APPLYING NEW UNCERTAINTY RELATED THEORIES AND MULTICRITERIA DECISION ANALYSIS METHODS TO SNOW AVALANCHE RISK MANAGEMENT

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ABSTRACT:

Taking the "best" decision is an important issue in the natural risks expertise and management process because of lack of information and knowledge about natural phenomena and also because of the heterogeneity and reliability of information sources (historical data, field measures, expert judgements). One main problem is therefore to help decision making with regard to the respective quality, importance, reliability of available information. This article presents a new method called *ER-MCDA* to help decision making considering information imperfections arising from several of more or less reliable and possibly conflicting sources of information.

First, principles of existing methods are reminded. Classical methods of multi-criteria decision making and existing theories to represent and propagate information imperfections are described.

In a second point, we describe the principle of a the *ER-MCDA* method mixing from one hand multicriteria decision analysis (*MCDA*) to model the decision problem and from the other hand Fuzzy Sets theory, Possibility and Evidence Theories (*ER*) to represent, fuse and propagate information imperfections. Experts, considered as more or less reliable, provide imprecise and uncertain evaluations of quantitative and qualitative criteria which are combined through information fusion.

As an example, the method is applied to a simplified version of an existing system aiming to evaluate the sensitivity of avalanche sites. This new method allows to consider both information importance and reliability in the decision process. It also contributes to the traceability improvement. Some others developments are under progress to deal with other expertise problems such as avalanche triggering conditions or data quality.

KEYWORDS: snow avalanches, risk management, expert judgement, reliability, uncertainty, decision making, multicriteria decision analysis, Analytic Hierarchy Process (*AHP*), Information Fusion, Fuzzy Sets theory, Possibility theory, Evidence theory, Dempster Shafer Theory (*DST*), Dezert-Smarandache Theory (*DSmT*).

1. INTRODUCTION

Rapid mass movements hazards such as snow avalanches put humans and material assets at risk with dramatic consequences. In a context of lacking knowledge about the natural phenomena, expertise is required to provide analyses for decision and risk management purposes using multi-disciplinary quantitative or qualitative approaches.

Those decisions are closely linked to available information. Expert judgements depend on the availability, quality and uncertainty of the available information that may result from measures, historical analysis, testimonies but also subjective, possibly conflicting, assessments done by the experts themselves. At the end, phenomenon scenarios and decisions may very well rely on very uncertain and conflicting information without being able to really know what was completely true, imprecise, conflicting or simply unknown in the hypotheses leading to the result. At the same moment, traceability and shared decision-aid tools are expected from the stakeholders for better understanding and use of expertise results in an integrated

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risk management framework able to consider both technical, environmental and social aspects of decision (Tacnet, 2009).

This article proposes a new method to both help decision and consider information imperfection represented by subjective, imprecise, uncertain qualitative and quantitative evaluations . First, we briefly remind the existing methods related to information imperfection and multicriteria decision analysis.

In a second part, referring to a recent avalanche, qualitative elements related to reliability are described. A quantitative evaluation methodology, based on the Analytic Hierarchy Process, is then proposed.

Finally, the limits of the proposed approach and needs for further developments are discussed. The link between reliability and data traceability appears as a main issue.

2. EXPERTISE, INFOMATION AND DECISIONS

2.1 *Why is expertise needed in snow avalanche risk management*

Expertise, involving technical decisions or choices, is required at all steps of the risk management process (crisis, post-crisis and prevention steps).

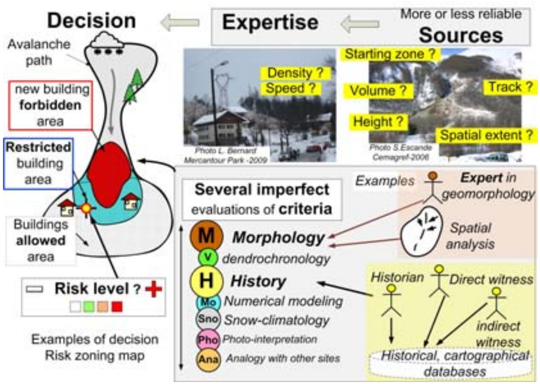

Figure 1 : Expertise often results from or uses imperfect information coming from heterogeneous sources

The snow avalanche expertise process concern all steps of the risk management process ranging from post-event analysis to risk analysis and protection measures. To describe avalanches conditions, information availability is highly variable (Tacnet et al., 2006) and subject both to spatial, qualitative and quantitative uncertainty (figure 1).

