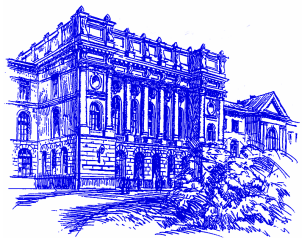
Nikolai Bobylev, PhD, Ian Jefferson, PhD, Dexter Hunt, PhD,
and Lewis Makana, MEng, PhD Cand

Multiple Criteria Decision Analysis application for urban infrastructure planning

E-mails: n.bobylev@bham.ac.uk, i.jefferson@bham.ac.uk, huntd@bham.ac.uk, LXM095@bham.ac.uk



Urban Physical Infrastructure (IPU) - a set of artificial structures interconnected physically or functionally

Presentation outline:

- The research problem: assessing and upgrading UPI
- Tasks/issues to consider (UPI and its energy efficiency; energy in the city; climate change adaptation+mitigation, SEA, land use planning)
- Solving the problem: GIS, MCDA, other tools
- MCDA application (AHP – ANP) *top-down/bottom-up hierarchy, innerdependance, feedback, effectiveness, mcda follow up*
- Perspectives for urban resilience: SIRUE

Opportunities with MCDA

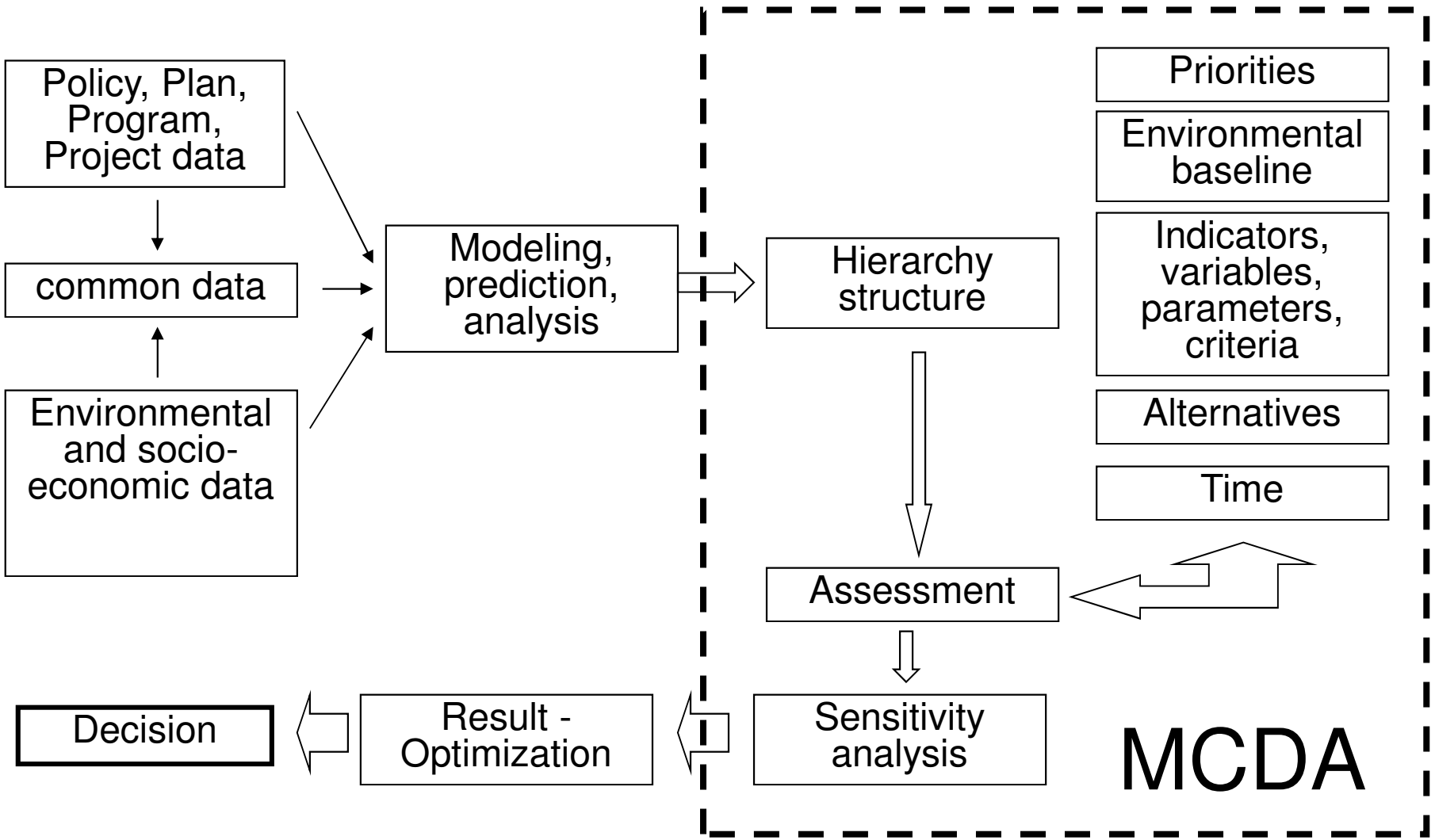
How tools can help?

Tasks

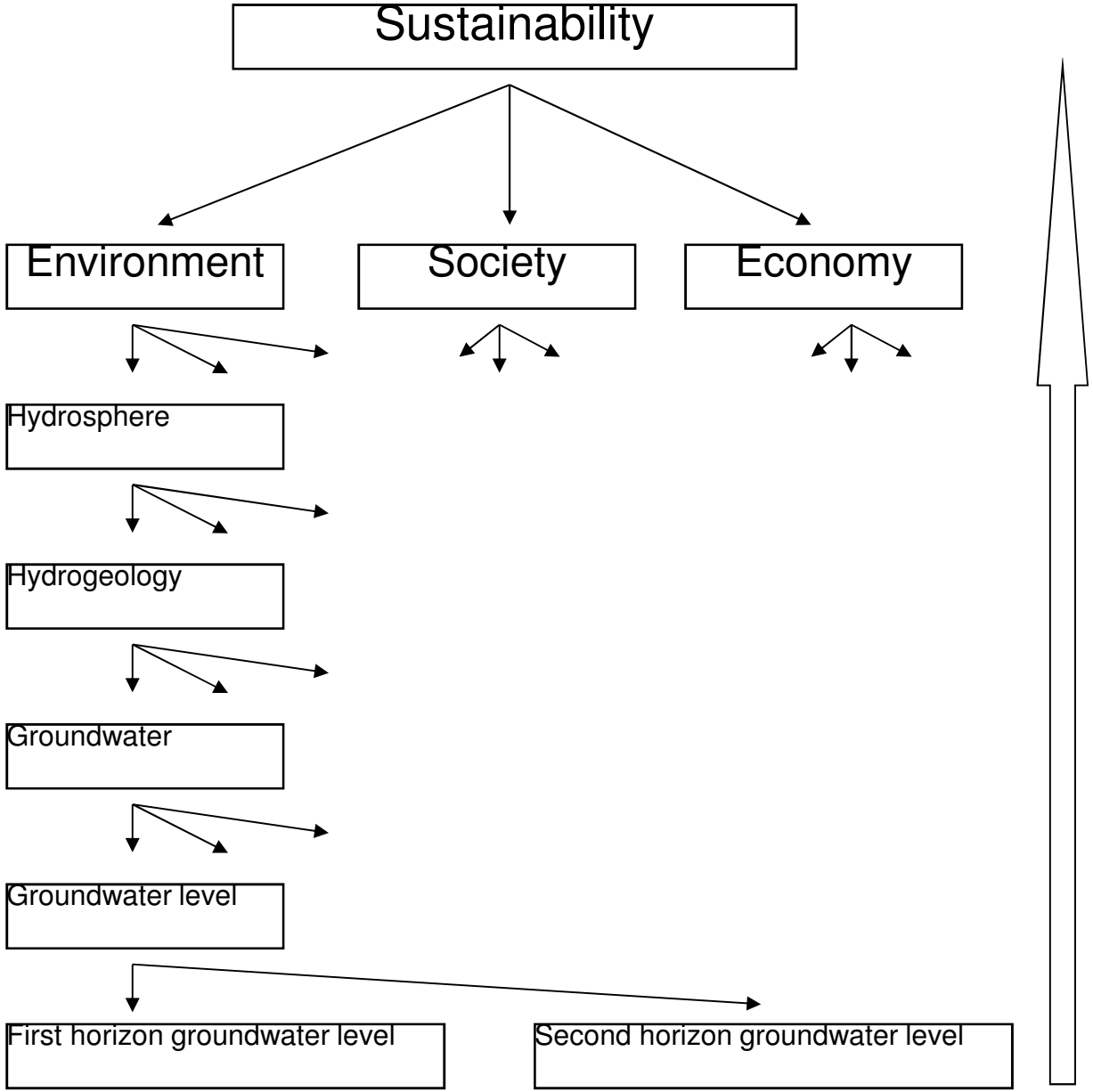
Cases

MCDA Introduction

MCDA in EA. A methodological flow-chart



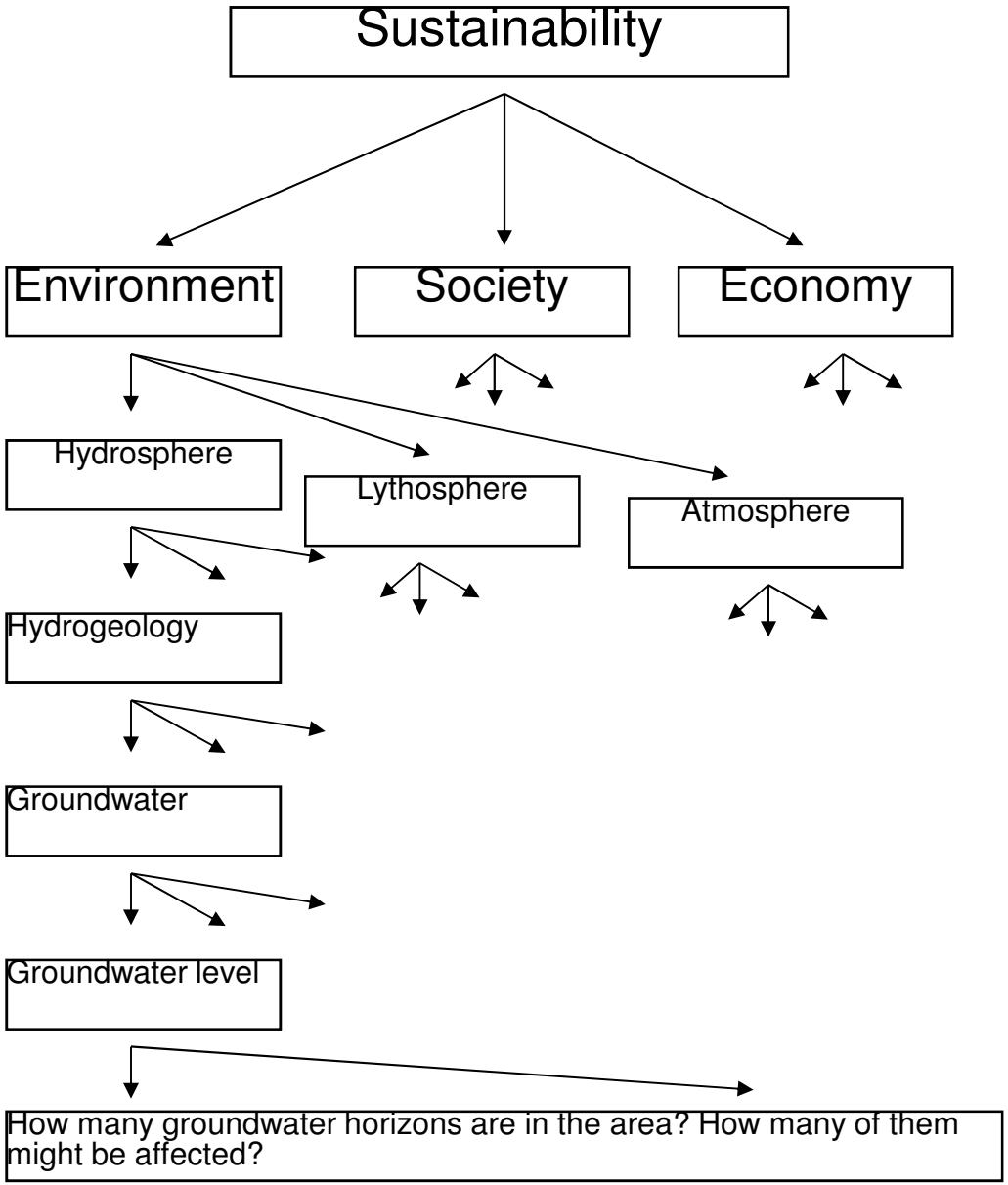
Findings/issues/research: hierarchy elaboration techniques



