implying several months of severe consultance and analysis work, as for instance when a new production unit must be selected among several possible sites.



	Crit. 1	Crit. 2	Crit. 3	Crit. 4	Crit. 5	Crit. 6	 Crit. 7
Weights	80	40	25	90	3	1	 17
Alt. 1	5	10	2	9	etc.		
Alt. 2							
Alt. 3							
Alt. 4							



	Crit. 1	Crit. 2	Crit. 3	Crit. 4	Crit. 5	Crit. 6	 Crit. 7
Weights	80	40	25	90	3	1	 17
Alt. 1	5	10	2	9	etc.		
Alt. 2							
Alt. 3							
Alt. 4							
••••							

- The matrix often must be evolutive (additional alternatives may be considered according to the gain in information during the progress of the decision procedure)
- New evaluation criteria could be considered, some others temporarily deleted
- The structuration of the matrix is achieved progressively
- Normative, constructive, descriptive and prescriptive arguments can be considered



	Crit. 1	Crit. 2	Crit. 3	Crit. 4	Crit. 5	Crit. 6	 Crit. 7
Weights	80	40	25	90	3	1	 17
Alt. 1	5	10	2	9	etc.		
Alt. 2							
Alt. 3							
Alt. 4							

- Also in use: *Decision table *Consequence table *Rating matrix
- Each row relates to an option
- Each column describes the performance of the options against each criterion
- Single performance assessment is often numerical, but may also be expressed as 'bullet point' score, color coding, linguistic value etc.



- In simplest MCDA:
 - * Performance matrix may be the final product of the analysis
 - * DM must assess the extent to which objectives are met by entries in the matrix

(Such an intuitive processing of the data can be speedy and effective, but it may also lead to the use of unjustified assumptions, causing incorrect ranking of options)

 In advanced MCDA the information in the matrix is usually converted into consistent numerical values.

	Crit. 1	Crit. 2	Crit. 3	Crit. 4	Crit. 5	Crit. 6	 Crit. 7
Weights	80	40	25	90	3	1	 17
Alt. 1	5	10	2	9	etc.		
Alt. 2							
Alt. 3							
Alt. 4							
••••							



DECISION MATRIX

... prerequisite for most MCDM methods

- In certain phase of the decision making process the decision matrix is created.
- Entries of the matrix represent scores (ratings) of alternatives with respect to criterions.
- Values (W1, W2,..., Wm) written above the matrix are the importance weights of criterions defined by the DM, or derived in another way; they usually (but not necessarily) sum up to 1.



SAW (Simple Additive Weighting)

- One of the most simple, but nevertheless good decision making methods.
- Its results are usually very close to more sophisticated methods.
- Three basic steps: 1 scale the scores to make them comparable, 2 apply weights, and 3 sum up the values for each source.



SAW (Simple Additive Weighting)

• If zero-values for alternative scores are allowed, the scaling should be applied for all alternatives over each criterion. This means to apply Eqs. (2) and (3) along columns of decision matrix (1). The alternative is to perform normalization by using Eq. (4).

For benefit criterions:
$$x_{ij} = \frac{r_{ij} - r_j^{**}}{r_j^* - r_j^*}$$
 (scaling) (2)

For cost criterions:
$$x_{ij} = \frac{r_j^* - r_{ij}}{r_i^* - r_i^*}$$
 (scaling) (3)

For any criterion:
$$x_{ij} = \frac{r_{ij}}{\sum\limits_{k=1}^{n} r_{kj}}$$
 (normalization) (4)



SAW (Simple Additive Weighting)

- Values rj^* and rj^{**} are the best and the worst value of all alternatives for criterion Cj, respectively.
- With scaling given by Eqs. (2) and (3) all scores are in interval [0,1]; the best scored alternative obtains the value 1, and the worst scored alternative obtains the value 0.
- This property assures comparability of scores.
- Note that scalarization differs from normalization, and so may lead to different final results.



SAW (Simple Additive Weighting)

• The final preference score for each alternative is:

$$S_i = \sum_{j=1}^m w_j x_{ij}, i = 1, 2, ..., n$$
 (5)

• The best alternative is the one with maximum value of Si.



