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

Jean-Marc Tacnet*, Mireille Batton-Hubert, Jean Dezert, Didier Richard*

ABSTRACT:

Making the best decision in the event of a snow avalanche encounters problems in the assessment and management process because of the lack of information and knowledge on natural phenomena and the heterogeneity and reliability of the information sources available (historical data, field measurements, and expert assessments). One major goal today is therefore to aid decision making by improving the quality, quantity, and reliability of the available information. This article presents a new method called evidential reasoning and multicriteria decision analysis (ER-MCDA) to help decision making by considering information imperfections arising from several more or less reliable and possibly conflicting sources of information.

First, the principles of the existing methods are reviewed. Classical methods of multicriteria decision making and existing theories attempting to represent and propagate information imperfections are described.

In a second point, we describe the principle of the ER-MCDA method combining multicriteria decision analysis (MCDA) to model the decision-making process and fuzzy sets theory, possibility theory, and evidence theory to represent, fuse and propagate information imperfections. Experts, considered more or less reliable, provide imprecise and uncertain evaluations of quantitative and qualitative criteria that are combined through information fusion.

The method is applied to a simplified version of an existing system aiming to evaluate the sensitivity of avalanche sites. This new method makes it possible to consider both the importance of the information available and reliability in the decision process. It also contributes to improving traceability. Other developments designed to handle other assessment problems such as avalanche triggering conditions or data quality are in progress.

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 movement hazards such as snow avalanches put humans and property at risk with dramatic consequences. In a context of insufficient knowledge on natural phenomena, expert assessment is required for decision and risk management purposes using multidisciplinary quantitative or qualitative approaches.

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These decisions are closely related to the information available. Expert assessments depend on the availability, quality, and uncertainty of the available information resulting from measurements, historical analysis, eye witness accounts as well as subjective, possibly conflicting, assessments made by the experts themselves. In the end, phenomenon scenarios and decisions may very well rely on very uncertain and conflicting information without being able to fully determine what actually occurred, with imprecise, conflicting, or simply unknown information used in the hypotheses attempting to explain the result. In addition, traceability and shared decision-aid tools can be advantageously used to better understand and exploit the results of expert assessments in an integrated risk management system able to consider the technical, environmental and social aspects of a decision (Tacnet, 2009).

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

In a second part, the principles and main steps of the ER-MCDA methodology are is described.

Finally, the limits of the proposed approach and needs for further developments are discussed.

## 2. EXPERTISE, INFORMATION AND DECISIONS

### 2.1 *Why is expert assessment needed in snow avalanche risk management*

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

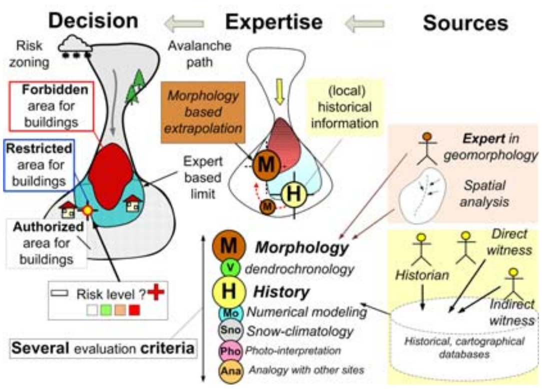


Figure 1: Expert assessment is often based or uses imperfect information from heterogeneous sources

The snow avalanche assessment process covers all steps of the risk management process ranging from post-event analysis to risk analysis and protection measures. The information available to describe avalanche conditions highly variable (Tacnet et al., 2006) and is subject to spatial, qualitative, and quantitative uncertainty (Figure 1).

### 2.2 *Data quality impacts the risk management process*

Due to restricted data availability or imperfect survey conditions, the quality of the data used in decision making is not always as complete, precise, and certain as expected in ideal conditions. In the end, risk management decisions depend on the primary data and information available as well as on the reliability of data sources, including experts (Figure 2). The traceability of this information should be included in information systems in order to describe both existing links between information and its quality (Barral et al., 2010).