Elaboration of hierarchy

bottom-up technique

Findings/issues/research: hierarchy elaboration techniques



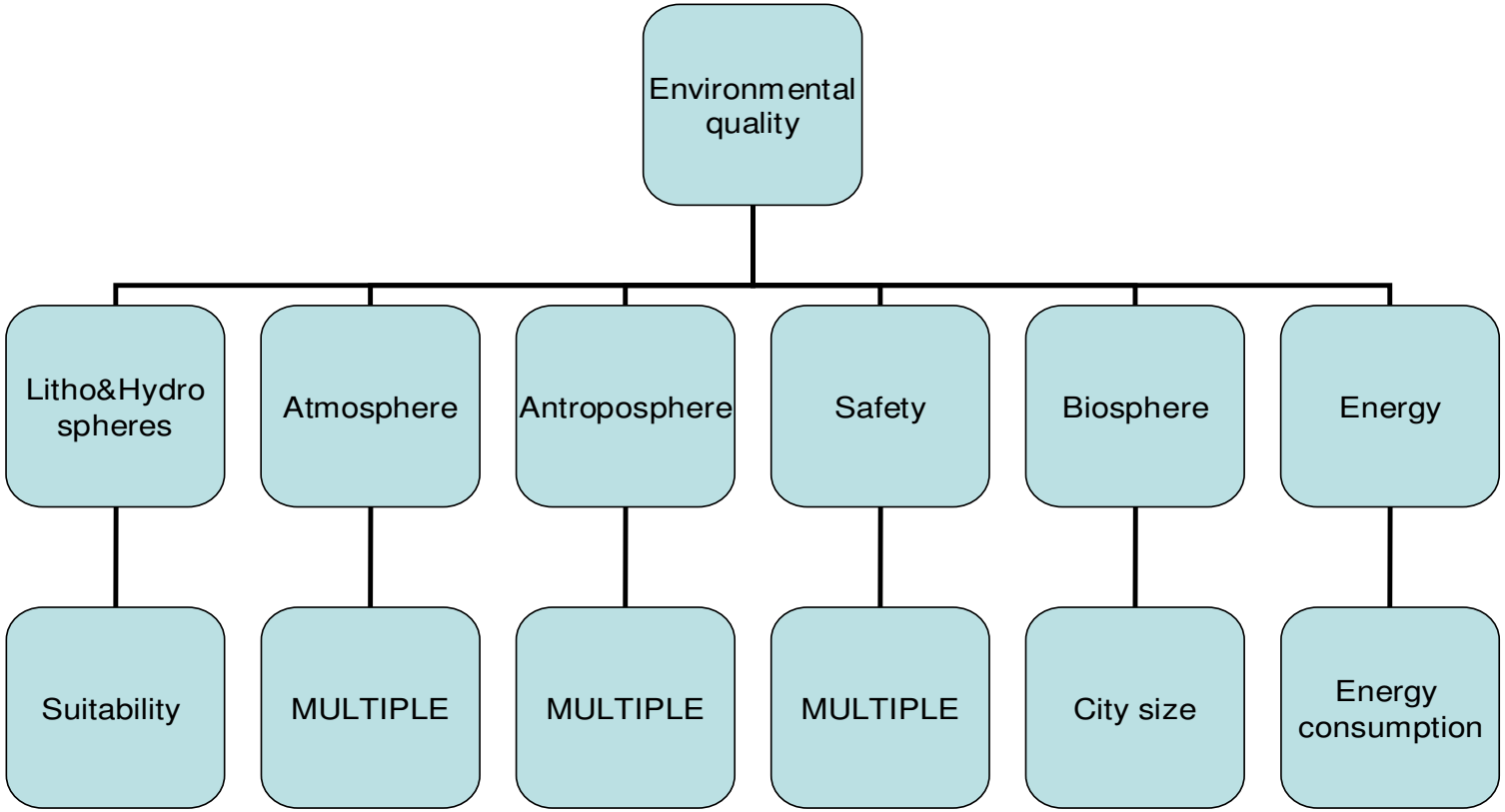
Elaboration of hierarchy

top-down technique

Findings/issues/research: hierarchy – a case example

Assessment of infrastructure development policies

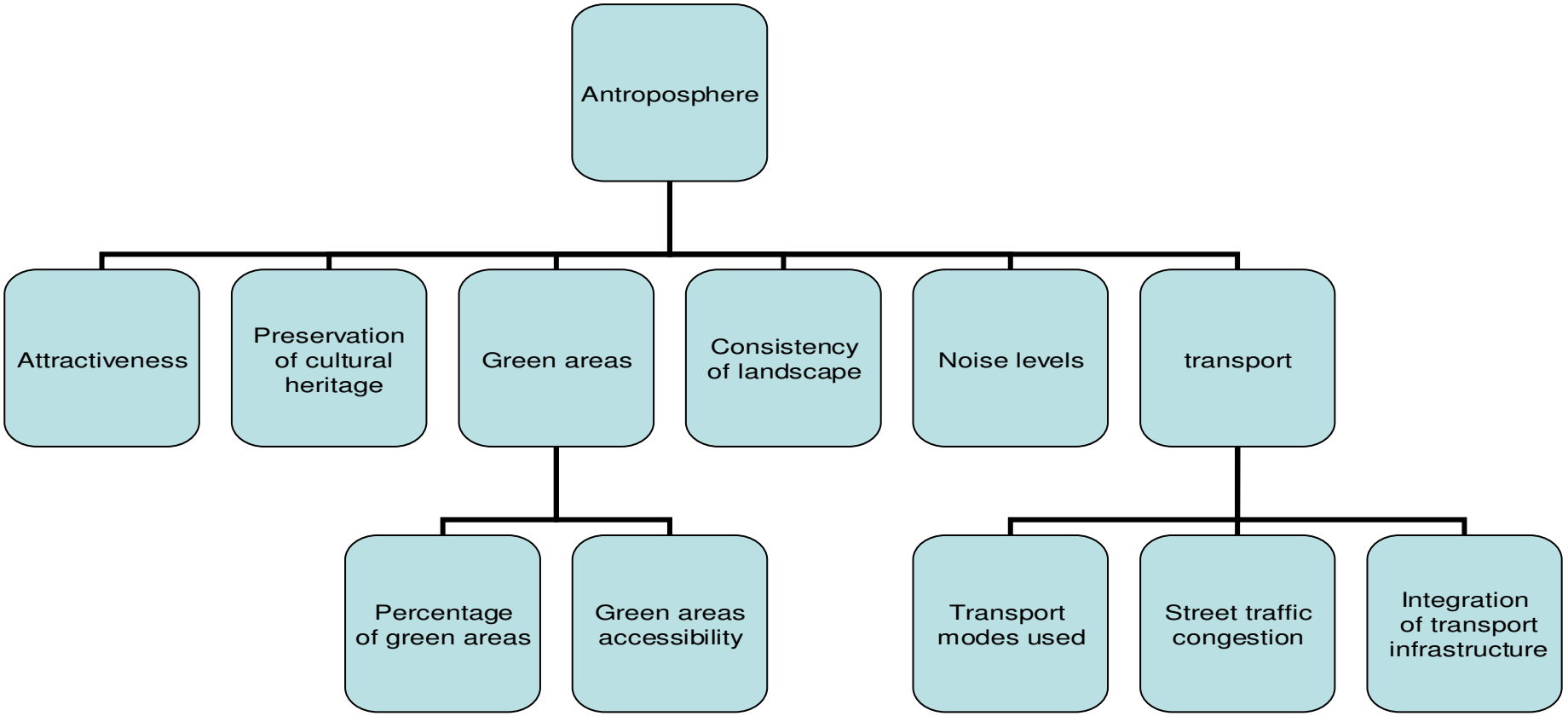
A hierarchical structure of criteria (excerpt)



Findings/issues/research: hierarchy – a case example

Assessment of infrastructure development policies

A hierarchical structure of criteria (excerpt) Antroposphere node



MCDA Methods [which I am using]

American school:

Analytic Network Process

Analytic Hierarchy Process

by Thomas Saaty

http://www.superdecisions.com/

European school:

MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique)

by Carlos Bana e Costa et.al.

http://www.m-macbeth.com/index.html

Findings/issues/research: using MCDA

Assessment experiment:

The problem: 3 underground construction technologies (UCT):

- Open cut
- Conventional tunneling
- TM (microtunneling, pipe jacking)

The method: Analytic Network Process by Thomas Saaty

Bobylev, Nikolai (2011) Comparative analysis of environmental impacts of selected underground construction technologies using analytic network process. *Automation in Construction*, Elsevier. Volume 20, Issue 8, December 2011, Pages 1030-1040. doi:10.1016/j.autcon.2011.04.004