SPW (Simple Product Weighting)

- The SPW method is similar to SAW. Scaling is not necessary, as well as normalization. However, both are permitted.
- Here, the Eq. (6) is used.

$$S_i = \prod_{j=1}^m (r_{ij})^{w_j}, i = 1, 2, ..., n$$
 (6)

• The best alternative is the one with the highest value of Si.



Compromise Programming (CP)

- CP is a technique which ranks alternatives according to their closeness to ideal point. The best alternative is the one whose point is at the least distance from an ideal point in the set of efficient solutions.
- Minimisation of this closeness to ideal point is a surogate of the standard maximization of the criterion function.
- The distance measure used in CP is the family of Lp-metrics given as

$$L_{p}(i) = \left[\sum_{j=1}^{m} w_{j}^{p} \left| \frac{r_{j}^{*} - r_{ij}}{r_{j}^{*} - r_{j}^{**}} \right|^{p} \right]^{1/p}$$

where Lp(i) is the Lp-metric for alternative Ai, rij is the rating of alternative Ai for criterion C_i^* , rj^* and rj^{**} are the best and the worst values respecively over the set of all alternatives for criterion C_i^* , and p is the parameter reflecting an attitude of the decison maker. An alternative with minimum Lp-metric is considered as the best.



- Weighting coefficients of criterions wj (j = 1, 2, ..., m) must sum to 1. They are usually obtained by normalizing values of original scoring of criterions performed by the DM, or as objective values computed by the methods such as ENTROPY or CRITIC.
- A parameter p implicitly expresses the DM's attitude to balance criterions (p=1), to accept decreasing marginal utility (p>1), or to search for absolutely dominant solution ($p=\infty$); the last is well known min-max Chebishev criterion. The most common value is p=2.



Worthily to mention an important instruments known as Intelligent Support To The Decision Making Process

EXPERT SYSTEMS (ES)

STOCHASTIC SEARCH ENGINES (SSE)

Simulated Annealing Tabu Search Genetic Algorithms

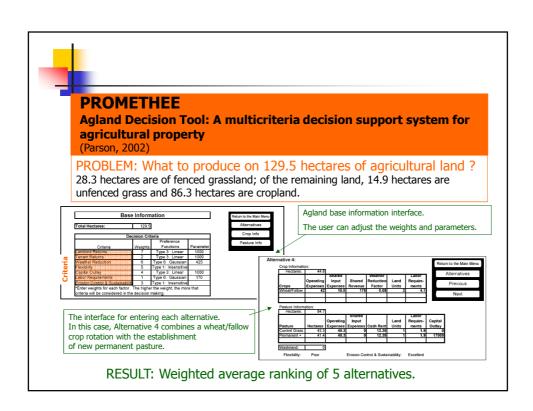
ANT COLONY OPTIMIZATION (ACO)

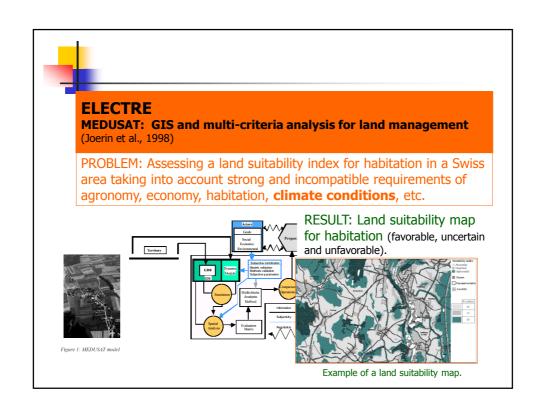
PARTICLE SWARM OPTIMIZATION (PSO)

