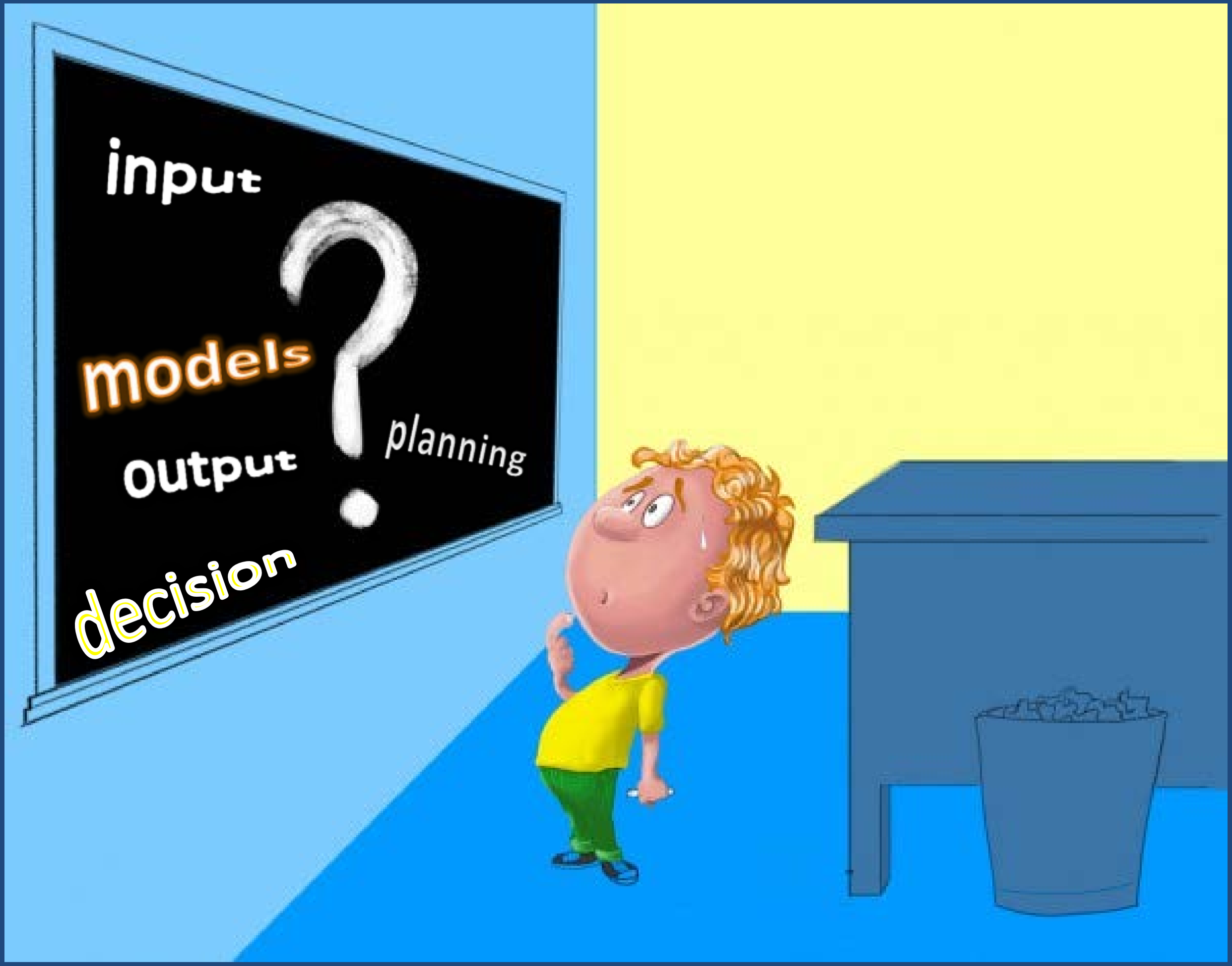
European Geosciences Union General Assembly 2015

Vienna / Austria/ 12-17 April 2015

Decision under Uncertainty



Disciplinary Session:
Hydrological Sciences

HS7.6

Using Models for Decision Support and Long Term Planning under Climate and Environmental Uncertainty

UNIVERSITY OF PATRAS

Department of Civil Engineering

Evaluation of decision making and negotiation processes under uncertainties regarding the water management of Peiros-Parapeiros Dam in Achaia Region (Greece)

M.V. Podimata & P.C. Yannopoulos

Vienna, 15 April 2015

Decision-making in water management

Why it remains a challenging task?

increasing complexity/severity of environmental problems

growing conflicts in the exploitation of water resources

solutions may be good/bad but never true/false

An interdisciplinary research approach is required

in order to find a joint, fair and wise agreement among water users

Key Concepts

Decision Support Systems (DSS)

Interactive computerized systems providing assistance in understanding semi-structured or unstructured problems and increasing the effectiveness of decision-making

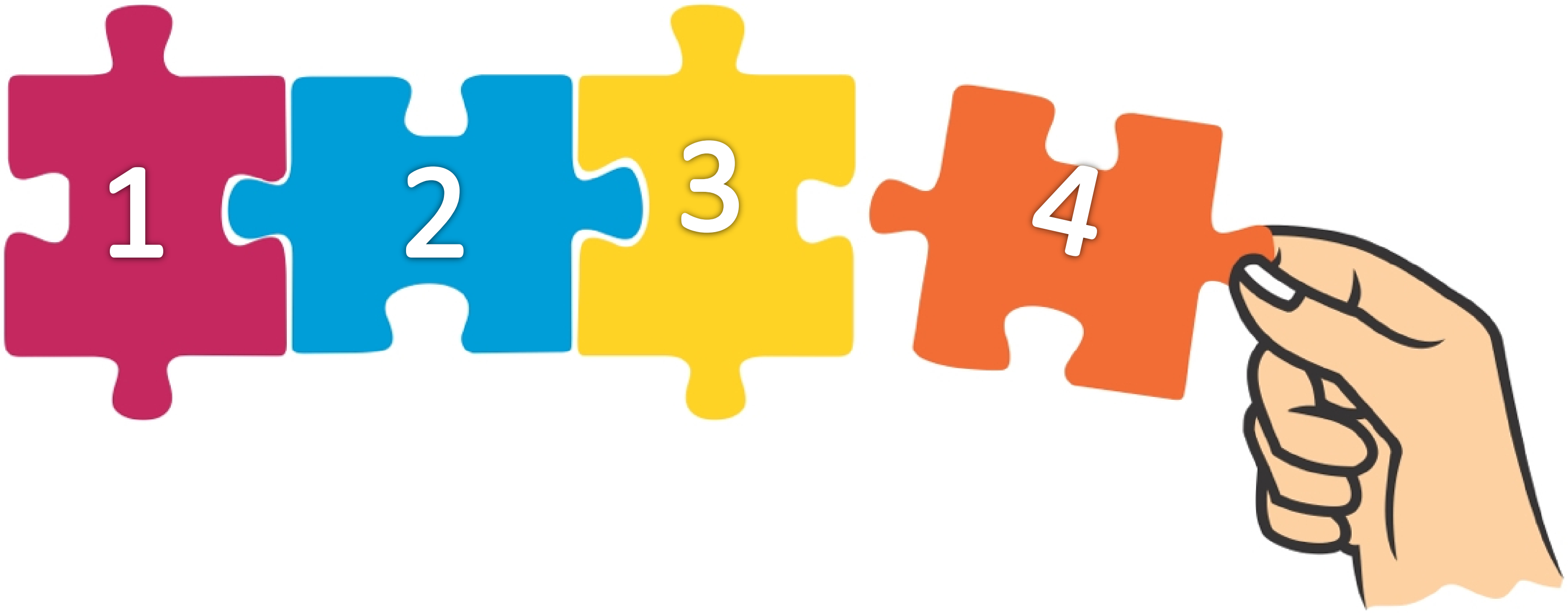
Interaction

Game Theory

Conflict Analysis (CA)