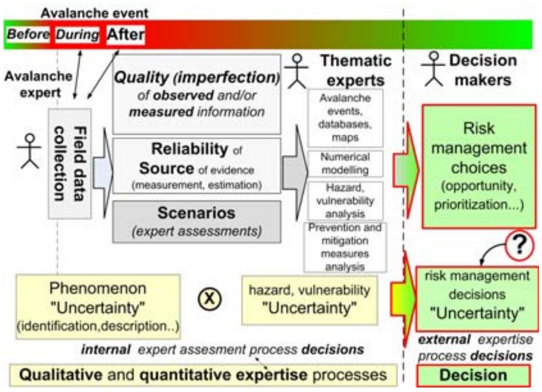


Figure 2: Expert assessment process and information imperfection propagation (Tacnet,2009)

Given the nature of natural hazards, information is often quite imprecise and subjective, thus compromising the decision-making process and the decision made when such events occur. In an attempt to remedy this situation, information quality, source reliability, and propagation of data imperfection from data collection to risk management decisions is an important issue.

Although expert assessments are essential components of the risk management process, none of the existing methods can trace the reasoning processes and consider both information imperfection and source heterogeneity and/or reliability. This requires decision-aid methods and theories for uncertainty management.

## 3. PRINCIPLES OF MULTICRITERIA DECISION ANALYSIS

Multicriteria decision analysis (MCDA) aims to choose, sort, and rank alternatives and solutions according to predefined criteria in the decision-making process. MCDA consists in identifying decision purposes, defining criteria, determining preferences between criteria, evaluating alternatives and solutions and analyzing sensitivity with regard to weights and thresholds (Figure 3).

Complete aggregation methods such as the multi-attribute utility theory (MAUT) (Keeney, 1976) (Dyer, 2005) synthesize in a single value the partial utility related to each criterion chosen by the decision-maker. Each partial utility function transforms any quantitative evaluation of a criterion into a utility value. The additive method is the simplest method to aggregate these utilities (Figure 3).

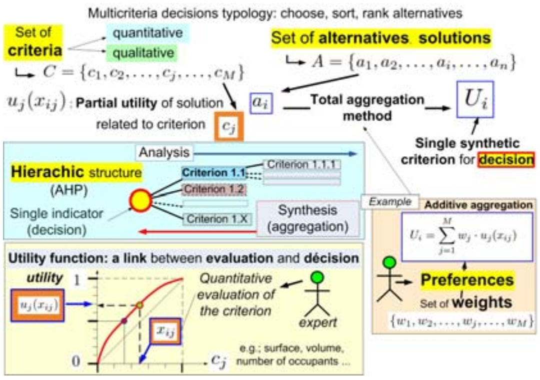


Figure 3: Multicriteria decision analysis principles – Classical approach

The AHP principle is to arrange the factors considered to be important for a decision in a hierarchic structure descending from an overall goal to criteria, subcriteria, and finally alternatives at successive levels. It is based on three fundamental steps: breaking the problem down into its components, comparative assessments and hierarchic structure or synthesis of priorities. As a single synthesizing criterion approach, the analytic hierarchy process (AHP) (Saaty,1980) is a special case of a complete aggregation method based on an additive preference aggregation.

These methods cannot natively consider the imperfection of criteria evaluations or multiple and possibly conflicting evaluations.

## 4. REPRESENTATIONS OF INFORMATION IMPERFECTION

A decision is closely related to information quality. Uncertainty, as often used in common language, is indeed only one of all the various types of information imperfection: inconsistency, imprecision, incompleteness and uncertainty (Figure 4).

