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Decision in the face of risks: optimization of decision schedule

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Abstract

The reasoning schedule leading to the decision making is the same whatever the addressed risks: a set of data to be collected, one or several models to be developed and a decision to be made. This schedule must integrate: (1) data that are uncertain, incomplete, censured, (2) models and decision processes that are imprecise or based on strong hypothesis of models and, (3) economical, political and sociological aspects. Considering the triplet {risks; context of decision making; variety of data, models and decision making}, the following problem directly emerges: what is the best triplet {data; models; decision making} that will allow taking the best decision when faced to risks in a fixed context? Our proposition is a methodology to collect and use at best data in order to obtain a coherent chain of risk analysis. As an illustration, we propose the case study of the service life assessment of building components.

1. Introduction

The evolution of new technologies, climate change and, at the same time, increasing knowledge stimulate mankind to assess the risks that are confronted, that is to say, in our context, technological and natural risks.

The reasoning schedule leading to decision making is the same whatever the addressed risks: data → models → decision making, in an economical, political and sociological context that contributes more or less thought and study time.

Different types of data are available, such as sightings, results from experimentations, instrumentations and numerical or theoretical models. Several models of data treatment may be useful: statistical model (Siemes et al. 1985), probability (Brandt and Wittchen 1999) and possibility (Shafer, 1976; Lair, 2000) approaches, expert judgements (as an example (ISO, 2006)), etc. Decision making is usually aided by optimization methods (Fletcher, 2000) or multicriteria decision making methods (Roy, 1985). A succinct critical review of these available data, models and decision making methods is done in the second section of this paper.

The problem that is directly emerging from this context is to find the best triplet {data; models; decision making} that will allow taking the best decision when faced with risks in a given context.

Our proposition is a methodology to collect and use at best data in order to obtain a coherent chain of risk analysis. In concrete terms our proposition compounds: (1) a model to formalise the objectives of the decision making and the available data to responds to these objectives, (2) a model to assess the data quality that appears essential to best choose the models of data treatment and, (3) a generic and iterative process of the decision schedule. This proposition is detailed in the third section of this paper.

The fourth section of this paper is dedicated to an illustration of the above proposition with regard to a case study of the assessment of service life of building components. The considered risks for this illustration are associated with the failures of these building components likely to be caused by a random environment. The context of this assessment is characterized by the heterogeneity of available data (sources, scales, imperfections in terms of uncertainty, imprecision and incompleteness) and the will of improvement of building components in the phase of design as well as in the phase of service life (inspection, maintenance and repair). The different types of data, models and decision makings as previously cited are integrated in the decision schedule.

2. Problem of the optimization of decision schedule

In the construction domain, problems to be solved are numerous, as the diversity of the sub-domains of application (characterisation of materials behaviour, of building components behaviour, of structures behaviour, stability of buildings, of civil engineering constructions considering current conditions, accidental conditions or exceptional conditions, etc.), as the diversity of materials, building components and structures, as the diversity of actors, as the diversity of the technical and usage functions ensured by these constructive entities and as the diversity of the requirements and the political, economical and social stakes. Among all the possible problems some examples can be shown: (1) the modeling of the alkali-reaction phenomenon for NPKA concrete tests, (2) the assessment of the fire resistance of firebreak doors, (3) the failure probabilities of a dam for a project flood of 10 000 years, (4) the assessment of the service life of a double glass unit considering real exposure conditions, (5) etc.

The optimization problem of the decision schedule is based on two observations. To solve the different problem of the construction domain, several data, several models of data treatment and several methods of decision making have been developed. These methods present similarities, divergences and they are more or less accurate to the available data; in consequence it seems to be evident that a unique triplet {data, model of data treatment, method of decision making} cannot solve the entire set of the problem. Then, we propose in this section a critical review of the main types of data, of the main models of data treatment and of the main methods of decision making before detailing in section 3 the proposed tools that allow to aid the solving of the problem of decision making that is, in our opinion, to find the triplet {data, model of data treatment, method of decision making} that best corresponds to the given objective and the given study context.

