From data to decision-making under conditions of uncertainty

RISK Summer School 2025

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Multi-criteria decision-making methods in the context of imperfect information for the assessment and management of natural risks

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Natural risks management and **contexts** of **decision-making**

Decision-making context: natural risks management

Rapid mass movements in mountains (avalanches, floods, rockfalls….)



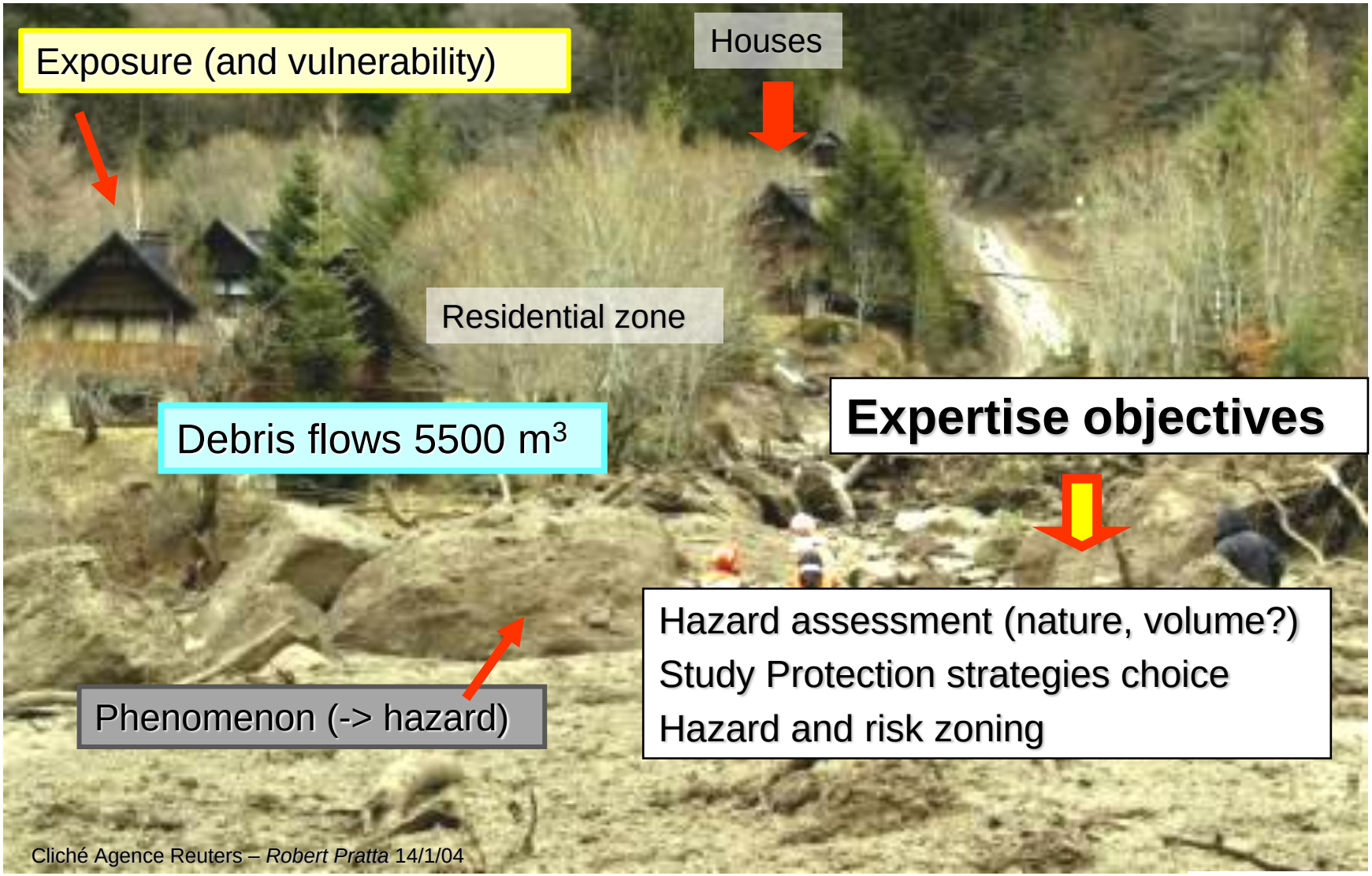
... **threaten** people and infrastructures



We try to **get protected** against them with good decisions and actions

Examples of **challenging decisions** associated to expertise process

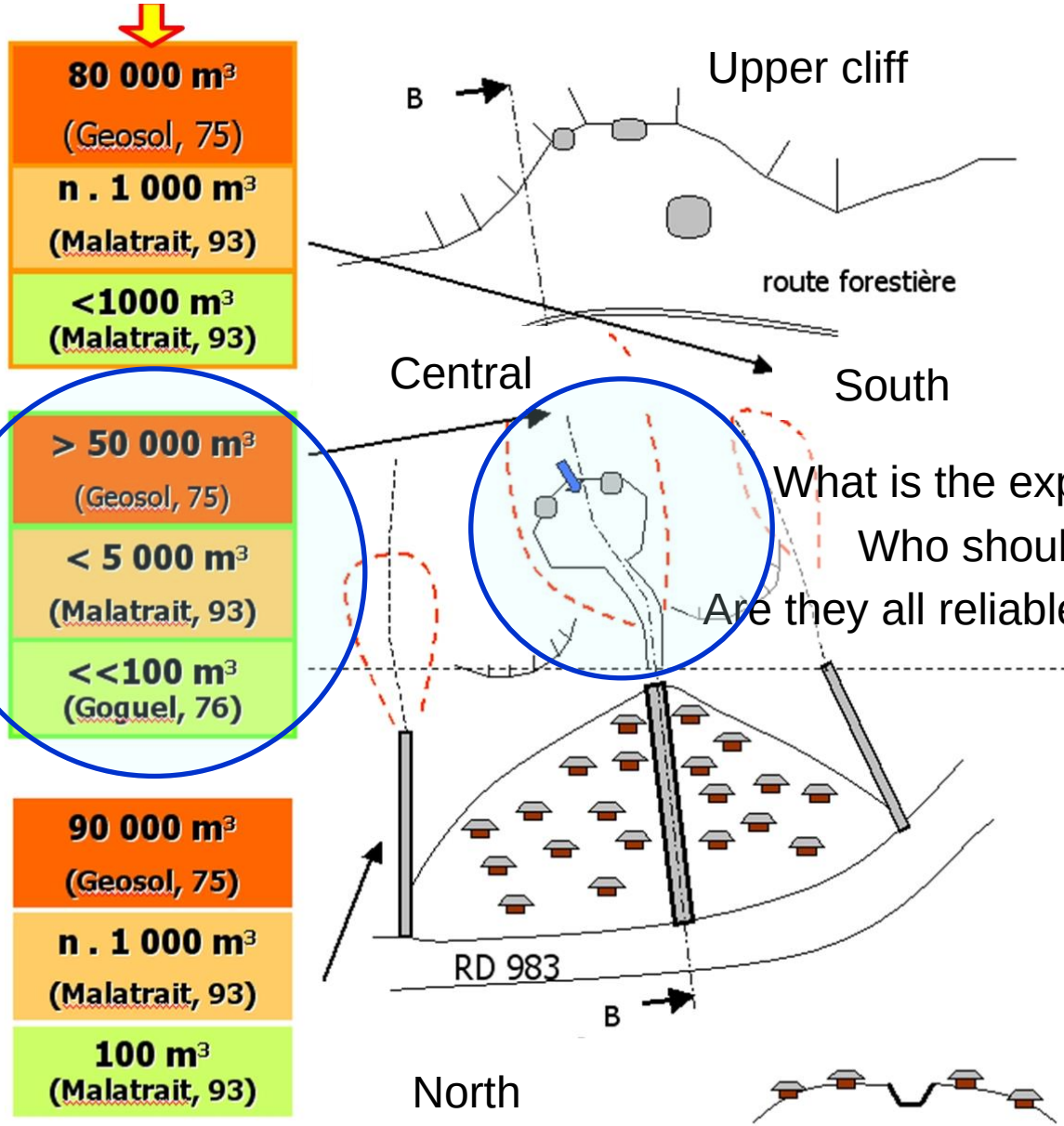
Emergency zone evacuation (50 houses): Should we **protect** or **destroy**?



Cliché Agence Reuters – *Robert Pratta* 14/1/04

(Tacnet, 2009)- PhD

Landslide's **potential volume** estimated by **experts** ....



What is the expected volume ?

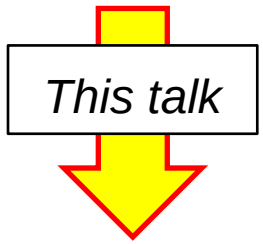
Who should we trust ?

Are they all reliable in the same way ?

Motivation

- **Risk management** itself is a **complex decision process** (actors, time and spatial scales…)

- **Information** used to analyze risk is often **imperfect** (not only uncertain): how can we **take a decision** in this context ? How can we be **confident** in the decision taken?



To **introduce multicriteria decision-making methods (MCDM)** and show some developments using (new) uncertainty theories for decision-making under information imperfection

Outline

Context and motivation

Information imperfection and some (useful) theories

Developments mixing MultiCriteria Decision-Making (MCDM) and information imperfection

Conclusion

Information imperfection…

rather than (only) uncertainty

“Not everything that can be counted counts.
Not everything that counts can be counted.”

“Tout ce qui peut être compté ne compte pas forcément.
Tout ce qui compte ne peut pas forcément être compté”

(Cameron, W.B., 1963) in “Informal Sociology: A Casual Introduction to Sociological Thinking”

Some situations (e.g.)...