2.2 *Data quality impacts the risk management process*

Due to restricted data availability or survey conditions, data quality are not always as complete, precise and certain that expected in ideal conditions. At the end, risk management decisions depend both on available primary data and information but also on reliability of sources including experts (figure 2). This traceability of information should be included in information systems (Barral et al., 2010).

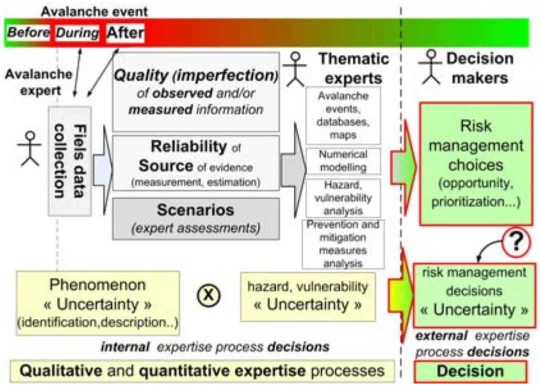

Figure 2 : Expertise process and information imperfection propagation (Tacnet,2009)

Due to the context of natural hazards, information is often quite imprecise and subjective. Qualification of information quality, sources reliability and propagation of imperfection quality from data collection to risk management decisions is an important issue.

Though expert judgements are essential components of the risk management process, none of the existing methods can both trace the reasoning processes and consider both information imperfection, and sources heterogeneity and/or reliability. This implies to consider decision-aid methods and theories for uncertainty management.

3. PRINCIPLES OF MULTICRITERIA DECISION ANALYSIS

Multi-criteria decision analysis (MCDA) aims to choose, sort or rank alternatives or solutions according to criteria involved in the decision-making process. MCDA consist in identifying decision purposes, defining criteria, eliciting preferences between criteria, evaluating alternatives or solutions and analyzing sensitivity with regard to weights, thresholds....(figure 3).

Complete aggregation methods such as the Multi-Attribute Utility Theory (M.A.U.T.) (Keeney,1976) (Dyer,2005) synthesizes in a unique value the partial utility related to each criterion and chosen by the decision maker. Each partial utility function transforms any quantitative evaluation of criterion into an utility value. The additive method is the simplest method to aggregate those utilities (figure 3).

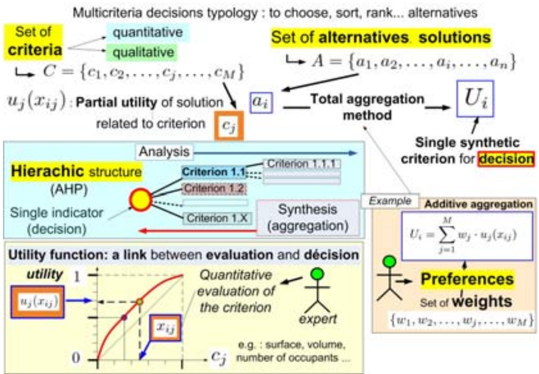

Figure 3 : Multicriteria decision analysis principles – Classical approach

The AHP principle is to arrange the factors considered as important for a decision in a hierarchic structure descending from an overall goal to criteria, sub-criteria and finally alternatives in successive levels. It is based on three basic steps: decomposition of the problem, comparative judgments and hierarchic composition or synthesis of priorities . As a single synthesizing criterion approach, the Analytic Hierarchy Process (AHP) (Saaty,1980) AHP is a special case of complete aggregation method based on an additive preference aggregation.

Those methods are neither natively able to consider imperfection of criteria evaluations or multiple and possibly conflicting evaluations.

4. REPRESENTATIONS OF INFORMATION IMPERFECTION

Decision is closely linked to information quality. Uncertainty, as often used in common language, is indeed only one among all kinds of information imperfection: unconsistency, imprecision, uncompleteness and uncertainty (figure 4).

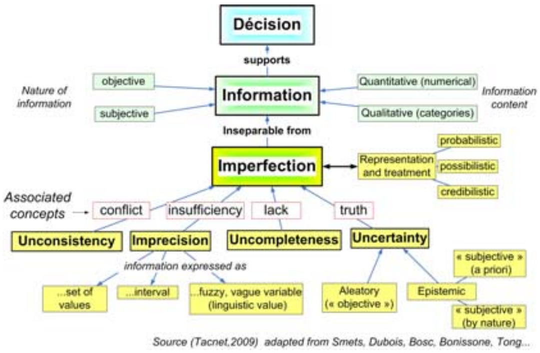

Figure 4 : Different kinds of information imperfection (Tacnet,2009)

Probability theory is widely used in the natural hazards context to represent uncertainty but fails to handle both vague, imprecise, uncertain and conflicting information. “New uncertainty theories” have been proposed to handle different kinds of imperfect information such as evaluations provided through natural hazards expert judgements: fuzzy Sets Theory for vague information (Zadeh,1965), Possibility Theory for uncertain and imprecise information (Zadeh,1978) (Dubois,1988) and Belief Function Theory that allows to consider uncertain, imprecise and conflicting information. In addition to original *Dempster-Shafer* theory (DST) (Shafer,1976), *Dezert-Smarandache* (DSmT) theory has proposed new principles and advanced fusion rules to manage conflict between sources (Dezert and Smarandache,2004-2009).

