METHODOLOGY OF SNOW AVALANCHE POST-EVENT FIELD INVESTIGATIONS: TOOLS, DIFFICULTIES AND PERSPECTIVES

Jean-Marc Tacnet *, Sébastien Escande, François Rapin, Roland Burnet (*Cemagref* – France)
Mireille Batton-Hubert (Ecole des Mines de Saint-Etienne – France)

ABSTRACT:

Avalanche post-event field investigations are usually made immediately following the event. Assessments and results often vary depending on the person in charge. The reliability of these data is sometimes discussed when used in applications such as hazard assessment mapping, defence works design, and rescue plan implementation. This article proposes a contribution to the evaluation of post-event data reliability.

First, the need for a reliability index and the role of post-event analysis in the overall risk management process are analyzed. Preliminary challenges comprise expert assessment development processes and sufficiently distinguishing between facts and expert assessment or analysis.

In the second part of this article, qualitative elements related to expert assessments and the corresponding levels of reliability are listed. A recent (winter 2006) snow avalanche event in France – the Bouisset path avalanche (Pelvoux, Hautes-Alpes) – is used as an introduction. Data record contents are described, with particular attention given to how they are obtained (measurement, visual impression, testimonies, etc.) and to their possible reliability. A quantitative evaluation methodology, based on the Analytic Hierarchic Process, is then proposed. This methodology appears to closely match the data structure standards for both efficient storage and information sharing (ISO 19 115).

Finally, the limits of the proposed approach and needs for further developments are discussed. The Analytic Hierarchic Process-based methodology is an easy and understandable method for explaining expert assessment but cannot cope with paradoxical or conflicting information. Considering the use of recorded data in information systems, the link between reliability and data traceability is a major issue.

KEYWORDS: snow avalanche assessment, analytic hierarchic process, reliability, traceability, information systems

1. INTRODUCTION

Snow avalanches often threaten human or material interests with sometimes tragic consequences. Risk reduction is achieved through structural and non-structural measures such as zoning control and preventive information. Historical information is often the main source of information and researchers most often choose a reference avalanche and then a prevention strategy. One of the essential elements of the information related to an avalanche description come from post-event analysis. How trustworthy is the data collected during this initial phase? What are the criteria that condition the information's reliability? How can we evaluate this reliability?

This paper proposes a few answers to these questions. First, the need for a reliability index and the role of post-event analysis in the overall risk management process are analyzed. In the second part, with reference to a recent avalanche, qualitative elements related to reliability are described. A quantitative evaluation methodology, based on the Analytic Hierarchic Process, is then proposed. Finally, the limits of the proposed approach and further developments are

* *Corresponding author address:* Jean-Marc Tacnet, *Cemagref*, Snow avalanche engineering and torrent control research unit (ETNA) - 2 , rue de la Papèterie B.P. 76 38402 Saint Martin d'Hères Cedex - FRANCE email: jean-marc.tacnet@cemagref.fr

discussed. The relation between reliability and data traceability appears as a main issue.

1.1 Post-event analysis is the foundation of the assessment process

Avalanche scenarios are basically the expected results of an avalanche post-event expert analysis. These scenarios are essential to describing observed consequences of past events. These information then become the foundation of the overall risk management process: such data are used either to choose the most efficient protection strategy or to fix the limit for risk zoning. Nevertheless, reasoning processes leading to hazard assessment or risk management decisions are not always sufficiently detailed. Expertise is needed whenever elements are missing from the current knowledge base. Throughout the assessment process, several steps can successively be identified over time depending on decision making needs (Figure 1).