- *"The avalanche will follow this track, no this one " :* **Two** (several) **experts** have **different conclusions** ;

- "*I am sure that the volume will be between 5000 and 10000 m³*": the expert is **certain** but **imprecise** ;

- "*I am 75% confident in the fact that the volume will be between 5000 and 10000 m³*": the expert is **uncertain** and **imprecise**: ;

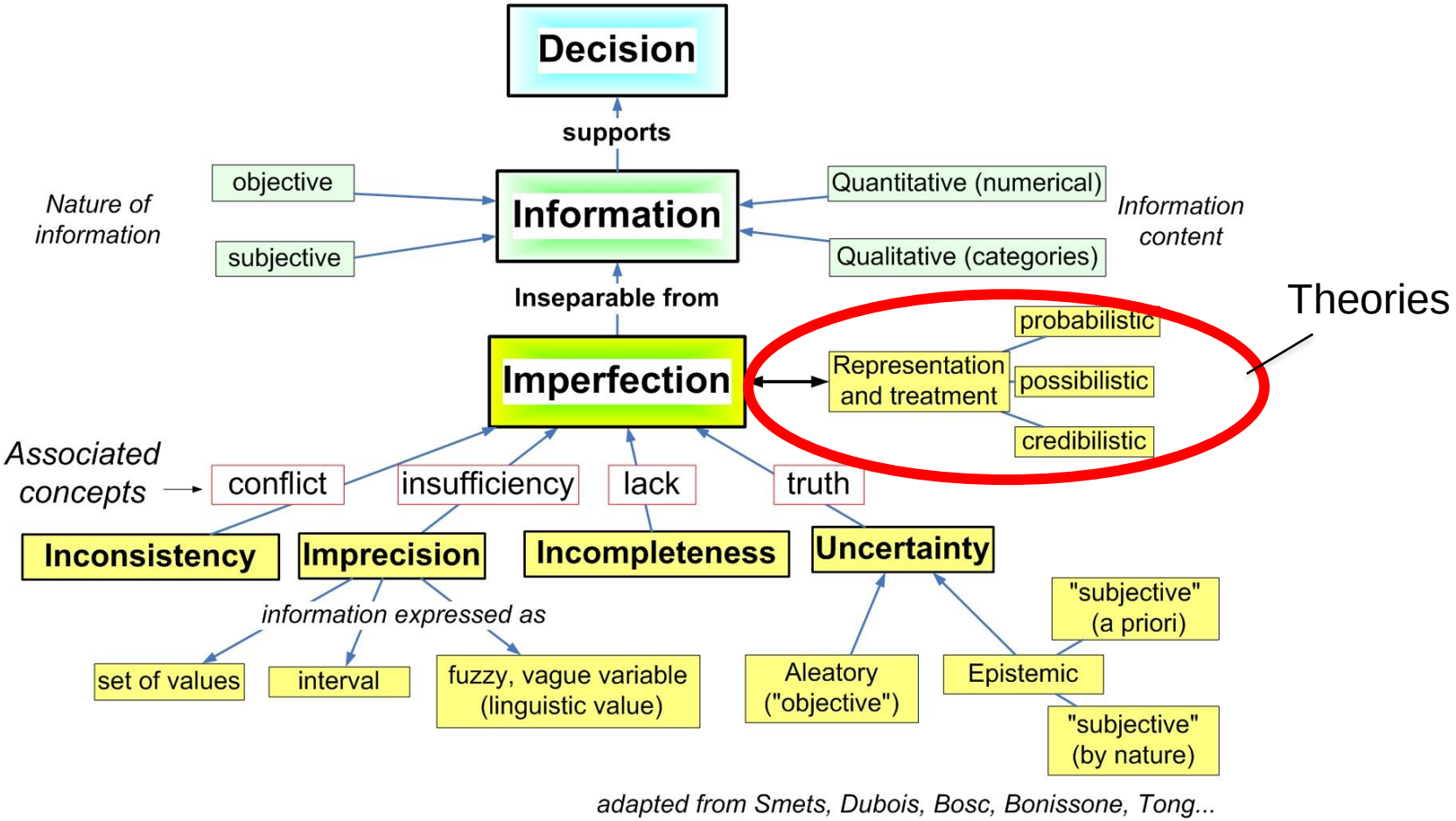
- *"I just do not know what is the physical process (the expert may even not know that it exists)" :* the expert is **lacking** of **information** , **information** is **missing**;

- *" We will get 10mm rain today" :* Nature is **uncertain** (**aleatory)** ;

- *"1% chance that the cliff will collapse but we can investigate more precisely" : a*n expert is **uncertain** (**partial knowledge**, epistemic)

Uncertainty is **not the only kind** of **information imperfection**…

Probabilities are mostly used but different frameworks may have an interest*



adapted from Smets, Dubois, Bosc, Bonissone, Tong...

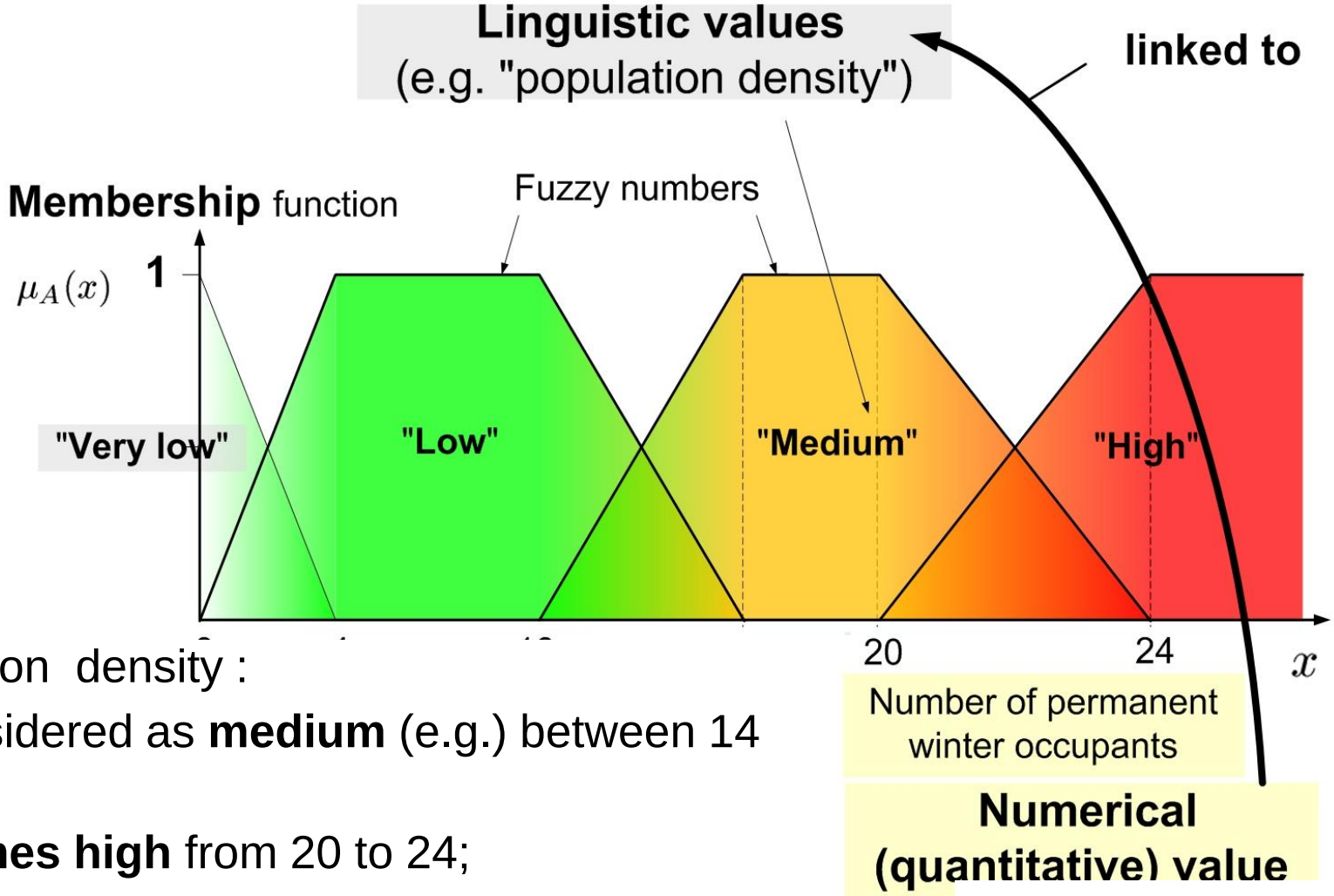
(Tacnet, 2009)

* See also Konieczny, S. et Prade, H. (Eds.), 2020. *L'intelligence artificielle, De quoi s'agit-il vraiment*, Cepadues Editions, Toulouse, France.

Fuzzy sets** and **possibility theories

Fuzzy sets theory links **numerical** and **linguistic** values

(Zadeh,1965)



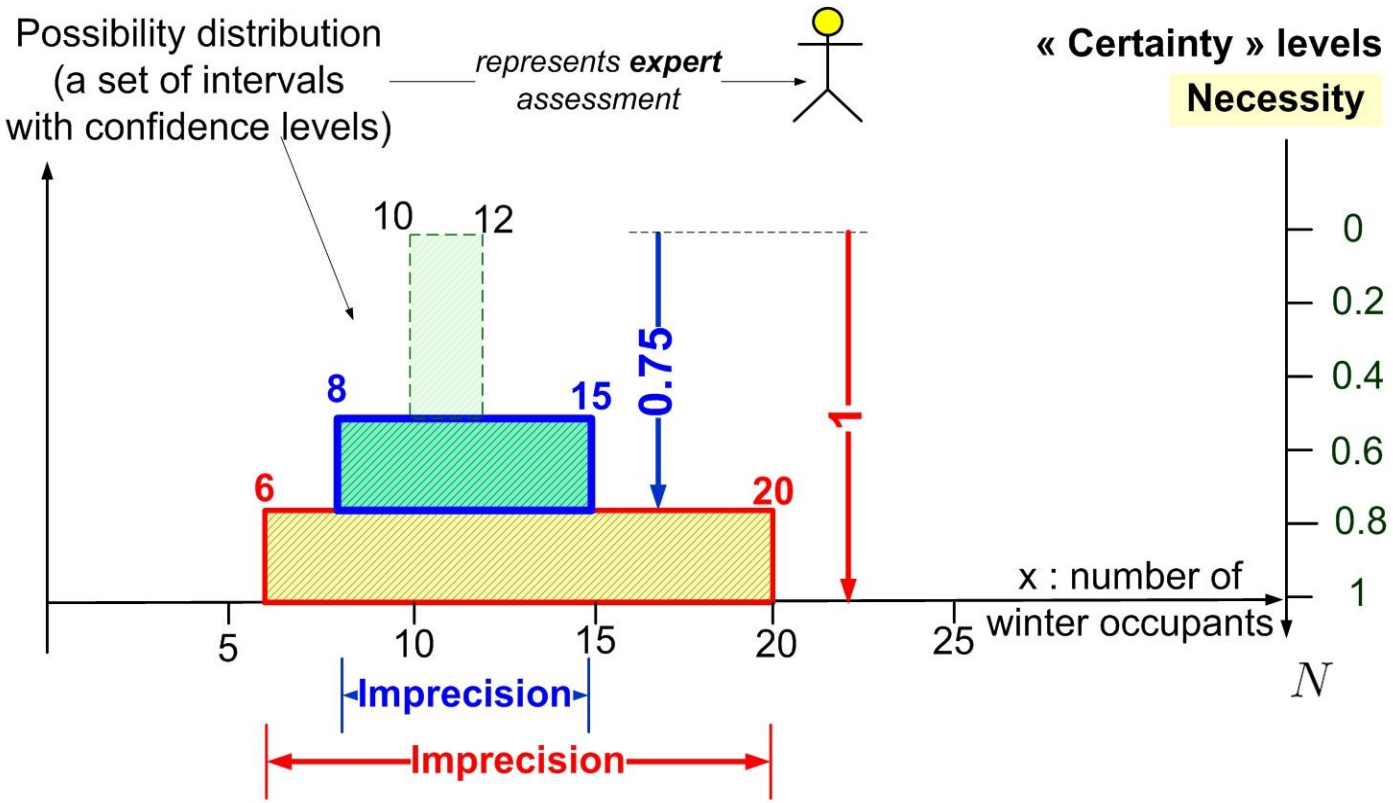
Population density :

- is considered as **medium** (e.g.) between 14 and 20;
- **becomes high** from 20 to 24;
- **becomes low** from 14 to 10.