2.1. Critical review of available type of data

The main type of available data are: (1) sightings, (2) experimentations, (3) instrumentations,(4) simulations, (5) statistics, (6) expert opinions and, (7) probabilities.

a. Sightings
The sightings correspond to the data provided by the feedback; data may be providing from visual examination or instrumentation measures on available constructive entities (as an example, the crack spacing measured with a crack meter or the piezometric height measured with a piezometer). The main advantage of sightings is that they are obtained for real constructive entities and real environment conditions. The major disadvantage are: (1) the eventual imprecision of the observed values, (2) the unawareness of the climatic and usage conditions and, (3) the censorship (i.e., selective sampling) of data if the sightings are not made in a continuous way that is the current case.

b. Experimentations
The experimentations correspond to data provided by an experimental assembly that is done in order to characterise the behaviour of constructive entities when considering controlled climatic and usage conditions. As an example, for the ageing tests of constructive entities, three type of exposure conditions can be distinguished: long term exposure, short term exposure and accelerated short term exposure (Jernberg *et al*., 2004). The main advantage of experimentations is that they are obtained for controlled exposure conditions. The main disadvantage of this type of data is inherent to the difficulty to transpose these results to other case studies in real environment conditions.

c. Instrumentations
The instrumentations correspond to data provided by measurement tools. The main advantage of this type of data is to have access to results that are not visually measurable and that are reproducible. The main disadvantages of this type of data are: (1) the implementation cost, (2) the censorship if the measurements are not obtained in a continuous way and, (3) the transposition to other case study.

d. Simulations
The simulations correspond to the results of numerical models. The main advantage of such type of data is the possibility to realise a consequent number of simulations that correspond to different case studies. The main disadvantages of this kind of data are: (1) the number of simplifying hypothesis for a generic numerical model, (2) the difficulty of transposition to other case studies for an accurate numerical model and, (3) the difficulty of feedback analysis.

e. Statistics
The statistics correspond to a value or a set of values for a fixed sample. The advantage of this type of data is to have a global vision of a phenomenon that is difficulty explicable by the variation of the set of parameters that characterise this phenomenon. The main disadvantage is to obtain a representative sample.

f. Expert opinions
The expert opinions correspond to the expert conclusions as regards observed facts. The advantages of expert opinions are that results can be provided quickly, however the major disadvantages are that such data is subjective and quite difficult to be extracted.

g. Probabilities
The probability data corresponds to probability laws and parameters of these probability laws that characterise phenomena. The advantage of such type of data is the numerous available probability laws to best model the studied phenomena. The main disadvantage of such data is the number of simplifying hypothesis that must be fixed.

2.2. Critical review of available models of data treatment

Five models of data treatment are generally distinguished: (1) statistical approach, (2) probability approach, (3) approach based on the possibility theory, (4) behaviour models and, (5) expert models.

Statistical approach
The statistical approach is relevant when several data of one same type, that is to say data associated to a same problem, is available in order to provide a coherent sample.

Probability approach
The probability approach is relevant when well known phenomena are studied, that is to say when sufficient information is available in order to define the best appropriate probability law and its characteristic parameters.

The statistical and the probability approaches allow taking into account together several random parameters; however these approaches use only one type of data for one study and the obtained results are difficult to transpose to other case studies.

Approach based on the possibility theory
The possibility approach allows taking into account all the available data whatever its type; however such approach needs a good knowledge of the obtaining conditions of the used data in order to define the belief mass (i.e., degree of confidence) attached to each data. It is possible to use the entire set of possible types of data as all types of data can be modeled with a possibility format (Boissier and Talon, 2007).

Behaviour models
They allow providing a theoretical modeling of the behaviour of constructive entities; however the more accurate the obtained model is, the more difficult the transposition of this model to other case studies is.

Expert models
The expert models correspond to the modeling of the reasoning of experts that allows obtaining conclusions on the basis of observed facts. The expert models allow quickly obtaining a result, but it is a subjective result.

Table 1 regroups the different types of data, defined in the section 2.1, usable by the five models of data treatment previously presented.

Table 1: Correspondence between data type and model of data treatment

Data treatment model \ Data type	a	b	c	d	e	f	g
Statistic approach	✓	✓	✓	✓	✓		
Probabilistic approach	✓	✓	✓	✓	✓	✓	✓
Approach based on possibility theory	✓	✓	✓	✓	✓	✓	✓
Behaviour model		✓	✓	✓			
Expert model	✓	✓	✓			✓	

2.3. Critical review of available methods of decision making

Two types of methods of decision making may be generally distinguished: (1) optimisation methods that search the parameters values that maximise or minimise the most relevant criterion of the considered problem and, (2) methods of multi-criteria decision making that consist in choosing, sorting, ordering or describing a set of solutions as regards the different criteria that characterise the problem. The main available methods of multi-criteria analysis are: multiplicative and additive models, MAUT, Goal Programming, Condorcet, ELECTRE, PROMETHEE, EXPROM, etc. (Lemaire, 2006; Roy, 1985).

