CHEMICAL ENGINEERING TRANSACTIONS
VOL. 33, 2013
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet
Guest Editors: Enrico Zio, Piero Baraldi

ISBN 978-88-95608-24-2; **ISSN** 1974-9791
DOI: 10.3303/CET1333033

Risk Analysis Holistic Approach as a Base for Decision Making under Uncertainties

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Many engineering facilities are complex prototypes which manage huge energy quantities. Their interaction with the surroundings may impact significantly on the population, economy and the environment. Different areas of engineering and technologies take part in all the stages, from the initial conception of the project to the construction and further on.
In the other hand the concept of risk is widely treated in the bibliography. This concept includes both undesirable consequences and likelihoods. A very common definition of risk represents it as a set of:

- scenarios (set of accident scenarios),
- likelihoods (evaluation of the probabilities of these scenarios), and
- consequences (estimates their consequences)

Within each set are uncertainties. The uncertainties relate to whether all the significant accident scenarios have been identified, and whether the probabilities of the scenarios and associated consequence estimates have properly taken into account the sources of variability and the limitations of the available information.
Risk analysis not only is about technical factors (mostly random) but the non technical like organizational or due to the human factor. It is well known that the principal cause of failures is due to human errors. Diverse approaches have been proposed from deterministic to qualitative methods which in essence try to take into account and represent with more refinement the different types of uncertainties. Nevertheless it is accepted that risk is the union (convolution) among the probability of failure and the consequences on the surroundings.
With the aim to take into account and incorporate all these aspects in risk analysis, a holistic approach is presented in this paper. A hierarchical scheme permits incorporate random and epistemic uncertainties. Some considerations about the human factor role are made and a possible treatment is proposed. An estimation of loss of lives downstream a dam under a failure scenario is presented as an example. A map is the outcome of the analysis which can contribute in decision making within dam safety management.

1. Introduction

Risk analysis is used in different disciplines and is considered a genuine tool for the decision-making process.
Different areas of science and technology have diverse views of the concept of risk but nevertheless there is a coincidence in that it is directly associated with uncertainty. Thus the risk analysis process necessarily leads to a detailed study and determination of all the uncertainties present in the process.
On the other hand, uncertainties have a wide and varied treatment in the specialized bibliography; there are different postures. There are also a variety of mathematical tools that allow representing, evaluating or including them in the calculation algorithms in terms of the treatment of uncertainties. The best known and most successful is Probability Theory which allows working with the so-called random or inherent uncertainties (hard). These uncertainties present in the majority of the engineering processes can be taken into account on the basis of probabilistic approaches, when sufficient quantity and quality of information is available, being this fact not always possible.

Please cite this article as: De La Canal M., Ferraris I., 2013, Risk analysis holistic approach as a base for decision making under uncertainties, Chemical Engineering Transactions, 33, 193-198 DOI: 10.3303/CET1333033

In specific engineering fields, there is a broad consensus about the importance of the probabilistic schemes but technicians and managers have also become aware that not all the variables that intervene in the processes are random, especially those relating to the human factor. Uncertainty related to human behavior (soft) is significant and is present in all activities related to engineering. It is well known, Reason J., 1990 and Turner B., Pidgeon N., 1997 say, that according to available statistic information and international experience the principal cause of failures is due to human errors. In order to include human factor in risk analysis two general alternative schemes are found in the bibliography. Some authors allow including these variables in the calculation algorithms and others propone to analyze them quite separate using measures of control, i.g. QA strategies, in such a way that the human factor is maintained under certain values considered not influential on the results. Different approaches and formal tools are used by both perspectives.

The organization, economy, regulations and external pressures for example are aspects that have a direct influence on the quality of the human factor. We believe they should be considered when analyzing risk. With the aim to address risk analysis including the aspects described, a holistic hierarchical scheme that shows their state and interrelation will be presented in the following paragraphs.

The output is a map which offers useful information to guide the decision making process and risk control. It points out where and how intervene if necessary in which level within the whole process and can help to define the order of actions.