See (Tacnet et al., 2009, 2010)

Possibility theory (to represent both imprecision and uncertainty)

(Zadeh,1978)
(Dubois,1988)



Evaluation of the **expert** is **imprecise** : he thinks that "Number of occupants is between **8** and **15**"
The expert is **uncertain**: his certainty level for "Number of occupants is between **8** and **15**" equals **0.75**

The **expert** is **still imprecise** but **certain** that "Number of occupants is between **6** and **20**"

See (Tacnet et al., 2009, 2010)

Belief function theory

… or how to go beyond probabilities

Belief = State of **mind** in which **one thinks something to be true**

Paradigm shift

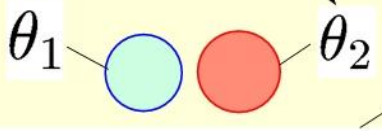
Beliefs often are related with singular event or evidence, and are **not necessarily related with statistical data** and generic knowledge.

Belief function theory *(Shafer,1976)*

The frame of discernment is a set of possible decisions, alternatives...

Frame of discernment

$\Theta = \{\theta_1, \theta_2\}$



Decision hypothesis (e.g. "flooded", "not flooded")

e.g. "flooded" OR "not flooded" : uncertainty...

Powerset → $2^\Theta = \{\emptyset, \theta_1, \theta_2, \theta_1 \cup \theta_2\}$

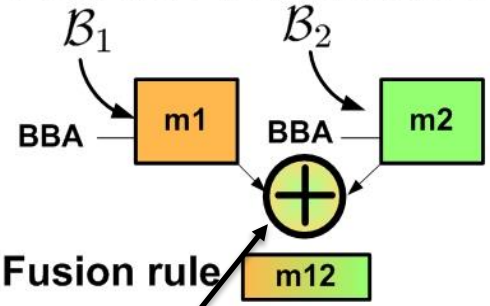
Basic Belief Assignment (BBA)

$$\begin{cases} m(.) : 2^\Theta \rightarrow [0,1] \\ m(\emptyset) = 0 \\ \sum_{\theta_i \in 2^\Theta} m(\theta_i) = 1 \end{cases}$$

$$m(\theta_1) + m(\theta_2) + \underbrace{m(\theta_1 \cup \theta_2)}_{uncertainty} = 1$$

e.g. "expert ***x***", "model ***y***", "database ***z***"

Fusion of 2 sources



See Information fusion

(Shafer,1976)

Many fusion rules exist

See (Tacnet,2009)

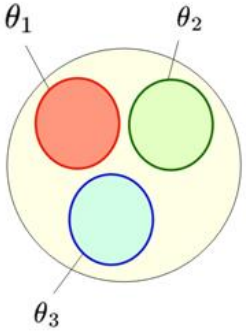
Belief functions' principles

[Dempster 1967,Shafer 1976]

Hypotheses

Frame of discernment (FoD) $\Theta = \{\theta_i, i = 1, \ldots, n\}$ **Power-set** $2^\Theta \triangleq \{X | X \subseteq \Theta\}$

Example



Impossibility — partial ignorances — full ignorance

$$2^\Theta = \{\emptyset, \theta_1, \theta_2, \theta_3, \theta_1 \cup \theta_2, \theta_1 \cup \theta_3, \theta_2 \cup \theta_3, \theta_1 \cup \theta_2 \cup \theta_3\}$$

Basic belief assignment (BBA) $m(\cdot) : 2^\Theta \mapsto [0,1]$ s.t. $m(\varnothing) = 0$ and $\sum_{A \in 2^\Theta} m(A) = 1$

Belief in A: $Bel(A) \triangleq \sum_{B \in 2^\Theta | B \subseteq A} m(B) = Pl(\Theta) - Pl(\bar{A}) = 1 - Pl(\bar{A})$ — **Degree** of **support** of A

Plausibility of A: $Pl(A) \triangleq \sum_{B \in 2^\Theta | B \cap A \neq \varnothing} m(B) = Bel(\Theta) - Bel(\bar{A}) = 1 - Bel(\bar{A})$ — **Degree** of **non contradiction** of A

Interpretation

$$0 \leqslant Bel(A) \leqslant P(A) \leqslant Pl(A) \leqslant 1$$

Lower bound **Upper bound**

(subj.) unknown proba P(A)

The Uncertainty of unknown value of P(A) is **Pl(A)-Bel(A)**

Belief function theory

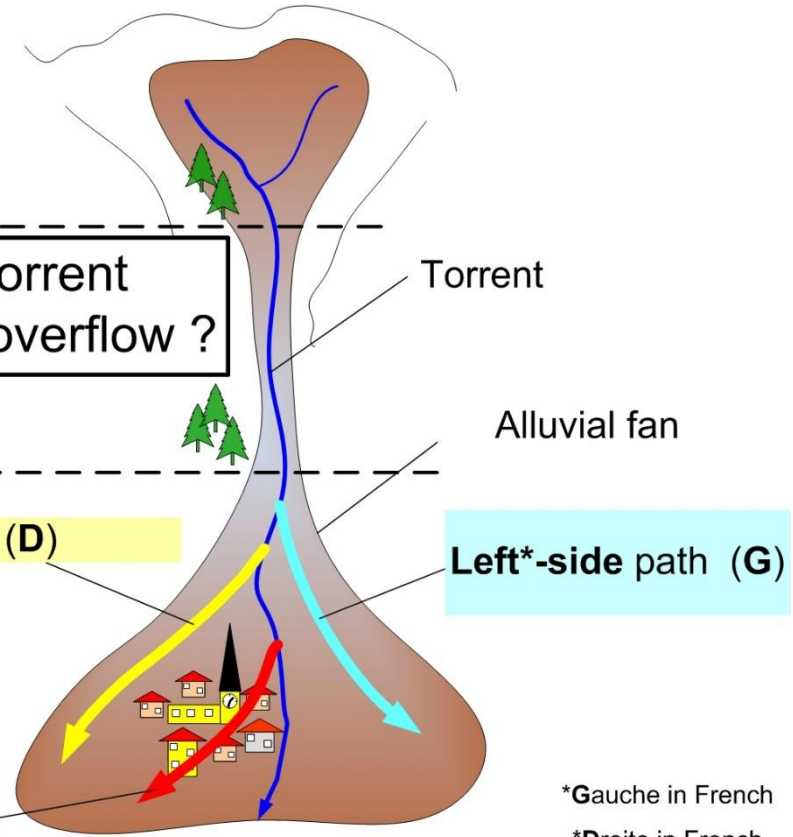
Frame of discernment (hypotheses)

$$\Theta = \{G, D, V\}$$

2 experts (*sources*)

m_1 m_2

Where will the torrent (mountain stream) overflow ?



Experts provide **basic belief assignments** (bbas) on the different hypotheses

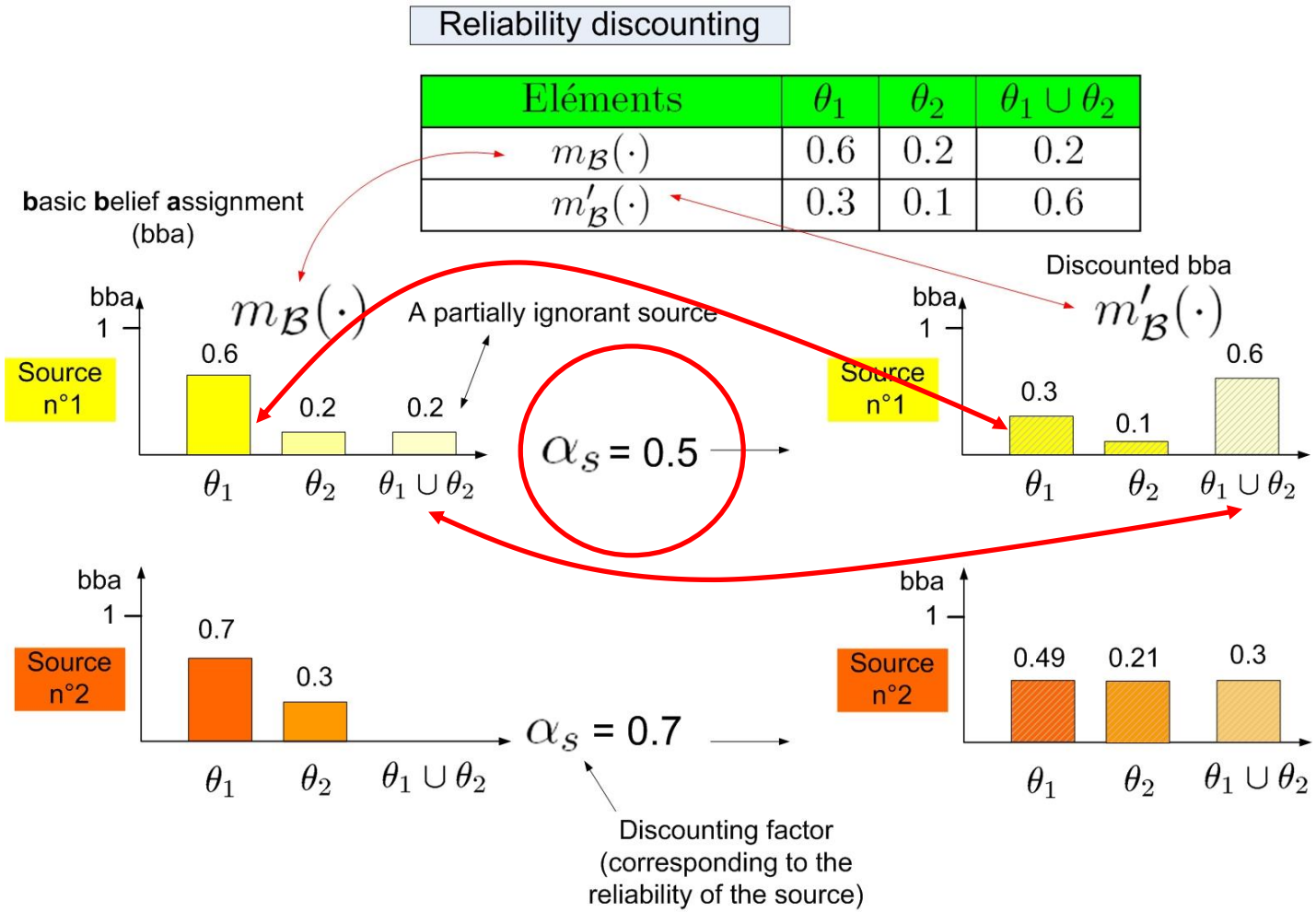
Sources

2 experts

Eléments	Left path G	Right path D	Village path V
m_1	0.99	0	0.01
m_2	0	0.99	0.01

Concept of **conflict**

Different information sources related to the **same « truth »** can be **discounted** according to their **reliability**