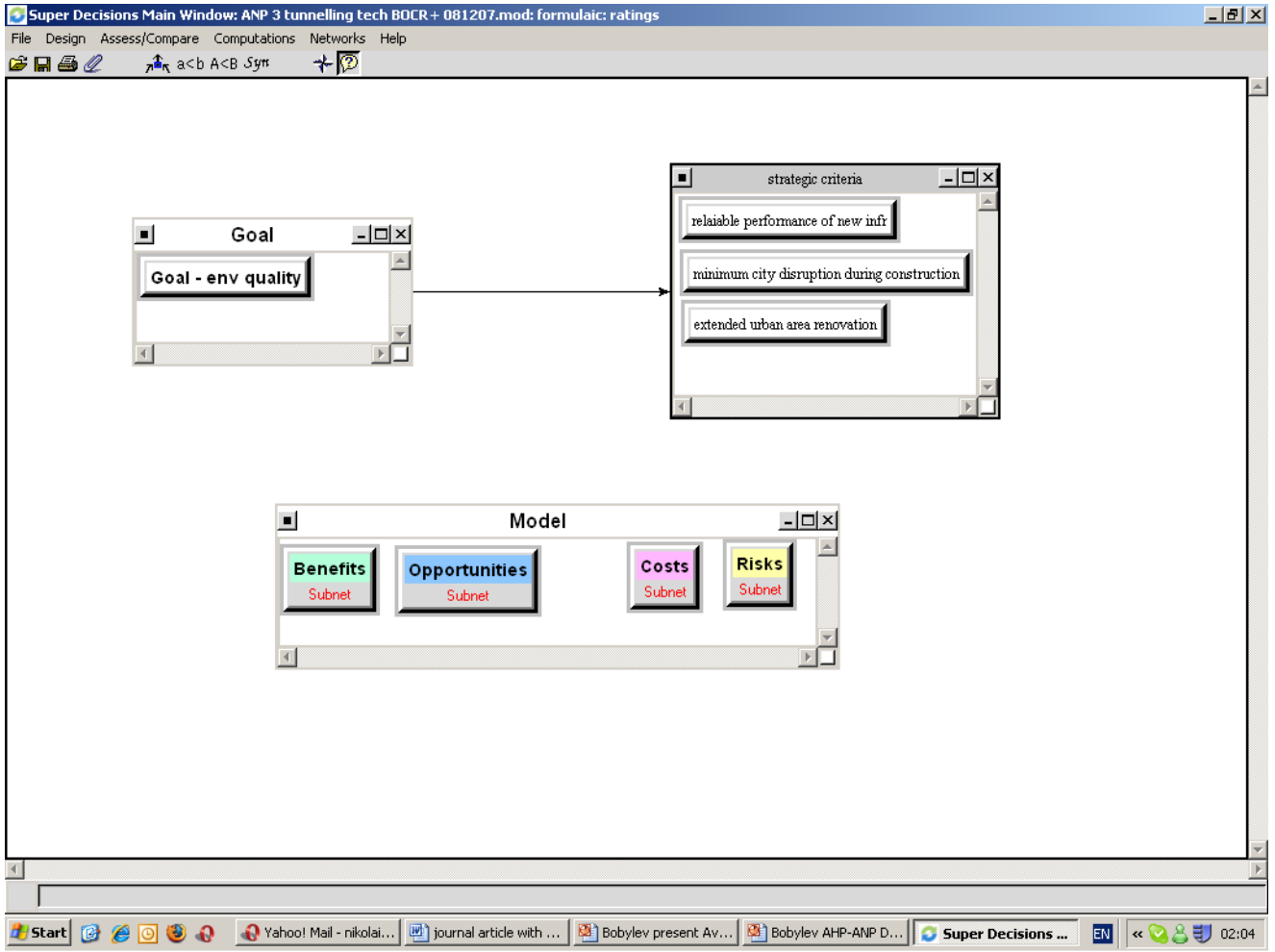
By Creative Decisions Foundation
4922 Ellsworth Avenue
Pittsburgh, PA 15213
Phone: 412-621-6546
Fax: 412-681-4510

Concepts in the ANP:

- Benefits, Opportunities, Costs and Risks
- Hierarchies and Networks
- Pairwise comparisons and ratings
- Dependence and Feedback
- Inner and outer Dependence
- Nodes and Cluster comparisons
- Control Criteria
- Strategic Criteria

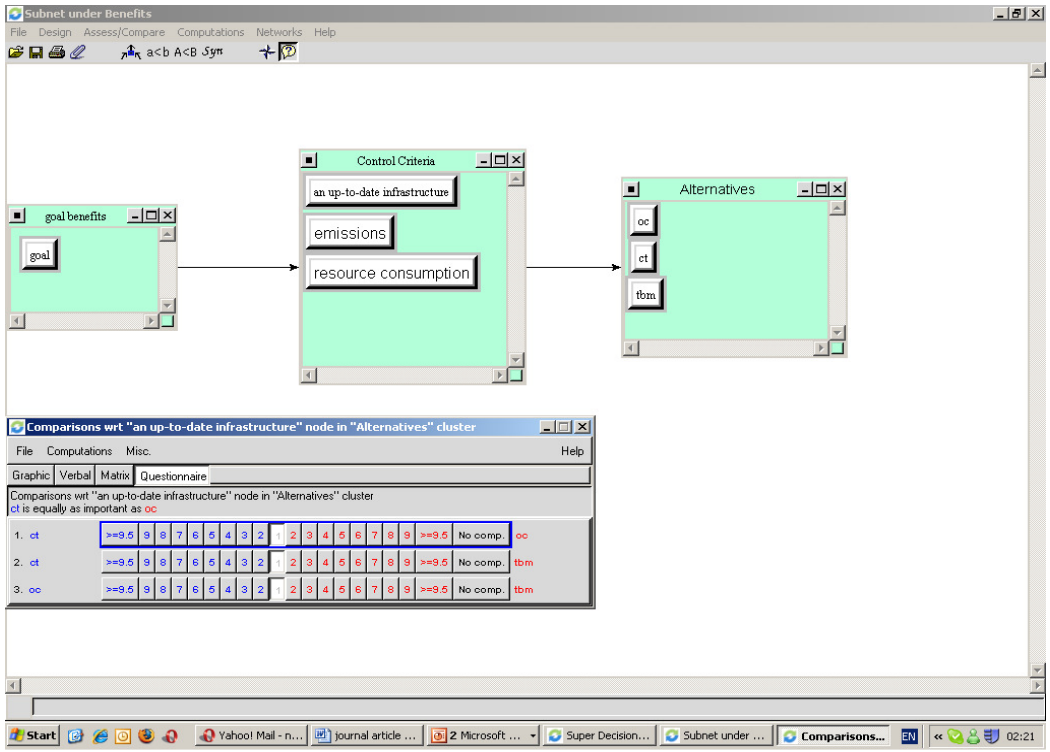
Assessment goal:

Determine which initiative is the best for the environment



Benefits (direct of UCT):

- Up-to-date infrastructure (which UCT creates a more up-to-date infrastructure?)
- Low emissions (which UCT provides less emissions? e.g. better for the environment?)
- Less consumption of resources



Benefits (direct of UCT) (AHP model):

Number of comparison sets:

•1 – compare control criteria (3) with respect to the goal (benefits for the environment)

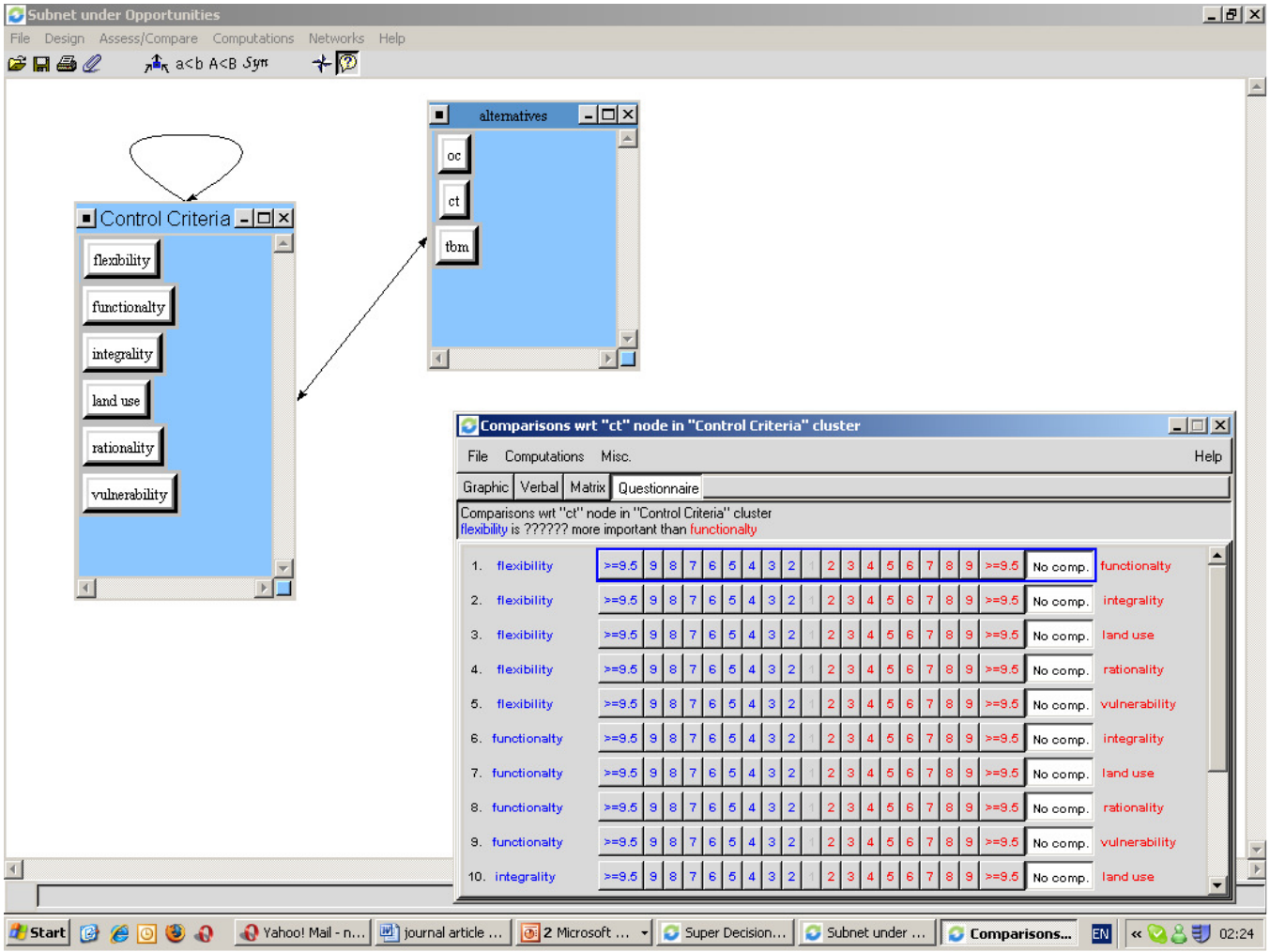
Sample pairwise comparison question: what is more important for the benefits of the project: "Low emissions" or "Less consumption of resources"?

•3 – compare alternatives (3) with respect to each control criterion (3)

e.g. which UCT creates more up-to-date infrastructure?

Opportunities (potential benefits):

- Functionality
- Land use
- Integrality
- Flexibility
- Rationality
- Vulnerability



Opportunities (potential benefits):

Criteria here:

- represent complex concepts,
- are difficult to measure,
- are subjective,
- are difficult to prioritize with respect to an assessment goal.

These criteria are best evaluated by measuring in the context of the alternatives themselves (feedback)

These criteria may also be interdependent, and this is measured by innerdependent comparisons

Opportunities (potential benefits) (ANP model):

Number of comparison sets:

•6 –alternatives (3) with respect to each control criteria (6)

e.g. which UCT would provide more opportunities for the underground structure integration with existing structures?