A set of techniques to model and analyze strategic conflicts among agents, to predict interaction patterns and to indentify potential states for conflict resolution

Contribution of DSS and CA



1. Answering What-if Questions
2. Assessing Potential Outcomes
3. Aiding Negotiations
4. Evaluating and Limiting Risk

Provide the decision-makers with an insightful strategic advice

Graph Model for Conflict Resolution

A flexible and comprehensive Decision Support System based on conflict analysis techniques for deeper understanding of strategic aspects of conflict games and envisioning possible pathways for optimal decision making

Original formulation: Kilgour et al. (1987)

Full representation: Fang et al. (1993)

Wide range of applications including water resources management

Basic components

Basic Structure

Set of Decision-Makers

$$\mathbf{N} = \{1, 2, \ldots, n\}$$

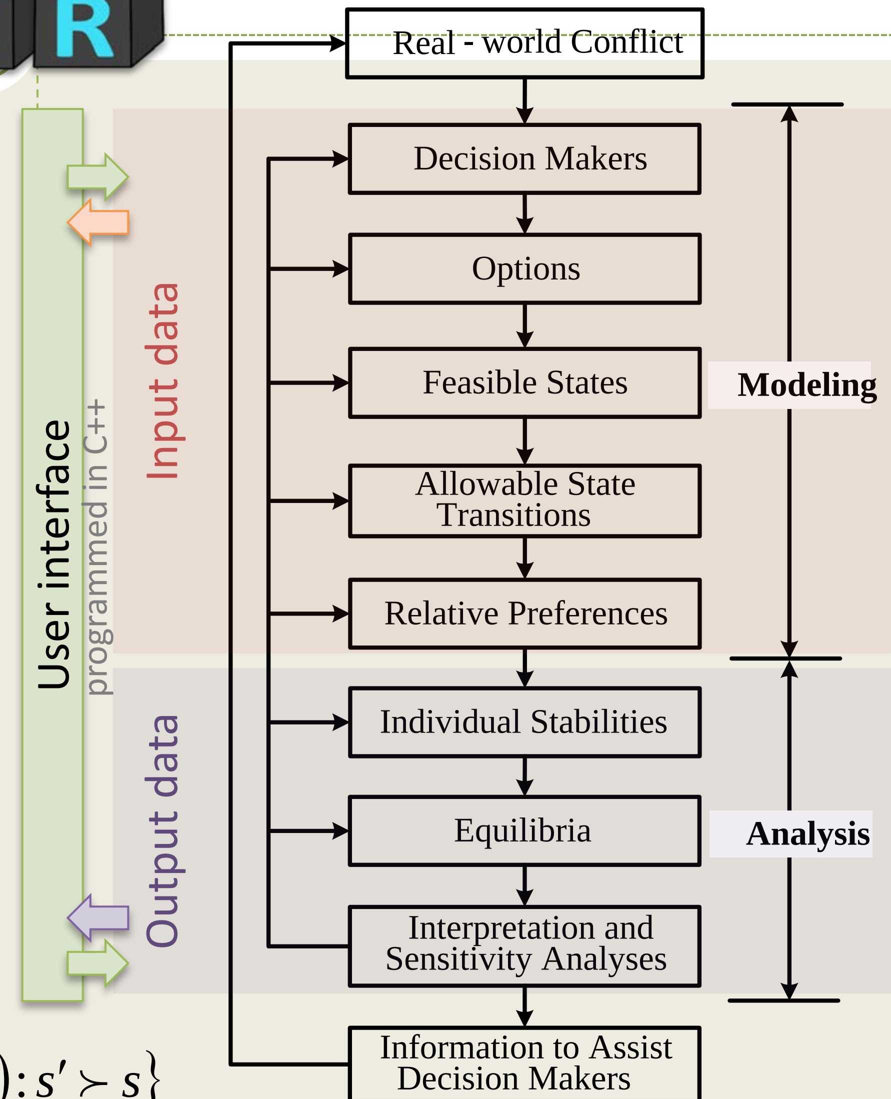
Set of States

$$\mathbf{S} = \{s_0, s_1, \ldots, s_m\}$$

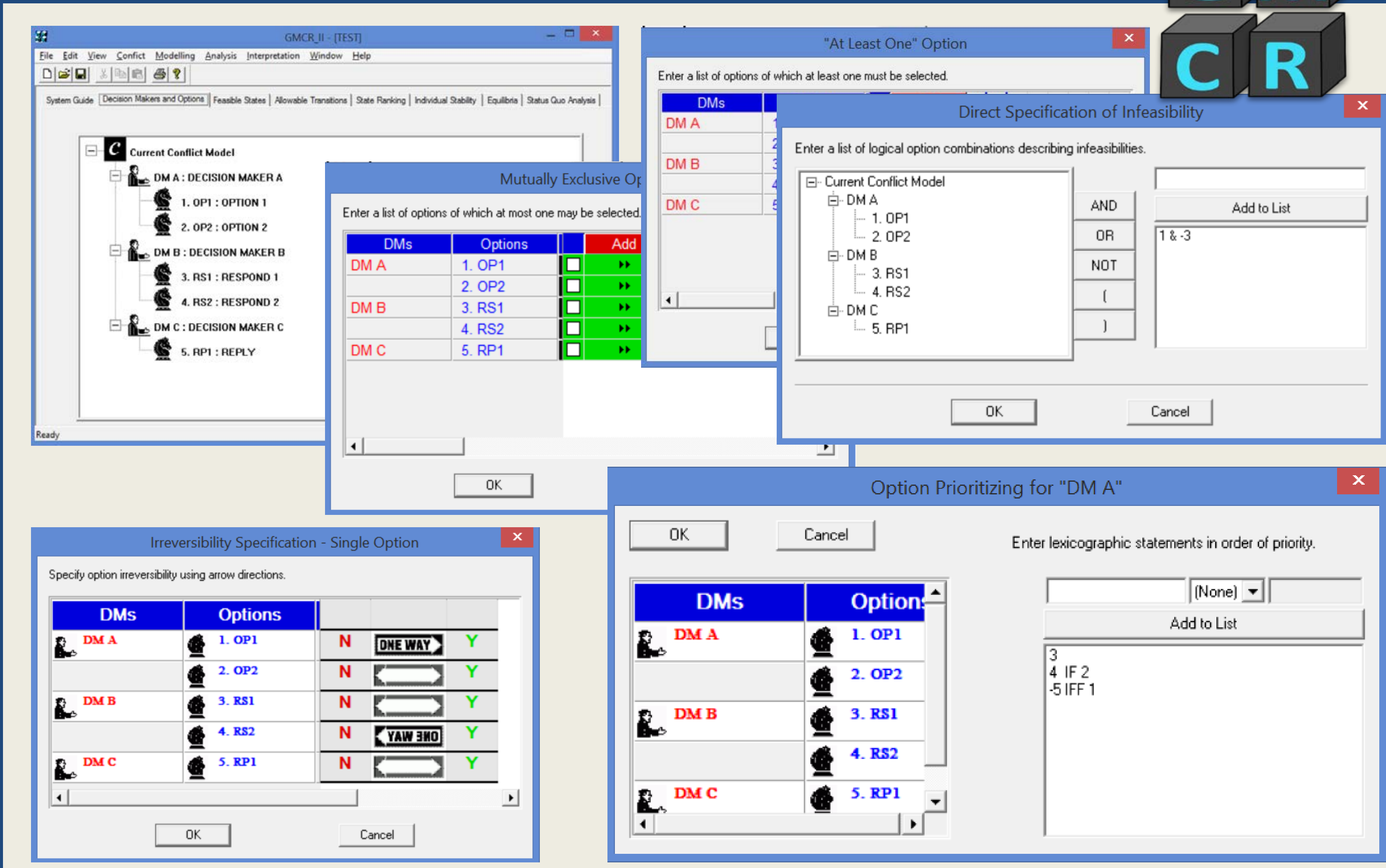
Set of directed graphs depicting available moves among states