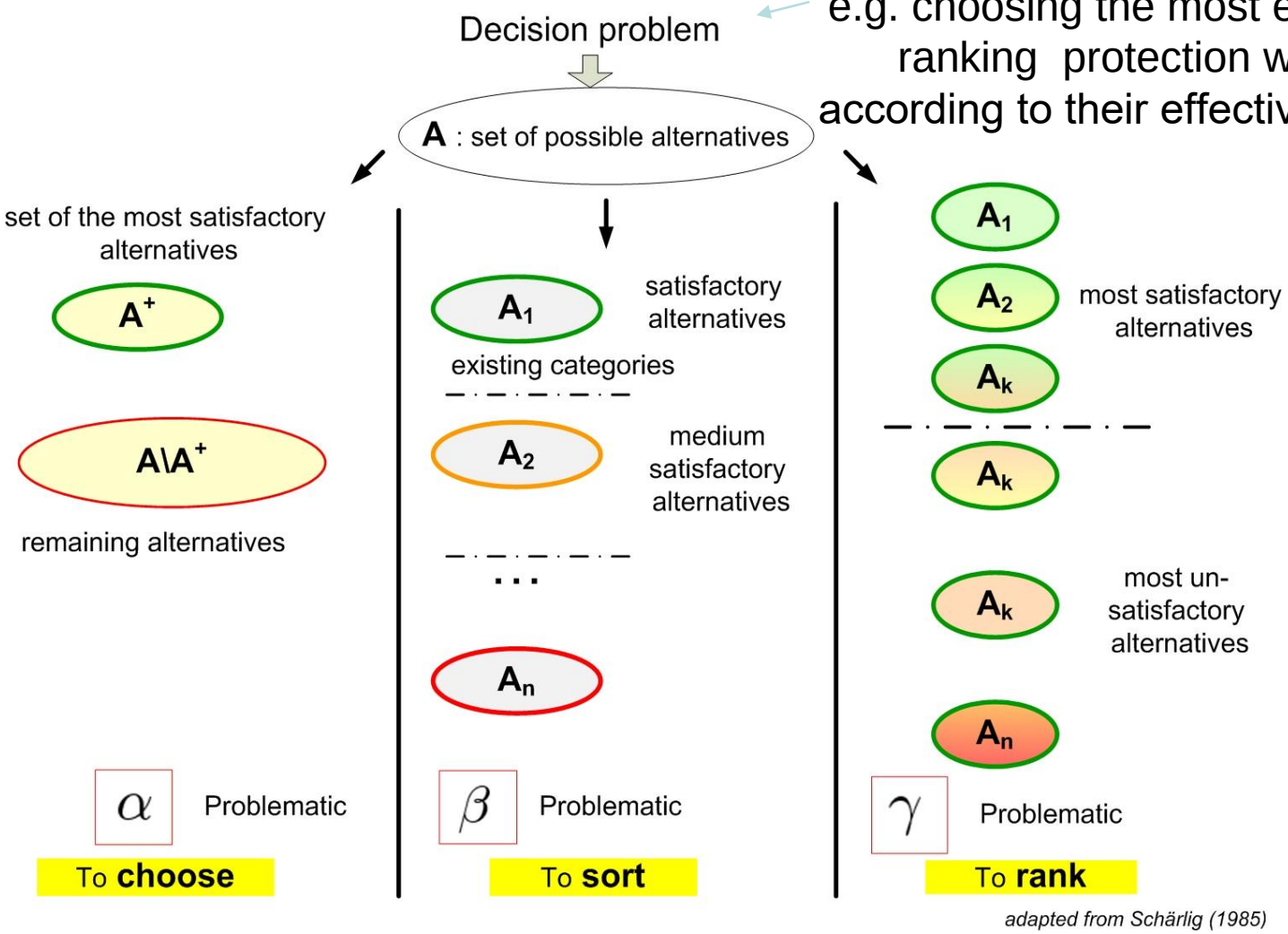


Multicriteria decision-making principles and methods

Difference between total and partial agregation

3 main categories of multicriteria decision-making problems

e.g. choosing the most effective, ranking protection works according to their effectiveness…

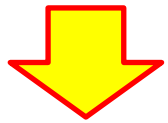


adapted from Schärlig (1985)

See (Tacnet,2009)

Development of **multicriteria decision-making methods** …considering **information imperfection**

Objective: to design **decision-aiding methods** in a context of **heterogeneous** and **imperfect information** provided by **more** or **less reliable sources**…



Use of **belief function theory** (and others theories) to improve **multicriteria decision-making** (MCDM) **methods**

Principles of methods *(several developped since 2009)*…

- ER-MCDA: replacing aggregation by a fusion process (*Choice, Sorting…*)

…. many others such as Soft Electre TRI: improving outranking method (*Sorting*) see references

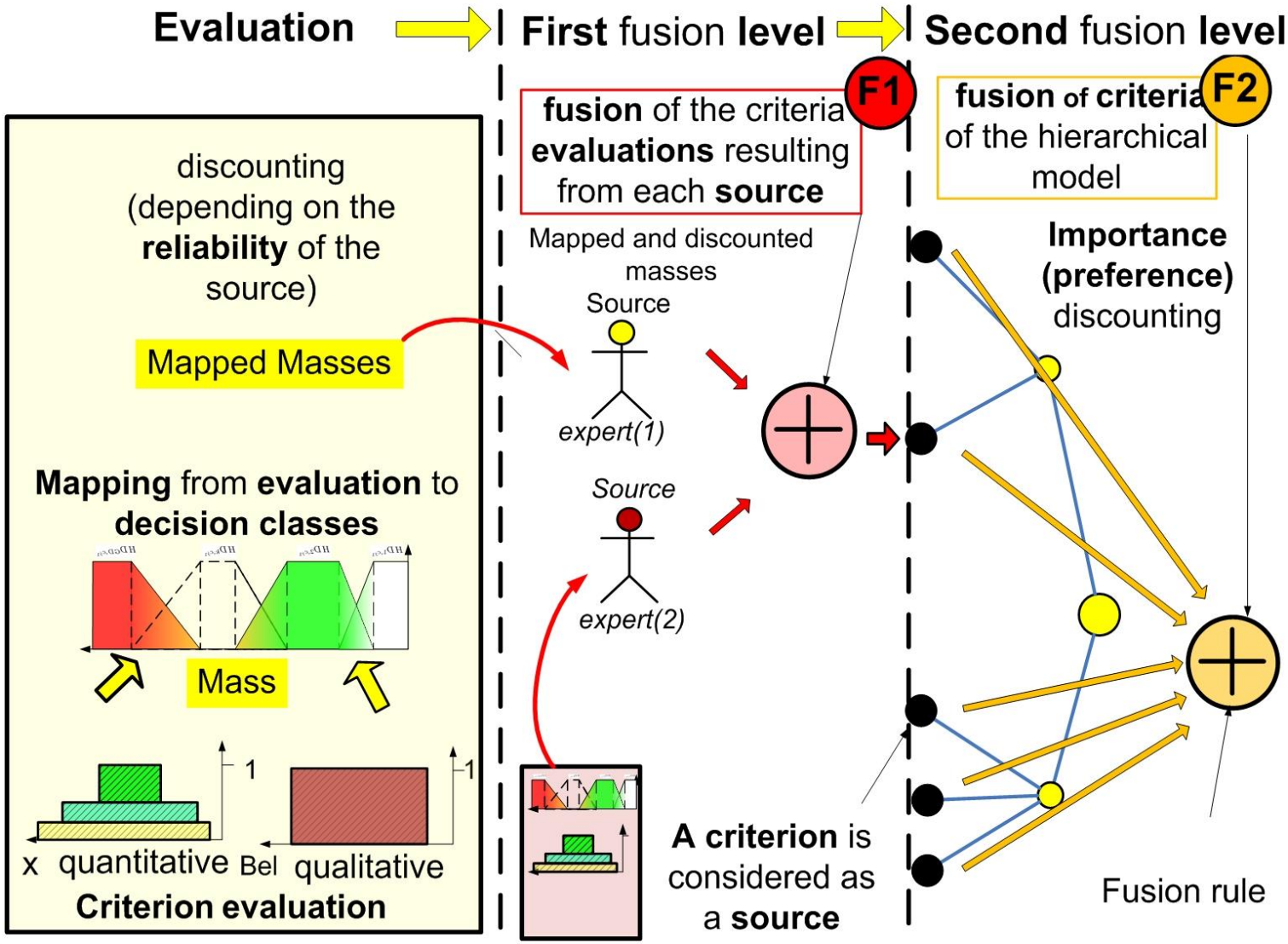
See (Tacnet,2009)

ER-MCDA* methodology overview

**Evidential Reasoning – MultiCriteria Decision Analysis*

ER-MCDA* associates (principles of) multicriteria decision analysis (AHP), fuzzy sets, possibility and belief function theories

(Tacnet, 2009)