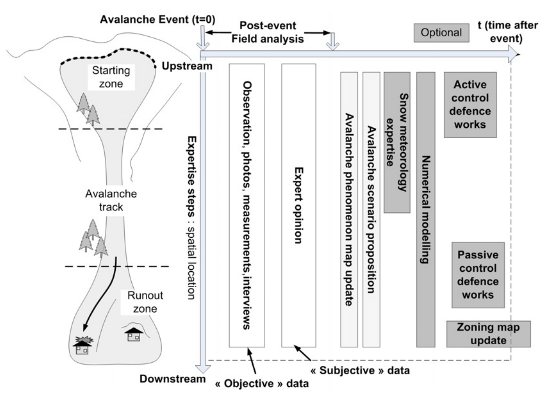

Figure 1: The different steps of an avalanche assessment can be plotted on a Gantt-like diagram

Expert analysis generally aims to determine the most plausible scenarios for the three main zones of the avalanche paths. A scenario is the description of the avalanche phases. It includes objective data resulting from observations, measures, and subjective evaluation based on these observations. For each zone, data are expected to determine the avalanche's type, volume, nature, physical properties, and where the snow originated. Some avalanche dynamics data are more specific of the avalanche track and the deposit zone (Figure 2). Information gathered during the post-event analysis will make it possible to confirm the hypothesis and the propose avalanche scenarios.

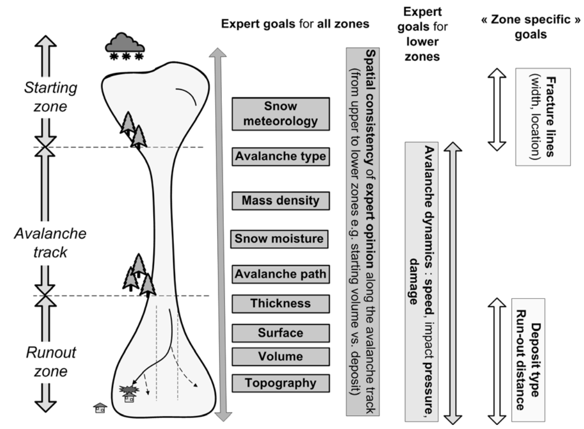

Figure 2: Expert analysis goals depend on studied zones: some aspects are shared

1.2 Reliability is related to data quality and traceability

Post-event analysis and scenario description are the basis for any further assessment or risk management action (Figure 3). Information collection conditions are therefore almost as important as Information content itself.

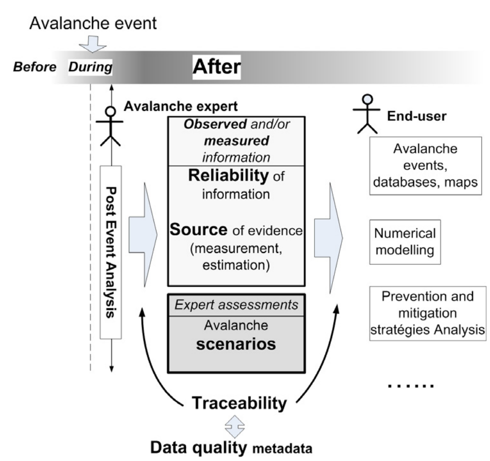

Figure 3: Reliability of expertise is related to traceability

Post-event information are used in many different contexts. Uncertainty or imprecision at this step of the technical process will propagate to all other steps: numerical modelling will use data related to the starting zone and the avalanche scenario, zoning maps will use extension limits. Therefore traceability is essential (Tacnet, Burnet et al. 2005).

Some reliability evaluation indexes have already been proposed in event descriptions (Hübl, Kienholz et al. 2002). In this case, a simplistic distinction is made between the measured value, the observation, the hypothesis. Some data are described as unclear (to ascertain) and not ascertainable information. Criteria for the initial choice of level and rules for further use are not described.

1.3 The risk management process is conditioned by the initial data quality

On the 2nd of January 1995, a specific national law created the Risk Prevention Plans (Plan de Prévention des Risques - P.P.R.) in France. They remain the government's main non-structural instrument to protect populations and property against natural hazards. Most often, it is based on existing information and studies. No specific hazard modelling is required, except in very critical situations where the nature of the hazard requires a high level of protection.

The zoning map and the building and land-use regulation documents are the two main components of the risk prevention plan. The zoning map shows the limits of the zones where the following may be applied :

- prohibitions;
- homogenous building and land-use regulations;
- protection and prevention measures.

Three types of zones are identified:

- red zones where all construction is prohibited;
- blue zones where building is possible only following specific instructions;
- (new) yellow zones without building restrictions but with evacuation plans.