$$\{D_i = (S, A_i),\ i \in \mathrm{N}\}$$

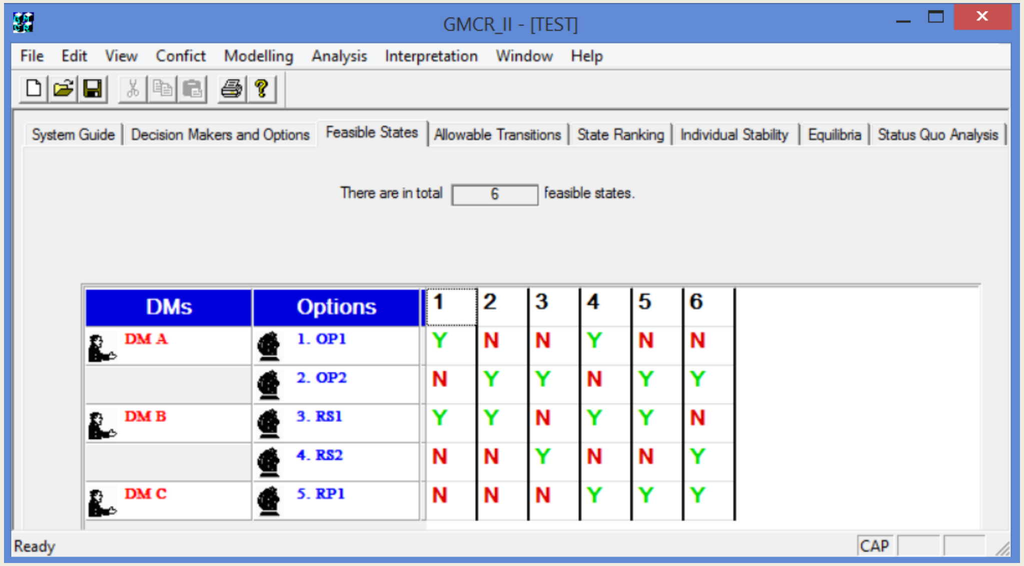
- Reachable list $R_i(s) = \{s' \in S : (s', s) \in A_i\}$
- Unilateral improvement list $R_i^+(s) = \{s' \in R_i(s) : s' \succ s\}$

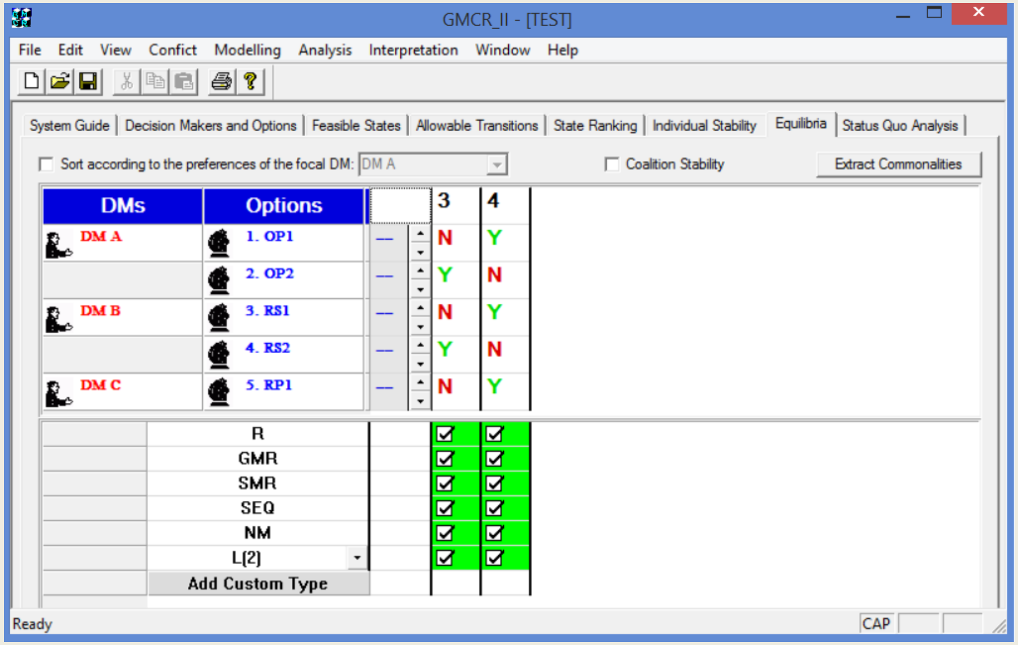


Dialog Box


GMCR_II - [TEST]
File Edit View Conflict Modelling Analysis Interpretation Window Help
System Guide
Decision Makers and Options
Feasible States
Allowable Transitions
State Ranking
Individual Stability
Equilibria
Status Quo Analysis
Current Conflict Model
DM A : DECISION MAKER A
1. OP1 : OPTION 1
2. OP2 : OPTION 2
DM B : DECISION MAKER B
3. RS1 : RESPOND 1
4. RS2 : RESPOND 2
DM C : DECISION MAKER C
5. RP1 : REPLY
Ready
Mutually Exclusive Op
Enter a list of options of which at most one may be selected.
DMs
Options
Add
DM A
1. OP1
2. OP2
DM B
3. RS1
4. RS2
DM C
5. RP1
OK
"At Least One" Option
Enter a list of options of which at least one must be selected.
DMs
DM A
DM B
DM C
Direct Specification of Infeasibility
Enter a list of logical option combinations describing infeasibilities.
Current Conflict Model
DM A
1. OP1
2. OP2
DM B
3. RS1
4. RS2
DM C
5. RP1
AND
OR
NOT
(
)
Add to List
1 & -3
OK
Cancel
Irreversibility Specification - Single Option
Specify option irreversibility using arrow directions.
DMs
Options
DM A
1. OP1
2. OP2
DM B
3. RS1
4. RS2
DM C
5. RP1
N
ONE WAY
Y
OK
Cancel
Option Prioritizing for "DM A"
OK
Cancel
Enter lexicographic statements in order of priority.
DMs
Options
DM A
1. OP1
2. OP2
DM B
3. RS1
4. RS2
DM C
5. RP1
(None)
Add to List
3
4 IF 2
-5 IFF 1