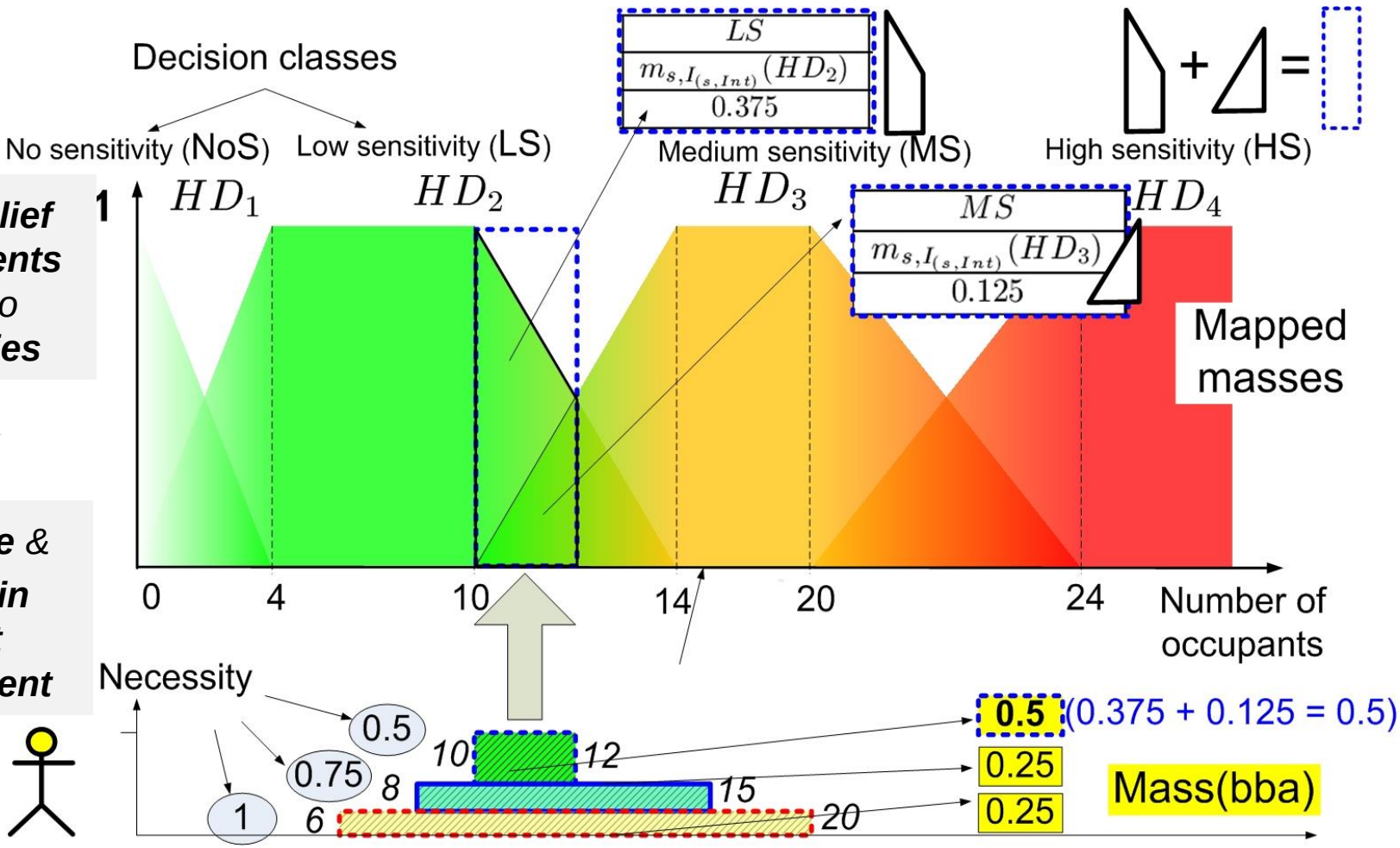


Analytic Hierarchy Process is (only) used to model the problem
(aggregation is replaced by information fusion)

A mapping process to link fuzzy sets, possibility and belief function theories

Basic belief assignments *linked to* ***categories***

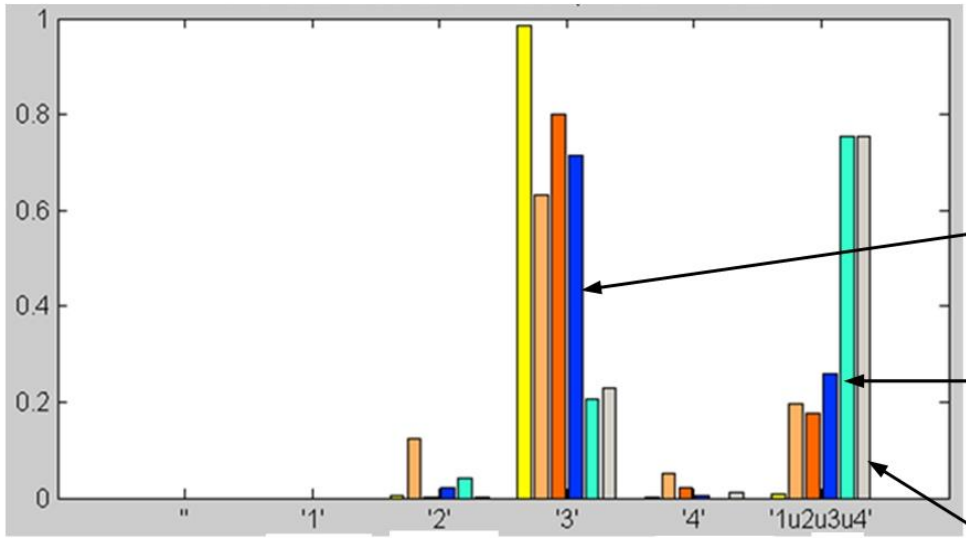
Imprecise & uncertain expert assessment



Source n°1 proposes an imprecise and uncertain evaluation of criterion "Number of occupants"

The method provides not only a single choice but also proposes a **"decision profile"** that informs about **information quality level**

Basic belief assignments (bba's)



For each criterion, we can check the **contribution** to **decision** and the **associated uncertainty**

A **measure of uncertainty** (also for the result)

Hypotheses from the frame of discernment

The possible categories for assignment

No sensitivity

Low sensitivity

Medium sensitivity

High sensitivity

Chosen hypothesis is $\{\mathrm{NoS}\}$

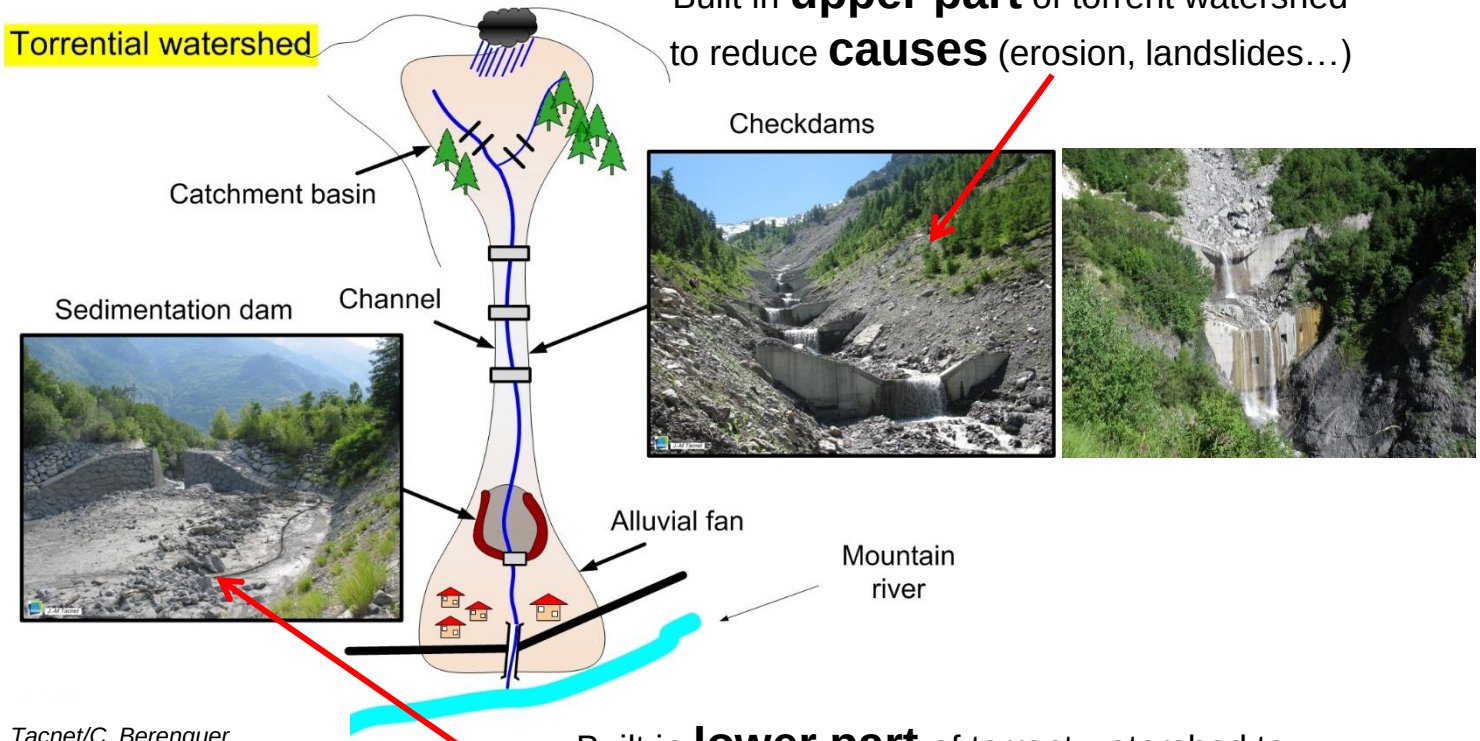
The method **allows** not only **to take a decision** but also **to know how much sources** (criteria) **are supporting the choice**

An application example

Protection works’efficacy assessment

Jean-Marc Tacnet

Structures are built to protect against, reduce natural risks

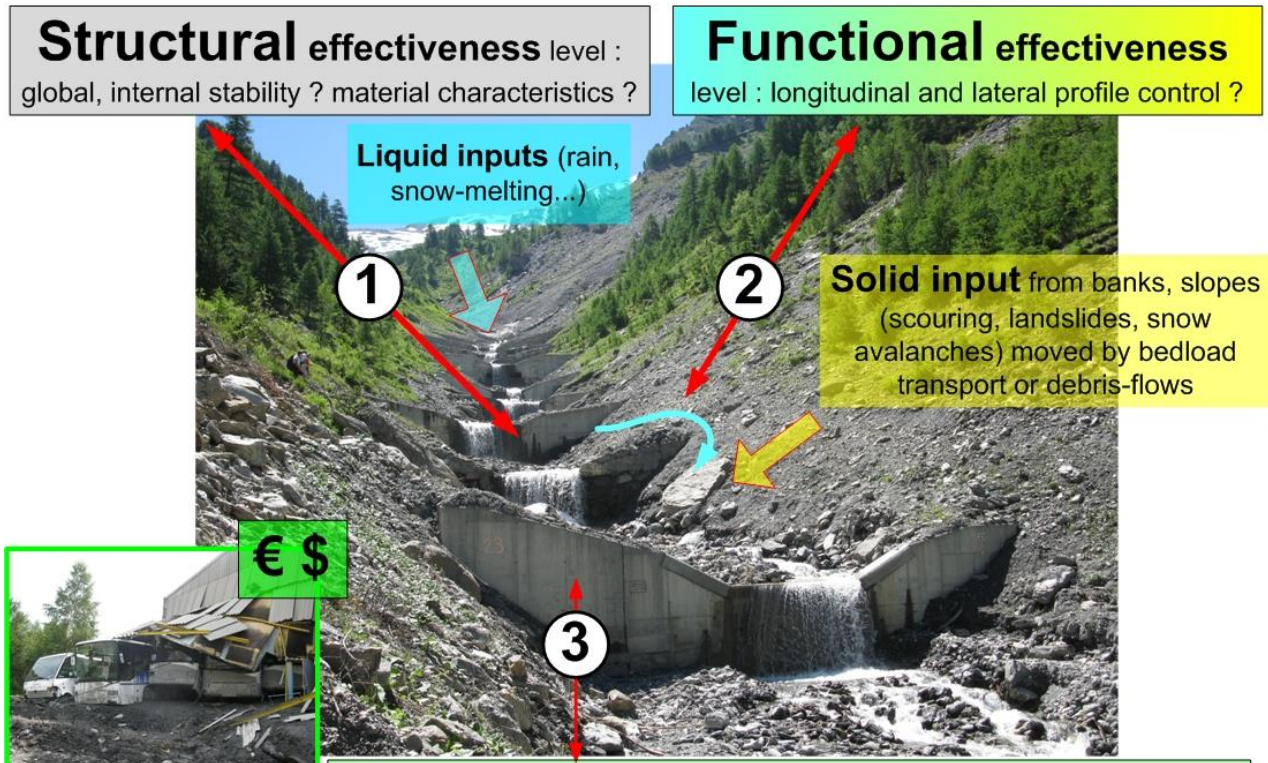


Built in **upper part** of torrent watershed to reduce **causes** (erosion, landslides…)

J.-M. Tacnet/C. Berenguer

Built in **lower part** of torrent watershed to reduce **consequences** near **exposed elements** (people, buildings) **at risk**

Operational question:
Are **protection measures** & **strategies effective**?