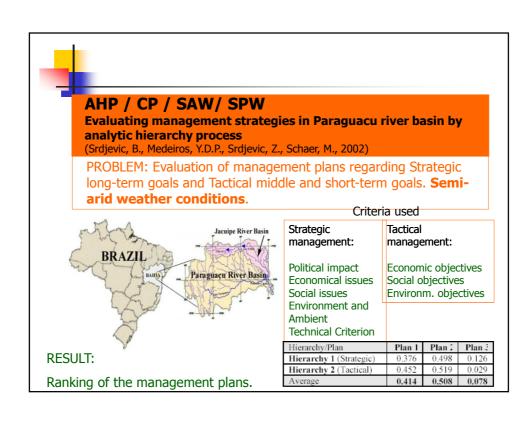
HONEY BEES OPTIMIZATION (HBO)

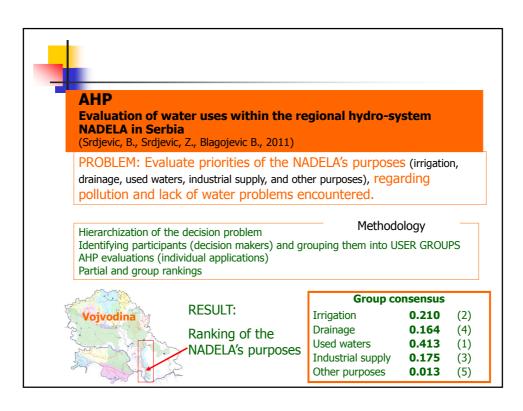


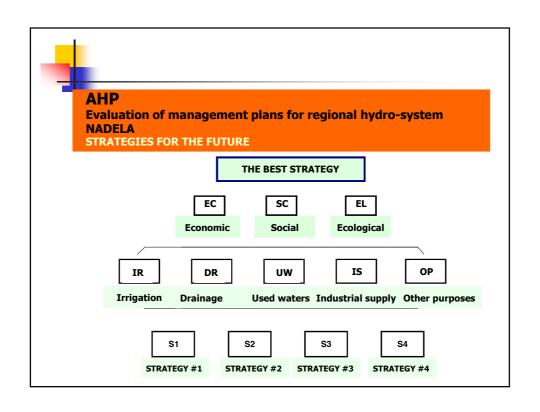
EXAMPLE USES OF MCDM METHODS AND TOOLS

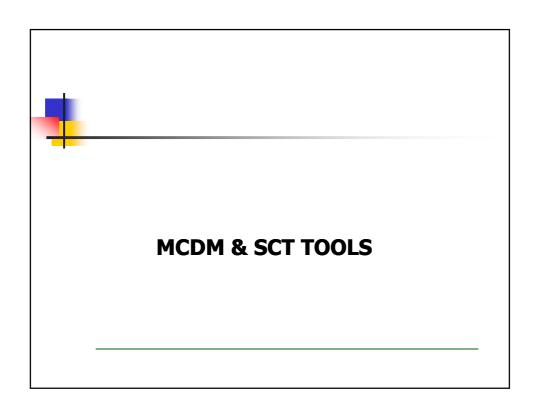














Claim #1:

Any decision making process can be organized/manipulated in hierarchical way

- 1. Good to think this way because most people inherently try to 'structure problem' in hand, i.e. to decompose it into a hierarchy, or a set of smaller problems.
- 2. Hierarchy can mean many things
 - Top managers, executive directors, staff (professionals, experts,...)
 - Decision trees (root, branches, leaves)
 - Problem hierarchy (goal, objectives, altrnatives)
- 3. Hierarchy can have single or multiple levels
 - Single: goal-criteria, goal-objectives, goal-attributes
 - Multiple: goal-criteria-sub criteria (- sub sub criteria) alternatives



HIERARCHICAL DECISION-MAKING PROCESS

HIERARCHICAL ...

Means

- Structuring the decision-making process
- Identifying decision elements (DEs) and key players decision makers (DMs)
- Defining decision lines: vertical and horizontal
- The "hierarchical" arrangement has been found to be the best way for human beings to cope with complexity.



HIERARCHICAL DECISION-MAKING PROCESS

... DECISION-MAKING ...