Dialog Box





A state is stable for a DM if it is not advantageous for the DM to unilaterally move away from it

A solution concept is a mathematical description of how a DM may behave in a dispute

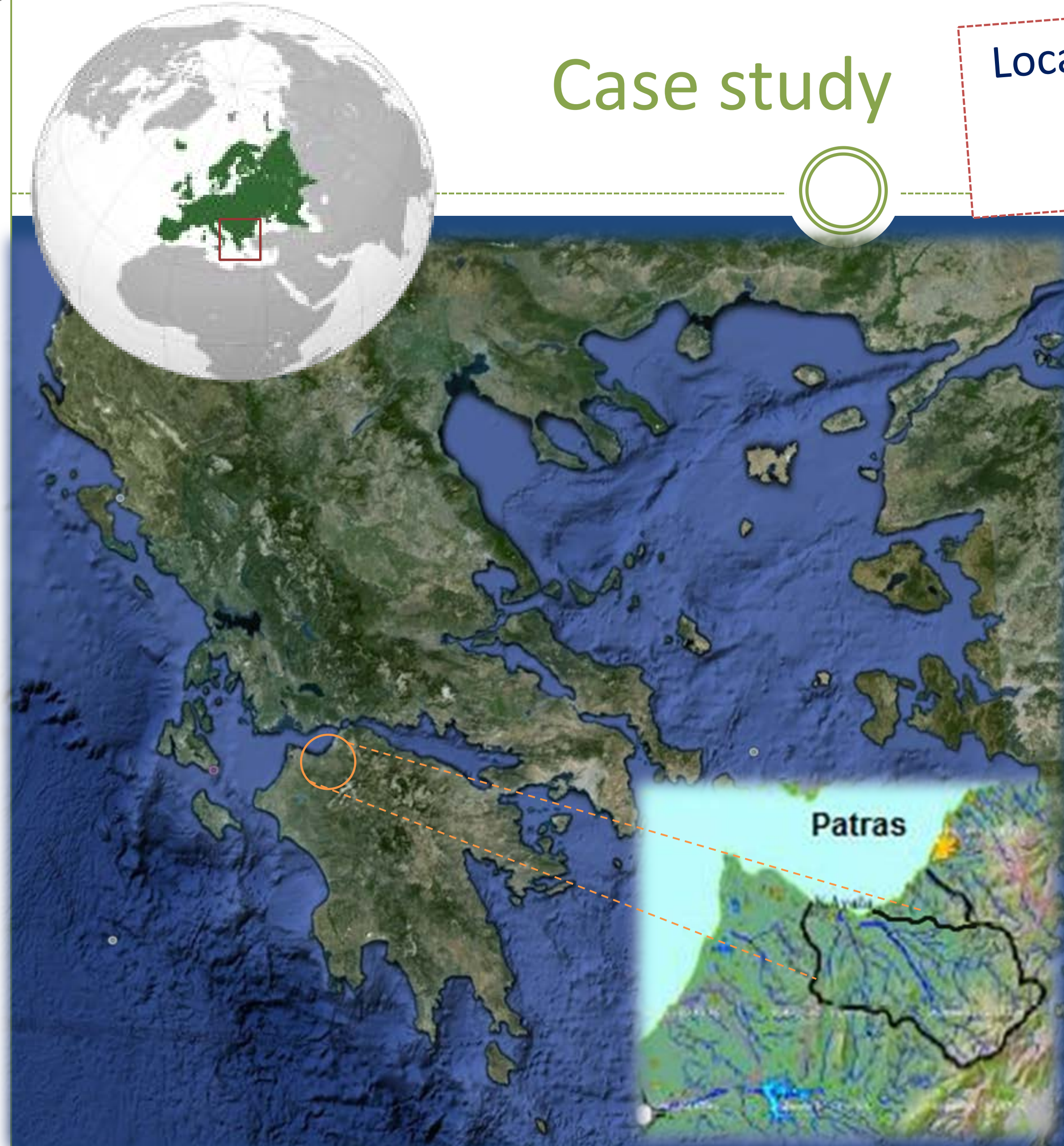
Solution Concepts

Solution Concepts	Stability Descriptions	Characteristics			
		Foresight	Disimprovement	Knowledge of Preferences	Strategic Risk
Nash Stability	DM cannot unilaterally move to a more preferred state.	Low	Never	Own	Ignores risk
General Metrationality	All of the focal DM's unilateral improvements are sanctioned by subsequent unilateral moves by others.	Medium	By Opponent	Own	Avoids risk; conservative
Symmetric Metarationality	All focal DM's unilateral improvements are still sanctioned even after possible responses by the focal DM.	Medium	By Opponent	Own	Avoids risks; conservative
Sequential Stability	All of the focal DM's unilateral improvements are sanctioned by subsequent unilateral improvements by others.	Medium	Never	All	Takes some risks; strategizes.
Limited-move Stability (L_h)	All DMs are assumed to act optimally and a maximum number of state transitions (h) is specified.	Variable	Strategic	All	Accepts risk; strategizes
Non-myopic Stability	Limiting case of limited move stability as the maximum number of state transitions increases to infinity.	High	Strategic	All	Accepts risk; strategizes