•3 – the control criterion (6) with respect to the alternatives (3)

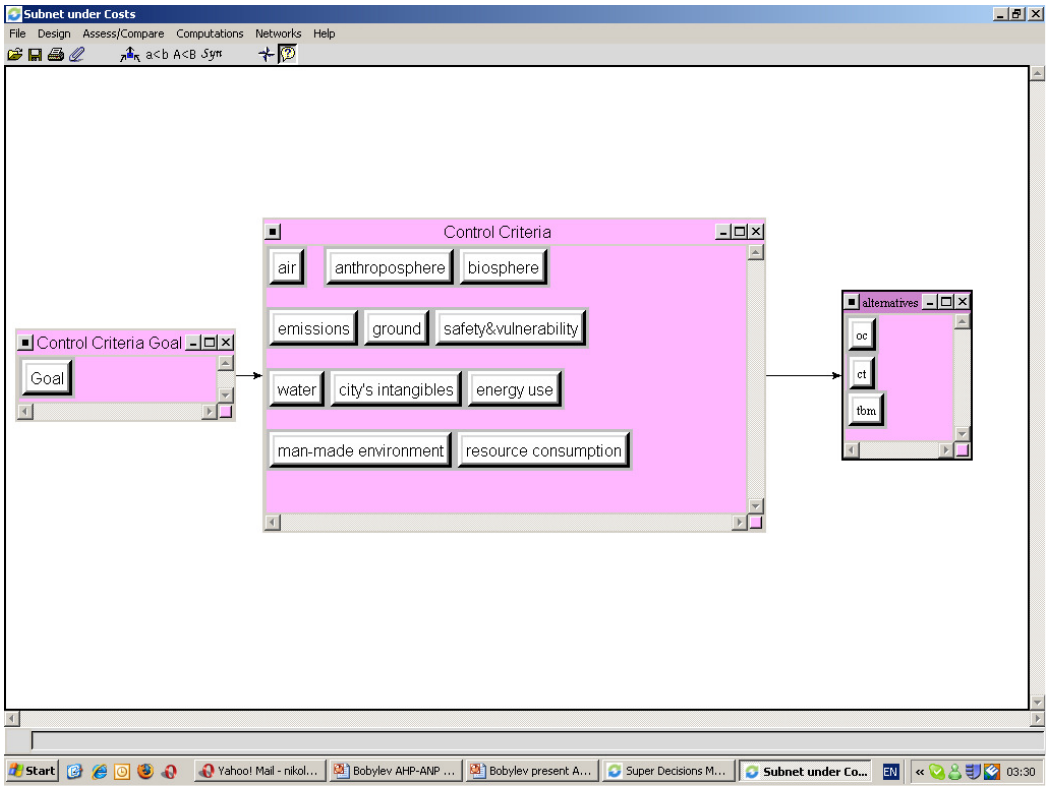
e.g. what would be the main benefit of UCT TM? flexibility, rationality, etc? (feedback)

•6 – all the control criteria in the cluster but one (6-1=5) with respect to this control criterion (6)

e.g. what is more important to ensure rationality: flexibility, integrality, etc.?

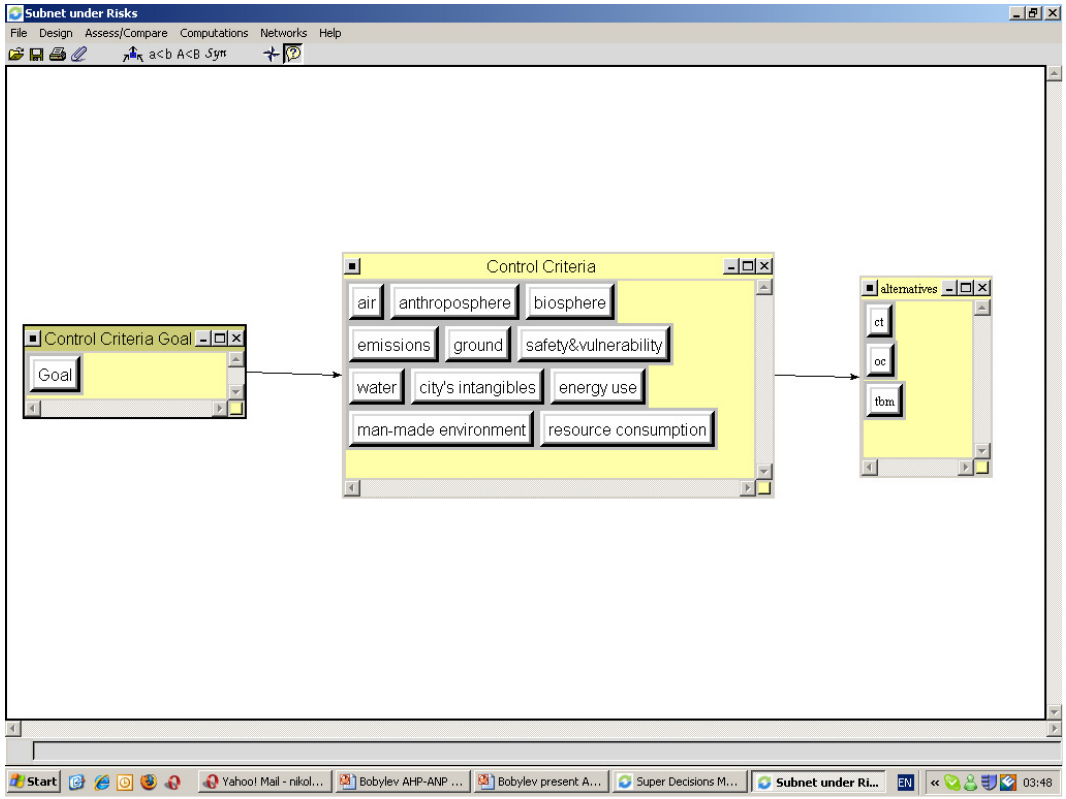
Costs (direct – that will surely occur):

- Lithosphere
- Atmosphere
- Hydrosphere – groundwater
- Hydrosphere – surface water
- Waste/emissions (not directly into any sphere)
- Resource consumption
- Energy
- Intangible impacts
- Man-made environment
- Anthropo sphere
- Biosphere
- Safety/vulnerability
- Temperature



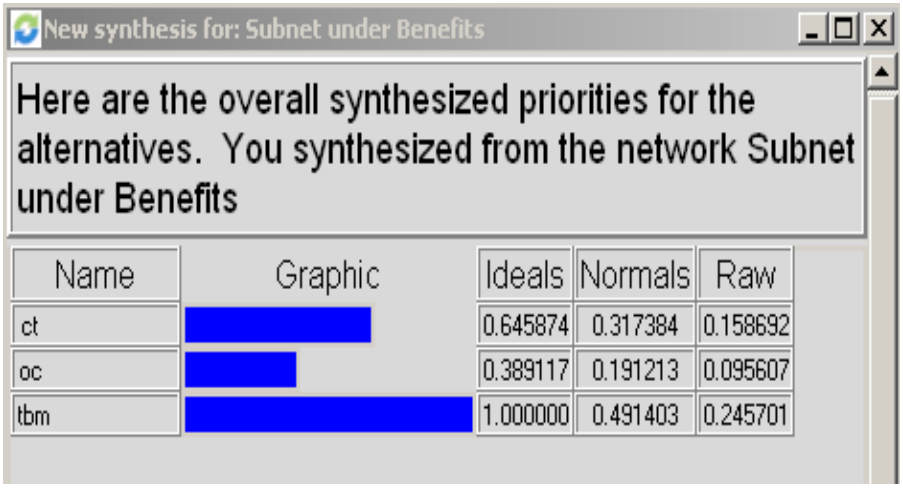
Risks (potential costs):

- Lithosphere
- Atmosphere
- Hydrosphere – groundwater
- Hydrosphere – surface water
- Waste/emissions (not directly into any sphere)
- Resource consumption
- Energy
- Intangible impacts
- Man-made environment
- Anthropo sphere
- Biosphere
- Safety/vulnerability
- Temperature



Intermediate results:

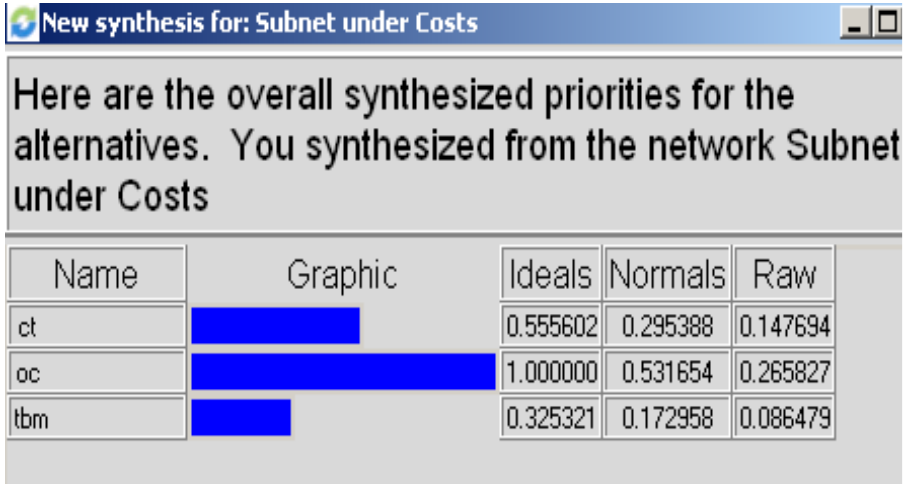
Benefits, Opportunities, Costs and Risks (BOCR):



New synthesis for: Subnet under Benefits

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Subnet under Benefits

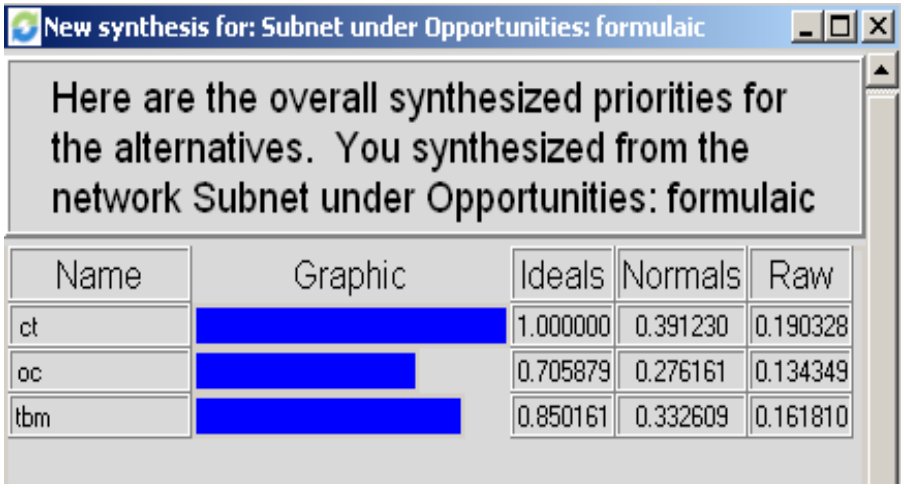
Name	Graphic	Ideals	Normals	Raw
ct		0.645874	0.317384	0.158692
oc		0.389117	0.191213	0.095607
tbm		1.000000	0.491403	0.245701



New synthesis for: Subnet under Costs

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Subnet under Costs

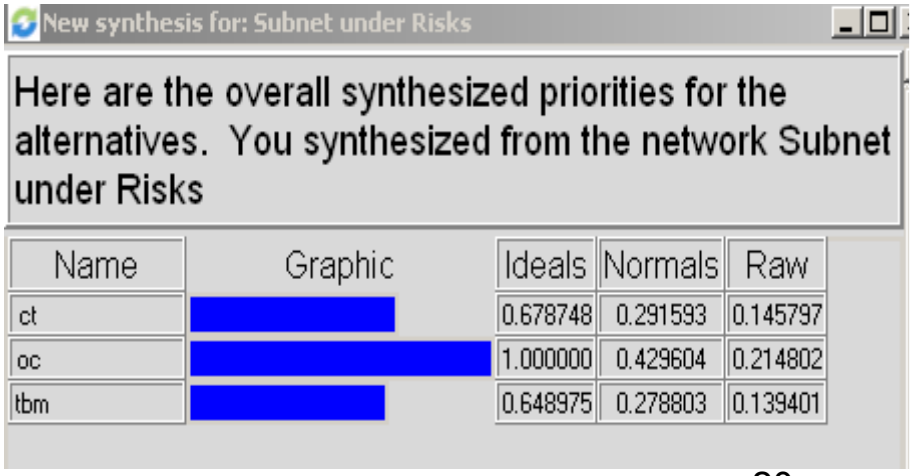
Name	Graphic	Ideals	Normals	Raw
ct		0.555602	0.295388	0.147694
oc		1.000000	0.531654	0.265827
tbm		0.325321	0.172958	0.086479



New synthesis for: Subnet under Opportunities: formulaic

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Subnet under Opportunities: formulaic