4.1 Fuzzy sets theory : from quantitative to vague concepts

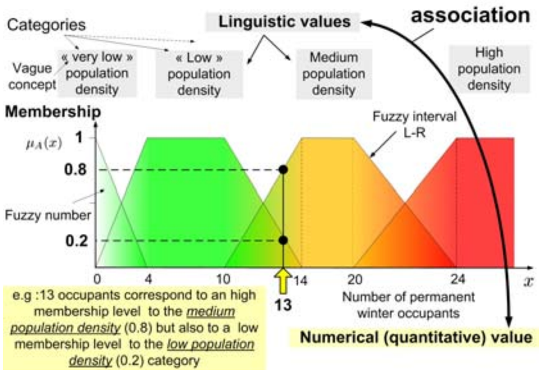

Figure 5 : Fuzzy sets associate numerical and linguistic values

Fuzzy sets theory allows to make a link between an imprecise evaluation of a quantitative criterion (e.g. number of occupants) and a qualitative category (e.g. high, medium or low number of occupants) (figure 5).

4.2 *Possibility theory : imprecision and uncertainty*

Possibility theory propose to represent both imprecision and uncertainty using possibility distribution. Instead of giving a unique discrete value, several consonant intervals with increasing confidence levels can be chosen: the wider is the interval, the more confident is the expert in its evaluation (figure 6).

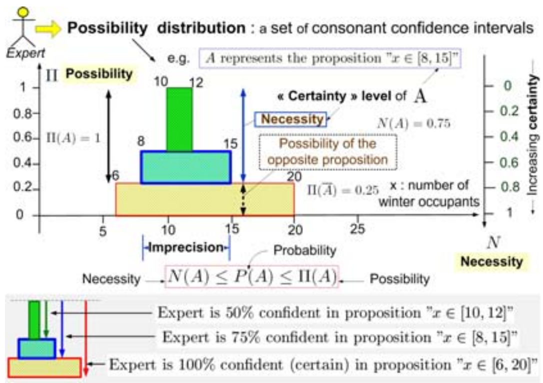

Figure 6 : Expert propose imprecise and uncertain evaluations of quantitative criteria

4.3 *Evidence or Belief function theory : fusion of (un)reliable and conflicting sources*

Evidence or Belief function theory allows to represent and fuse information evaluation provided by more or less reliable and conflicting sources on the same hypotheses of a set called the *frame of discernment*. Each source (e.g. an expert) defines basic belief assignments (bba's). In the classical *Dempster-Shafer* Theory (*DST*), all the hypotheses are exhaustive and exclusive. A new theory called *Dezert-Smarandache* Theory (*DSmT*) offers a more versatile framework to represent uncertain, imprecise but also vague concepts (figure 7).

Information fusion consists in "conjoining or merging information that stems from several sources and exploits that conjoined or merged information in various tasks such as answering questions, making decisions, numerical estimation" (Bloch and al., 2001). Sources can be discounted with regard to their reliability. A specific discounting method has been proposed to consider separately importance and reliability (Smarandache et al., 2010).

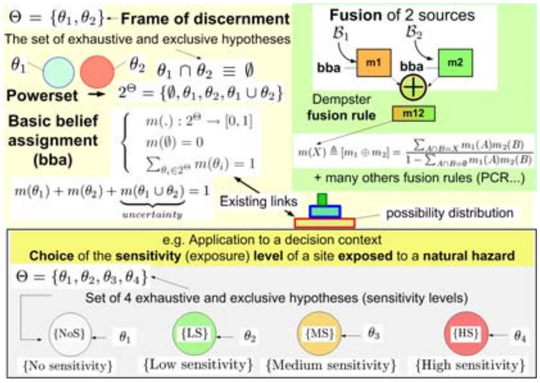

Figure 7 : Essentials of belief function theory: frame of discernment, basic belief assignments (bba) and fusion rules in *DST* context.