These regulations often stem from a combination of expert assessments. It is quite difficult to clearly identify the criteria and the processes used to establish the different limits on the zoning map (figure 4). Two types of shortcomings should therefore be pointed out: 1) it is difficult to update the existing prevention plans and 2) the population does not easily understand and accept the zoning maps. Improving traceability and quality indexes for data is therefore essential for the implementation of Risk Prevention Plans. Reaching this goal implies starting with quality evaluation of the first data collected (just after an avalanche event).

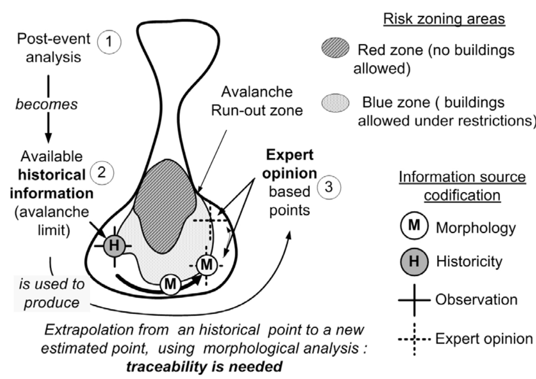

Figure 4: How trustworthy is an avalanche risk zoning limit? Where does it come from? How was it produced?

2. CASE STUDY

On March 5th, 2006 , a major avalanche (according to ski patrollers and National Forest Service technical staff) occurred in both Bouisset and Sapenier avalanche paths in Pelvoux (Hautes Alpes, France) (photo 1). A post-event assessment was carried out to describe the avalanche's main characteristics featuring triggering conditions, phases and snow type along the entire avalanche path. Two on-site visits, with and without snow cover, were carried out on the spot. The assessment included a factual description of the event (observation, testimonies, measurements). The main characteristics of the event were:

- an overall starting zone (covering both avalanche systems) approximately 1.5 km-wide with a dry snow fracture roughly 2 m-high) (photo 1) ;

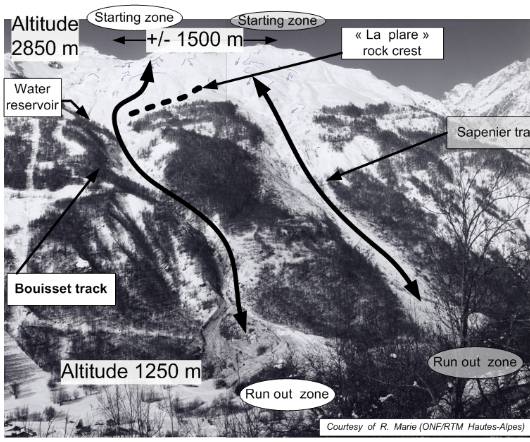

Photo 1: The Bouisset and Sapenier avalanche path location

- a mixed avalanche with an atypical powder snow phase deviation of roughly 60° in the middle of the flow path (photo 2);

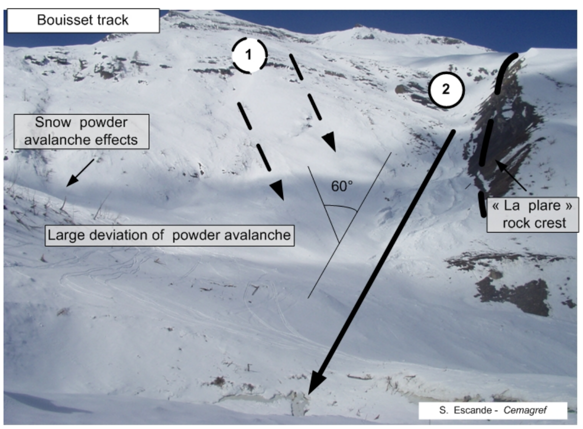

Photo 2: The Bouisset avalanche starting zone with an amazing deviation of the powder avalanche direction

- a huge wet snow deposit in the run-out zone (≈200,000 m³), featuring a top-down evolution of snow quality (photo 3).