Name	Graphic	Ideals	Normals	Raw
ct		1.000000	0.391230	0.190328
oc		0.705879	0.276161	0.134349
tbm		0.850161	0.332609	0.161810



New synthesis for: Subnet under Risks

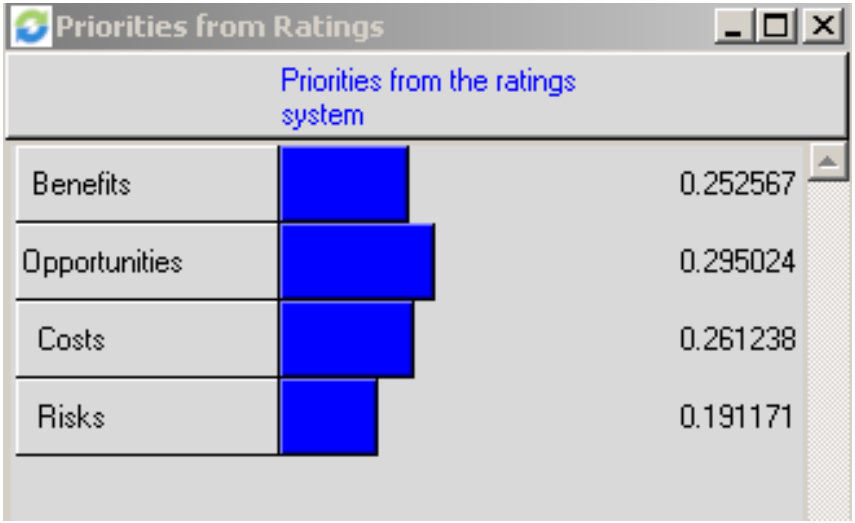
Here are the overall synthesized priorities for the alternatives. You synthesized from the network Subnet under Risks

Name	Graphic	Ideals	Normals	Raw
ct		0.678748	0.291593	0.145797
oc		1.000000	0.429604	0.214802
tbm		0.648975	0.278803	0.139401

Rating BOCR using strategic criteria:

Strategic criteria:

- Reliable performance of new infrastructure
- Minimum disruption of the city environment during construction
- Extended renovation of the urban area (opportunities for side projects)



Values of coefficients b,o,c,r in the Additive (negative) formula

Rating BOCR using strategic criteria:

•What is an importance (e.g. high, medium, low) of the best alternative under benefits (TM) for a strategic criteria e.g. “Reliable performance of new infrastructure”?

Ratings for Super Decisions Main Window: ANP 3 tunnelling tech BOCR+ 081207.mod: formulaic: ratings

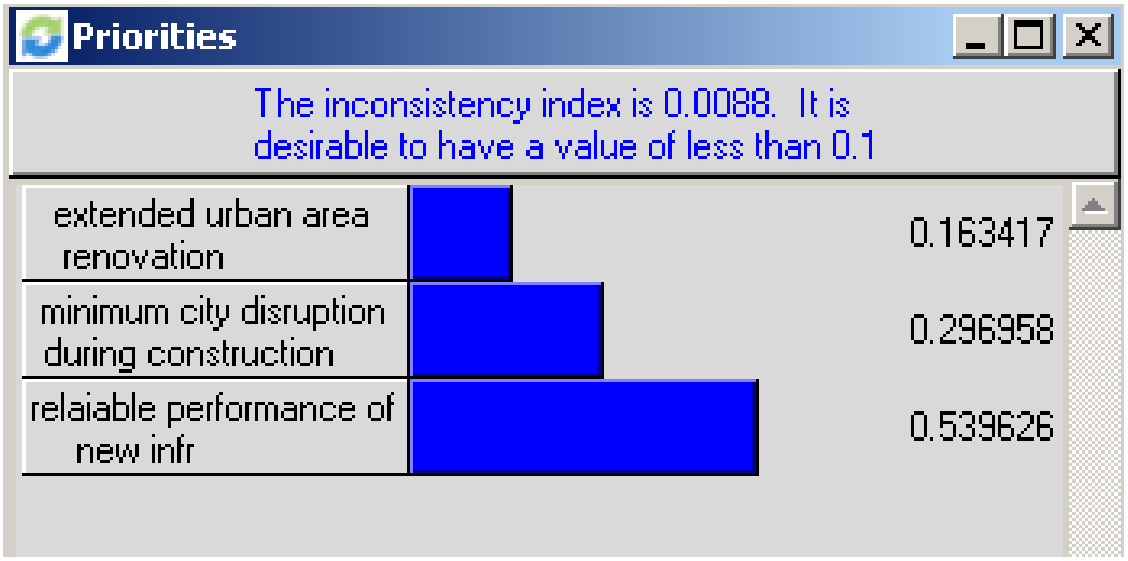
File Edit View Calculations Help

Super Decisions Ratings

	Totals	Priorities	minimum city disruption during constru 0.296958	extended urban area renovation 0.163417	relaiable performance of ne 0.539625
Benefits	0.856089	0.252567	high	low	high
Opportunities	1.000000	0.295024	high	high	high
Costs	0.885478	0.261238	high	medium	high
Risks	0.647983	0.191171	medium	low	high

Rating BOCR using strategic criteria:

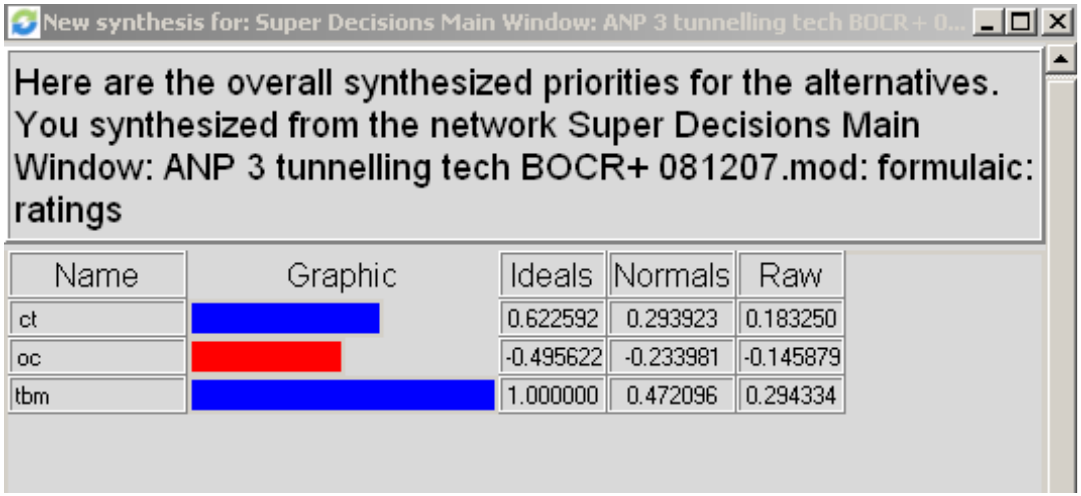
•Strategic criteria has their weight with respect to goal (one set of pairwise comparisons)



Final Assessment Step is to Combine the BOCR Using one of the Formulas:

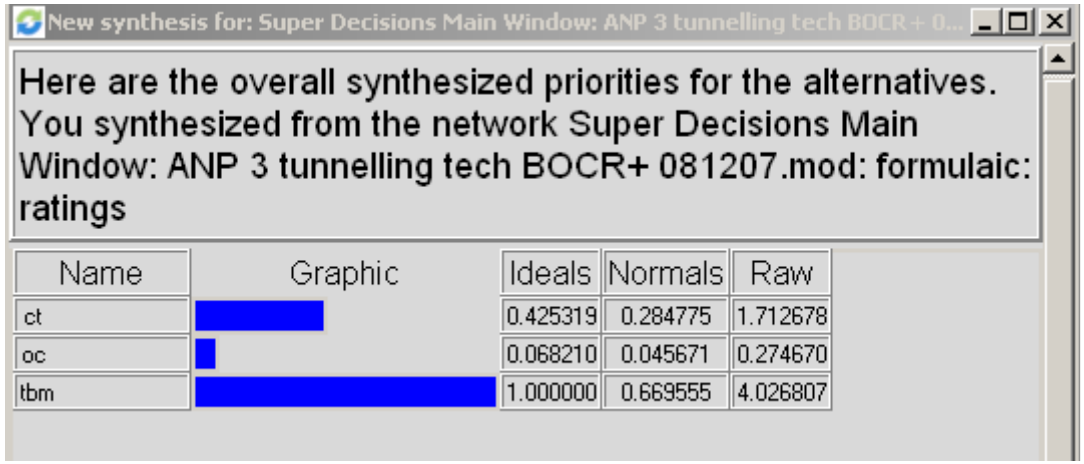
- Additive negative formula:

  bB+oO-cC-rR



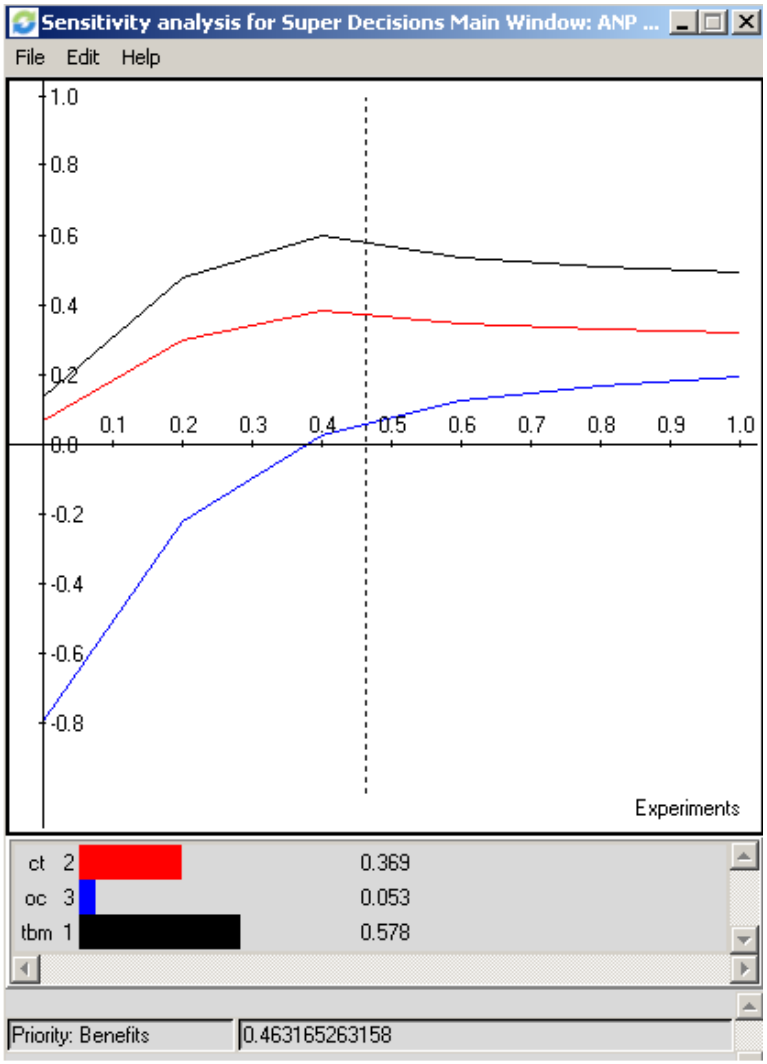
- Multiplicative formula:

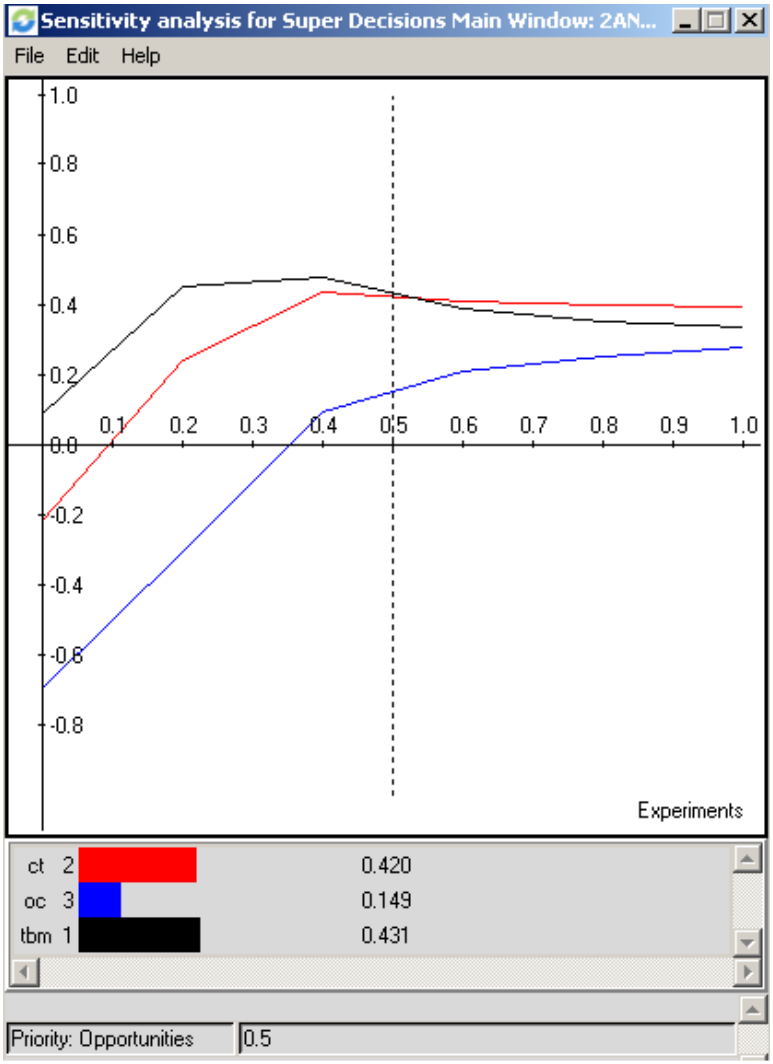
  BO/CR



Sensitivity Analysis:

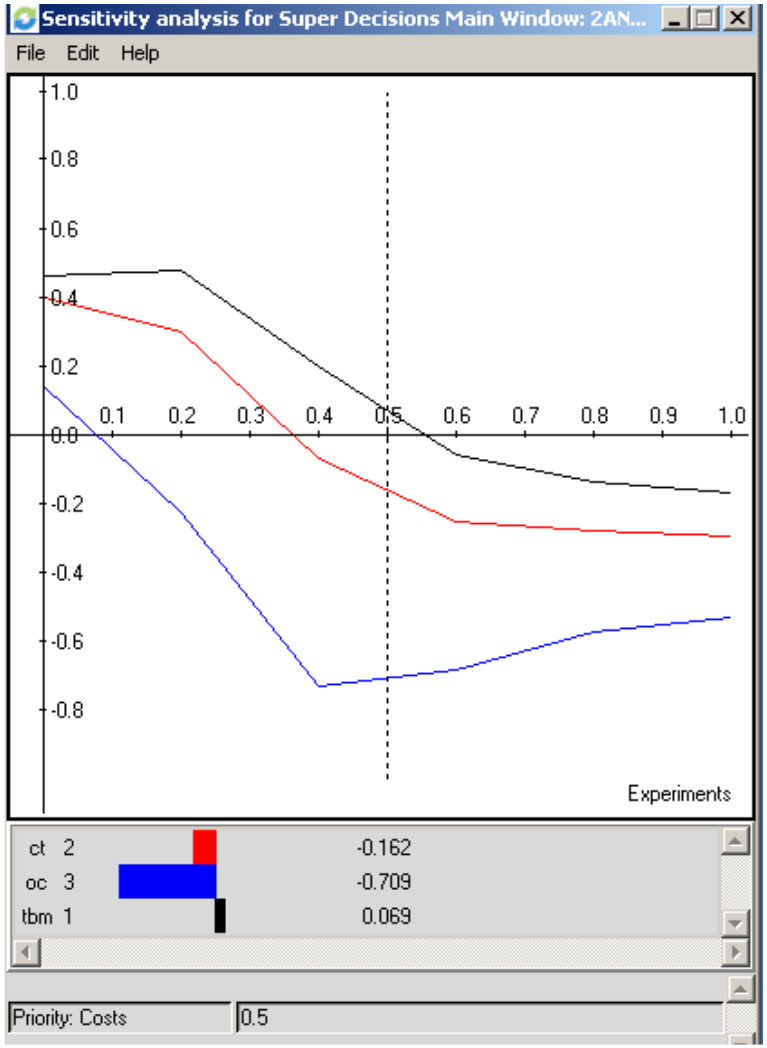
TM alternative is the best in the final result regardless coefficient b (which is weight of B)

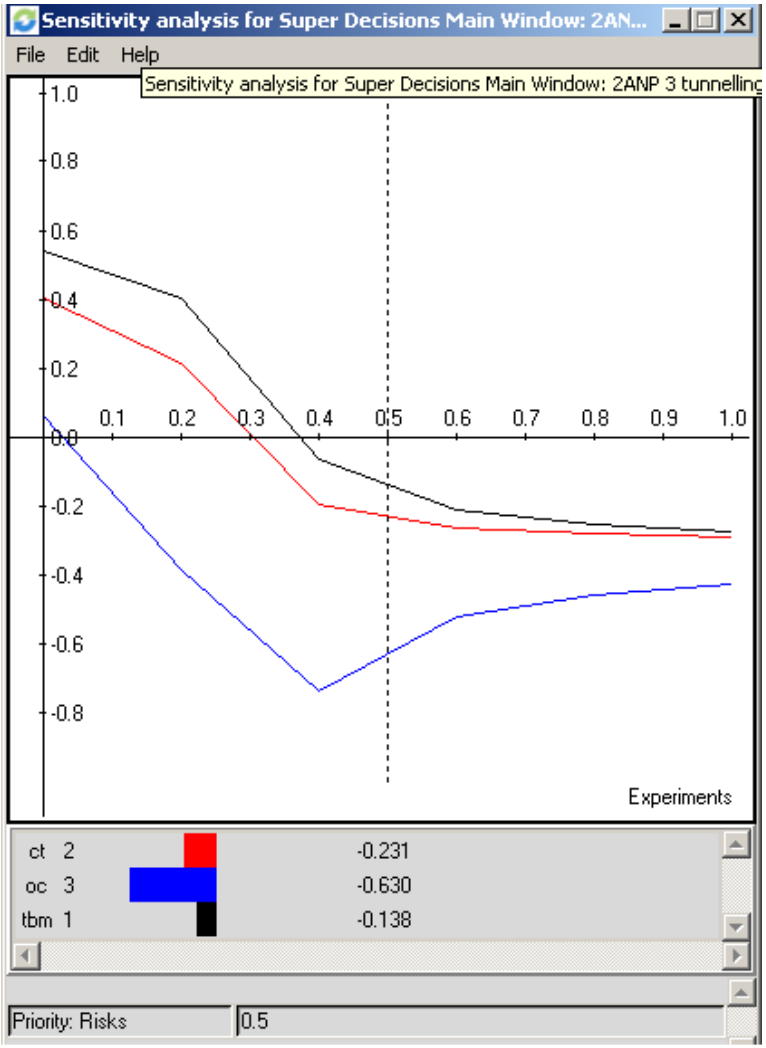




Sensitivity Analysis:

when costs or risks are dominant concerns (high coefficients c,r) all the alternatives are negative – it is not advisable to undertake the initiative





Findings/issues/research: using MCDA – What do we achieve?

Assessment results

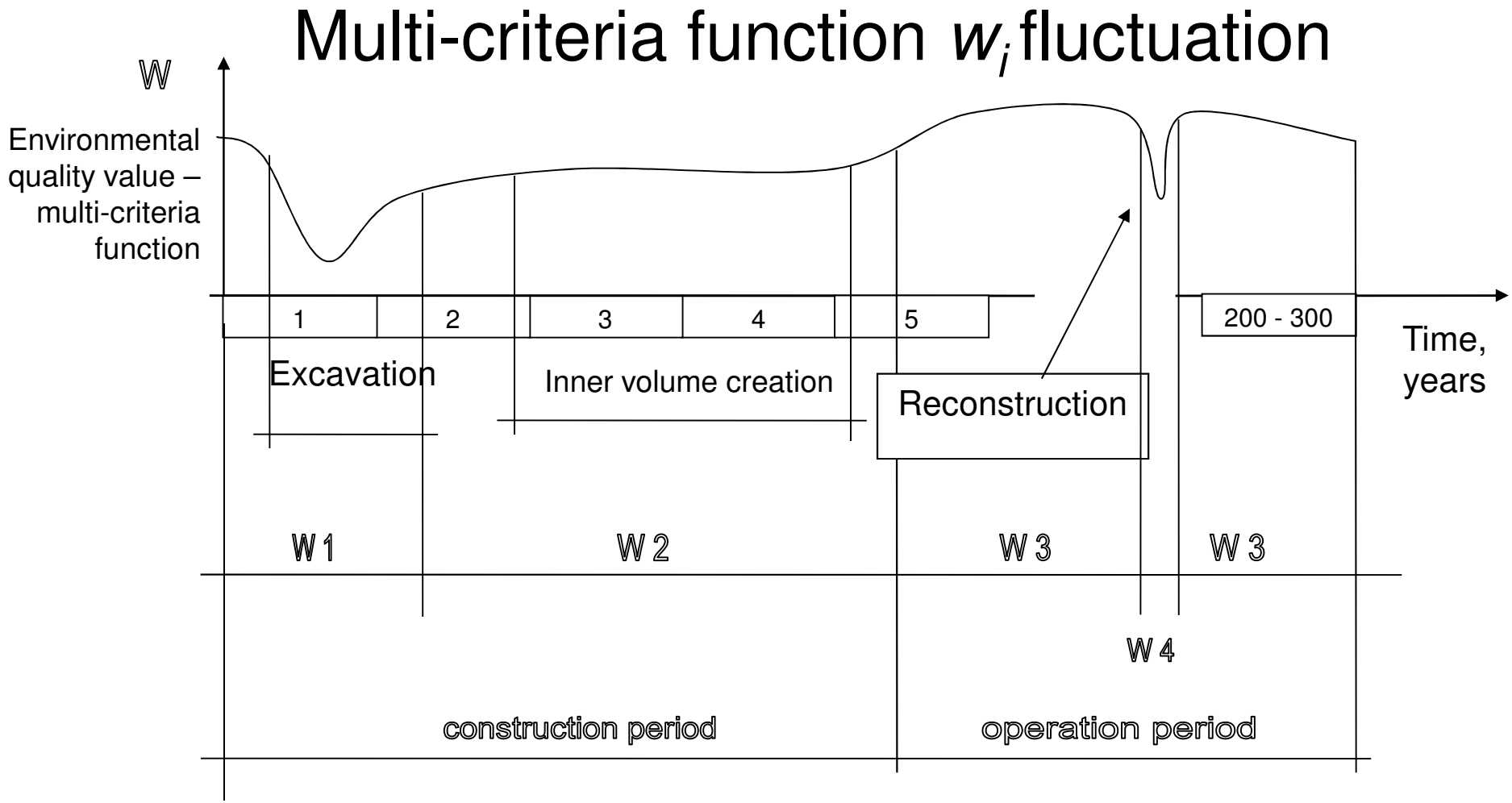
- Alternatives rating (which is the best?)
- How close are alternatives to each other? (quite close – difficult decision, similar alternatives, high probability of mistake; too far – obvious decision, no need for assessment, incomparable alternatives),
- Sensitivity analysis: how given criterion values affect the overall ratings?
- Identify criterion or criteria groups which has the most (least) significant impact on the rating

Findings/issues/research: using MCDA – What do we achieve?