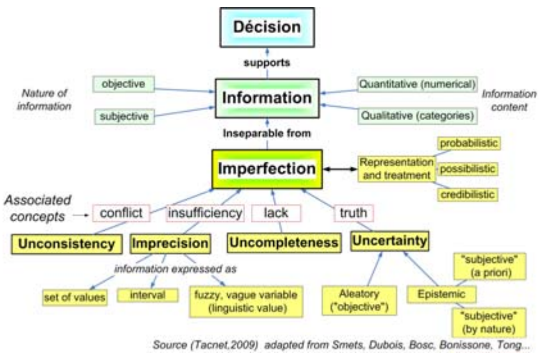


Figure 4: Different kinds of information imperfection (Tacnet,2009)

Probability theory is widely used in the natural hazards context to represent uncertainty but fails to handle vague, imprecise, uncertain, and conflicting information. New uncertainty theories have been proposed to handle different types of imperfect information such as evaluations provided through natural hazards expert assessment: fuzzy sets theory for vague information (Zadeh, 1965), possibility theory for uncertain and imprecise information (Zadeh, 1978) (Dubois, 1988), and belief function theory, which considers uncertain, imprecise, and conflicting information. In addition to the original Dempster-Shafer theory (DST) (Shafer,1976), the 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*

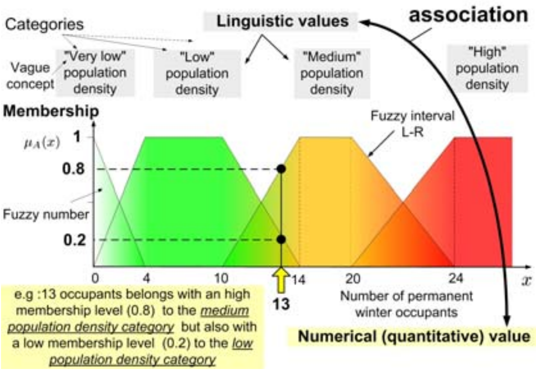


Figure 5: Fuzzy sets associate numerical and linguistic values

Fuzzy sets theory relates 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 proposes to represent both imprecision and uncertainty using possibility distribution. Instead of giving a single discrete value, several consonant intervals with increasing confidence levels can be chosen: the wider the interval is, the more confident the expert is in the evaluation (Figure 6).

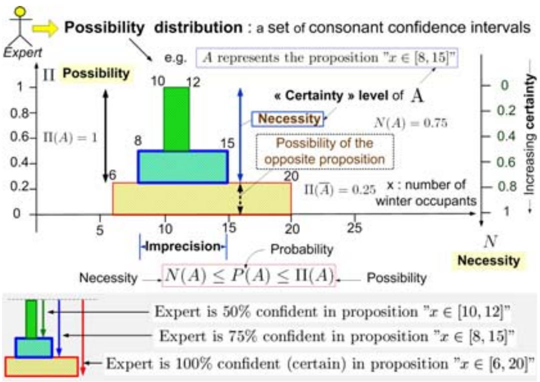


Figure 6: Experts propose imprecise and uncertain evaluations of quantitative criteria

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

Evidence or belief function theory allows one 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 (BBAs). In the classical Dempster-Shafer theory (DST), all the hypotheses are exhaustive and exclusive. A new theory called Dezert-Smarandache theory (DSmT) provides 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 importance and reliability separately (Smarandache et al., 2010).

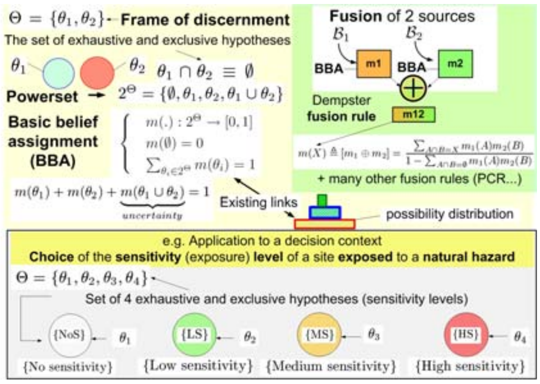


Figure 7: Essentials of belief function theory: frame of discernment, basic belief assignments (BBAs) and fusion rules in the *DST* context.