2. Risk Analysis - Holistic Approach. Hard and Soft

The concept of risk adopted in this paper takes as a starting point the definition given by ICOLD (International Committee of Large Dams) Bulletin 130 (2005) where the process of *Risk Assessment*, comprises two parts: *Risk Analysis* and *Risk Evaluation.*

Based on this we can say that two factors influence the *risk assessment:* the possibility of the occurrence of an unwanted event, the **threat** and the characteristics and proneness of the exposed community and environment to be affected what we call **consequences**.

A *holistic approach* is proposed as a framework of thought which permits to capture complexity. Its origin is in biology and now is widely used to indicate an idea of the whole. Koestler A., (1967) defines a holon as a process which is both a whole and a part. Holons are structured in a conceptual hierarchy from top (higher conceptual content and little precision) to bottom (lower conceptual content and high precision). Under this perspective the whole is much more than an aggregation of parts. The idea of union or convolution is present here. In the other hand holons can be hard or soft as mentioned earlier.

A 'hard' one is the traditional physical system that does not involve people and which consists fundamentally in the functioning of devices. A typical example is the structural devices of a large dam. A ‘soft’ holon involves people and consists fundamentally in individual or collective behavioral aspects. The organization, operation and control of the hard systems of the large dam are performed by people. Those are soft holons. For additional characteristics see Blockley D., Godfrey P., (2000).

Taking into account what has been said, the analysis of risk implies the study and determination of the threat **(T Holon)** and the consequences **(C Holon)** in an integrated form. Risk **(R Holon)** results from the convolution of both. Having thoroughly explored and analyzed the significant set of accident scenarios and having chosen the critical, Figure 1 shows the hierarchical structure which represents the process of *risk analysis* presented in this paper. **T** like **C** value depends on factors of different nature, hard and soft. Their characteristics, joint action and mutual conditioning would determine the status attained for each one and, **R** can be obtained from both. In the analysis of **C**, following ICOLD Bulletin 130, (2005) two holons are defined: *direct damages* that we call *direct consequences* **DC** and *indirect damage* that we call *indirect consequences* **IC. LL** holon is highlighted as it will be explained in more detail later.

As can be seen, the holistic approach defines within each part, an analogous structure to the whole and permits to “get deeper in knowledge” in the sense that enables to descend in information precision, if required, towards empirical evidence. In this sense a critical issue to address is to determine where and when stop “going down” in precision. That is a matter of expertise and context. In the other hand all approaches to dam safety, be they deterministic or not, incorporate in different ways strong elements of judgment, and all reflect in different degrees the need to bridge inadequacies or absences of data. At this level of definition of the analysis, the problem not only is interactive but also multidisciplinary. So it seems appropriate to use expert opinions.

In short all along risk analysis process, engineers have to deal with limited knowledge, information and *opinions*. Ignorance is lack of knowledge; uncertainty is a characteristic of the information, and *opinions* are logical propositions created by experts using knowledge and information (experience).