MCDA tools follow-up

- Look at alternatives ratings: formulate alternatives again, minor changes in alternatives (technologies), suggest new alternatives, group alternatives, brake down alternatives
- Analyze criteria performance: too many (aggregate), too few (add sub-criteria), similar performance (eliminate), difficult/unclear to compare (re formulate)
- Analyze hierarchic structures: re arrange nodes, add/delete criteria
- Analyze the whole model: change formula, model, or method
- Conclude on important trade-offs to be made (which criteria contribute most to the final judgment)

Findings/issues/research: using MCDA –
Next steps in Decision Making – using MCDA results



Source: Bobylev, 2003 (PhD dissertation)

Findings/issues/research: using MCDA –
Next steps in Decision Making – using MCDA results

Integral assessment function based on the values derived from MCDA

$$Q_j = \frac{\sum_{t=1}^{m} k_{jt} R_{jt} + \sum_{t=1}^{h} \bar{k}_{jt} (S_{jt} - N)}{N} \rightarrow \max \qquad k_t = \frac{t}{T}$$

Qj – integral assessment value for an *j* project alternative,
t – duration of a particular assessment period,
m – number of assessment periods within the operation period,
h – number of assessment periods within the construction period,
kt – time coefficients,
T – the whole period of project assessment
MCDA values:
N – without structure,
Sjt – construction period,
Rjt – operation period.

Source: Bobylev, 2003 (PhD dissertation)

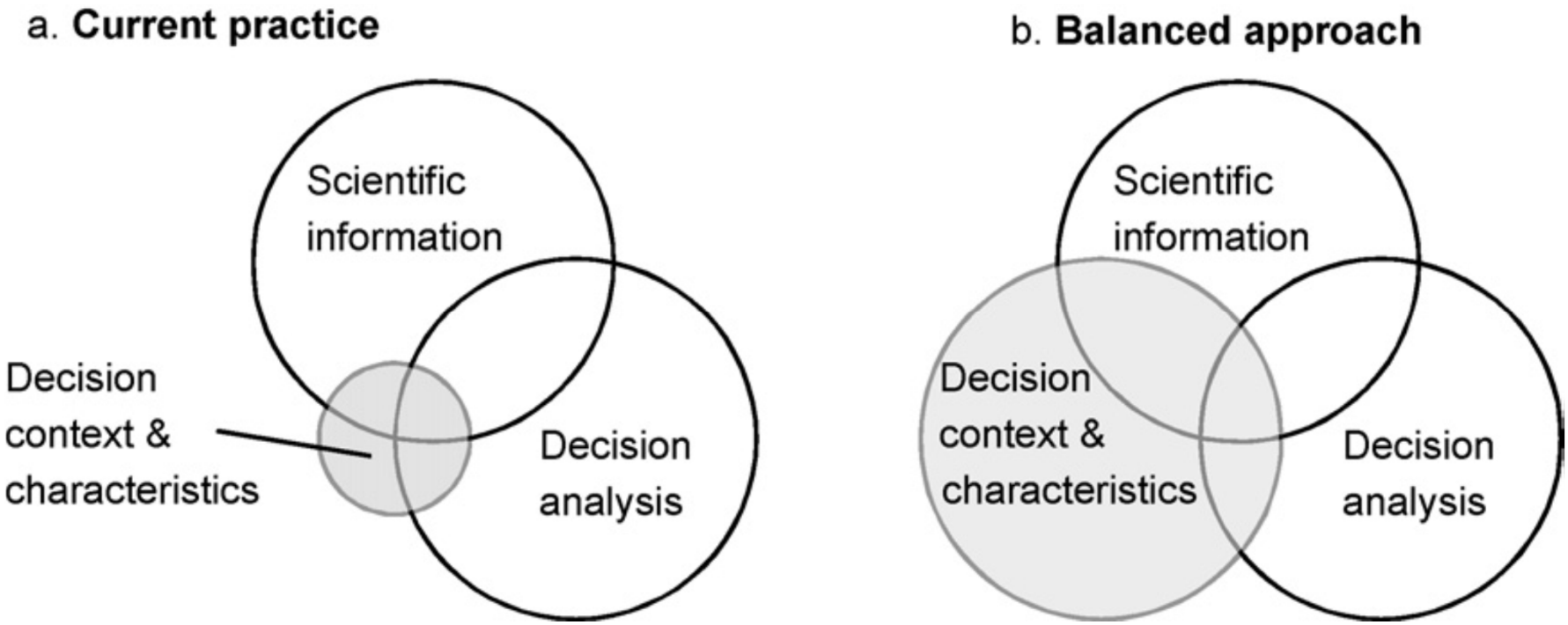
Effectiveness in MCDA

effective decision support tools:

- information needs, technology, human factors, and organizational routines (Wears and Berg, 2005)
- "sociotechnical" system approach (Randolph et al., 1999)

1. Credibility of a method itself
2. Abilities of individuals to use the method
3. Working environment (institutional, political, etc)

Effectiveness in MCDA



(from Pyke et al 2007)

Effectiveness in EA

a degree to which EA process works as intended and meets the purposes for which it is designed (Sadler, 1996)

Procedural

Substantive

Transactive

Criteria for EA effectiveness assessment

Criterion is a standard, rule, or test on which a judgment or decision can be based.

Criteria sets:

(based on review of suggested by Udo, 1992; McCartt and Rohrbaugh, 1989; Theophilou et al., 2010; Fischer and Gazzola, 2006; George, 1999; Noble, 2009; Retief et al., 2008).

Criteria for EA effectiveness assessment

Criteria	*Description*	*Desired value*
Timing of assessment	Timing of EA in relation to an initiative lifecycle. SEA usually considers that EA should start at the earliest possible stage of decision making	Just right
Resources required	A variety of resources: data, human, monetary, time	Just right (not minimum)
Data generation (internal learning effect)	EA process generates data, and/or additional significant knowledge, that could not be obtained otherwise (e.g. during design, modelling, surveys)	Maximise
Impact on an initiative	This is the central criteria to judge on effectiveness. The initiative should be improved as the result of an EA process	Maximise, concrete and solid
Wider influence (external learn. effect)	Influence that goes beyond considered initiative – impact on policies in the field	Maximise
Participation	All parties concerned and initiative stakeholders are willingly involved	Maximise willing, inclusive participation
Credibility	Opinion of professional communities on whether they trust EA results and believe that EA actually made an initiative better	Maximise

ANP EA effectiveness assessment

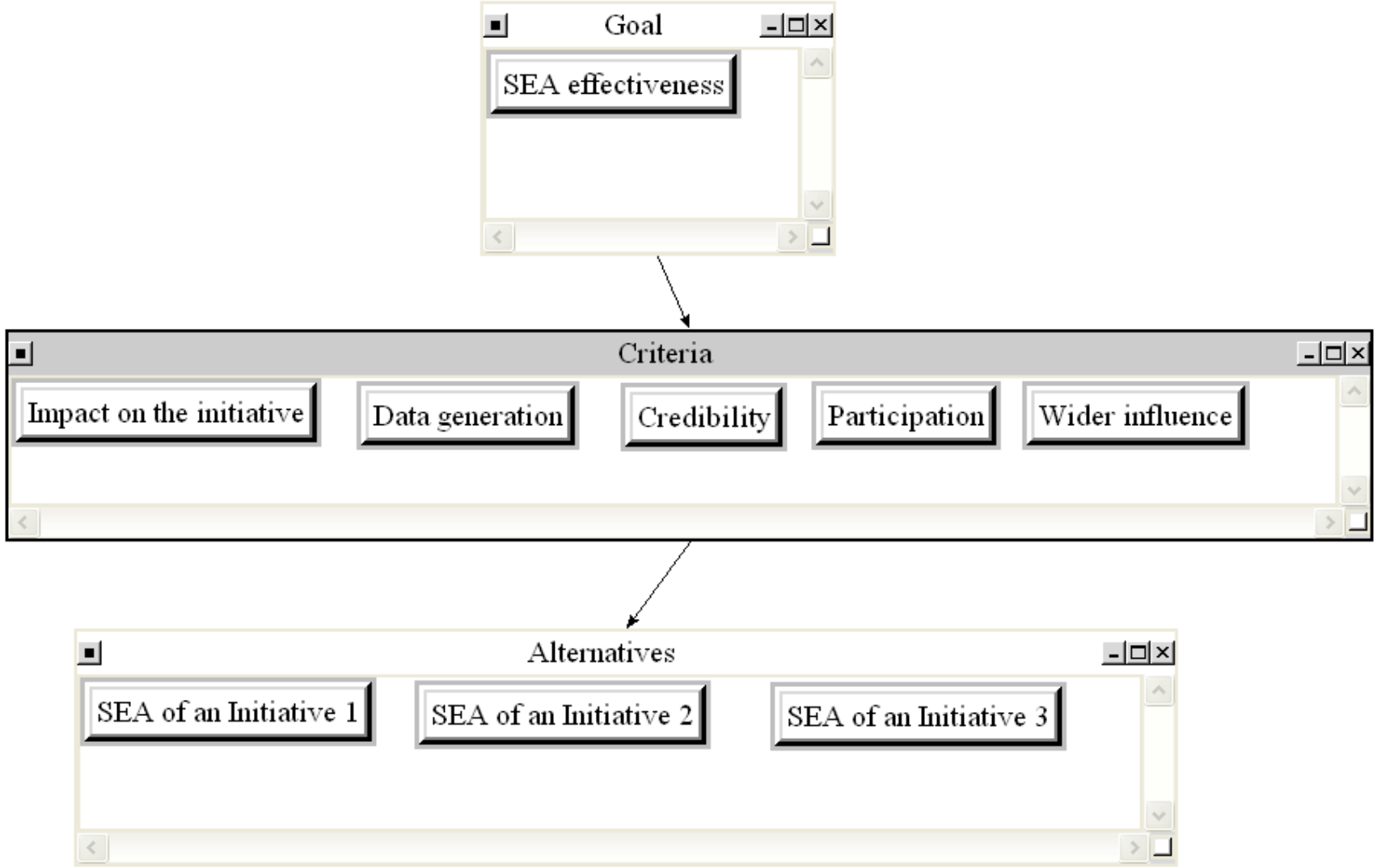
5 models:

1. Assessment model AHP with a simple hierarchy
2. Assessment model AHP with a hierarchy and ratings
3. Assessment model ANP with a single SEA and feedback network
4. Assessment model ANP with a single SEA and feedback and criteria inner-dependence network
5. Assessment model ANP with SEAs comparative effectiveness and feedback and criteria inner-dependence network

By Creative Decisions Foundation
4922 Ellsworth Avenue
Pittsburgh, PA 15213
Phone: 412-621-6546
Fax: 412-681-4510