Photo 3: The Bouisset avalanche deposition zone with a high-density wet snow deposit

As often occurs in such cases, information availability was highly variable. This case study points out many sources of uncertainty caused by the nature of the information sought and the data available. Although this assessment was handled by snow-avalanche specialists, it still appears difficult to be certain of the scenarios proposed. How much can the assessment conclusions be trusted?

In a preliminary approach, some qualitative elements likely to influence the conclusions on reliability are listed below for the three main zones of the avalanche path: starting zone (figure 5), avalanche track (figure 6) and run-out zone (figure 7). These proposals must be considered as the first step before reliability index evaluation.

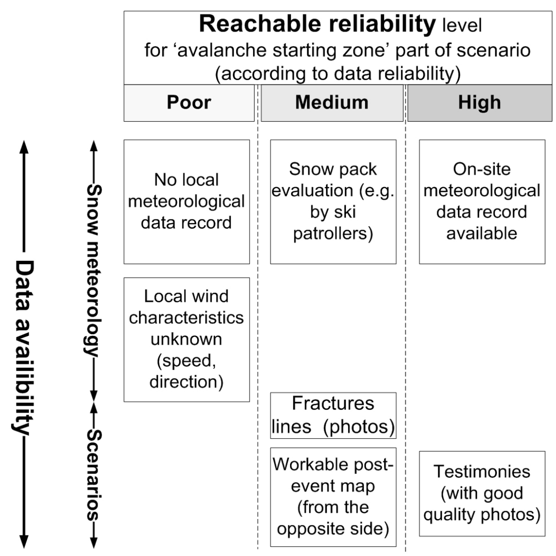

Figure 5: Relations between achievable reliability and data sources for the starting zone

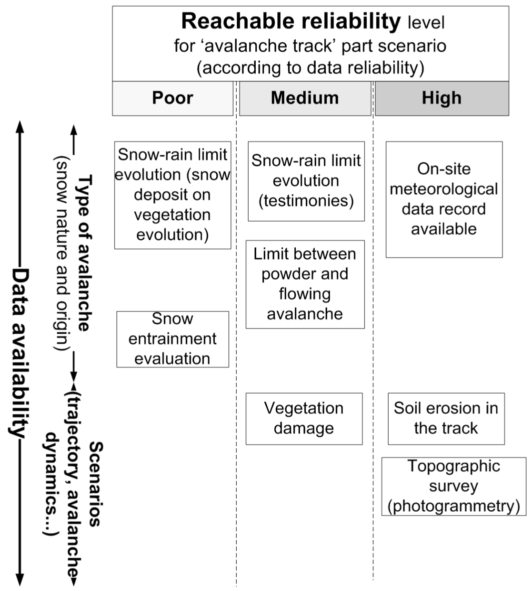

Figure 6: Relations between achievable reliability and data sources for the avalanche path

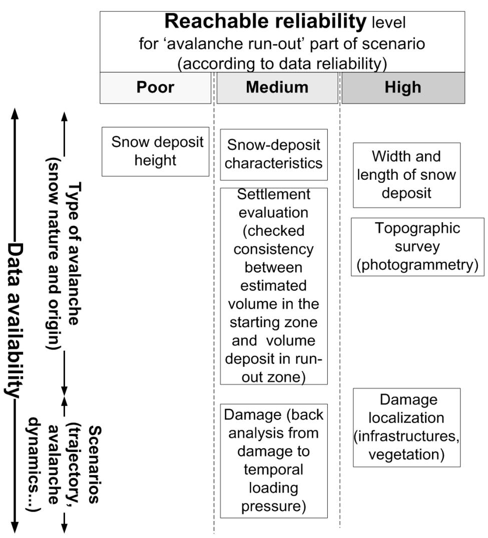

Figure 7: Relations between achievable reliability and data sources for the run-out zone description

These criteria remain quite qualitative. To evaluate the quality of this basic information in a standard way and propagate this evaluation in the following steps of the risk management process, a reliability evaluation framework is needed.

3. METHODOLOGY FOR RELIABILITY EVALUATION

3.1 The choice of Analytical Hierarchy Process for expert assessment elicitation

Expert assessment is an essential part of the process of natural hazards assessment. In the same situation, different experts can produce different evaluations. Because of the nature of the natural hazard environment, information is often quite imprecise and subjective. Therefore, there is a need to comprehensively highlight the expert hypotheses.