3. Tools for aiding the decision schedule

Three tools are proposed in this section that allow aiding the definition of the best triplet {type of data, model of data treatment, method of decision making} to solve some problems of the construction domain.

3.1. Model of data formalisation

This first tool is dedicated to the data formalisation and aims to build cartography of the endorsed objective and of the available data to reach this objective. The goal of this cartography is twofold: (1) to appropriately define the endorsed objective, that is to say the wanted level of accuracy and the study limits and, (2) to locate the correspondence (accuracy and scales) between available data and endorsed objective in order to best select the most relevant model of data treatment when several types of data are available.

We consider that all objectives and all data may be formalised in accordance with four parameters: (1) a geometrical granularity, (2) a phenomenological granularity, (3) a functional granularity and, (4) a temporal granularity.

A referential of formalisation is proposed in which four graduated axes are associated to these four factors. The first axis is the geometrical axis that compounds four levels: (1) the material (such as concrete), (2) the element (such as a concrete beam), (3) the building component (such as a concrete wall covered by an insulating complex) and, (4) the construction (such as a building with a reinforced concrete structure). The second axis is the phenomenological axis that regroups three levels: (1) the phenomenon (such as the shock of an avalanche against an anti-avalanche wall), (2) the scenario (such as the chain of events that leads to the destruction of a firebreak door) and, (3) the scenarios (as an example, the entire set of chains of events that leads to the failure of a building). The third axis is the functional axis; it characterises the requirements as regards the objective; two levels are defined: (1) the mono-function level, the main requirement is considered and, (2) the multi-function level, all the requirements are taken into account. The fourth axis is the temporal axis; it is possible to consider a study during the duration of the research project, during the duration of a test or during the service life of a constructive entity, etc.

This formalisation model of data is detailed in (Talon *et al*., 2007; Talon, 2006).

3.2. Model of data quality assessment

This model is dedicated to the quality assessment of collected data and aims to affect a belief mass (confidence degree) to each data in order to allow: (1) to judge if the collected data has a sufficient quality in order to pursue the study, that is to say in order to apply the model of data treatment and, (2) to provide a priority of the different types of data that has the highest belief mass when several types of data are collected.

The data quality is inversely proportional to the imperfections associated to this data; three types of imperfections may be distinguished:

– Inherent imperfection: this one integrates the obtaining process of this data, the reliability of the information source, the censorship (due to the duration and the means of the sightings) and the incompleteness;
– Imperfection due to the modeling of data: this imperfection corresponds to the efficiency of the modeling of all types of data in a possibility format;
– Imperfection due to the usage: on the one hand, this imperfection regroups the fit between collected data and studied case and, on the other hand, this imperfection includes the rate of information of the data. As an example, the combustion duration of a wood beam in an air oven and the combustion duration of a wood frame in service will not have: (1) the same geometrical granularity (element level for the first and building component level for the second) and, (2) the same exposure conditions correspondence (different exposure environments). The rate of information of a data, measured with the Shannon's Entropy, represents the idea that an assessment provided by a particular value integrate more uncertainty (there is a higher chance that the result is realistic) than an assessment provided by an interval that includes this particular value.

An assessment grid of data quality is proposed in Table 2 and detailed in (Talon, 2006) in order to facilitate the assessment of the data quality process and to make the assessment homogeneous for all collected data. This grid is based on the NUSAP method, for Numerical Unit Spread Assessment Pedigree, (Funtowicz and Ravetz, 1990) and of the PhD thesis of J. Lair (2000). The result of the assessment of belief mass is equal to the average of the values taken by the entire set of the quality criteria.

Table 2: Assessment grid of data quality

	Values			
Criteria	1	2/3	1/3	0
Data modeling	Established theory	Non established theory	Statistical study	Non modeled
Hypothesis of modeling	Poor	Fair	High	Very high
Obtaining mode	Experience plan	Feedback	Good estimation	Poor estimation
Source	Referenced	Internal	Conference	Isolated
Censorship	Non censored	Partially censored	Censored	Not taken into account
Coherence of the modeling of data	Excellent	Good	Fair	Poor
Correspondence between data and fixed objective	Excellent	Good	Fair	Poor

Entropy	$\frac{\sum_{x \in X} f_{mc}(x) ln(f_{mc}(x))}{ln(1/\Theta)}$ where X represents the interval of values of the data (such as [5; 10] years for an duration assessment), x is a value of the discrete data (a date for the duration assessment), Θ is the frame of discernment (observation period $[t_{min}\ ;\ t_{max}]$ for the duration assessment), and $f_{mc}(x)$ is the belief mass function associated to the x value, as detailed in (Talon, 2006).

