Airbus Group Innovations

Quantification des incertitudes - Partie I

Saclay, February 2014

Fabien MANGEANT, fabien.mangeant@eads.net

February 12, 2014

Outline

1. **Motivation**
   - Philosophy...
   - Domains of application
2. **Developing uncertainty management in an applicative context**
   - Uncertainty management and associated decision
   - Risk and uncertainty
   - Description of the industrial environment
   - Strategies to deal with uncertainty
   - Survey of the main trends and popular concepts
   - Existing referentials to deal with the uncertainty
   - UQ environement
3. **Practitionner's difficulties**
   - Building several images of the world
   - General model presentation
   - Basics in validation and verification
   - What kind of complexity do we face to validate a numerical simulation ?
4. **Bibliography**

Outline

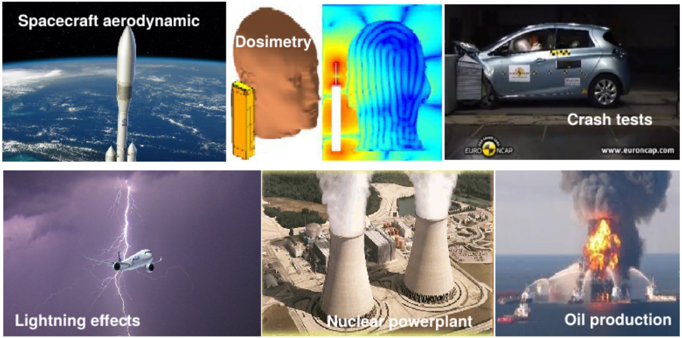
Complexity and uncertainty

"***Complexity*** *lies within the entanglement that does not allow to tackle things separately, it severs what binds groups, and produces a crippled knowledge. The problem of complexity further appears since we are part of a world, which is ruled not only by determination, stability, repetitions, or cycles, but also by outbursts and renewal. Throughout complexity, there are* ***uncertainties****, either empirical or theoretical, but, most of the time, both.*"

Edgar Morin, Philosopher.

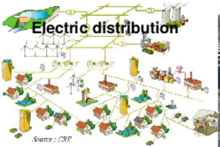
Various contexts of uncertainty

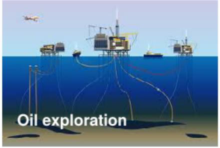
SAFETY CONTEXTS



Various contexts of uncertainty

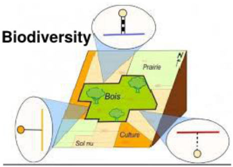
ECONOMICAL CONTEXTS

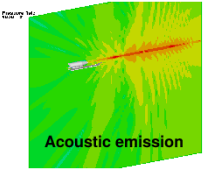


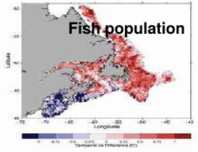


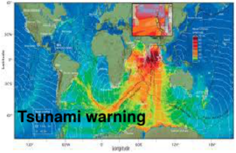
Various contexts of uncertainty

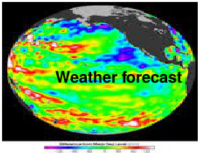
ENVIRONMENTAL CONTEXTS











EADS

Several types of systems

Technical systems

Car, airplane, nuclear power plant, hydrowind farm, ...