Means

- Understanding the problem in hand
- Following selected consistent and coherent methodology eligible for evaluating DEs
- DMs being responsible in validating objectives, criteria and alternatives (willingness, good attitude, best knowledge etc.)
- Understanding that there will be consequences of decisions made



HIERARCHICAL DECISION-MAKING PROCESS

... PROCESS

Means

- Considering the spatial and temporal component of the problem
- Recognizing the process in selected methodology of evaluating DEs.
- Necessity of feed-back loops envisioned.

D-M contexts



- Individual
- · Group (aggregations usually required)

D-M control

- D-M can be subjective process (usually highly manipulated), or
- D-M can be objective process (in parts controlled by the decision-maker(s))

D-M methods and tools

- · MCA (Multicriteria analysis)
- · MCO (Multicriteria optimization)
- · SCT (Preferential and non-preferential voting)
-



D-M information availability

· D-M can be with complete and incomplete information

D-M trustfullness

· D-M with certinty and uncertainty

D-M computing mechanisms

- · D-M mathematics, modeling, models, and tools
- D-M other supporting mechanisms and systems (DSM, DSS)
- · Balots, counting votes, additional computations



Typical Stages In The Decision-Making Process

Not necessarily that order

• Information Collection and Management



Modelling and Rational Decision Support



Visualization and the Human Interface



- Knowledge Capture and Representation
- Integration and synthesis

Overlaps and feedback are usual!



Groups, aggregations

Weighted Arithmetic Mean Method - WAMM,

$$z_i^G = \sum_{k=1}^K \alpha_k z_i(k)$$

 α_k - Normalized weight of the kth member of

a group G

 $z_i(k)$ - Weight of the ith alternative for kth

member of a group G

Geometric Mean Method - GMM

 $\boldsymbol{\mathcal{Z}}_i^G$ — Aggregated weight of the /th alternative for a group \mathbf{G}

$$z_i^G = \prod_{k=1}^K [z_i(k)]^{\alpha_k}$$

In either aggregation, WAMM or GMM, the final additive normalization of the weights of all alternatives is required!



Claim #2:

In group D-M contexts, MCDM methods can be replaced by, or combined with, SCT methods

- 1. There is a lot of possibilities to use SCT voting methods instead of MCDM methods
 - Balots instead of questionnaries or matrices
 - Simplicity of use
 - Easy computing
- 2. Preferential methods preserve some similarity with standard MCDM
 - Majority methods
 - Pair-wise (face-to-face) comparisons
 - Hare system
 - Borda Count
 - Dictatorship



- 3. Non-preferential methods enable group to act in more democratic environment
 - · Fairness preserves some similarity with standard MCDM
 - Most often one or more candidates are simply approved without exposing any preferences .



STORY

Sector/Domain: Water Resources

Software product: MODSIM

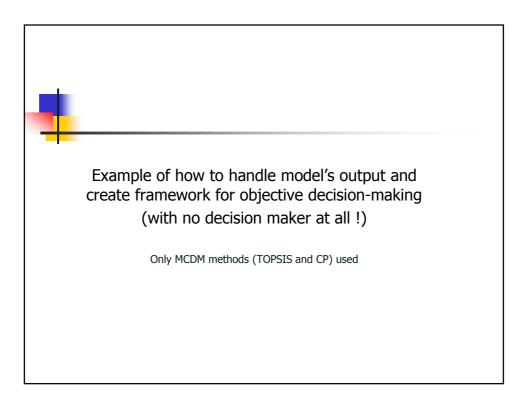
(worldwide recognized software for combined simulation and optimization of water allocation within large scale water resources systems)

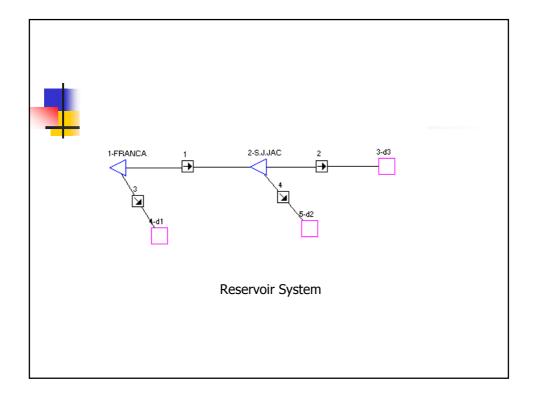


PROBLEM IS HOW TO USE THE MODEL TO ASSESS WHICH MANAGEMENT (WATER ALLOCATION) SCENARIO IS BEST, ONCE THE SET OF SCENARIOS IS DEFINED.