Determines how DMs respond with respect to a given solution concept

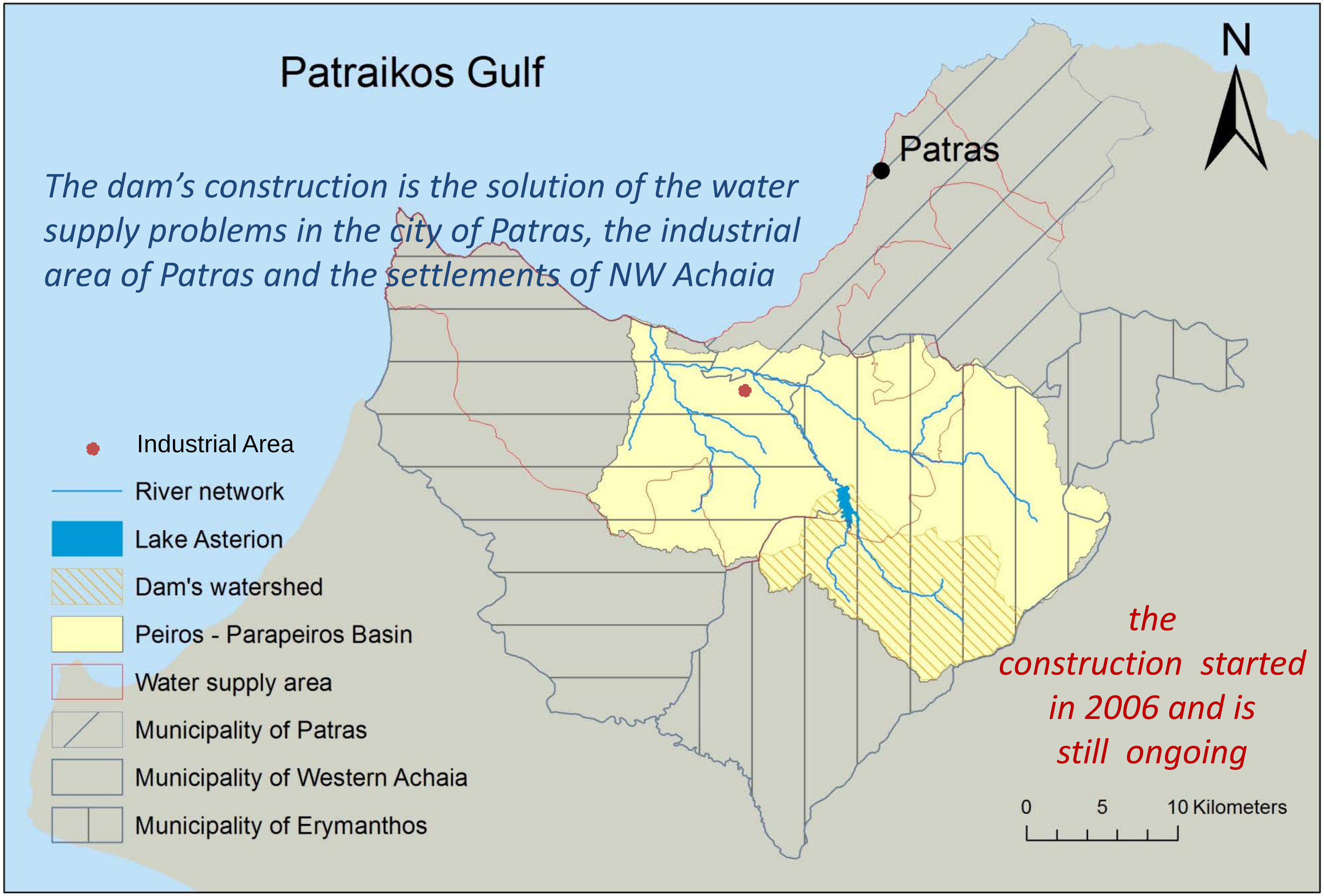
Case study

Location: Peiros-Parapeiros Basin
Peloponnisos Peninsula,
Greece



Catchment area	500 km^2
River length	33 km
Mean catchment elevation	463 m
Mean annual precipitation	986 mm
Flow	All the year
Average Discharge (outlet of the basin)	265 hm^3/y
Maximum flow	0.5 hm^3/d

Study Area



Patraikos Gulf
Patras
N
The dam's construction is the solution of the water supply problems in the city of Patras, the industrial area of Patras and the settlements of NW Achaia
Industrial Area
River network
Lake Asterion
Dam's watershed
Peiros - Parapeiros Basin
Water supply area
Municipality of Patras
Municipality of Western Achaia
Municipality of Erymanthos
the construction started in 2006 and is still ongoing
0
5
10 Kilometers

Peiros – Parapeiros Dam

High storage dam on Parapeiros River	
Location	Asterion
Height	75 m
Crest length (width)	790 m (14m)
Area of artificial lake	210 ha
Capacity storage	40.000.000 m^3

Pipeline networks	
Diversion pipeline from Valmadoura to Asterion	10.5 km
Bulk water transmission to Patras	31.6 km
Water supply network to I.A.P + MWA+ME+MP (periurban area)	60 km

Low diversion dam on Peiros River	
Location	Valmadoura
Height	8 m
Crest length	30 m

Water treatment plant	
Capacity	400 L/s

Total construction budget	
Budget	140,000,000 €

Planned annual abstraction	
Year 2020	22,000,000 m^3

Conflicts regarding Peiros – Parapeiros Dam

Involved Parties

Municipality of Patras
Municipality of W.Achaia
Municipality of Erymanthos
Industrial area of Patras

Conflicts and contradictions regarding:

- the jurisdiction and legal status of the dam operator
- the undertaking of cost operation

Diverse goals and preferences

Incompatible interests

Luck of trust

Miscommunication

Financial Crisis

Application of GMCR II

Decision Makers

1. Patras Municipality (PM)
2. W.Achaia Municipality (WAM)
3. Erymanthos Municipality (EM)
4. Industrial area of Patras (IAP)