To evaluate the reliability of the evaluation process, a theoretical framework to formalize the expert assessments must be chosen. A qualitative evaluation of the reliability of data sources is the first step of our modelling approach (see Sect. 2). Moreover, a quantitative estimation is required to compare and combine different reliability sources.

Many different theories use imprecise and sometimes subjective information such as evaluations provided through natural hazards expert assessments.

For instance, the Fuzzy Sets Theory was introduced to handle non-numerical imprecision, while the Possibilities Theory appeared to work with non-probabilistic uncertainties (Zadeh 1978). These two approaches are joined in the Fuzzy-Logic Theory.

Non-probabilistic uncertainties can also be handled through Belief Function Propagation, Evidential Reasoning Theory. DSmT (the Dezert-Smarandache Theory in the literature) is an emerging branch of Information Fusion (Dezert and Smarandache 2004). Sometimes described as an evolution of Dempster-Shafer Evidential Reasoning Theory (Shafer 1976), DSmT is a new modelling approach for fusion problems, particularly when the information is both uncertain and highly conflicting. This method proposes a global framework based on belief functions related to expert evaluations for specific criteria. Specific combination rules are proposed to gather possibly conflicting expert opinions or information sources.

These methods, when applied to the context of natural hazards, always require that rules and reasoning processes be processed first. Criteria must be described and quantified through numerical values. Moreover, they are not easy to handle and to understand for non-specialists. To start with an easy and efficient method, we chose the Analytic Hierarchic Process (AHP) method, created to assist in decision making. It is based on three main principles (Saaty 1982):

- building a hierarchy between different homogenous groups of criteria;
- defining priorities between each criterion;
- checking logical coherence.

The Analytical Hierarchy Process is based on three main assumptions:

- preferences for solutions or alternatives depend on a combination of independent criteria valuated by numerical scores (figure 8) ;
- the final score (at the decision level) is calculated by a weighted sum that aggregates the score of each sub-criteria
- at each hierarchy level, weights can be calculated by pair comparison (coherence matrix).

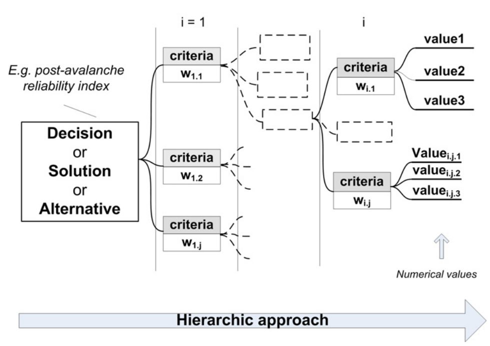

Figure 8: The analytical hierarchy process is based on breaking down the problem into criteria weighted according to mutual preference from one to another

Some limitations in this method are widely known such as aggregating the entire expert assessment into a single indicator (Schärlig 1999). However, this method was chosen because it was easy to carry out and easy to understand by both avalanche experts and end-users of the information produced. Simple properties are compared and the result of the evaluation process highlights a clear rationale for the expert choices.

3.2 The expert opinion development process

The initial purpose of an analysis based on Analytical Hierarchical Process is to assist in taking the best decision. In the avalanche post-event analysis context, our goal is to propose a ranking methodology for expertise reliability evaluation. A reliability index is therefore assimilated to a decision based on different criteria. In our specific example, the decision corresponds to a reliability index. The methodology is based on the following steps:

- breaking down the system into homogenous parts corresponding either to assessment steps or assessment studied spatial zones;
- collecting the expected results of post-event analysis assessment (working with snow avalanche experts);
- choosing criteria weighting;
- constructing a hierarchic tree;
- estimating real cases;

The reliability evaluation can be seen as an additional layer to the avalanche expertise description layer (Figure 9).