Natural systems

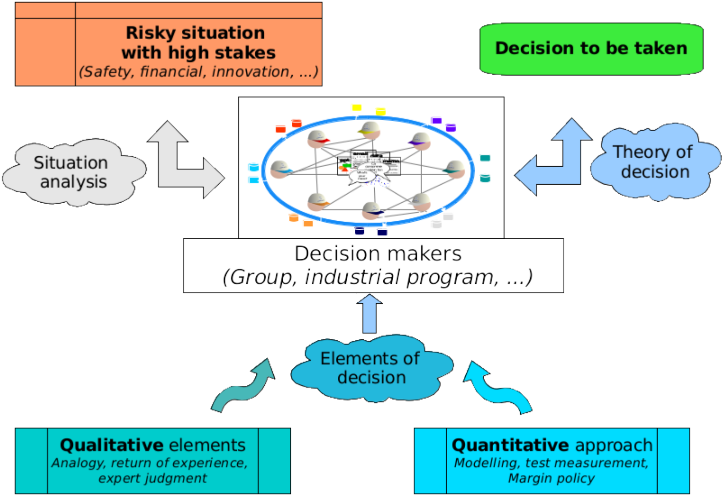
Fish population, weather forecast

Hybrid systems

Internet, social network models

Outline

Uncertainty analysis in a decision process



Uncertainty analysis in a decision process

Situation analysis

- Identification of constraints (applicable standards, group strategy)
- Identification of risks and opportunities
- Identification of the degrees of freedom in the situation
- Definition of the scenarii to be investigated
- Allocation of resources to undertake the analysis

Uncertainty analysis in a decision process

Technical analysis

Definition: *Technical work intended to generate and aggregate qualitative and quantitative elements within an allocated resource*

- **Qualitative approaches** refer to methods and tools that integrate past experience, intuition, return of experience, sense of analogy. They are not supported by a physical test or a numerical model at the time of their expression but they integrate engineering/expert judgement.
- **Quantitative approaches** are supported by tests or numerical models. Tests and models represent a simplified and theorized understanding of the situation. They are designed to be representative and reproducible for the situation of interest. Anyway, some problems arise when dependence is hidden between the different elements of the situation or when the cost of a test (physical or numerical) that is required is too expensive for the avalaible budget.

Uncertainty analysis in a decision process

Decision

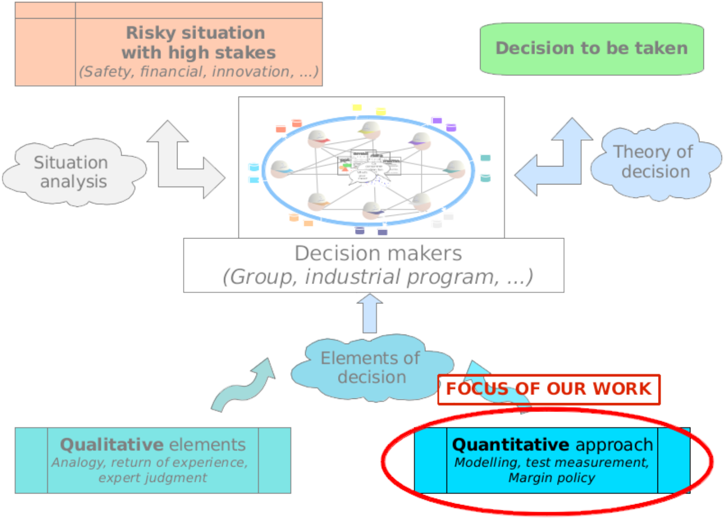
Definition: Act of deciding, responsible for the consequences in a certain context (risk adverse, knowledge and positioning of the decision maker).

- Risk adverse
- Decision under constraints

Remark

Choosing the appropriate decision criteria for decision-making under uncertainty is a large and specific domain of research: it involves in-depth understanding of the larger decision processes, and potentially a conceptual decision-theory approach to the decision-maker's preferences, attitudes towards risk and uncertainty

