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Strengthening quantitative risk assessments by systematic treatment of uncertain assumptions

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ABSTRACT

The results of quantitative risk assessments (QRA) are conditional on the background knowledge on which the assessments are based, including phenomenological understanding, models, data and expert statements used, as well as assumptions made. Risk indices established in the risk assessment, such as individual risk numbers and *f–N* curves, may have a more or less solid foundation, depending for example on the validity of assumptions made. Poor models, lack of data or simplistic assumptions are examples of potential sources of uncertainty "hidden in the background knowledge" of a risk assessment. These uncertainties need to be reflected in the risk assessment. Recently, a method for treating uncertain assumptions in a QRA was suggested. The method is based on the different settings faced when making assumptions in risk assessments, considering beliefs about assumption deviation, sensitivity of the risk index to changes in the assumption, and the overall strength of knowledge involved. In the present paper we apply, test and adjust the method using a risk assessment of a lifting operation related to the oil and gas industry as a case. We find that an adjusted version of the method provides systematic guidance on how to treat uncertainties in a QRA.

1. Introduction

When performing a risk assessment a number of assumptions are typically made. By 'assumptions' we understand conditions/inputs that are fixed in the assessment but which are acknowledged or known to possibly deviate to a greater or lesser extent in reality. In a risk assessment of an offshore oil and gas producing platform, assumptions may for example relate to:

- the number of personnel on board the platform and the distribution of these between different parts of the platform;
- the impact energy that the platform will be able to withstand in the event of a ship collision; or
- the blowout rate in case of an uncontrolled blowout.

The results of the risk assessment are then conditional on these assumptions holding true, and do not reflect the possibility that, in reality, the conditions may deviate from what has been assumed. These assumptions are important (see for example [1–4]) and need to be communicated in a suitable manner.

A risk assessment less reliant on assumptions is clearly preferable. Relying too heavily on assumptions could in some cases place undesirable restrictions on carrying out a specific activity, creating situations where a strong focus on fulfilment of the assumptions is required to secure the validity of the risk analysis. Ideally, any uncertain condition should be accounted for in the risk assessment, using some representation of uncertainty. However, the solution is often rather to make conservative assumptions, making the results more robust but at the same time not properly reflecting uncertainties. 'Conservative assumptions' is used to mean assumptions that are more unfavourable than that which is believed to be the case and thus lead to risk indices reflecting a higher risk level than if more realistic assumptions had been made. Conservative assumptions involve value judgements, and these judgements should be made by the decision makers, not the risk analyst; firstly because conservative assumptions mean that uncertainties are not faithfully reflected, and secondly because a higher assessed risk level will justify higher costs related to the implementation of risk reducing measures. It is up to the decision maker to decide whether this is acceptable or not, and to evaluate the results of the risk assessment in light of other concerns (reputation, economy, etc.).

In practice, some assumptions are always required to establish the basis of either quantitative or qualitative risk assessments. In the present paper we consider the setting of quantitative risk assessment and extend the work described by [5]. We consider the

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following setting: An unknown quantity Y is defined denoting some aspect of loss, for example the number of fatalities. A probabilistic risk index R in the form of the (possibly normalised) expected value of Y is defined, linking the expected value of Y with some other unknown quantity X. That is, conditional on X:

$R(X) = c\mathrm{E}[Y|X, K]$,

and conditional on $X = x_0$ we have

$R(x_0) = cE[Y|X = x_0, K]$,

where c is a normalising constant and K is the background knowledge on which the risk index is based, including phenomenological knowledge, models, data, expert statements and assumptions. The class of risk indices included in the above definition includes:

- expected loss (e.g. potential loss of life, PLL, defined as the expected number of fatalities during some specified time period)
- probabilities of specific events (e.g. individual risk, IR, defined as the probability of death for a randomly selected person in a population),
- frequencies (e.g. fatal accident rate, FAR, defined as the expected number of fatalities per 10^8 exposed hours)
- the probability/frequency distribution of Y (e.g. f–N curve, defined as the frequency of events with N or more fatalities, here taking $Y = N =$ number of fatalities).

For a comprehensive overview of risk measures/indices for loss of life and economic damage, including those mentioned above, see [6] and also [7,8] for such indices in the context of offshore risk assessment.