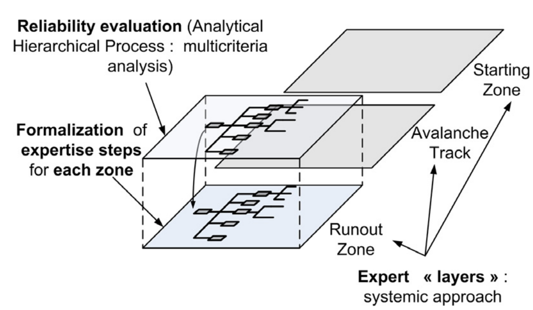

Figure 9: Systemic breaking down of the expert approaches

4. RESULTS

The different hierarchic trees proposed below (Figures 10–12) correspond to a partial itemization of the reliability index for the entire avalanche path. We consider here that the reliability of the avalanche scenario depends on the unitary reliability of the analysis done for each spatial part of the avalanche path. The reliability index is calculated for each specific assessment topic.

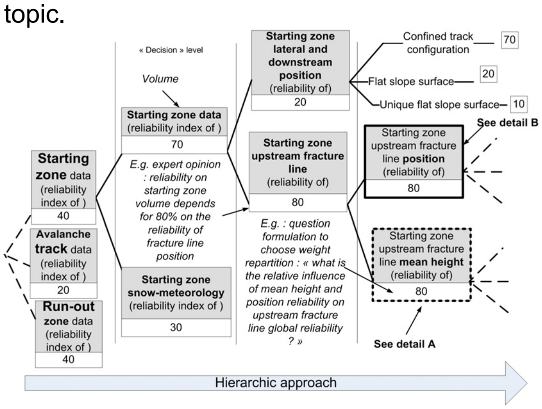

Figure 10: The reliability index for starting zone scenario depends on snow meteorology and starting zone

All the criteria used in the Analytical Hierarchic Process must be broken down until the valuation level is reached (e.g. Figure 12). At this level, the post-analysis assessment is valuated. Figures 11 and 12 show partial details of the upper hierarchy level shown on Figure 10.

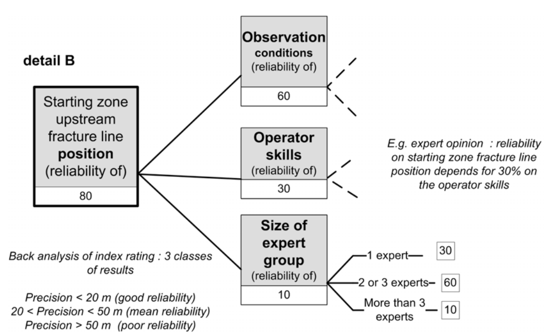

Figure 11: Breaking down fracture line position reliability into sub-criteria

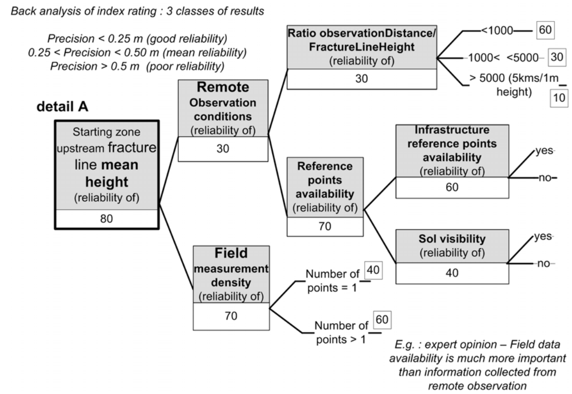

Figure 12: Breaking down fracture line mean height reliability into sub-criteria

5. DISCUSSION

5.1 Reliability and stochastic modelling

We have focused on the avalanche post-event analysis, ignoring the use of the data to compute reference avalanches for hazard zoning or dam design purposes. When one the many deterministic, statistical or statistical-dynamical approaches proposed in the literature is applied, the data reliability problem is rarely considered. Data reliability, however, directly conditions the uncertainty level associated with the results obtained with any of these methods. Neglecting the data reliability level can result in being dramatically overconfident, especially when a particularly advanced approach has been employed. Handling data reliability in a consistent manner in the stochastic avalanche models used for computing the return period associated with avalanche limits is not easy when a rigorous calibration method is employed. Some recent developments have been proposed (Eckert, Parent et al. 2006) but more work is still needed to convert the results of data reliability studies into robust stochastic operators.