Options

SC1: Only 3 Municipalities

SC2: 3 Municipalities + IAP

SC3: Only PM

SC4: State

SC5: Public limited

Preferences

PM

- SC4 $\succ$ SC1 $\succ$ SC3 $\succ$ SC2 $\succ$ SC5

WAM

- SC1 $\succ$ SC2 $\succ$ SC5 $\succ$ SC4 $\succ$ SC3

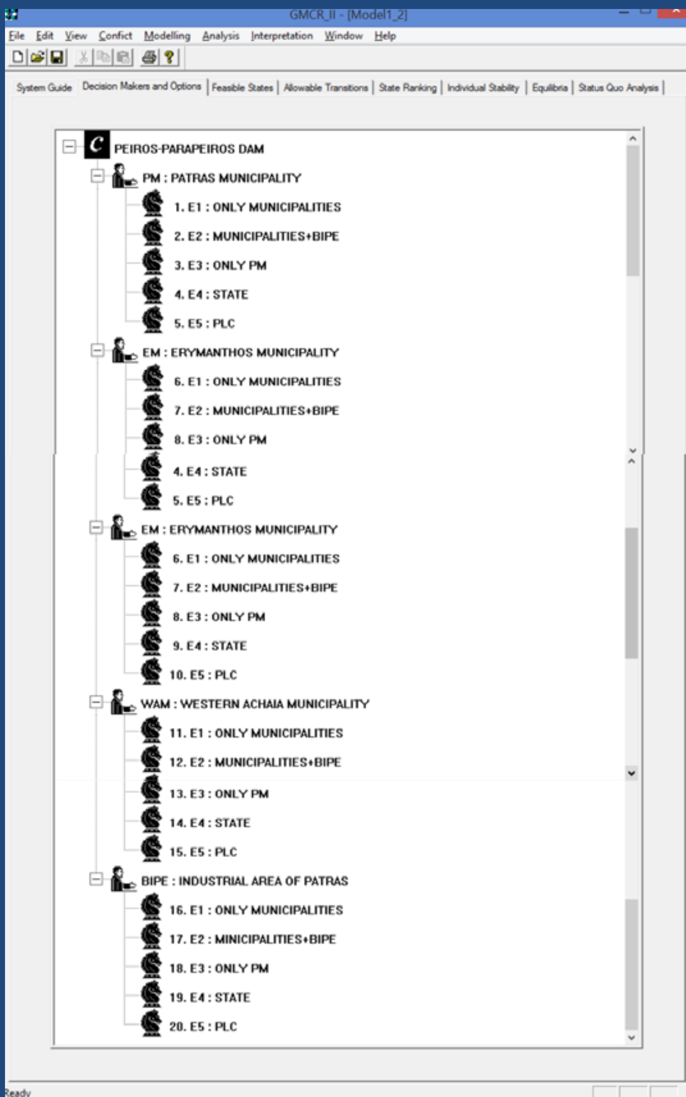
EM

- SC1 $\succ$ SC2 $\succ$ SC4 $\succ$ SC5 $\succ$ SC3

IAP

- SC2 $\succ$ SC5 $\succ$ SC4 $\succ$ SC3 $\succ$ SC1

Conflict model



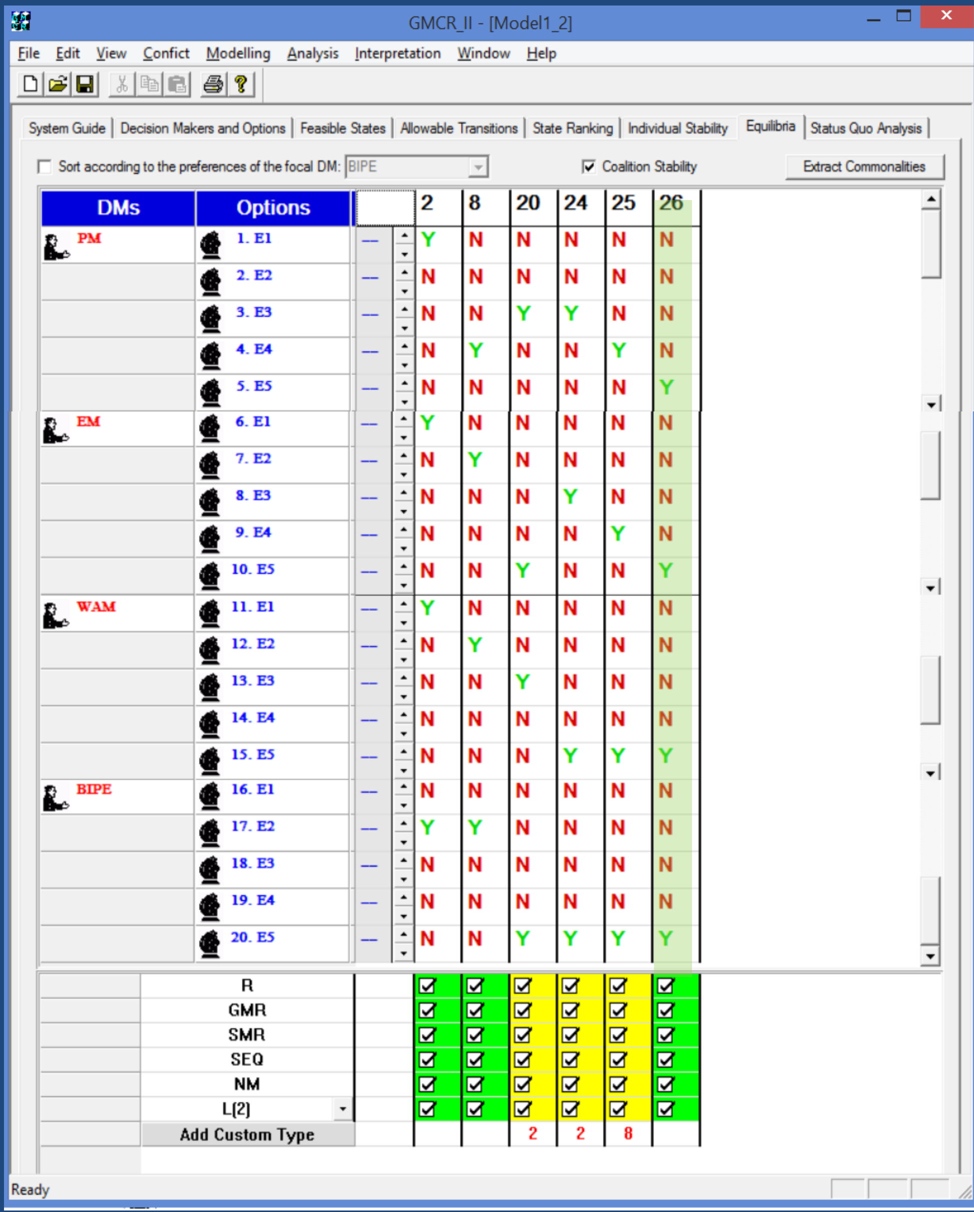
Each option can be selected (Y) or not taken (N)

There are 2^{20} =1,048,576 possible states

In practice, states that cannot occur (infeasible) should be omitted

After removing the infeasible ones, 26 feasible states remain

Conflict stability analysis



DMs	Options	2	8	20	24	25	26
PM	1. E1	Y	N	N	N	N	N
	2. E2	N	N	N	N	N	N
	3. E3	N	N	Y	Y	N	N
	4. E4	N	Y	N	N	Y	N
	5. E5	N	N	N	N	N	Y
EM	6. E1	Y	N	N	N	N	N
	7. E2	N	Y	N	N	N	N
	8. E3	N	N	N	Y	N	N
	9. E4	N	N	N	N	Y	N
	10. E5	N	N	Y	N	N	Y
WAM	11. E1	Y	N	N	N	N	N
	12. E2	N	Y	N	N	N	N
	13. E3	N	N	Y	N	N	N
	14. E4	N	N	N	N	N	N
	15. E5	N	N	N	Y	Y	Y
BIPE	16. E1	N	N	N	N	N	N
	17. E2	Y	Y	N	N	N	N
	18. E3	N	N	N	N	N	N
	19. E4	N	N	N	N	N	N
	20. E5	N	N	Y	Y	Y	Y

	2	8	20	24	25	26
R	☑	☑	☑	☑	☑	☑
GMR	☑	☑	☑	☑	☑	☑
SMR	☑	☑	☑	☑	☑	☑
SEQ	☑	☑	☑	☑	☑	☑
NM	☑	☑	☑	☑	☑	☑
L(2)	☑	☑	☑	☑	☑	☑
Add Custom Type			2	2	8	

A state is stable (and constitutes an equilibrium) if a decision maker has no incentive to move unilaterally to another state.

Based on the ranking of states, GMCR II analyzes the stability of each state.

States 2, 8, 20, 24, 25 & 26 constitute strong equilibria i.e. satisfy all stability concepts.

State 26 constitutes coalition states for SC5.

Coalition analysis algorithm shows states which would be upset by any subset of two or more DMs.

GMCR II disadvantages

The simplicity of the model itself	Questions involving allocation in a continuum are awkward in a graph model.
Incorporating partial information	There are difficulties in incorporating clues into a graph model. Strong reliance to user's judgment.
Main objective	The main objective is stability identification, rather than the evolution of negotiations (reaching agreement).
Consideration of negotiators' power	GMCR II does not take into account the power of parties (which is often used, in practice, during negotiations).

Evolutionary Model for Multilateral Negotiations (EMMN)

A flexible Decision Support System, based on conflict analysis techniques, aiming at identifying the most likely outcome of a negotiation process by taking into account the power of negotiators as a determining factor in the final resolution

Original formulation: Sheikhmohammady (2009)