Scope of application of our mathematical tools

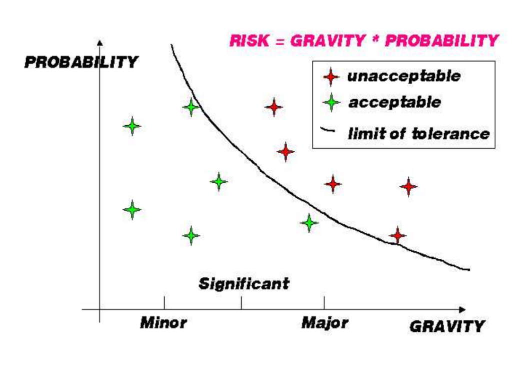


Risk and uncertainty

Risk

A risk is defined by the effect of uncertainty on specific objectives. A risk is both attached to the realization of a certain event towards its subjective scale of gravity/criticity. It is very common to define the risk by the following formula:

$$Risk = probability * gravity \quad (1)$$



Risk and uncertainty

Uncertainty

Distinction between types of uncertainties encountered in practice:

- “irreducible” or “aleatory” (or random, stochastic, objective, inherent,...) vs. “reducible” or “epistemic” (or lack of knowledge, ignorance, subjective, imprecision, ...)
- “variability” (spatial, temporal, ...) vs. “uncertainty” (lack of knowledge, measurement error etc)
- “epistemic uncertainty” (invevitable ignorance) vs. “error“ (deliberate ignorance)
- uncertainty that is "parametric" (associated with model inputs according to the level of information available on those inputs) vs. ”modelling uncertainty” affecting the adequacy of the model itself to reality (structure, equations, discretisation, numerical resolution etc.)

EADS

Internal/endogeneous *versus* external/exogeneous uncertainties

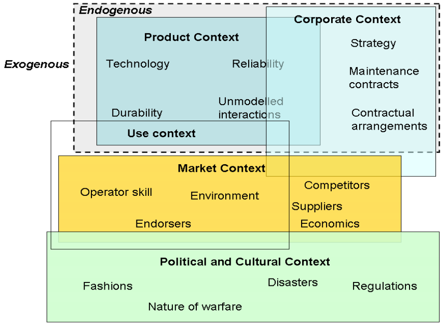


Figure : Links between uncertainties and industrial contexts

1. **Internal/endogeneous**: Each product or system bears its own uncertainties with it, which arise primarily from the "inside". It can be influenced by the system designer or company to a certain extent.
2. **External/exogeneous**: Uncertainties outside the system boundary can be influenced by the designers or company to a lesser extent.

Layers of uncertainty

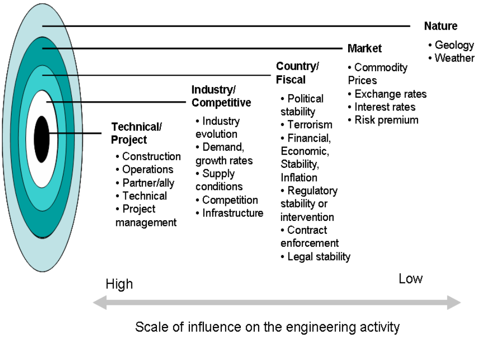


Figure : Links between uncertainties and external contexts

- The degree of influence decreases sharply from the inner to the outer layer.
- The possibility of mitigating risks or exploiting opportunities arising from these uncertainties thus also decrease.

Time scale and uncertainty management strategies

Short-term

These decisions concern immediate issues. Being limited to the available data and pre-existing models, the objective is to treat the existing information to aid the decision-maker.

Mid-term

Unlike short-term decisions, these involve situations in which a support is conceivable, such as the development of refined models or collection of additional data to improve the understanding of the global phenomenon.

Long-term

These concern long-term issues, including the influence of societal, political and market evolutions.

New opportunities to improve procedures and practices around uncertainty management

1. Recent conceptual reformulation: shift from "failure-driven risk approach" to "option-exploring approach" in uncertainty management.
2. Recognition that the performance of an engineered system has to be taken into account in its larger commercial and political environment:
   - To bullet-proof design against technical and human failure
   - To enable the system to evolve to new circumstances and usages
3. New advances in information technology (development of models, acquisition of computer, etc) make it possible to conceive of a much more coherent uncertainty management approach.