3.3. Generic and iterative process of the decision schedule

The proposed generic and iterative process of the decision schedule is schematised in the following Figure 1.

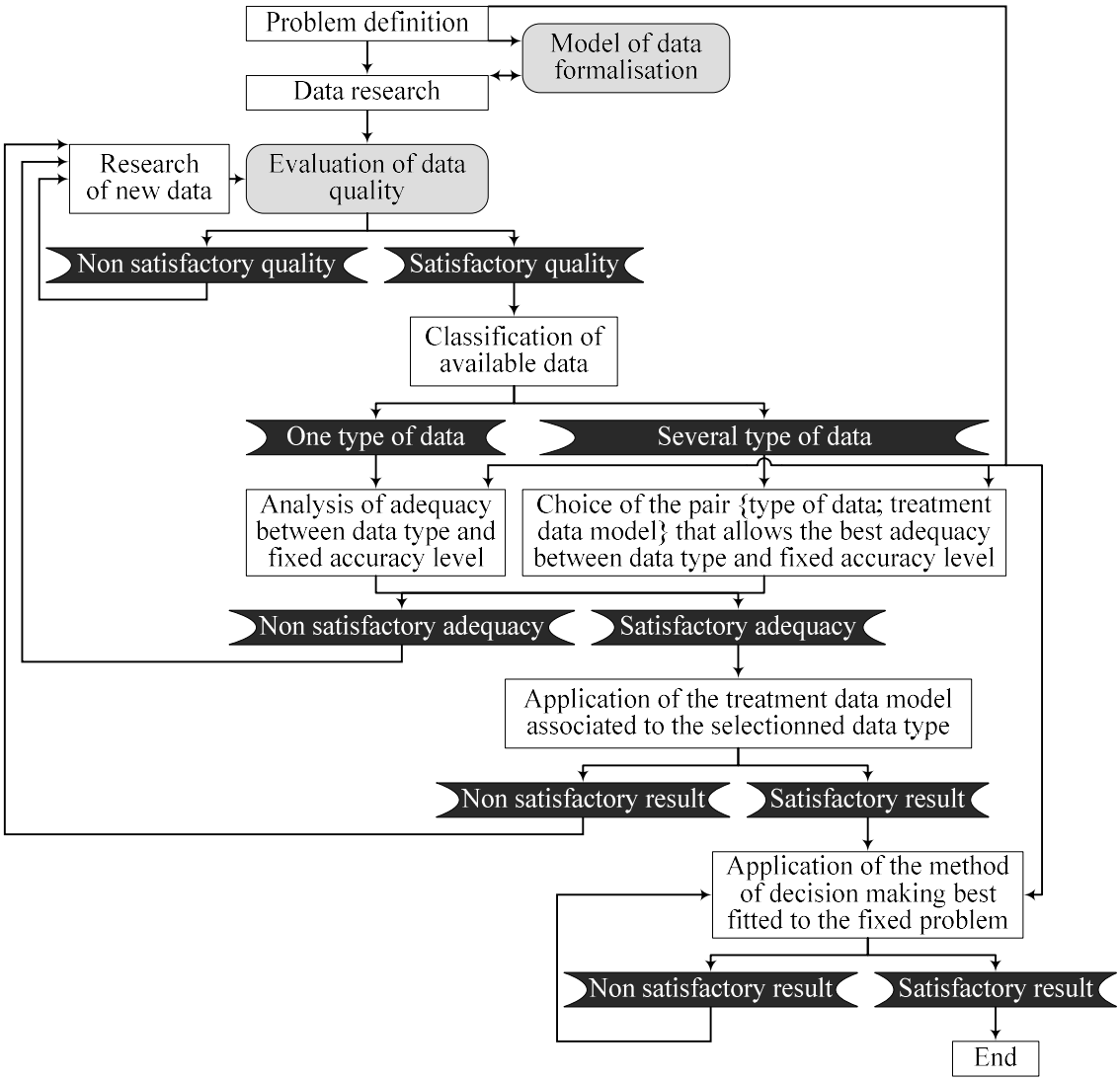


Figure 1: Schematisation of the generic and iterative process of the decision schedule