The Dempster fusion rule operating in the classical DST framework is only one of the many existing rules. The DSmT framework proposes powerful fusion rules such as proportional combination rules (PCR) when conflicting sources are present (Dezert and Smarandache,2006).

## 5. THE *ER-MCDA* METHODOLOGY

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

Evidential reasoning and multicriteria decision analysis (ER-MCDA) is a new methodology mixing the analytic hierarchy process (AHP), a multicriteria decision analysis (MCDA) method, fuzzy sets, possibility theory, and information fusion using the belief function (Tacnet, 2009) (Tacnet et al., 2009) (Tacnet et al., 2010a).

First, a simplified application is described. Secondly, we describe the method's overall principle and the four main steps.

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

A simplified version of an existing method, developed to assess the sensitivity of a snow avalanche site (Rapin et al., 2006), is used to show how multicriteria decision analysis principles and information fusion can be used to characterize and take information quality or imperfection into account for decision-making purposes (Figure 8). The principle is to evaluate the sensitivity of an avalanche site according to the main criteria denoted as hazard (morphology, history, and snow climatology) and vulnerability (permanent winter occupants, dwellings, and infrastructures).

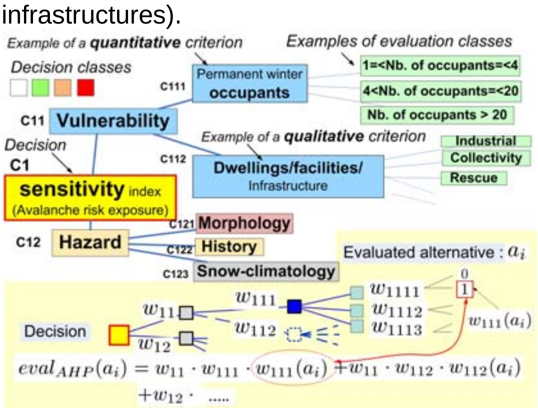


Figure 8: Simplified decision-making problem

The first step consists in describing the decision-making problem including identifying qualitative and quantitative decision criteria and assessing the dimensions of the event. The decision hypotheses (e.g., a site's sensitivity levels) 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 representing both imprecision and uncertainty. The source (an expert) provides evaluations as intervals, e.g., 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).

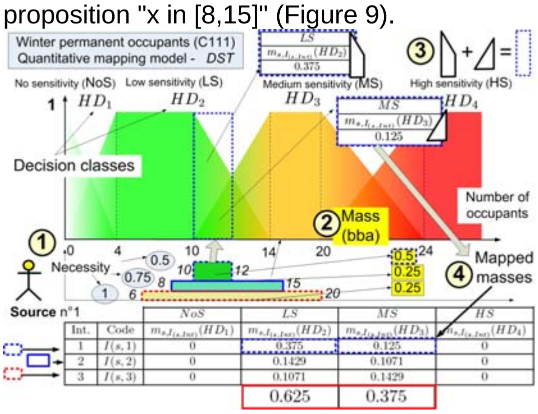


Figure 9: The source provides an imprecise evaluation that is mapped into the frame of discernment for making a decision. The steps are numbered from 1 to 4.

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

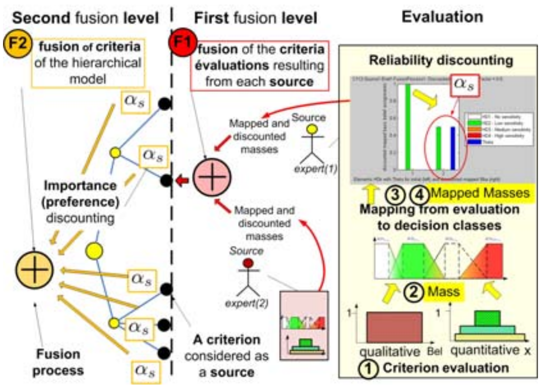


Figure 10 : Criteria are considered to be sources in the second step of fusion – adapted from (Tacnet et al.,2010a).