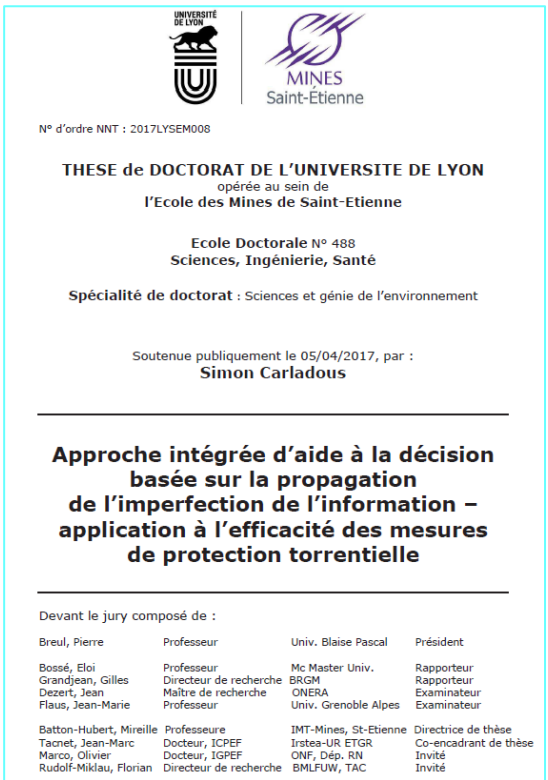


Adapted from (Tacnet, Carladous et al., 2016)

Decision to be taken : what is the checkdams' series efficacy?

1. **Alternatives** A_i to be assessed, ranked, stored

See Simon Carladous' PhD



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Spécialité de doctorat : Sciences et génie de l'environnement

Soutenue publiquement le 05/04/2017, par :
Simon Carladous

Approche intégrée d'aide à la décision basée sur la propagation de l'imperfection de l'information – application à l'efficacité des mesures de protection torrentielle

Devant le jury composé de :

Breul, Pierre	Professeur	Univ. Blaise Pascal	Président
Bossé, Eloi	Professeur	Mc Master Univ.	Rapporteur
Grandjean, Gilles	Directeur de recherche	BRGM	Rapporteur
Dezert, Jean	Maître de recherche	ONERA	Examinateur
Flaus, Jean-Marie	Professeur	Univ. Grenoble Alpes	Examinateur
Batton-Hubert, Mireille	Professeure	IMT-Mines, St-Etienne	Directrice de thèse
Tacnet, Jean-Marc	Docteur, ICPEF	Irstea-UR ETGR	Co-encadrant de thèse
Marco, Olivier	Docteur, IGPEF	ONF, Dép. RN	Invité
Rudolf-Miklau, Florian	Directeur de recherche	BMLFUW, TAC	Invité

3 check dams' series

Function: stabilization

A_1

28 check dams

A_2

25 check dams

A_3

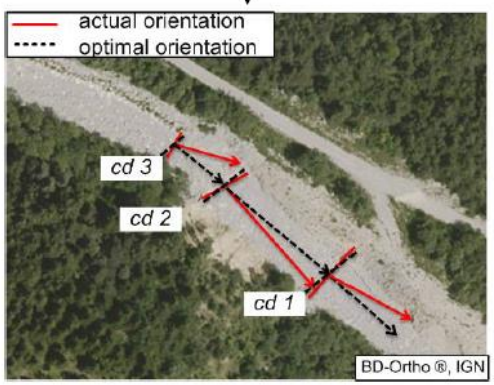
3 check dams

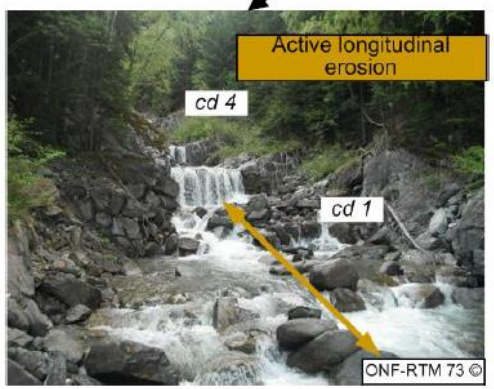
Identifcation of relevant criteria

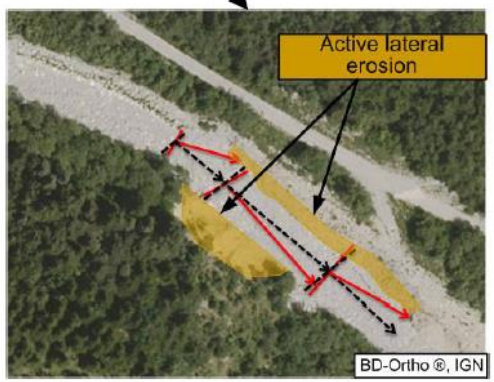
2. **Effectiveness criteria** g_j to be taken into account

g_1 - smallest free spillway dimensions	g_2 - check dams' mean orientation	g_3 - longitudinal implantation of check dams	g_4 - stability of significant check dams	g_5 - stability of other check dams	g_6 - active longitudinal erosion	g_7 - active lateral erosion
w_1=0.1	w_2=0.2	w_3=0.1	w_4=0.15	w_5=0.05	w_6=0.2	w_7=0.2
0 - 100%	0 - 90°	meters	0 - 10	0 - 10	0 - 100%	0 - 100%

definition
weight
scoring scale







Considering information imperfection to assess criteria

Expert assessment of structural effectiveness

is actually based on **imperfect information** to evaluate each criterion

expert

evaluates

g_6

"***I'm sure*** the scouring depth is lower than 4 m and higher than 2 m.

I'm 30% sure it is lower than 3.5 m and higher than 2.5 m."

g_1: rotation angle around the vertical axis – *degree (°)*

g_2: slipping / translation – *meter (m)*

g_3: lateral support erosion through bypass – *meter (m)*

g_4: rotation angle around the horizontal axis – *degree (°)*

g_5: collapse – *meter (m)*

g_6: support erosion through scouring – *meter (m)*

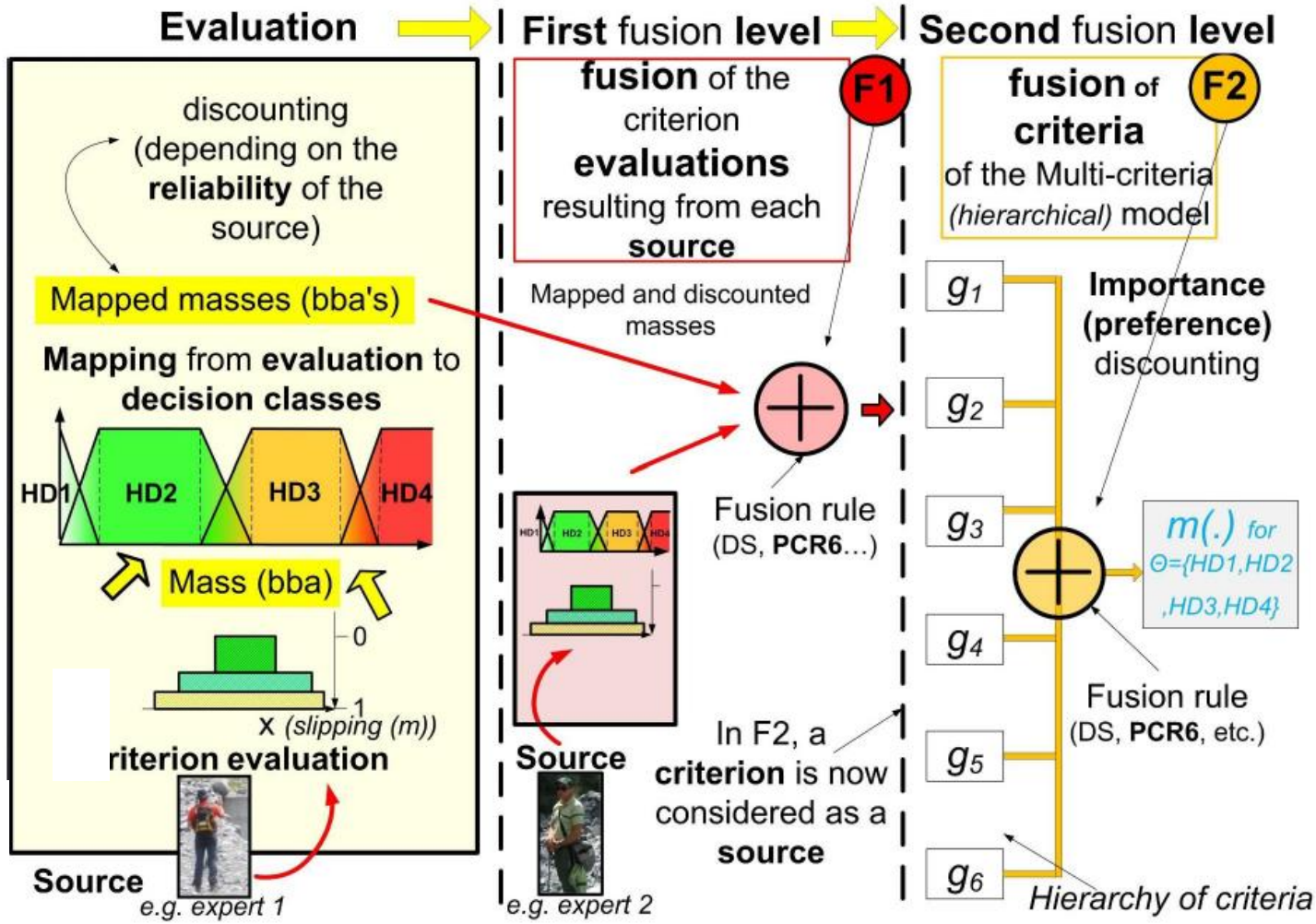
→ Observed external **structural effectiveness**

Imprecise and uncertain information

Imperfect assessment are fused to take a decision

Evidential Reasoning for Multi-Criteria Decision Analysis

(Tacnet, 2009)



Imperfect assessment are fused to take a decision

Evidential Reasoning for Multi-Criteria Decision Analysis

can be actually applied

Structural effectiveness

Expert 1 *more reliable than* Expert 2

evaluates with imperfection

evaluates with imperfection

g_1 g_2 g_3 g_4 g_5 g_6

structural effectiveness

θ={HD1,HD2,HD3,HD4}

HD1: high
HD2: medium
HD3: low
HD4: none

High
Medium
Low
None

Floods with bed-load transport

S_3: $Q_s < Q_{s1}$

A_2

	$m^{normalized}_{PCR6_\emptyset}(.)$
$\emptyset$	0
HD1	0.16094
HD2	0.45901
HD3	0.33559
HD4	0.00494
Θ	0.03951

Basic belief assignments resulting from information fusion

A_2 is **mainly medium effective**.
Its actual effectiveness is more **between low and medium**, but not high, nor none.