The general principle of this decision schedule process is to assess the quality of the available collected data, to choose the method of data treatment that is best adapted to the type of data that had the highest belief mass as well to the accuracy of the required objective. As an example, if one wants to assess with a high accuracy a material behaviour as regards specific environmental actions, the obtaining of a behaviour model will be more appropriate (if data is sufficient and has a satisfactory quality) than an expert opinion. The general principle is then led by the assessment of the result obtained by the chosen model of data treatment; if the result is satisfactory, then the application of the decision method that best corresponds to the weighted objective is done. When the obtained result is satisfactory, the process is stopped. This process is iterative as, if the results are not satisfactory, new data may be searched or a new method of data making may be applied.

An added aim of this decision schedule process is the definition of missing data in the construction domain that can lead to underline the new experimentations, simulations, examinations … that may be proceed.

4. Application to the case study of the service life assessment of building components

The problem of the case study presented in this section is to assess the service life of all building components in a given climatic and usage in-service environment while considering: (1) all the degradation scenarios that can affect the performance of this building component over its service life, (2) all the technical and usage functions ensured by this building component.

As regards the referential proposed in the section 3.1, this problem may be modeled by the four following levels: (1) geometrical axis = building component, (2) phenomenological axis = all degradation scenarios, (3) functional axis = all the functions ensured by these building components and, (4) temporal axis = service life.

The service life assessment is a major research field in the construction domain, as it is proved by the international work group ISO/TC59/SC14 and the national French work group P01E for the standardization of the service life, as well as the CIB work groups, notably the CIB W080. As a consequence, many sources of data are available: the seven types of data defined in the section 2.1 are available for this problem. Some data concerns the durability of the materials, the elements and the building components. This data is relevant to the phenomena or the degradation scenarios of these constructive entities. This data characterises one or several functions ensured the building components and is associated to different phases of the life cycle of the building components (design, implementation, service life, rehabilitation and deconstruction). Then, the available data is multi-sources and multi-scales.

The main models of data treatment used in the domain of the service life assessment of the constructive entities are: methods based on a probabilistic approach, statistical approaches, comparisons between long-term and short-term exposure tests, feedback from practice and factorial method for service life estimation. The major disadvantages of these models are: (1) use of a unique type of data and, (2) difficulty to the transpose to other constructive entities considered in other climatic and usage conditions. Those are the reasons why we prefer using the approach based on the possibility theory as it allows: (1) to model all data types with a possibility format and then to use all available data, (2) to integrate the belief mass attached to each collected data (obtained by the model of data quality assessment – *cf.* § 3.2), into the model of data treatment; this model is a compound of:

– a data unification that is applied when several data relevant to a same problem is available that is to say when the levels in the referential of the problem objective (as proposed in § 3.1) are the same as the levels of the collected data;
– a data aggregation that is applied when data relevant to different sub-problems that allow obtaining the problem result is available that is to say when the levels in the referential of the problem objective are different from the level of the collected data associated to the different sub-problems.

The method of decision making of the problem of the service life assessment of building components aims to obtain a consensual data that regroups the maximum of consensus and an estimation of the quality of the obtained consensual data.

Illustration:
Considering the following problem: "to assess the cracking time of a reinforced concrete structure in contact with external environment". We also consider that this problem may compound three sub-problems:
– sub-problem 1: "to assess the duration of the carbonation front to reach the reinforcement",
– sub-problem 2: "to assess the duration of the reinforcement corrosion",
– sub-problem 3: "to assess the duration of the cracking to reach the structure surface due to the reinforcement corrosion".
Considering that the nine available data are grouped in the Table 3.

Table 3: Duration data associated to the assessment problem of the cracking

Sub-problems	Data		
Reaching of the reinforcement by the carbonation front	D1. Statistics	D2. Theoretical model	D3. Experimentations
Reinforcement corrosion	D4. Simulations	D5. Simulations	D6. Experimentations
Cracking reaching of the structure surface	D7. Theoretical model	D8. Experimentations	D9. Expert opinions

The approach for the resolution problem associated to the available data of the Table 3 is schematised in the Figure 2.