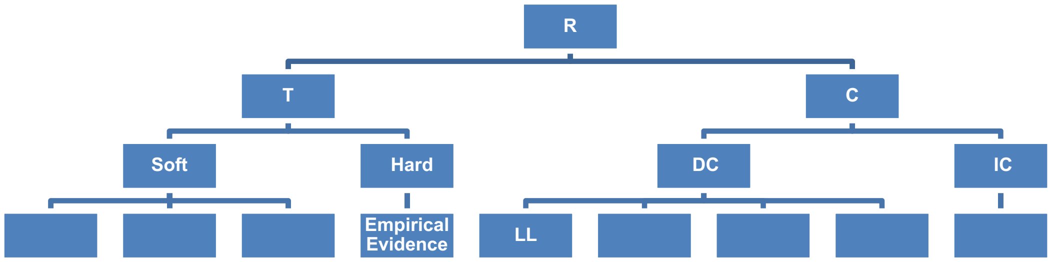

Figure 1: Holistic Approach for Risk Analysis

3. Uncertainty

3.1 Knowledge – Information – Opinions

The origin of uncertainties is basically referred to variability itself information which is expressed and the quality of the same (Physical variability / Inherent Uncertainty / Aleatoric Uncertainty), in addition we never know the whole of the situation in analysis, ignorance another uncertainty (Epistemic Uncertainty).
Ayyub B, (2003) pointed out that uncertainties in engineering systems can be mainly attributed to: Ambiguity, *Likelihood*, *Approximations*, and *Inconsistency* in defining the architecture, variables, parameters and governing prediction models for the systems.
The ambiguity component comes from either not fully identifying possible outcomes or incorrectly identifying possible outcomes. Likelihood builds on the ambiguity of defining all the possible outcomes by introducing probabilities to represent randomness and sampling.
Therefore, likelihood includes the sources physical randomness and statistical uncertainty due to the use of sampled information to estimate the characteristics of the population parameters.
Simplifications and assumptions, as components of approximations, are common in engineering.
Other sources of ignorance include inconsistency with its components of conflict and confusion of information and inaccuracies due to, for example, human and organizational errors.

3.2 Uncertainty Clasification

A rigorous risk analysis involves modeling all sources of uncertainty that may affect failure of the all component of the system. This involves modeling all the fundamental quantities entering the problem and takes into account the uncertainties that arise from lack of knowledge and idealized modeling. Table 1, shows the more general uncertainty classification used in engineering.

Table1: Types of Uncertainties

Type I ALEATORIC OR INHERENT	Variability in structural and other properties.	**Inherent uncertainty in time**	Fluctuations in time.
		Inherent uncertainty space	Natural space variations of material properties.
		Measurement uncertainty	Associated with the measuring device.
Type II **EPISTEMIC**	Deficiency in the knowledge base.	**Statistical uncertainty** **(**Due to a shortage of information, and originates from a lack of sufficiently large samples of input data.)	**Parameter uncertainty** Parameters of a distribution are determined from a limited set of data. **Distribution type uncertainty** Arises from the choice of a theoretical distribution fitted to empirical data
		Model uncertainty	Simplifications necessary to model the behaviour in a reliability analysis or to an inadequate understanding of the physical causes and effects.

A relevant aspect may be introduced in relation to this classification as there are some uncertainties which are aleatoric in nature but have epistemic characteristics. This type of uncertainty is referred to as informal uncertainty.

In general among engineering professionals there is consensus about the fact that uncertainties are present in all problems and this classification is adopted. However a problem arises sometimes when their formal treatment is to be done.

3.3 Uncertainties in Risk Analysis in Dams

Cooke R., (1991) has reported: the result of risk analysis is a transparent mathematical construct of the uncertainty in the future performance of a dam, the most common form of this statement of uncertainty being in terms of probabilities

From ICOLD (2010): Traditionally, in dam engineering, natural hazards such as floods and earthquakes are considered to be unpredictable or random events in space and time. Such events are unpredictable because it is impossible to know when, where, or how large the events will be at some time in the future. Characterization of such random events in terms of probabilistic properties is common in many jurisdictions, with the probabilities of exceedance of the physical parameters used to characterize the hazards expressed in numerical terms. In other jurisdictions there is a preference to account for this same unpredictability through conservative estimation of the “probable maximum” values of the physical parameters.

Beyond natural flood and earthquake hazards, other factors that enter into the dam safety management process such as variability in foundation characteristics, fill and concrete properties, etc., are characterized in terms of exceedance frequency or conservative upper (or lower) bound parameters.

Such unpredictable occurrences are known as *aleatoric* uncertainties. The term *probability*, when applied to such random events, is taken to mean the frequency of occurrence in a long or infinite series of similar trials. This frequency is a property of nature, independent of anyone’s knowledge of it. It is innate, and has a “true” value. Two observers, given the same evidence, and enough of it, should eventually converge to the same numerical value for this frequency.

In dam safety assessment it is not possible to have complete and perfect knowledge of the condition of a dam or its performance and, as such, knowledge uncertainties permeate the dam safety assessment and management processes.

Three facets of uncertainty have been identified with respect to the safety of dams, uncertainty with respect to:

- **the world** :an outcome or result is unknown or not established and therefore in question;
- **the state of knowledge**: a conclusion is not proven or is supported by questionable information;
- **a course of action**: a plan is not determined or is undecided.

Each of these expresses an aspect of uncertainty that must be addressed.