5.2 The Analytic Hierarchic Process is limited

Analytical hierarchy is used in order to specify the main factors that could be used to describe the confidence in data collected from expert field investigations. This approach is useful both to obtain a global index and to identify the reasoning process.

A hierarchic classification can produce different results, but a sensitivity analysis is needed. Research is being conducted at the moment to analyze to what extent the initial models and hypotheses govern the final result and the reliability index evaluation. Considering more than one expert evaluation is another possibility. In this case, the Analytical Hierarchy Process will show its limits. Another theoretical framework such as DSmT Theory seems then to be more appropriate (see Sect. 3.1).

5.3 The reliability index must be linked to data through "metadata"

Many information systems exist and collect information on natural hazards. A great deal of them were designed claiming their "generic and universal" approach. In fact, sharing information between them remains difficult: interoperability is still a great challenge from semantic and technical points of view.

Evaluation of the reliability index cannot be the only goal for improving assessment data. This information must be connected to initial data, included and propagated through information systems as part of the data. The first level for interoperability is to adopt a common terminology for post-event description. Different projects have already proposed glossaries (SAME1999;Rapin2004; EuropeanAvalancheForecastingServices 2006).

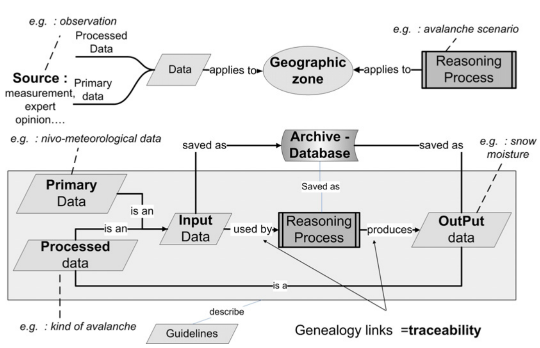

Figure 13: Metadata are used to trace the relations between primary and processed data

In the specific case of snow avalanches, progress is being made in analyzing how to improve the traceability of data and reasoning processes. Metadata and special patterns for genealogy (based on ISO 19115) are under construction (figure 13).

These metadata can describe the way the information is produced and used. Primary, processed data and reasoning processes should be clearly identified in Information systems. The Analytic Hierarchy Process appears to be highly compliant with data structures handled in electronic information management (e.g. tree structure used in XML [eXtended Markup Language] compliant applications). Therefore, reliability indexes must be included in metadata developments.

5.4 Data quality and reliability in a historical perspective

Reliability should be considered in an historical perspective. Post-event analysis should become part of historical information. The current event documentation will join the database for future generations. Nothing can compensate for the lack of data quality stemming from errors during the immediate post-event period. The post-event analysis data should be the complete and exhaustive repository of our event knowledge.

Working with historians teaches us that a contextual analysis is always required. For instance, connections between the authors of historical information and the avalanche event description are always needed. Somebody may have an interest in changing a zone limit in order to preserve rights to build in avalanche-exposed areas, for example. However, retrieving experience from different past studies with historians (Granet-Abisset and Brugnot 2002), some criteria appear essential to reach or maintain a good reliability level for future historical information. The main points concern the archive location, the data storage material, the traceability for geographic references, and terminology.

An archive is useful only if it can be found. In contrast with classical paper archives, electronic archives have tremendously increased in volume.

A classical challenge for a historian is to find or check links between geographical locations as they are described in historical documents and present geography. Spatial references and absolute positioning are essential, including the geographical referencing system used. Locating a past avalanche near a road is worth nothing if the road position has changed.

Terminology is another possible source for misunderstanding past data in the future. To prevent basic errors, reference documentation citations and glossaries linked to the information are essential.

Finally, the software, languages and hardware used are important factors to preserving data. Will our data storage hardware (CD, DVD) still be readable in the future? In that perspective, the choice of generic storage formats, platforms and languages is essential.

6. CONCLUSION

Guidelines and criteria to evaluate the reliability of a snow avalanche event post-analysis are proposed in this paper.