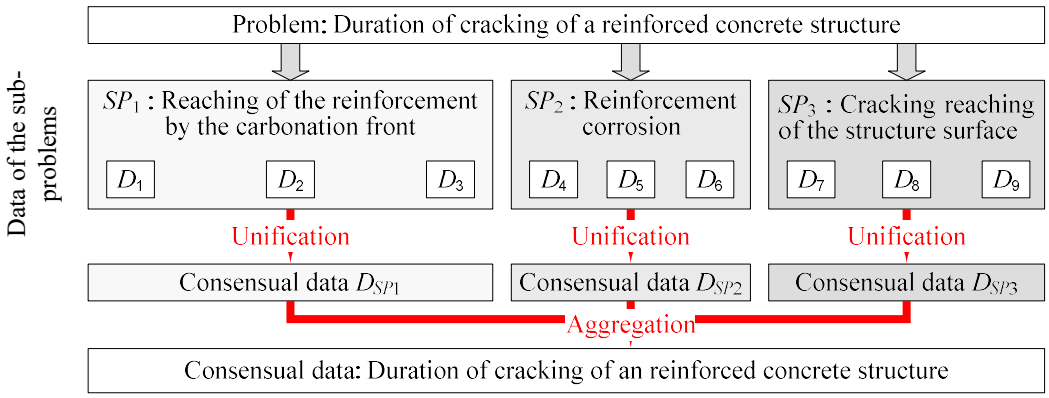


Figure 2: Approach of data treatment for the problem of the cracking time of an reinforced concrete structure

Conclusions

Many problems solving in the construction domain may be schematized by the following decision schedule: data → model of data treatment → method of decision making. The second part of this paper has proposed a critical review of the different types of data, of the different models of data treatment and of the different available methods of decision making. From this critical review, we deduced that all problem solving in the construction domain is done by the choice of the triplet {data type, model of data treatment, method of decision making} that best responds to the given problem. Three tools have been proposed in order to facilitate this choice; they are: (1) a formalisation model of the fixed objective and the available data, (2) an assessment model of the quality of the available data (3) a generic and iterative process of the decision schedule. Their applications to the case study of the assessment of the service life of building components has proved the applicability and the efficiency of these three tools.

References

Brandt, E. and Wittchen K. B. (1999) *EPIQR – A new surveying tool for maintenance and refurbishment*, Proc. of the Durability of Building Materials and Components 8, Vancouver, pp. 1576-1584.

Fletcher, R. (2000) *Practical methods of optimization*, John Wiley & Sons, New-York.

Funtowicz, S.O., Ravetz, J.R. (1990) *Uncertainty and Quality in Science for Policy*, Kluwer Academic Publishers, Dordrecht.

ISO, (2006) *Building and constructed assets – Service life planning – Part 8: Reference service life and service-life estimation*, ISO/DIS 15686-8.

Jernberg, P., Lacasse, M.A., Haagenrud, S.E., Sjostrom, C. (2004) *Guide and Bibliography to Service Life and Durability Research for Building Materials and Components*, Publication CIB n°295.

Lair, J. (2000) *Evaluation de la durabilité des systèmes constructifs du bâtiment*, Thesis (PhD) of Clermont-Ferrand University, CSTB and LERMES.

Lemaire, S. (2006) *Aide au choix des produits de construction sur la base de leurs performances environnementales et saniataires*, Thesis (PhD) of Lyon University, LASH/ENTPE and CSTB.

Roy, B. (1985) *Méthodologie multicritère d'aide à la decision*, Economica, Paris.

Shafer, G. (1976) *A mathematical Theory of evidence*, Princeton University Press, Chichester.

Shannon, C.E. and Weaver, W. (1972) *The mathematical theory of communication*, University of Illinois Press, Urbana.

Siemes, A., Vrouwenvelder, A. and Van Der Beukel A. (1985) *Stochastic modeling of building materials performance in durability*, Proc. of the Problems in Service Life Prediction of Building and Construction Materials, NATO ASI Series, Dortrecht, pp. 253-263.

Talon, A., Boissier, D., and Lair, J. (2007) *Service life assessment of building components: Application of evidence theory*, Canadian Journal of Civil Engineering, accepted for publication.

Boissier, D. and Talon, A. (2007) *Approche probabiliste et possibiliste pour la prise en compte de l'incertain*, Report for the PNISI French project.

Talon, A. (2006) *Evaluation des scenarii de degradation des produits de construction*, Thesis (PhD) of Clermont-Ferrand University, CSTB and LGC.