In recent years, financial pressures and the emergence of consideration of societal interest and transparency of decision making concerning societal risks associated with dams and other hazardous installations has resulted in considerable emphasis on explicit treatment of uncertainty. The dam safety decision-making environment of today and of the future is starkly different to that of the past when the safety of dams was determined by engineers (individually or as professional and learned societies) thereby determining the level of cost and risk carried by the owner and the level of risk imposed on society.

Throughout the dam safety management process, there are some uncertainties that are simply not amenable to quantitative estimation based on data and models. These may reflect unique situations that are not found in the historical record of experience with dams. They may reflect uncertainties associated with poorly understood physical phenomena. They may reflect conditions for which data could, in principle, be collected but only at a prohibitive price, and so forth. Formerly incorporating such uncertainties in a dam safety assessment relies on professional judgment. In most cases, this judgment has to do with tacit rather than explicit knowledge. It is based on intuition, qualitative theory, anecdotal experience, and other sources that are not easily amenable to mathematical representation. Yet, this judgment of experts is important information in analyzing safety.

The role of judgment in dam safety management is even broader than that of dam safety analysis as it must also embody the prevailing laws, customs and societal values of the jurisdiction involved and also the values of the dam owning organization as they apply given the operating constraints. Against this background, there is a compelling case for the dam safety management system to describe how judgment pervades the management process, the conditions for which expert opinion is sought, and the processes for identifying selecting appropriately qualified experts.

4. Proposal

Based on the considerations presented in previous paragraphs an estimation of loss of lives downstream a dam under a failure scenario is presented as an example and a possible treatment of the human factor is outlined. The detailed methodology proposed can be found in Ferraris I., de la Canal M., 2012. We summarize here the conception and the foundations on which it was designed.

In Figure 1, holon Loss of Lives **LL** can be identified within the hierarchical structure. According to Wayne J., Graham, (1999), **LL** depend on the number of people of the flood plain (**NP**), the amount of warning provided **(AW)** and the severity of flood **(SF)** that in time have in lower levels, hard and soft components which interact in different degrees. Figure 2 shows the same holistic scheme in more detail where it can clearly be seen that the proposed model is repeated going down in the hierarchy for a significant dam failure scenario.

A problem to address here is how to combine information of different kind, sources and completeness. In other words how to mix objective with subjective data. It was also said that individual or panel expert judgment with its natural characteristics is sometimes necessary to deal with some topics.

In the so-called hard sciences in order to determine the quantitative value of a magnitude, three elements are necessary: an *instrument*, a *protocol* and a *unit* of measurement. They are just conventions about which the scientific community agrees in the sense that the obtained value can be considered "objective". Following this conception, the holistic hierarchy presented here represents a unique protocol used by experts of different disciplines in performing risk analysis. Different conceptions, interests and priorities inherent of each area of study can be modeled using the same scheme. This does not turn the latest in strictly objective values nevertheless subjective characteristics can be limited. In relation to the formal tool, triangular fuzzy numbers are proposed in the frame of fuzzy arithmetic which permits to mix information of different type and their associated uncertainties as can be found in Ferraris I., de la Canal M., 2012. The procedure is run by an interdisciplinary group of experts, gathered to such aim, coordinated by a qualified expert who knows the whole problem.

In the other hand experts opinions must be gathered through a rational consensus process. Cooke R.. (1991) argues that a rational consensus process should meet the following requirements: reproducibility, accountability, empirical control, neutrality and fairness in order to be in agreement with acceptable scientific research.

In relation to the human factor treatment we adhere to the second option described in 1, which is to analyze it quite separate using measures of control. In a first step, levels of acceptability of the quality of the human factor involved in the collection of evidence and dealing with the algorithm are established. Then an evaluation through an analogous holistic structure managed by experts as described in 2. is proposed. In this way human factor is taken into account and a control of the process of risk analysis can be performed. The result of this process is as well a map that in the case of human factor allows intervening in the holons, if necessary, to improve organizational or individual matters to validate the calculation algorithms.

5. Conclusion

Risk analysis is a combination of subjective judgment and scientific rigor as a formal and consistent approach to assess the likelihood of an unwanted event. Lafitte (1993) pointed out that its implementation has raised great interest around the world and despite its shortcomings is becoming more accepted. Ongoing research will contribute to reduce defects and improve its implementation.