Standards and tools

BIPM

JCGM 100:2008

GUM 1995 with minor corrections

Evaluation of measurement data — Guide to the expression of uncertainty in measurement

Évaluation des données de mesure — Guide pour l'expression de l'incertitude de mesure

ΜΕΤΡΩ ΧΡΩ

First edition September 2008

© JCGM 2008

Standards and tools

Example of Credibility Scoring – With Factor Weighting (NASA HRP Implementation)

	Credibility Assessment Factors	Evidence			Technical Review		Factor Score	Weighted Subfactor Score	Overall Score	Sufficiency Threshold
		Score*	Weight+	Threshold*	Score*	Threshold*				
1	Verification	2	0.20	3	2	3	2	0.40	1.75	2.54
2	Validation	2	0.25	2	2	3	2	0.50		
3	Input Pedigree	2	0.10	3	2	3	2	0.20		
4	Results Uncertainty	0	0.10	2	0	3	0	0.00		
5	Results Robustness	2	0.10	2	2	3	2	0.20		
6	Use History	1	0.15	2	N/A	N/A	1	0.15		
7	M&S Management	2	0.05	3	N/A	N/A	2	0.10		
8	People Qualifications	4	0.05	3	N/A	N/A	4	0.20		

* Maximum = 4; where 0=insufficient evidence and 4=highest fidelity/rigor achievable

+ Minimum = 0.05, maximum = 0.25 and sum of all weights must equal 1.0

*Threshold: The required score agreed to by the end-user/customer and M&S provider to achieve sufficient confidence in the M&S for intended use

Subfactors	Weight
Evidence	0.7
Technical Review	0.3

Legend	
Blue	CAS Score > Threshold *Exceeds credibility requirements*
Green	Threshold ≥ CAS Score ≥ (Threshold-0.5) *Ready for use*
Yellow	(Threshold-0.5) > CAS Score ≥ (Threshold-1.0) *Use with caution*
Red	CAS Score < (Threshold-1.0) *Use not recommended or to be used with EXTREME CAUTION by subject matter experts only*

EADS

UM environment

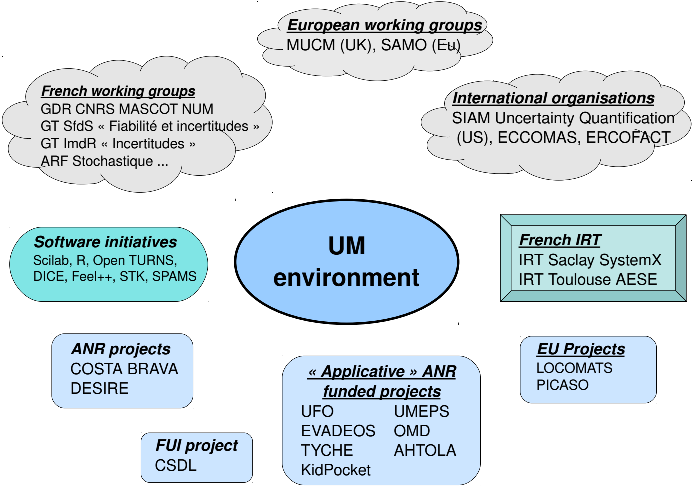


Figure : On-going initiatives in UM that I know... See for example MASCOT NUM [20] or MUCM [23]

Outline

Two types of images of the world

- **The Empirical Image**: made of material experiments
- **The Rational Image**: essentially a theory-based image which rests on (supposed-to-be) physical models and derived codes (models are scientific images of a theory).