University of Waterloo

First application: Negotiations over the legal status of the Caspian Sea

Basic components

Set of Decision-Makers

$$\mathbf{N} = \{1, 2, \ldots, n\}$$

Set of Alternative Agreements

$$A = \{a_1, a_2, \ldots, a_q\}$$

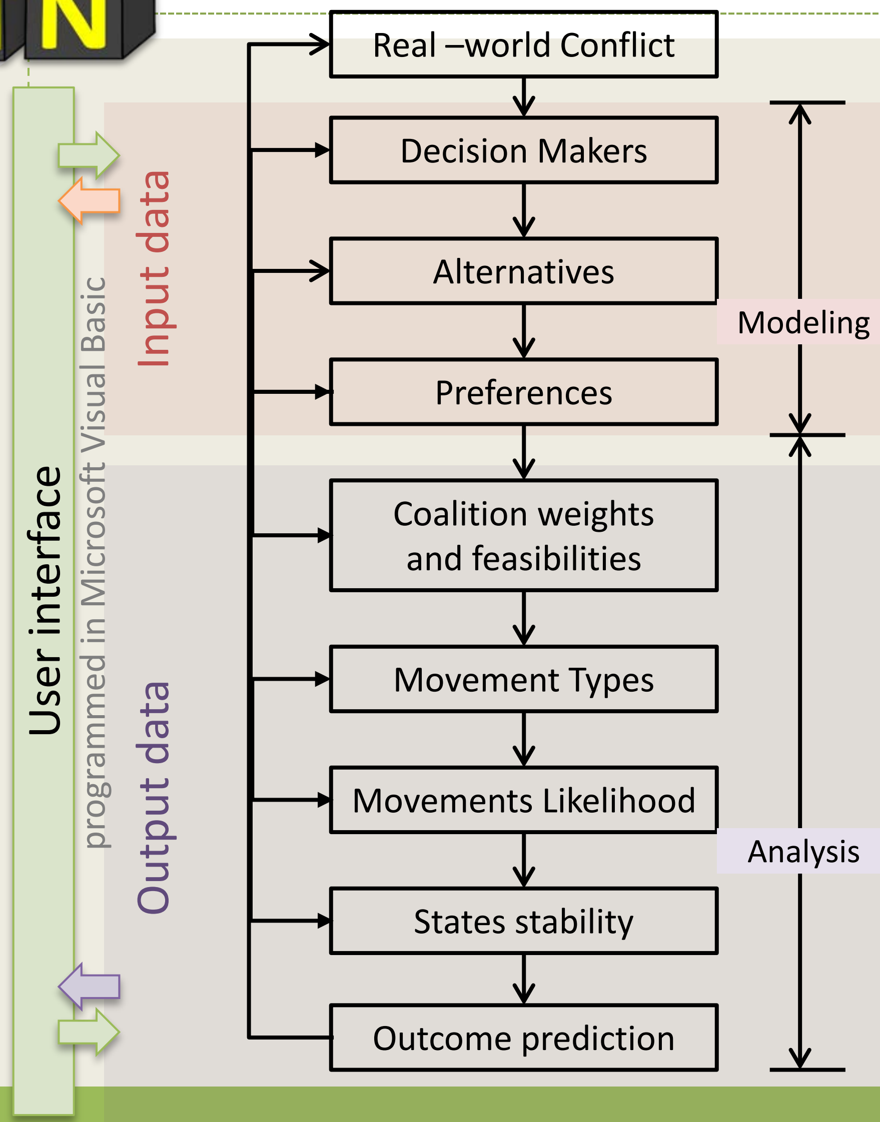
Set of states

$$S = q\left(2^n - 1\right)$$

Set of possible movements (fuzzy analysis)

$$\left(a_j, C\right) \rightarrow \left(a_k, C'\right)$$

Basic Structure



Movement reasons

Likelihood of movements (fuzzy criteria)

Preferential Improvement (PI)

- Move to a more preferred alternative

$$(a_j, C) \to (a_k, C) \quad , \quad a_k \underset{i}{\succ} a_j \quad , \quad i \in C$$

$$PI-L1 = \begin{cases} 1 & P_i(a_j) - P_i(a_k) > 1 \quad i \in C \\ 0 & otherwise \end{cases}$$

$$\{PI-L\} = \{PI-L1\} + \{PI-L2\}$$

$$PI-L2 = \begin{cases} 1 & \text{if } |C| > 1 \\ 0 & otherwise \end{cases}$$

Agglomeration (AG)

- Join a coalition since new state is acceptable to all DMs

$$(a_j, C) \to (a_k, C') \quad , \quad C \subset C' \quad , \quad a_j \text{ acceptable for all } i \in (C' - C)$$

$$AG-L1 = \begin{cases} 1 & \text{if } (a_j, C') \text{is feasible} \\ 0 & otherwise \end{cases}$$

$$AG-L2 = \begin{cases} 1 & \text{if } P_i(a_j) = 1 \text{ , for } \forall i \in C' - C \\ 0 & otherwise \end{cases}$$

$$\{AG-L\} = \{AG-L1\} + \{AG-L2\}$$

Disloyalty (DL)

- Move from a coalition to other coalition more preferred

$$(a_j, C) \to (a_k, D) \quad , \quad C \neq D, C \cap D \quad , \quad a_k \succ a_j \text{ and } (a_k, D) \text{is feasible for all } i \in D$$

$$DL-L1 = \begin{cases} 1 & \text{if } (a_j, C) \text{is infeasible} \\ 0 & otherwise \end{cases}$$

$$DL-L2 = \begin{cases} 1 & \text{if } P_i(a_k) \leq Acc_i \text{ , for } \forall i \in D \\ 0 & otherwise \end{cases}$$

$$\{DL-L\} = \{DL-L1\} + \{DL-L2\}$$

Strategic Disimprovement (SD)

- Move from infeasible coalition to a less preferable but feasible coalition

$$(a_j, C) \to (a_k, D) \quad , \quad C \neq D, C \cap D \quad , \quad a_k \prec a_j , (a_j, C) \text{is feasible and } (a_k, D) \text{is feasible}$$

$$SD-L1 = \begin{cases} 1 & \text{if } P_i(a_k) \leq Acc_i \text{ , for } \forall i \in C \cap D \\ 0 & otherwise \end{cases}$$

$$SD-L2 = \begin{cases} -1 & \exists i \in C \cap D \ \therefore \mathrm{a_k} \text{ is iniquely worst for } i \\ 0 & otherwise \end{cases}$$

$$SD-L3 = \begin{cases} 1 & \text{if } P_i(a_k) = 1 \text{ for } \forall i \in D - C \\ 0 & otherwise \end{cases}$$

$$\{SD-L\} = \{SD-L1\} + \{SD-L2\} + \{SD-L3\}$$

Application of EMMN

Decision Makers

1. Patras Municipality (PM)
2. W.Achaia Municipality (WAM)
3. Erymanthos Municipality (EM)
4. Industrial area of Patras (IAP)

Options

SC1: Only 3 Municipalities

SC2: 3 Municipalities + IAP

SC3: Only PM

SC4: State

SC5: Public limited

Preferences

PM

- SC4≻SC1≻SC3≻ SC2≻ SC5

WAM

- SC1≻ SC2≻ SC5≻ SC4≻ SC3

EM

- SC1≻ SC2≻ SC4≻ SC5≻ SC3

IAP

- SC2≻ SC5≻SC4≻ SC3≻ SC1

Estimation of DMs' power weights

Methodology

Data Envelopment Analysis (DEA)
(a MCDA model)

$$\max \theta = \sum_{r=1}^{s} u_r y_{rj}$$

$$s.t. \quad \sum_{i=1}^{m} v_i x_{ij} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} \le \sum_{i=1}^{m} v_m x_{mj}$$

i number of inputs

r number of outputs

v_i coefficient of input weight

u_r coefficient of output weight

j number of service unit

x_{ij} amount of the i^{th} input used by j^{th} service unit

y_{rj} amount of the r^{th} input used by j^{th} service unit

θ efficiency rating of the service

Application

Criteria inputs:

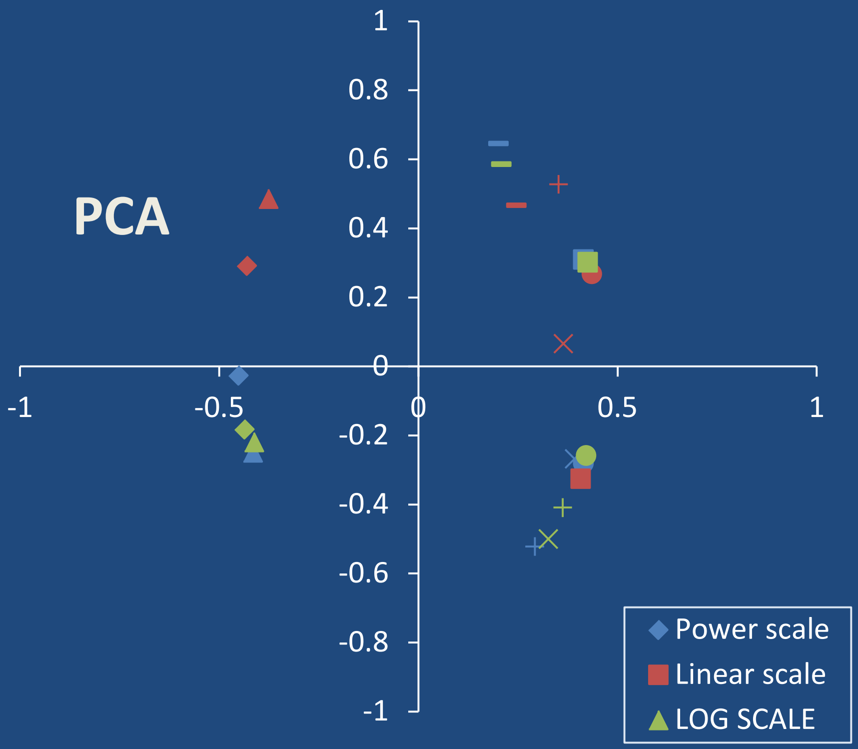
1. Population served by dam's operation
2. Territorial jurisdiction of the dam and of the watershed
3. Water release rate
4. Coverage rate of water supply needs
5. Administrative capacity and other administrative characteristics

Criteria scaling:

1. Linear (analogue)
2. Logarithmic (strengthens weak DMs)
3. Power (weakens weak DMs)

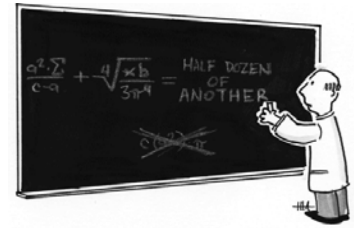
Power Index Results & PCA

DM	Linear Weight	LW Rating	Logarithmic weight	LGW Rating	Power weight	PW Rating
PM	68,53	2	64,57	2	73,45	2
WAM	49,12	3	42,38	3	67,16	3
EM	44,38	4	40,56	4	66,58	4
IAP	70,08	1	70,51	1	73,99	1



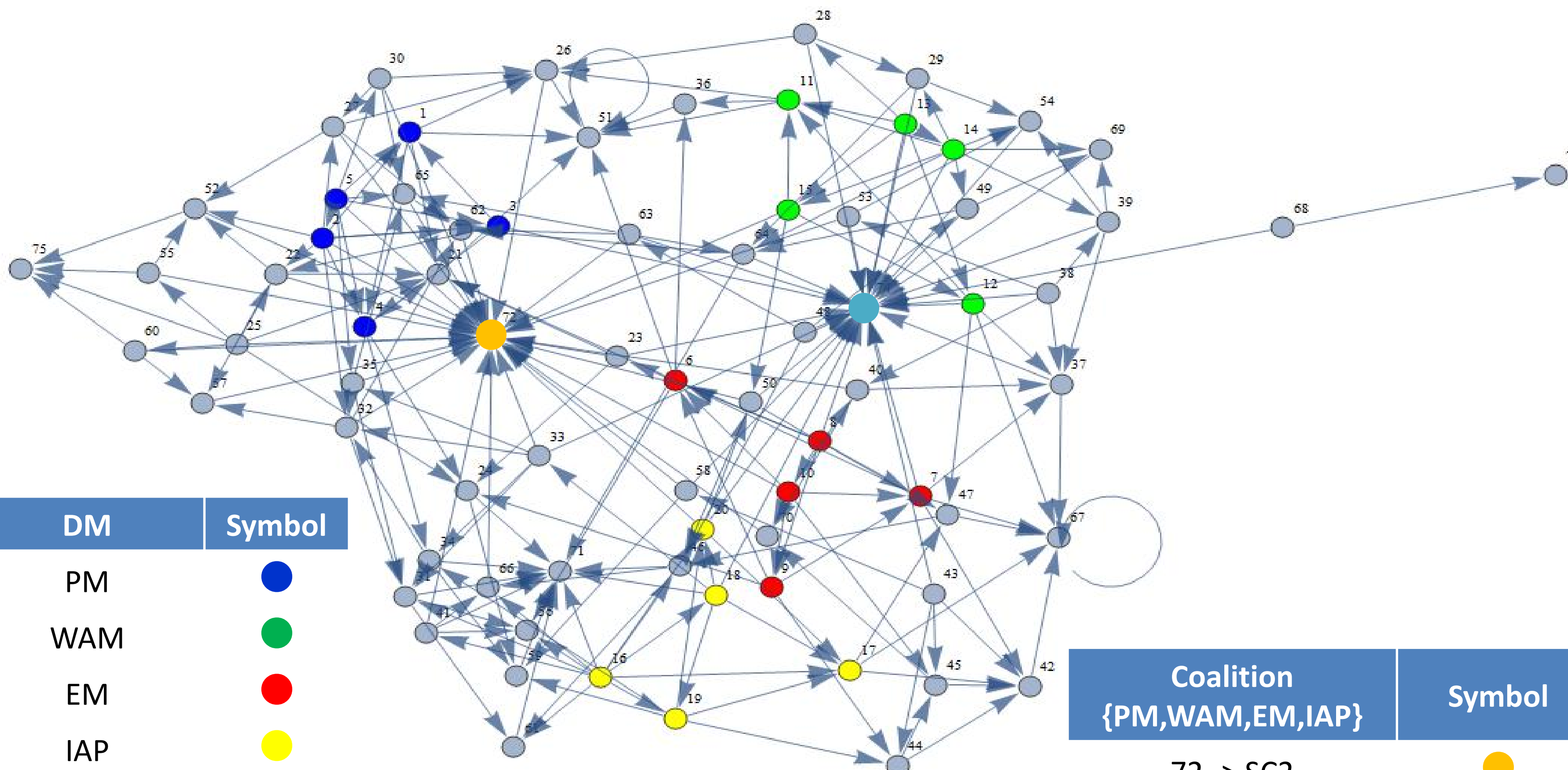
Symbol	Criteria Detail
■	Population served by dam's operation
×	Water release rate
—	Coverage rate of water supply needs
◆	Territorial jurisdiction of the dam
▲	Territorial jurisdiction of the watershed
●	Administrative characteristics
+	Administrative capacity

Evolution of the conflict



Power Threshold = T> 218

Only unanimous agreements are feasible



DM	Symbol
PM	
WAM	
EM	
IAP	
DMs Coalitions	

Coalition {PM,WAM,EM,IAP}	Symbol
72 -> SC2	
74-> SC4	

Conclusion Notes

GMCR II & EMMN

- Both examine possible states during negotiations
- Both indicate strategic interactions and arrangements

NOTES

- Challenge: satisfying all involved parties regarding the management of a water body
- More what-if analyses are needed to minimize uncertainty

Finding a joint agreement remains a thorny issue

ACKNOWLEDGMENTS

The copyright for GMCR II is owned by L. Fang, K.W. Hipel, D.M. Kilgour, and X. Peng.