The Dempster fusion rule operating in the classical *DST* framework is only one of the many others existing rules. The *DSmT* framework proposes powerful fusion rules (PCR rules) in case of conflicting sources (Dezert and Smarandache,2006).

5. THE *ER-MCDA* METHODOLOGY

Expertise is here considered as a decision process based on imperfect information provided by more or less heterogeneous, reliable and conflicting sources.

ER-MCDA is a new methodology mixing the Analytic Hierarchy Process (AHP), a multi-criteria decision analysis (*MCDA*) method, fuzzy sets , possibility theory and information fusion using Belief Function (Tacnet,2009) (Tacnet et al., 2009) (Tacnet et al., 2010a).

First, a simplified application case is described. Secondly, we describe the global principle and the four main steps of the method.

5.1 Step 1 : Analytical Hierarchy Process is used to describe the decision problem

A simplified version of an existing method, developped to assess the sensitivity a snow avalanche site (Rapin et al., 2006), is used to show how the use of multi-criteria decision analysis principles and information fusion can be used to characterize and take information quality or imperfection into account for decision purposes (figure 8). The principle is to evaluate the sensitivity of an avalanche site according to main criteria denoted as hazard and vulnerability which are respectively decomposed on one hand in permanent winter occupants, living places, infrastructures and on the other hand in morphology, history and nivo-climatology.

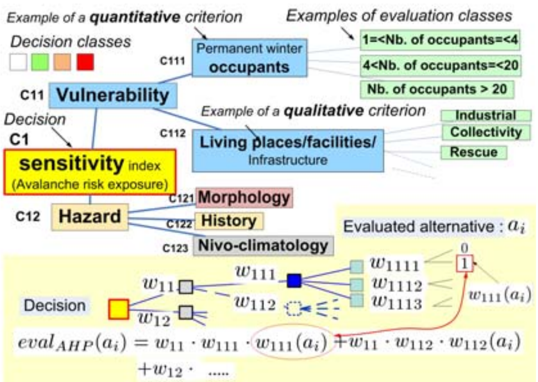

Figure 8 : Simplified decision problem

The first step consists in describing the decision problem including qualitative and quantitative decision criteria identification and importance assessment. The decision hypotheses (e.g. sensititivity levels of a site) are used to define the common frame of discernment that will be used for information fusion: low, medium and high sensitivity.

5.2 Step 2 : Imprecise evaluation

Quantitative criteria are evaluated through possibility distributions which allow to represent both imprecision and uncertainty. The source (an expert) provides evaluations as intervals: e.g. the criterion C_{111} corresponding to the number of permanent winter occupants: A represents the proposition "x in [8,15]". N(A)=0.75 represents the certainty level (confidence) in the proposition "x in [8,15]" (figure 9).

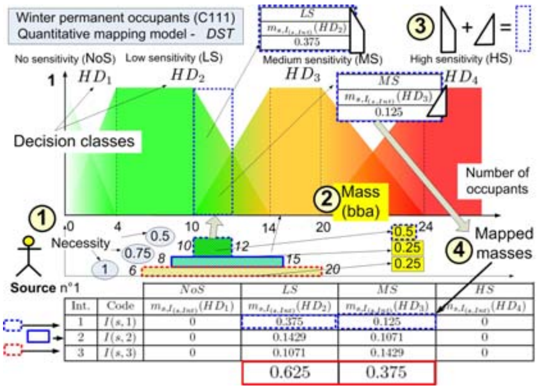

Figure 9 : The source provides an imprecise evaluation that is mapped into the frame of discernment for decision. Steps are numbered from 1 to 4.

5.3 Step 3 : Mapping and fusion of expert assessment of criteria

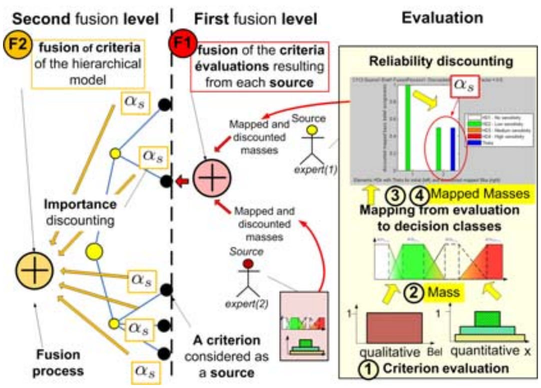

Figure 10 : Criteria are considered as sources in the second step of fusion – adapted from (Tacnet et al.,2010a).

A mapping model based on fuzzy intervals L-R links a criterion evaluation and the decision classes (low, medium, high). For each evaluation of a criterion by one source, each interval of the possibility distribution is mapped to the common frame of discernment of decision according to surface ratios (figures). At the end of the mapping process, all the criteria evaluations provided by each source are transformed in basic belief assignments (bba's) according the common frame of discernment of decision: these bba's are then fused in a two-step process.