Examples of scientific images

- Flight of an airplane
  - Rational : use of NS equations plus turbulence models
  - Empirical : Scale model (= wind tunnel)
- Tumor growth :
  - Rational : discrete reality of interest continuously representated through a set of coupled PDE
  - Empirical : analogical model (mice = men)
- Urban gang extension :
  - Rational : individuals thought as particles submitted to simple interacting rules.
  - Empirical : polls, police reports

Link between model and reality

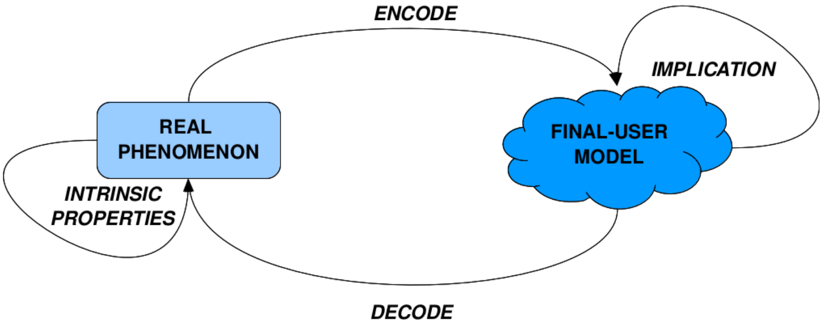


Figure : Interaction between model and reality

Simulation: A process which mimics the relevant features of a target process.
Numerical Simulation: A processis is a Computer Simulation iif it is a Simulation and a computer process

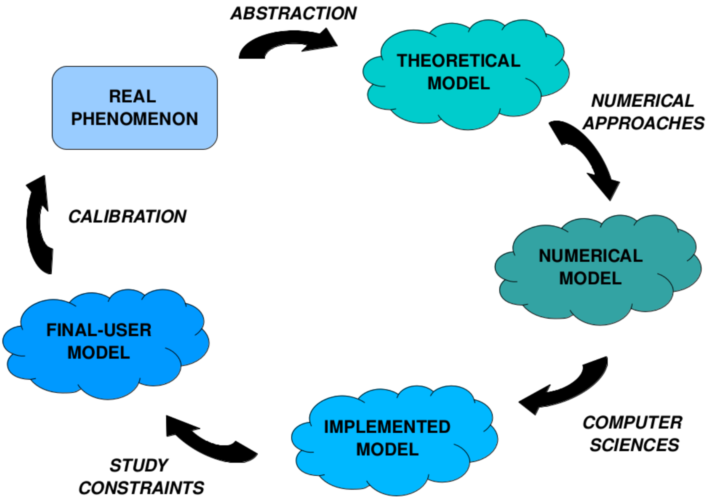


Figure : Modelling loop

Example in simulation contexts

Source	Vérification	Validation
Systems Eng. [1]	Proof of compliance with specifications. Verification may be determined by test, analysis, demonstration, and inspection.	Proof that the product accomplishes the intended purpose. Validation may be determined by a combination of test, analysis, and demonstration.
Software Eng. [2]	Software verification is a software engineering activity that demonstrates that the software products meet specified requirements.	Software validation is a software engineering activity that demonstrates that the as-built software product or software product component satisfies its intended use in its intended environment.
M&S [3]	The process of determining that a computational model accurately represents the underlying mathematical model and its solution from the perspective of the intended uses of M&S.	The process of determining the degree to which a model or a simulation is an accurate representation of the real world from the perspective of the intended uses of the model or the simulation.

[1] :*NASA systems engineering processes and requirements*, URL http ://nodis3.gsfc.nans.gov

[2] :*IEEE standard dictionary of electrical and electronics term*, ANSI/IEEE Std 100-1984 (1984)

[3] :*NASA standards for models and simulations*,NASA-STD-2009, 11 juillet 2008

Figure : Numerical Simulation contexts ([30]