In any given risk assessment there will be a number of assumptions, more or less explicitly stated. In this paper we first simplify and focus on a single assumption that may be formulated as $X = x_0$ for some fixed value x_0. Examples of assumptions made in an offshore risk assessment are:

- “The blowout potential is 80 kg/s” (i.e. $X = x_0 = 80$, where X is the blowout rate).
- “The number of immediate fatalities for a blowout given immediate ignition is 1” (i.e. $X = x_0 = 1$, where X is the number of immediate fatalities following a blowout when an immediate ignition occurs).
- “The jacket structure will withstand a ship collision energy of 9 MJ” (i.e. $X = x_0 = 9$, where X is the resistance of the structure).
- “A gas leakage will be detected within 30 s” (i.e. $X = x_0 = 30$, where X is the time for detection of a leakage).
- “The gas concentration is assumed to be reduced by 50% each 8 m away from the leakage point” (i.e. $X = x_0 = G(u, v) = u(1/2)^{v/8}$, where X is the gas concentration at a point v metres from a leakage source and u the gas concentration at the leakage point).

The last assumption in the list above involves a model G of gas dispersion, and in effect states that the model error $\Delta_{G(u,v)}(X) = G(u, v) – X$ is 0. The implication is that there is no need to consider model output uncertainty, i.e. uncertainty on the value of the model error. The terms ‘model error’ and ‘model output uncertainty’ are here used as defined by [9].

The assumptions made may be more or less reasonable, i.e. there may be more or less uncertainty about whether the condition (assumption) $X = x_0$ holds true. This uncertainty can in principle be handled quantitatively, perhaps most obviously using the law of total expectation but also using various non-probabilistic representations of uncertainty, such as interval or imprecise probability, possibility theory and evidence theory; see e.g. [10]. In practice, both these approaches may be prohibitively difficult to carry out, due to a large number of assumptions and hence a high workload involved in establishing an (ideally joint) distribution of X, where X is a vector of unknown quantities, and/or because the background knowledge K on which to base the quantification of uncertainty about X is poor.

An alternative approach is to report the risk index without any quantitative integration of uncertainty related to potential deviation from $X = x_0$, and then to perform a qualitative assessment of the strength of knowledge on which the resulting risk index is based. An example is the qualitative classification scheme suggested by [3], where a crude categorisation of i) strength of knowledge, and ii) risk index sensitivity, is performed with respect to so-called ‘uncertainty factors’, including assumptions, models and data. Looking at these two aspects combined gives an impression of how important (critical) the factor (assumption) is. The purpose of the qualitative characterisation is to capture aspects beyond what can be transformed into and expressed in quantitative form. A more formalised semi-quantitative approach is based on the concept of ‘assumption deviation risk’ [11], where the risk related to deviations from the assumptions made is assessed quantitatively, along with a qualitative assessment of the background knowledge.

In the present paper we consider the following approaches for treating uncertainty related to the condition (assumption) $X = x_0$:

1. Quantitative treatment of uncertainty
   a. Law of total expectation
   b. Interval probability
2. Semi-quantitative treatment of uncertainty
   a. Crude strength-of-knowledge and sensitivity categorisation
   b. Assumption deviation risk

To highlight ideas, the previously mentioned gas leakage assumption is used as an example when introducing the quantitative and semi-quantitative approaches listed above. The method we consider for handling uncertain assumptions is based on the different situations faced when performing a risk assessment, considering beliefs about deviation from $X = x_0$, the sensitivity of $R(x_0)$ with respect to x_0, and the overall strength of knowledge on which to base an uncertainty quantification of X. The method provides recommendations and guidance on how to balance the use of the quantitative and semi-quantitative approaches mentioned above. For testing and illustration purposes the method is applied on a case. In the case study we consider the risk related to the lifting (installing and dismantling) of equipment necessary to perform a riserless light well intervention on subsea wells on the Norwegian continental shelf (NCS).

The approach to risk analysis considered in the present paper may be referred to as predictive Bayesian, which is based on the following principles from [12]:

- ‘Focus is placed on quantities Y expressing states of the “world”, i.e. quantities of the physical reality or the nature, that are unknown at the time of the analysis but will, if the system being analysed is actually implemented, take some value in the future, and possibly become known. We refer to these quantities as *observable* quantities. […]
- The observable quantities are predicted.
- Uncertainties related to what values the observable quantities will take are expressed by means of knowledge-based probabilities $P(\bullet|K)$. This uncertainty is *epistemic*, i.e. the result of lack of knowledge.