A measure of global ignorance is provided

Key home messages

1) Uncertainty is **not** the **only kind** of **information imperfection :** several frameworks

2) Risk management requires taking **decision**s based on **imperfect, heterogeneous knowledge** and **more or less reliable** sources : **some models exist** to **assess risk ,** to **trace reasoning process** and to help decision-making

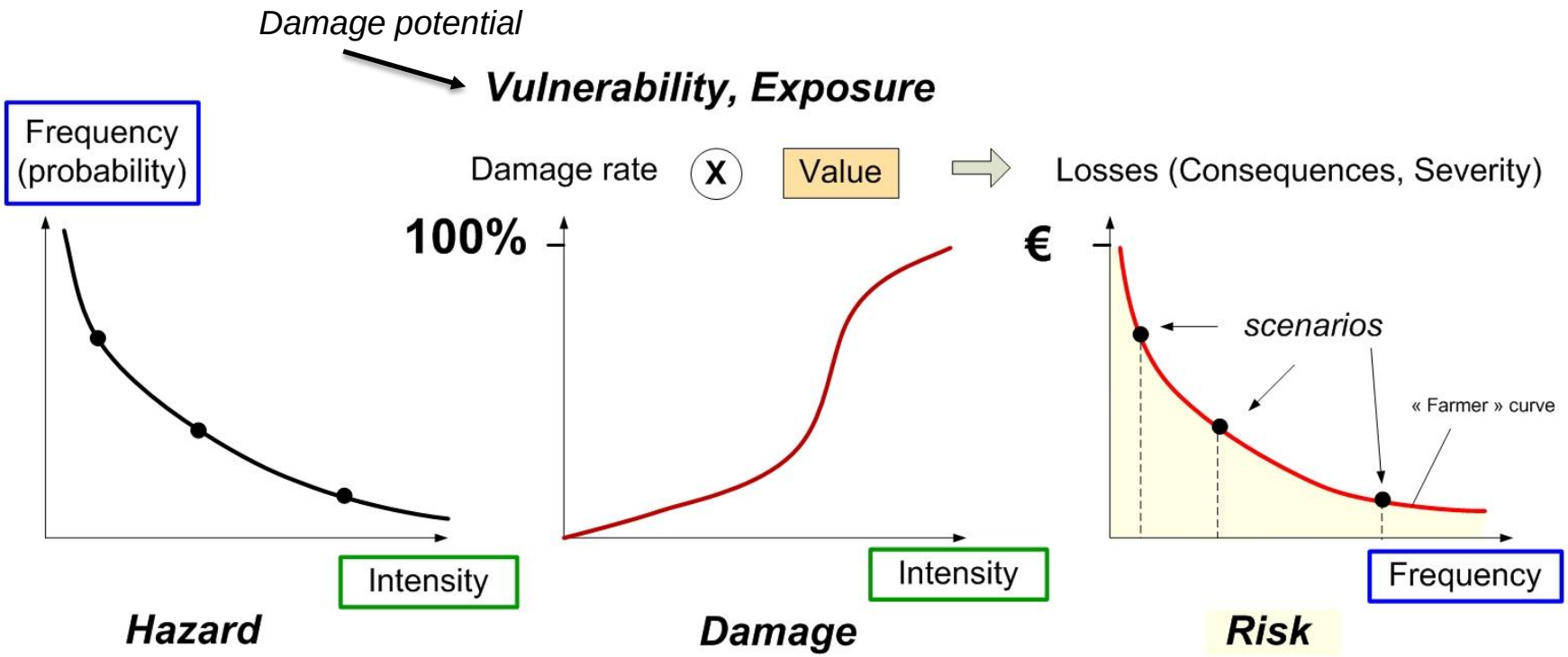
3) Considering multicriteria decision-aiding methods, some paradoxes remain : **simple methods may** have **drawbacks but** are **understandable**. **Powerful methods** are **difficult** to **explain** and **understand**, they become **black-boxes**…

4) Considering information imperfection is possible but **using it** for **decision-making** remains tricky since nobody (incl. a decision-maker) likes « uncertainties »

On-going applications relates to protection and strategies' effectiveness assessment and preventive maintenance of infrastructures, protection works

BONUS

Risk components



Source Tacnet et al., 2020 – Naiad project

How to decide with belief functions? Several strategies (e.g.)

Maximum of belief (**pessimistic/cautious**)

$$m(\cdot) \rightarrow Bel(\cdot) \quad \text{and} \quad \delta = \hat{\theta} = \arg\max_{\theta_i \in \Theta} Bel(\theta_i)$$

Maximum of plausibility (**optimistic**)

$$m(\cdot) \rightarrow Pl(\cdot) \quad \text{and} \quad \delta = \hat{\theta} = \arg\max_{\theta_i \in \Theta} Pl(\theta_i)$$

Compromise with **transformation** into a **probability** (e.g. BetP, links with probabilities)

$$m(\cdot) \rightarrow P(\cdot) \quad \text{and} \quad \delta = \hat{\theta} = \arg\max_{\theta_i \in \Theta} P(\theta_i)$$

Soft ELECTRE TRI (SET) method

for sorting alternatives into categories
based on multi-criteria analysis

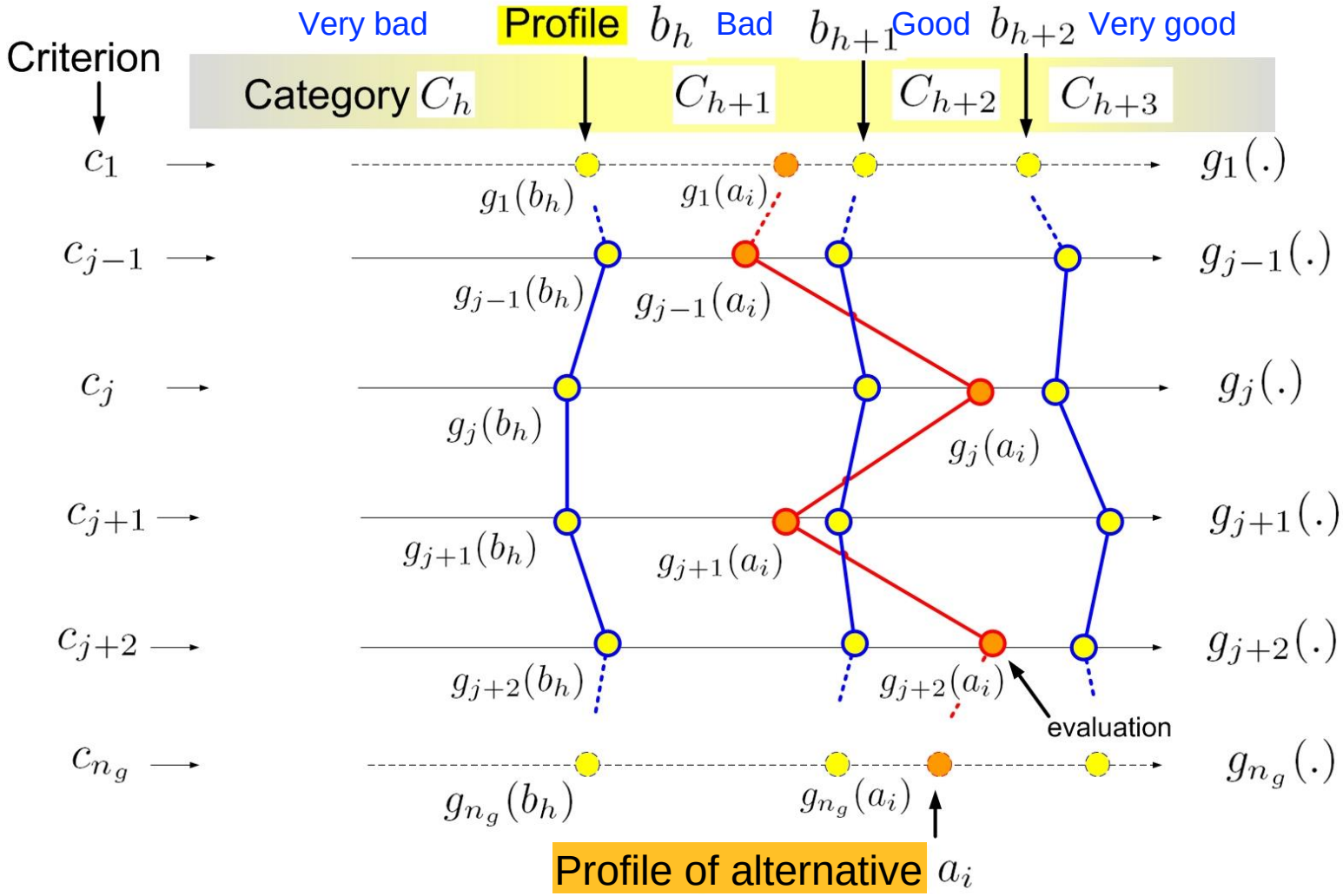
Introduction of BF Theory in … **ELECTRE** = **EL**imination **E**t **C**hoix **T**raduisant la **RE**alité [Roy 1968]

ELECTRE (1968) → *ELECTRE TRI (1992)* → *Soft ELECTRE TRI [Dezert-Tacnet 2012]*

Sorting alternatives in categories

For each criteria, we preset categories by some profile bounds

Which category does a_i belong to? $a_i > b_h$?