5.4 Step 4 : Decision – interpretation

Results of fusion have to be interpreted to decide what is the sensitivity level that will be chosen (No sensitivity – NoS , Low sensitivity - LS, Medium Sensitivity – MS, or High Sensitivity - HS) according either to the maximum of basic belief assignments, credibility (pessimistic decision), plausibility (optimistic decision) or pignistic probability (compromise). In comparison with classical aid-decision methods, the *ER-MCDA* methodology therefore produces a comparative decision profile in which decision classes (elements of the frame of discernment) can be compared one to each other (figure 11). The quality of information leading to the decision is linked to the decision itself.

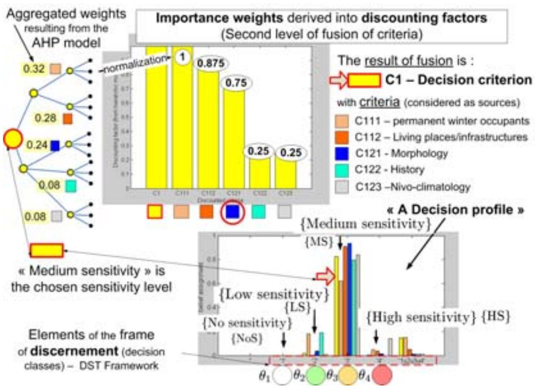

Figure 11 : A sensitivity level can be chosen according a decision profile – adapted from (Tacnet et al.,2010a)

6. MAIN ADVANTAGES OF THE ER-MCDA METHODOLOGY

6.1 A full dissociation of evaluation and decision

Assessing information imperfection and considering it for decision are two important but different problems. The *ER-MCDA* method dissociates clearly the information evaluation and its use for decision. Information imperfection is indeed independent from decision problems that will use it. In any case, the original data quality assessment is preserved and reachable. This can be used and stored in information systems using meta-data (Barral et al., 2010).

6.2 An easy-use evaluation method for field data collection

Despite of the different theoretical frameworks used in this approach, the input data, specially for quantitative values, is quite simple. The expert observing a real avalanche can provide a measure or an estimation and associate directly its imprecision to the collected value using a distribution possibility. This is a huge change in the practical way to proceed. Instead of a unique evaluation, both imprecision and source reliability can be valuated and traced.

6.3 Ad-hoc theories are used to handle information imperfection

For imprecise, vague and uncertain information in a context of multiple heterogeneous sources, fuzzy sets, possibility and belief function theories are more efficient than the classical probability framework. The different uncertainty theories allow to represent all kinds of information imperfection as they are expressed by experts. The methodology can be used in any thematic domain but their use in the natural hazards context is totally new.

6.4 Multicriteria decision analysis contributes to problem elicitation and expertise traceability

This method allows pointing out evaluation criteria with experts and elicitating the avalanche expertise process. The proposed method can also be considered as a kind of check-list for expertise quality. The Analytical Hierarchy Process (*AHP*) is used as a conceptual framework.

6.5 *Remaining issues: validation and expert judgement elicitation*

Remaining issues consist in the decision-support framework validation and expert elicitation.

7. CONCLUSION

Aid-decision methods and tools used for snow avalanche expertise and engineering always have to cope with information imperfection. *ER-MCDA* is a new versatile and generic methodology to both handle imperfection of information (including expert evaluations) and consider it for decision purposes. It uses and mixes uncertainty theories, information fusion and decision analysis methods with an original and new method to set a link between them through "mapping models".

On one hand, it provides and analyzes multi-criteria aid-decision tools able to consider information imperfection (uncertainty, imprecision) resulting from different, more or less reliable and conflicting sources, on the other hand, it contributes to improve traceability and quality description of the expertise process (Tacnet et al., 2006) in relation with information systems design and architecture (Barral et al., 2010).

Main interest of this methodology consists in dissociating evaluations imperfections and its uses for decision. It also provides a measure of imperfection related to existing and well-known theories (fuzzy sets, possibility and evidence theories).

New developments of this methodology are still under progress. One of them consist in spatial applications such as hazard and risk zoning maps. Imperfection concern not only attribute values of information (qualitative or quantitative criteria) but also their spatial extent (Tacnet et al., 2010b).

Finally, from a more general point of view, relations between uncertainty and decision remain an important issue : an important chalenge consists in analyzing, in collaboration with human sciences researchers how far the imperfection elicitation helps or not decision.

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