In this paper an alternative approach which takes into account the variety of information and their associated uncertainties is presented. In order to integrate all available information a holistic hierarchical structure is proposed. A map of the state of risk results as the outcome which is useful in the decision-making process, since it indicates where, how and when intervene if necessary.

The human factor, present in every engineering activity is the principal cause of failure according to the existing statistics. In order to complete any risk analysis procedure, human factor should be taken into account in a rational way. This proposal chooses not to include it in the calculation algorithms but to keep it below certain appropriate values. These values, previously defined based on the context and the characteristics of the risk problem, leads to the concept of acceptable risk. A holistic hierarchical structure analogous to that used for the evaluation of the hard factors is as well used.

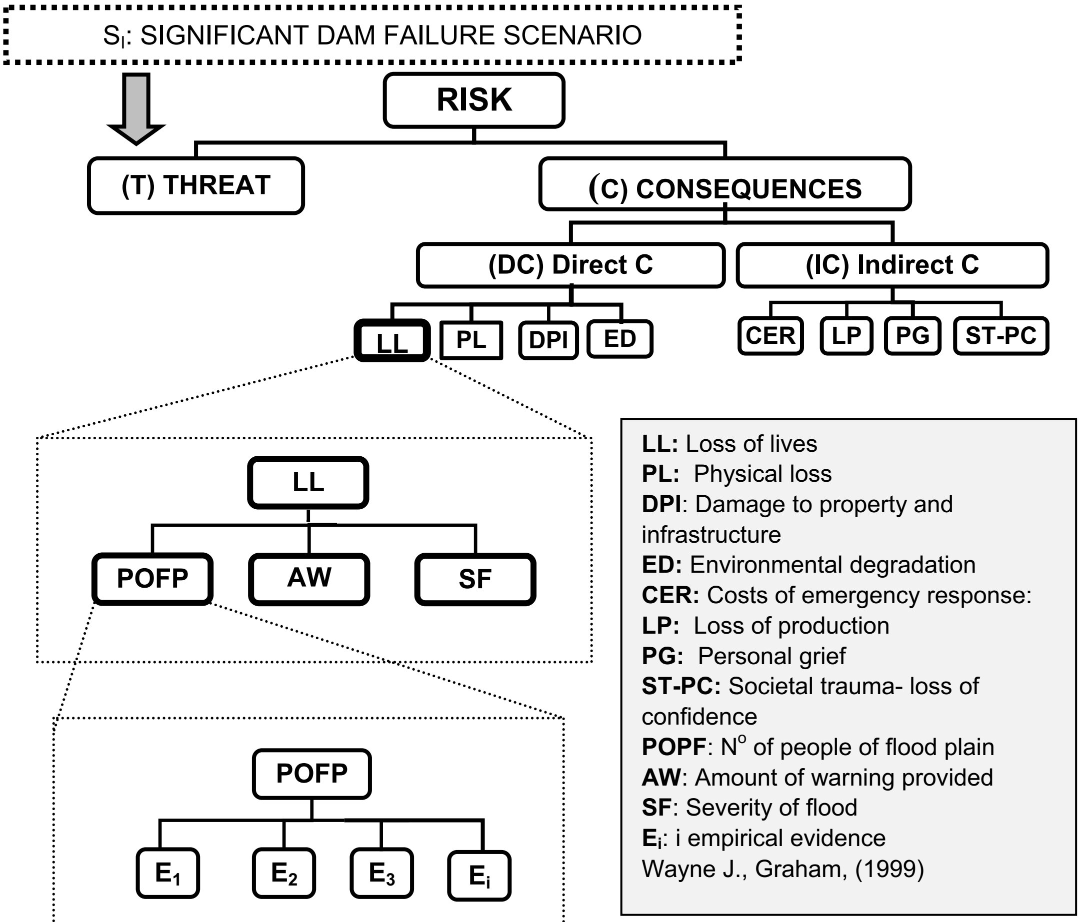

Figure 2: Holistic Approach for Risk Analysis. Holistic structure of Loss of Lives

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