The Analytical Hierarchy Process provides a simple preliminary framework. This method details evaluation criteria with experts and proposes an operational ranking method. Through a logical approach, some criteria used in the avalanche expertise process can be elicited and a reliability index can be estimated. The proposed method can also be considered as a kind of check-list for assessment quality. Further development steps should concern hierarchic modelling sensibility tests. Using other methods is also planned, especially those handling possibly conflicting information and those allowing connections between subjective evaluation and classical probabilistic approaches.

Integrating collected data into information systems is also important. There is an enormous need to link quality information and contents in the same information systems and secondly, to trace the data quality in the risk management process.

This evaluation framework must be considered as a first step to improve information quality and traceability. Further developments in integration with two major information systems related to avalanche data have existed in France since the 1970s: the permanent survey for avalanche events (“Enquête permanente sur les avalanches” E.P.A.) and the known avalanche limit maps (“Carte de localisation des phénomènes d’avalanche“ C.L.P.A). Their contents are checked and entirely updated. At the moment, progress mainly involves the data collection and management chain. In the future, data quality indicators should be added to basic information for better use of this information within the global risk management process (Eckert, Belanger et al. 2006).

Reliability analysis of expert opinion applied to avalanche description is an important issue that should be highlighted in all studies. Uncertainties appear as an important factor in improving the quality of the risk management process. Mixing subjective evaluation and imprecise information with probabilistic data remains a topic that requires further research.

7. ACKNOWLEDGEMENTS

The authors would like to thank the National Forest Office (ONF/RTM) technical staff from Hautes-Alpes department, in particular Robert Marie and Gillles Astier for their contribution to the avalanche post-event analysis.

8. REFERENCES

Dezert, J. and F. Smarandache (2004). Presentation of DSmT. Advances and applications of DSmT for Information Fusion - http://www.gallup.unm.edu/~smarandache/DSmT-book1.pdf. J. Dezert and F. Smarandache. Rehoboth, USA, American Research Press.

Eckert, N., L. Belanger, et al. (2006). "Evolution and promotion of French avalanche

databases (submitted)." Cold Regions Science and Technology.
Eckert, N., E. Parent, et al. (2006). "Stochastic models for snow avalanche predetermination : What can we learn from stochastic hydrology ? (submitted)." Stochastic Environmental Research and Risk Assessment (SERRA).
EuropeanAvalancheForecastingServices, W. (2006). GLOSSARY snow and avalanches - http://wa.slf.ch/index.php.
Granet-Abisset, A.-M. and G. Brugnot (2002). Histoval : Avalanches et risques - Regards croisés d'ingénieurs et d'historiens. Grenoble, Maison des Sciences de l'Homme (MSH).
Hübl, J., H. Kienholz, et al. (2002). DOMODIS - Documentation of Mountain Disasters : State of Discussion in the European Mountain Areas. Klagenfurt, Internationale Forschungsgesellshaft INTERPRAEVENT.
Rapin, F. (2004). Avalanches classification - internal report (in French), *Cemagref* - Snow avalanche engineering and torrent control research unit (ETNA).
Saaty, T. L. (1982). Decision-Making for leaders : the analytical hierarchy process for decisions in a complex word. Belmont, CA, 94002 USA, Life-time learning publications.
SAME (1999). Avalanche mapping model validation and warning system - EU project - Glossary - http://same.grenoble.cemagref.fr/public/Glossary/public/glossaireNT.htm.
Schärlig, A. (1999). Décider sur plusieurs critères - Panorama de l'aide à la décision multicritère. Lausanne, Presses polytechniques et universitaires romandes.
Shafer, G. (1976). A mathematical theory of Evidence, Princeton University Press.
Tacnet, J.-M., R. Burnet, et al. (2005). Information systems and Avalanche Risk Prevention Plans (P.P.R.) : contribution to improvement of data and reasoning processes traceability - Report (in French), *Cemagref* - ONF/RTM - Ministry for Ecology and Sustainable development (MEDD) / Directorate for risks and pollution prevention (DPPR).
Zadeh, L. A. (1978). "Fuzzy Sets as a basis for a theory of possibility." Fuzzy Sets and Systems **1**: 3-28.