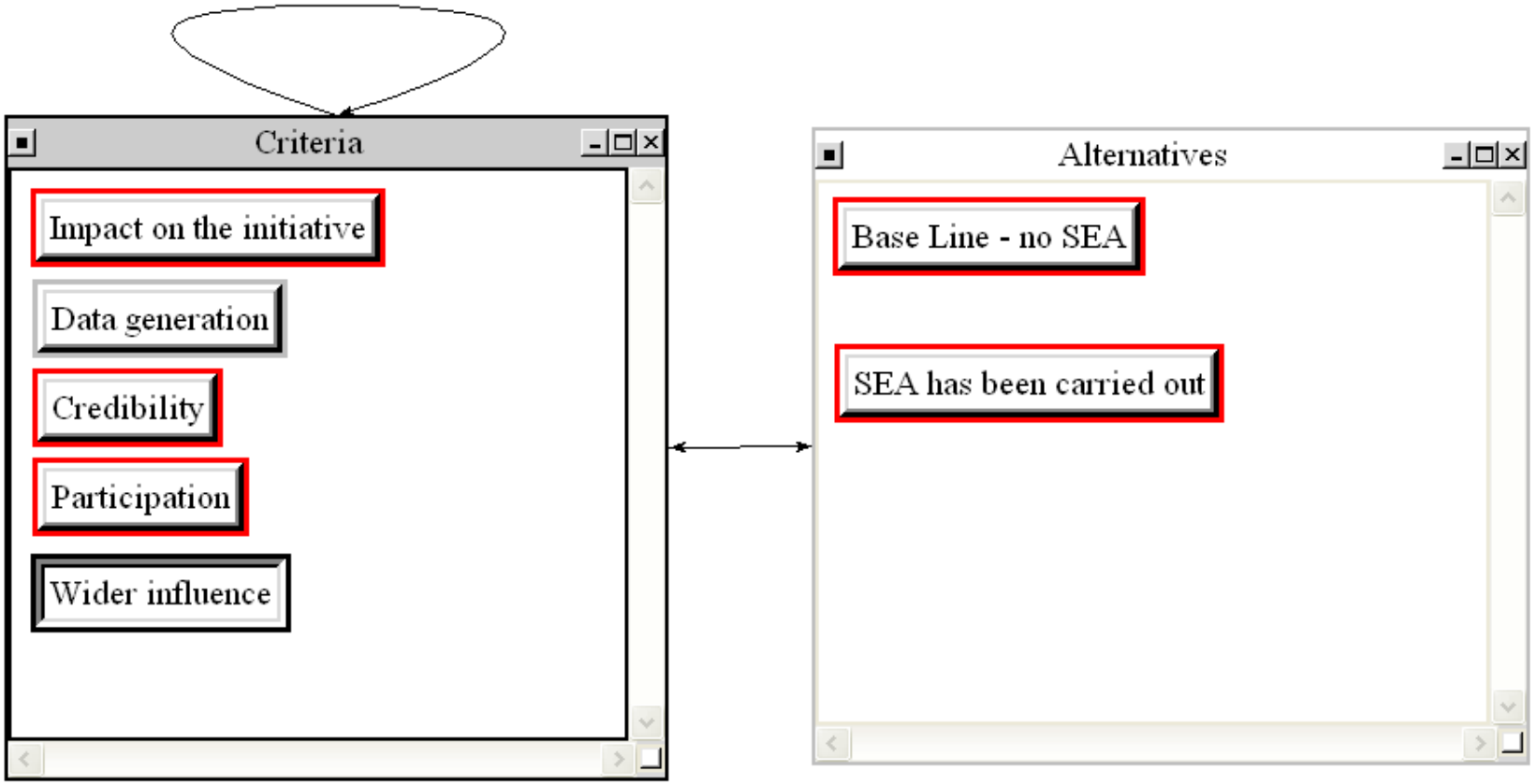
Findings/issues/research: effectiveness in MCDA

Assessment model AHP with a simple hierarchy



Findings/issues/research: effectiveness in MCDA

Assessment model ANP with a single SEA and feedback and criteria inner-dependence network



Findings/issues/research: effectiveness in MCDA

Conclusion:
it makes sense to use ANP because:

Inner-dependence concept reflects nature of EA effectiveness criteria. Taking into account relationships between criteria makes the evaluation study more reflective (pairwise comparisons in the same cluster);

Feedback concept captures obvious strong points of a particular alternative;

EA effectiveness: take criteria and study how they influence each other, than evaluate an initiative(s).

Ongoing research and perspectives

Sustainable Infrastructure for Resilient Urban Environments (SIRUE) 2012 - 2015

University of Birmingham, UK

St. Petersburg Research Centre for Ecological Safety of the Russian Academy of Sciences, Russia

The aim of the project is to identify

how the use of underground space and its physical infrastructure

influence, interact with and impact on

sustainability, vulnerability and resilience of urban areas

(and vice versa), both now and in the future

Background papers

Climate Change Mitigation and Adaptation in Strategic Environmental Assessment (2012) Wende, W., Bond, A., Bobylev, N., Stratmann, L. *Environmental Impact Assessment Review*, Elsevier.

Sustainability Issues for Underground Space in Urban Areas (2012) Sterling, R., Admiraal, H., Bobylev, N., Parker, H., Godard, J.P., Vähäaho, I., Rogers, C.D.F., Shi, X., Hanamura T. *Proceedings of the ICE - Urban Design and Planning*

Climate Protection and Compact Urban Structures in Spatial Planning and Local Construction Plans in Germany (2010) Wende, W., Huelsmann, W., Marty, M., Penn-Bressel, G., Bobylev, N. *Land Use Policy* Volume 27, Issue 3, July 2010, Pages 864-868. Elsevier

UNECE Energy Efficiency in housing Action Plan

Teaching MCDA and student's works

- http://www.ii.spb.ru/2005/ins_inn_material/document_baza.php?id=94

- St.Petersburg State University
- St.Petersburg State Polytechnical University

- ANP, MACBETH, other

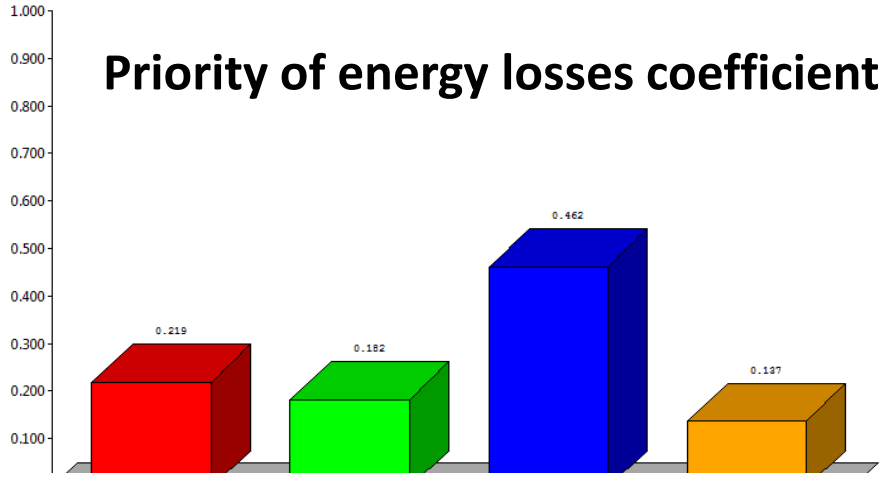
- One semester teamwork MCDA project focused on student's degree major subject (innovations, business, environment, civil engineering)

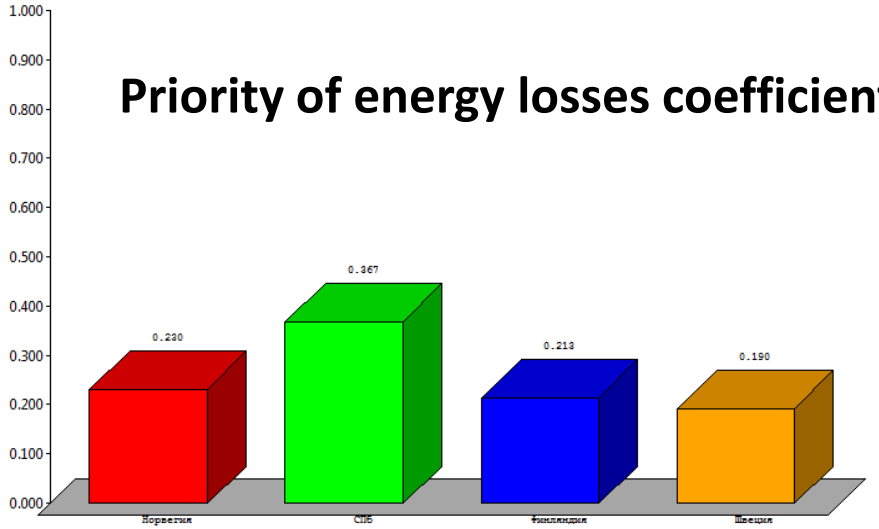
- So far about 100 cases, about 20 of them presentable

Teaching MCDA: student's works – cases (autumn 2011)

Название модели	*Model short name*	*Software used*	*Availab. files**	*Состав команды. The team.*
Выбор оператора для совершения голосовых звонков	Mobile phone netwok	Super Decisions	mr	Андреева Рада Исакова Алина
Выбор города для проведения летних олимпийских игр	Olympics	Super Decisions	mrp	Бигаева Александра Смелова Валентина Тэн Дмитрий Зотова Анастасия Олеговна
Выбор наиболее подходящего программного обеспечения для решения многокритериальных задач	MCDA software choice	СППР Выбор (SPPR Vibor)	mrp	Гаприндашвилли Нона Итс Алена Бедрина мария
Выбор интернет провайдера	Internet provider	M-Priority	mrp	Захарова Ксения Стальмаков Александр Евгеньевич Суомалайнен Ян Эрикович Хитёв Александр Антонович
Выбор места для создания аэроклуба на базе старого аэродрома в Московской области	Aero Club	Super Decisions	mrp	Сергеева Алена Садкова Марина
	Car tires	M-Priority		Шальнев Сергей Корнеев Родион Викторович Молчанов Андрей Олегович Мацко Алексей Александрович
Выбор кинотеатра	Movie theater	Super Decisions	rp	Хайрулина Асель Беляева Екатерина Юрьевна Карпова Мария Александровна
Расчет оптимального маршрута от станции метро Лесная до Политехнической	Route	Excel	mp	Ардонская Светлана Евгеньевна Пурышева Екатерина Алексеевна Тараканов Роман Вадимович
Выбор искусственного источника света	Light bulbs	Super Decisions	mrp	Савина Ирина Яковлевна
Выбор наиболее подходящего вложения денежных средств	Investment	Super Decisions	mrp	Селиванова Софья Васильевна Богославец Михаил Алексеевич
Выбор новой планеты, пригодной для жизни людей	Planet	Make it Rational	mrp	Жигалов Василий Андреевич Керсанова Любовь Валерьевна Щапин Дмитрий Александрович
Выбор пригородного поселка для покупки земельного участка	Dacha (cottage development location)	M-Priority	mrp	Константинова Александра Вадимовна Федорова Светлана Александровна Чистякова Полина Олеговна
Выбор автомобиля	Buying a Car	M-Priority	mrp	Томашевич Федор Лебедько Виктор
Выбор марки автомобиля B-класса	Best car B class	M-Priority	mrp	Артошин Александр Оксентюк Александр Цивилев Алексей

Teaching MCDA: student's works – cases (autumn 2011)





Case: Choosing the best strategy for improving energy performance of a residential building

Norway
Saint Petersburg
Finland
Sweeden

Андреева Р.П., Богославец М.А., Захарян Г.А., Бобылев Н.Г. (2011) Выбор наилучшей стратегии улучшения энерго-эффективности жилого здания с использованием метода аналитических сетей. Тезисы недели науки СПбГПУ. Изд-во СПбГТУ, 2011. С 13-14.

Nikolai Bobylev

E-mail: n.bobylev@bham.ac.uk