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 onto the so-called common frame of discernment of the decision according to surface ratios (figures). At the end of the mapping process, all the criterion evaluations provided by each source are transformed into BBAs according the common frame of discernment of decision: these BBAs are then fused into a two-step process.

### 5.4 *Step 4: Decision – interpretation*

The results of fusion have to be interpreted to decide which sensitivity level will be chosen (no sensitivity, NoS; low sensitivity, LS; medium sensitivity, MS; high sensitivity; HS) according either to the maximum basic belief assignments, credibility (pessimistic decision), plausibility (optimistic decision), or pignistic probability (compromise). In comparison with classical decision-aid methods, the ER-MCDA methodology therefore produces a comparative decision profile in which decision classes (elements of the frame of discernment) can be compared to each other (Figure 11). The quality of information leading to the decision is related to the decision itself.

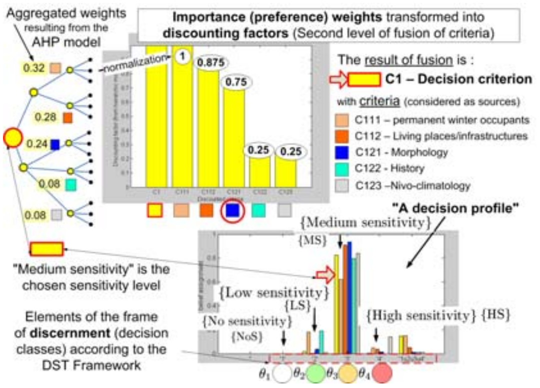


Figure 11 : A sensitivity level can be chosen according a decision profile: adapted from (Tacnet et al.,2010a)

## 6. MAIN ADVANTAGES OF THE ER-MCDA METHODOLOGY

### 6.1 *Full dissociation of evaluation and decision-making*

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

### 6.2 *An easy-to-use evaluation method for field data collection*

Despite the different theoretical frameworks used in this approach, the input data, particularly for quantitative values, is quite simple. The expert observing a real avalanche can provide a measurement or an estimation and directly associate its imprecision with the collected value using a distribution possibility. This radically changes how the expert proceeds. Instead of a single evaluation, both imprecision and source reliability can be evaluated 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 can 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 formalization and expertise traceability*

This method specifies evaluation criteria with experts and explicits the avalanche expertise process. The proposed method can also be considered a check-list for expert assessment quality. The AHP is only used as a conceptual framework: the aggregation is replaced by fusion.

### 6.5 *Remaining issues: validation and description of the expert assessment processes*

The first remaining issues consist in decision-support framework validation: what is the good decision for comparison. The second difficulty consists in describing, in collaboration with the experts, their reasoning and assessment processes.

## 7. CONCLUSION

Decision-aid methods and tools used for snow avalanche assessment and engineering will always be faced 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-making purposes. It combines uncertainty theories, information fusion, and decision analysis methods relating them in an original and new method for mapping models.

On one hand, it provides and analyzes multicriteria decision-aid 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 improving traceability and quality description of the assessment process (Tacnet et al., 2006) in relation with information systems design and architecture (Barral et al., 2010).

The main advantage of this methodology is its dissociation of evaluation of imperfections and its uses for decision making. It also measures imperfection related to existing and well-known theories (fuzzy sets, possibility, and evidence theories).

New developments are continuing, e.g., spatial applications such as hazard and risk zoning maps. Imperfection concerns 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 making have still to clarified. An important challenge consists in analyzing, in collaboration with human sciences researchers, whether or not the information imperfection and its influence on decision helps to improve operational decision making.

## 8. ACKNOWLEDGEMENTS

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