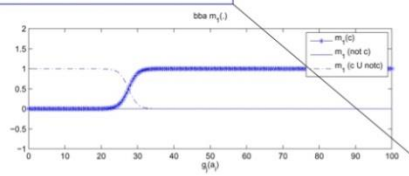


From **partial concordances and discordance indices** to **sigmoidal based bba's**

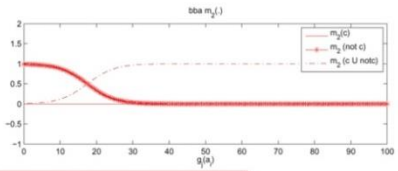
More consistent representation

(Dempster, PCR5, or hybrid rule)

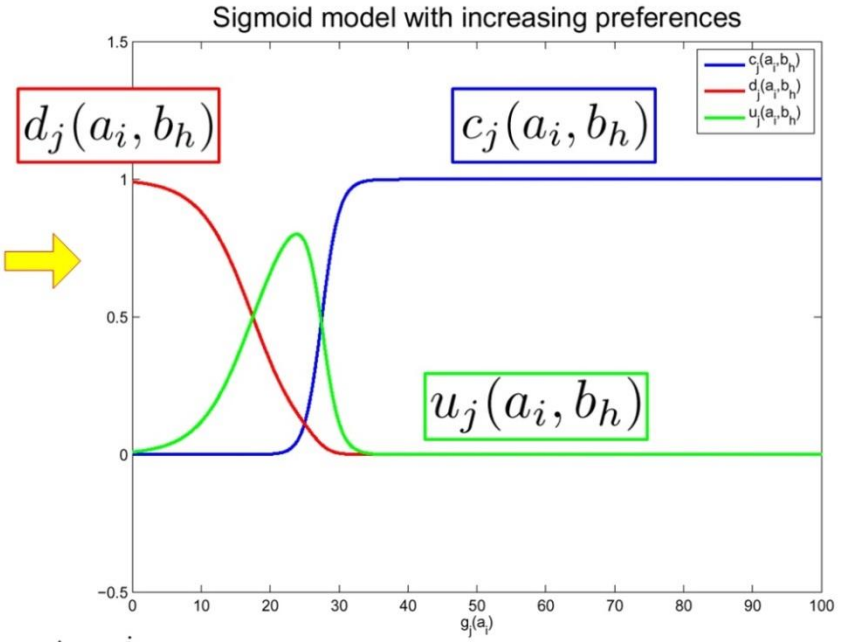
$f_1(g) \triangleq f_{s_c,t_c}(g)$



$$m^j_{ih}(.) = [m_1 \oplus m_2](.)$$



$f_2(g) \triangleq f_{-s_{\bar{c}},t_{\bar{c}}}(g)$



Local concordance	$c_j(a_i,b_h) \triangleq m^j_{ih}(c)$
Local discordance	$d_j(a_i,b_h) \triangleq m^j_{ih}(\bar{c})$
Uncertainty	$u_j(a_i,b_h) \triangleq m^j_{ih}(c \cup \bar{c})$

with $c_j(a_i,b_h) + d_j(a_i,b_h) + u_j(a_i,b_h) = 1$

c means that the alternative a_i is concordant with the assertion "a_i is at least as good as profile b_h"
$\bar{c}$ means that the alternative a_i is opposed (discordant) to this assertion

Soft ELECTRE TRI – An application to storm risk assessment

Physical parameters related to storm hazard are transformed in criteria

PConv is the 3-h accumulated **precipitation**

LI is the lifted index which characterizes the **instability** of the atmosphere

CAPE is the **convective** available potential **energy**

DivB is the **low-level wind divergence** if convective clouds in the cell

DivS is the **wind divergence above** the top of the convective **clouds**

Criteria	Units	Preference ordering	Importance weight
G_1 = PConv	kg/m^2	increasing	very high
G_2 = LI	$^\circ K$	decreasing	very high
G_3 = CAPE	J/kg	increasing	high
G_4 = DivB	s^{-1}	decreasing	low
G_5 = DivS	s^{-1}	increasing	low

Table I: Criteria used for SET method.

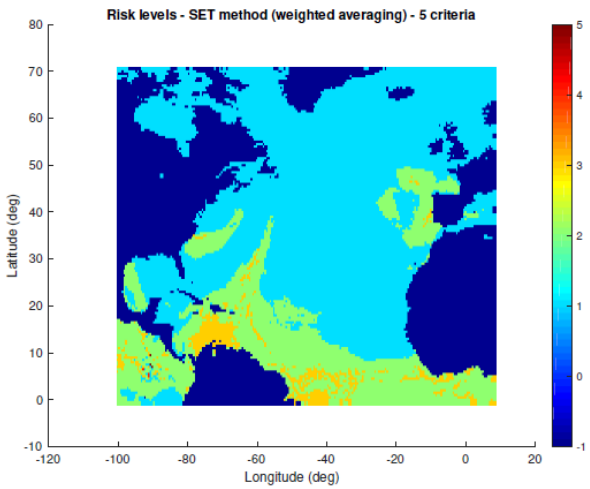


Figure 9: Storm risk levels based on SET (averaging rule).

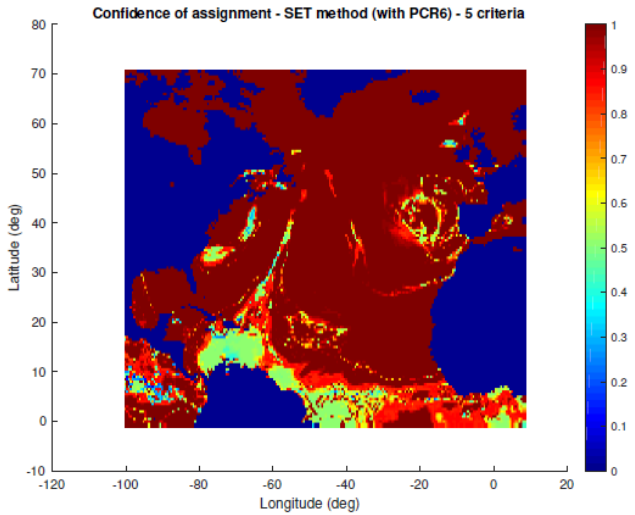


Figure 12: Confidence in decision (SET with PCR6 rule).

Rate of **good lightning prediction is 95%**; **rate** of **false alarms** (false predictions) **is 29%**.

(Dezert et al., 2021) in International conference on Information Fusion

(ONERA 2020-2021 study)

Many **decisions** involving several actors at different steps have to be taken to **assess** and **manage risks**

Decisions for **nonstructural mitigation measures**

PREVENTION

St Etienne de Tinée – 2009 (L. Bernard/National Park of Mercantour)

Torrent St Antoine – Modane - Savoie – 1987(M. Meunier – *Cemagref)*

What are the **hazard, risk levels**?

Land-use planning: where should **urbanisation** be **prohibited**, **regulated** or **fully allowed**?

Decisions for choice of **protection works design** and **maintenance strategies**

PROTECTION

Photo: *Cemagref*

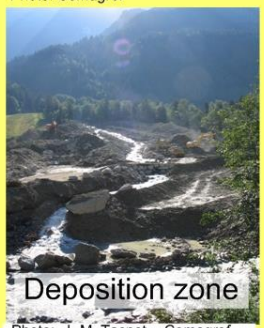


Photo: J.-M. Tacnet – *Cemagref*

Photo: J.-M. Tacnet – *Cemagref*

Which **protection** is **needed**? Is it **effective**?

Decisions for **(railroad) infrastructure** management

EVENT MANAGEMENT

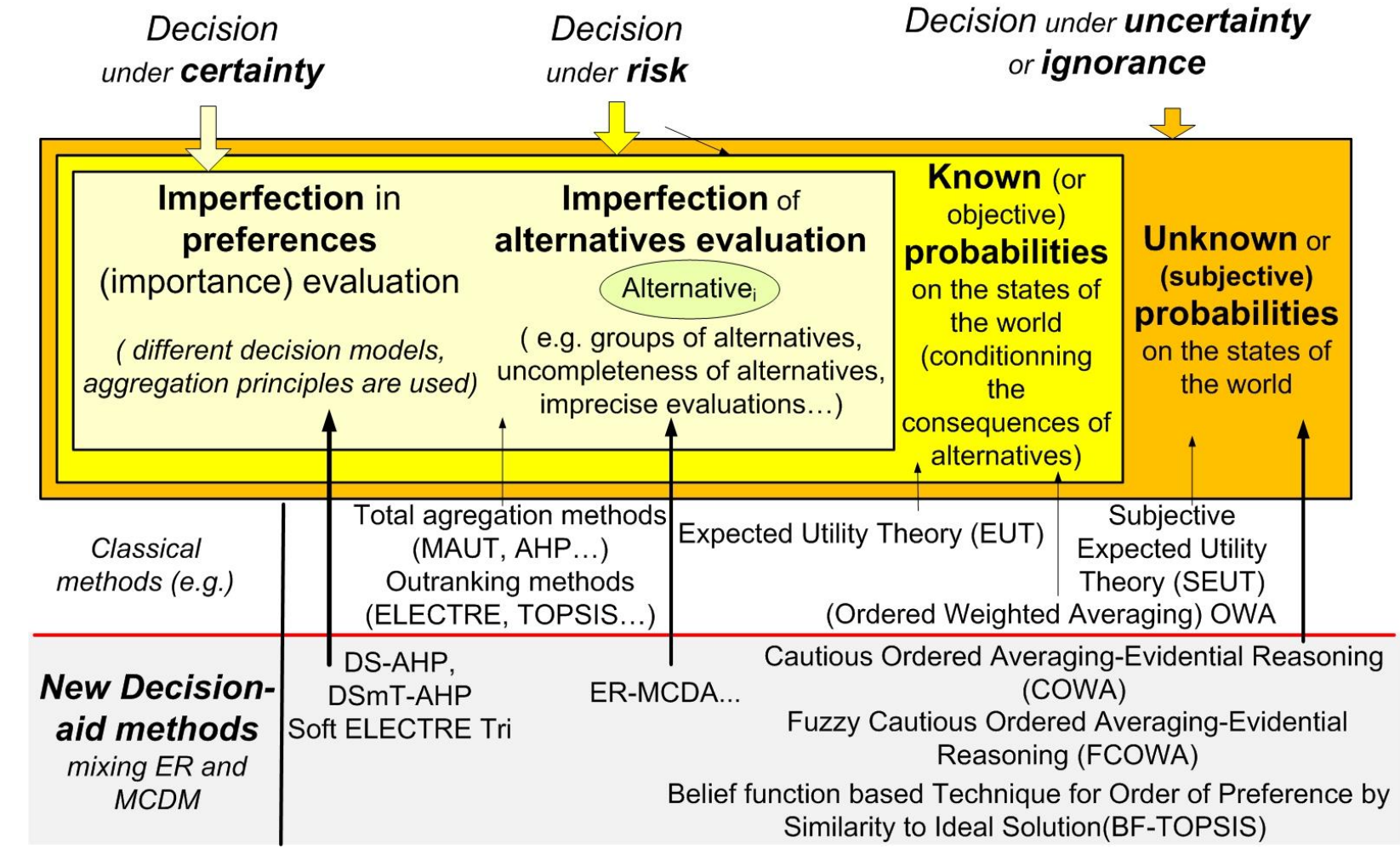
Photo: J.F. Casanova –Dauphiné Libéré

Photo: J.-M. Tacnet – *Cemagref*

Should we **close**, **re-open**, **monitor** this road?

(Tacnet et al., 2014)

Several (other) methods exist to decide under imperfect information contexts mixing uncertainty theories and multicriteria decision-making methods (e.g.) …



Adapted from (Tacnet and Dezert, 2012)

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