Example in simulation contexts

Simulation contexts differ from a field to another

	Geology	Epidemiology	Engineering
Purpose	Understand the Chicoxulub meteorit impact	Contain the spreading of some virus (ie. H1N1 flue)	Conceive some industrial product
Goals	Was it responsible of the extinction of dinosaurs ?	Minimize the number of infected people	Maximize performances while minimizing costs
Empirical grounds	Only one observation ; deduction, hypothetizing	Real time observations of spreading evolution	Many dedicated experiments
Confirmatory experiment	I hope not ! ! !	The end of the infection	Many experiments
Do it again	No	No	Yes
Faith enhanced if	New discoveries confirm theoritical computations	Not assessable [a]	If experiments agree with numerical simulations
External constraints	No one	Public opinion, Media, Crisis management	Markets, consumers attitude, costs

Figure : Numerical Simulation contexts ([30]

Complexity of the physical representation

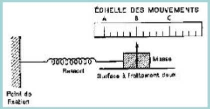
BASIC ELEMENTS TO MEASURE THE COMPLEXITY OF A SIMULATION

- Modelling assumptions
- Level of detail
- Linearity

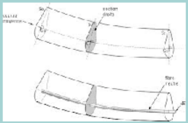
→ ***Complexity to represent the disciplinary problem***

Example

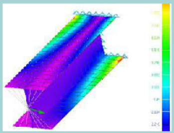
Spring



Beam

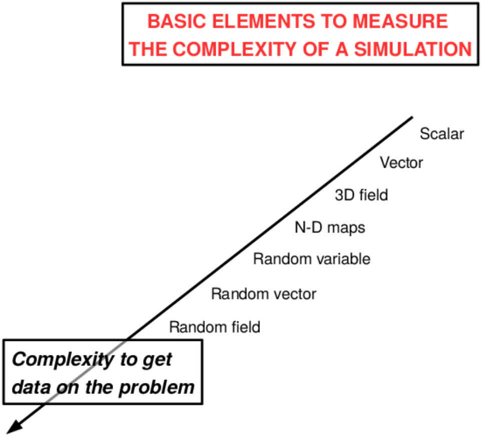


Linear elasticity



EADS

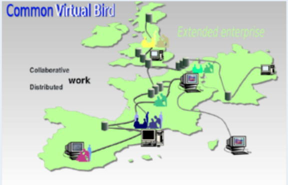
Complexity linked to the input data model



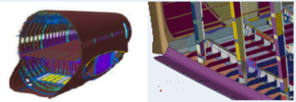
Complexity linked to the multiplicity of actors and location

BASIC ELEMENTS TO MEASURE THE COMPLEXITY OF A SIMULATION

Organisation



Size of the model



Complexity to build the numerical model

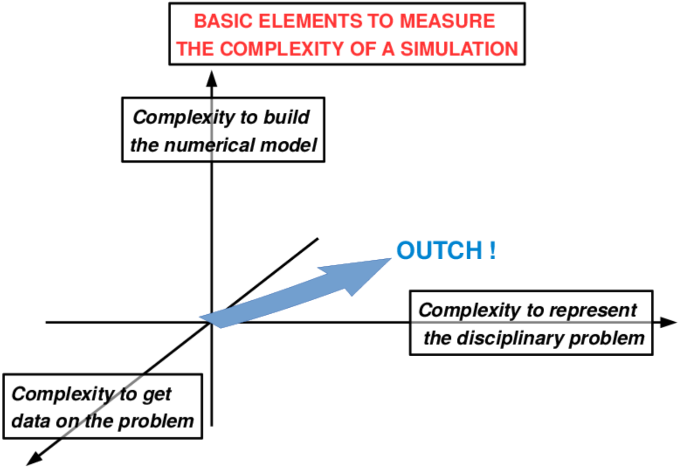
# of actors to build/shape/integrate the compoenents of the numerical model