POSSIBLY MORE THAN 10 SCENARIOS.

MODEL'S USER WILL SURELY BE OVERBURDENED WITH RICH, BUT MOSTLY USELESS INFORMATION (DIAGRAMS, CHARTS, TABLES).





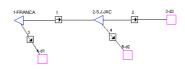


River basin simulation model MODSIM

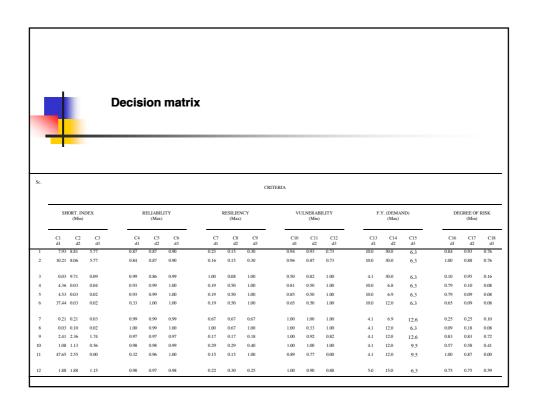
- Applied to the 2-reservoir system with 2 demand points and outlet demand for downstream users
- Network model (closed capacitated network; generalized minimum costs flow problem; out-of-kilter optimization algorithm within unit time frames)
- Simulation period 30 years
- Input sequences of hydrological data were samples of multivariate stochastic process (one historic and 20 generated with different dry, wet and ave periods in space in time)
- · Good interface of the model; diagrams and tables on user's request
- Simulation by simulation and user is faced with 'data flood'. Consequence: not possible to immediately say which management strategy is the best one.



Management scenarios



	PRIORITIES					DEMANDS [106 m ³]							
Scenarios	Der	mand po	oints Reservoirs Franca r.			Franca r.	S.J. de Jacuipe r.	System Outle					
	d1	d2	d3	r1	r2	d1	d2	d3					
1	2	2	1	10	15	10.0	30.0	6.3					
2	3	2	1	10	15	10.0	30.0	6.3					
3	1	10	1	2	15	4.1(y)*	30.0	6.3					
4	2	2	1	10	15	10.0	6.8 (y)	6.3					
5	3	2	1	10	15	10.0	6.9 (y)	6.3					
6	3	2	1	10	5	10.0	12.0 (y)	6.3					
7	2	2	1	10	15	4.1	6.9	12.6 (y)					
8	2	2	1	15	15	4.1	12.0	6.3					
9	3	2	1	15	15	4.1	12.0	12.6					
10	2	3	1	15	15	4.1	12.0	9.5					
11	2	2	1	2	3	4.1	12.0	9.5					
12	2	2	1	10	15	5.0	15.0	6.3					





DECIDE

Table III: Criteria weights derived by entropy method

	CRITERIA											
Weights	SHORTAGE INDEX				RELIABILITY				RESILIENCY			
	C1	C2	C3		C4	C5	C6		C7	C8	C9	
EW	0.193	0.156	0.234	Г	0.010	0.000	0.000	Г	0.062	0.039	0.031	
	VULNERABILITY				F.Y. (DEMAND)			DEGREE OF RISK				
	C10	C11	C12		C13	C14	C15		C16	C17	C18	
EW	0.004	0.010	0.020	П	0.019	0.031	0.009	П	0.032	0.053	0.095	

Table IV: Aggregated criteria weights

CRITERIA	Aggregated EW
SHORTAGE INDEX	0.583
RELIABILITY	0.011
RESILIENCY	0.132
VULNER ABILITY	0.034
FIRM YIELD (DEMAND)	0.059
DEGREE OF RISK	0.180