# of numerical components to build the model

# of degrees of freedoms

EADS

The challenge of complexities



Outline

- A. Antoniadis, Analyse de sensibilite, Seminaire de Toulouse 2006, www.gdr-mascotnum.fr
- Apostolakis G & Wu JS. (1993), Reliability and decision-making, Chapman & Hall London.
- Aven T. (2003), Foundations of Risk Analysis, John Wiley & Sons, Ltd.1
- Bedford T. & Cooke R. (2001), Probabilistic Risk Analysis - Foundations and Methods, Cambridge University Press.2
- R. Cont, R. Deguest, G. Scandolo (2010), Robustness and sensitivity analysis of risk measurement procedures, Quantitative Finance, Vol 10, No 6 - p593-606.
- Roger G. Ghanem and Pol D. Spanos (1991), Stochastic finite elements: A Spectral Approach, publisher Springer-Verlag - ISBN 0-387-97456-3 or 0-540-97456-3

- De Neufville R. (2003), Architecting/Designing engineering Systems using Real Options, MIT report ESD-WP-2003-01.09 (http://esd.mit.edu).
- De Neufville R. (2004), Uncertainty management for engineering systems planning and design, MIT Engineering
- EsREDA group (2008), Uncertainty in industrial practice: a guide to quantitative uncertainty management, Wiley
- Ghanem R, Spanos PD. (1991), Stochastic Finite Elements: A Spectral Approach. Springer: New York.
- Granger Morgan M. & Henrion M. (1990), Uncertainty - A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis, Cambridge University Press.3
- T. Hastie, R. Tibshirani, J. Friedman (2008) - The elements of statistical learning - Springer Series in Statistics.

- Kleijnen JPC (2009), Design and Analysis of Simulation Experiments
- Knight F.H. (1921), Risk, Uncertainty and Profit, Hart, Schaffner & Marx. Systems Monograph (http://esd.mit.edu/symposium/pdfs/monograph/uncertainty.pdf).
- P. Ladeveze (1999). Non linear Computational Structural Mechanics â New Approaches and Non-Incremental Methods of Calculation, Springer-Verlag, New York.
- Le Maitre O.P. and Knio O.M. (2010), Spectral Methods for Uncertainty Quantification With Applications to Computational Fluid Dynamics. Scientific Computation.
- Lucor D. (2006), Presentation at CEMRACS'06
- Maday Y., Reduced Basis Method for the Rapid and Reliable Solution of Partial Differential Equations, hal-00112152, version 1.

- F. Mangeant, *Joined initiatives around uncertainty management*, Annals of Telecommunications, DOI: 10.1007/s12243-011-0266-7
- GDR CNRS MASCOT-NUM, http://www.gdr-mascotnum.fr
- P. Massart (2007), Concentration inequalities and model selection: Ecole d'Ete de Probabilites de Saint-Flour XXXIII-2003. Springer Verlag.
- H.G. Matthies (2007), Uncertainty Quantification with Stochastic Finite Elements. Encyclopedia of Computational Mechanics.
- Managing Uncertainty in Complex Models (MUCM), http://www.mucm.ac.uk/
- Open Source initiative in uncertainty managempent, http://www.openturns.org
- A. Owen, J.R. Koehler, (1996), Computer Experiments

- N. Rachdi, J-C Fort, T. Klein (2010), Risk bounds for new M-estimation problems, http://hal.archives-ouvertes.fr/hal-00537236.
- N. Rachdi (2011), PhD thesis from University Paul Sabatier of Toulouse.
- J Sacks et al (1989), Design and Analysis of Computer Experiments, Technometrics
- Saltelli A., K. Chan, and E.M. Scott (2000). Sensitivity Analysis. Chichester: Wiley
- Sancandi M. GDR MASCOT NUM "Journée validation", www.gdr-mascotnum.fr
- Santner, Thomas (2003), The design and analysis of computere experiments -ISBN 0-387-95420-1

- Sobol, I. M. (1993). Sensitivity estimates for non linear mathematical models. Mathematical Modeling and Computational Experiment 1, 407-414
- de Weck O. & Eckert C. (2007), A classification of uncertainty for early product and system design, MIT report ESD-WP-2007-10 (http://esd.mit.edu/WPS).