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On the use of conservatism in risk assessments

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ABSTRACT

It is common to use conservatism in risk assessments, replacing uncertain quantities with values that lead to a higher level of risk. It is argued that the approach represents a practical method for dealing with uncertainties and lack of knowledge in risk assessment. If the computed probabilities meet the predefined criteria with the conservative quantities, there is strong support for the "real risk" to meet these criteria. In this paper we look more closely into this practice, the main aims being to clarify what it actually means and what the implications are, as well as providing some recommendations. The paper concludes that conservatism should be avoided in risk assessments – "best judgements" should be the ruling thinking, to allow for meaningful comparisons of options. By incorporating sensitivity analyses and strength of knowledge judgements for the background knowledge on which the assigned probabilities are based, the robustness of the conclusions can be more adequately assessed.

1. Introduction

In quantified risk assessments various probability-based metrics are computed, for example the probability of at least n fatalities, the probability that a fixed but arbitrary person in a population shall be killed due to an accident, or the expected number of fatalities for a specific group of people, during a defined period of time [19,20]. Let y denote such a metric. To compute y, models are developed and a number of assumptions made, for example that a wall will withstand an explosion pressure of 1 bar, that in the case of an ignited gas leakage 1 person will immediately be killed, the reliability of a safety system is 0.95, etc. Hence y is dependent on a number of quantities, for example the strength of the wall (s), the number of people that will immediately be killed in the case of an ignited gas leakage (n) and the reliability of the safety system (q). These quantities are assumed known – here 1, 1 and 0.95, respectively, but the choice is not always straightforward, as these quantities are unknown, subject to uncertainties.

In practice, quantified risk assessments cannot be conducted without making such assumptions, and the issue of how to make these assumptions is thus highly relevant. In this paper we address the use of conservative assumptions. Such assumptions are often referred to in quantified risk assessments (e.g. [17,12]), but the interpretation is not always clear. Commonly a link is made to overestimation of the risk, which means that the estimated risk is higher than the "best estimate" of the risk. Conservative assumptions are justified with reference to a cautionary thinking. Rosqvist and Tuominen [17] highlight this when stating that, with respect to risk, conservative modelling assumptions are preferred to optimistic, in order to ensure that the system does not falsely satisfy an acceptance criterion (a threshold risk level).

In this paper we rethink the concept of conservatism in risk assessment. Firstly we ask, what does it really mean? The above analysis seems to indicate that the concept is easily explained, but there are issues that need to be looked into more closely, in particular concerning the *level* of conservatism. To illustrate this, suppose that there are considerable uncertainties about n in the above example, and the number is increased to two in order to be conservative. But why not three or four? If an uncertainty analysis had been carried out for n, a probability distribution of n could be assigned, say 0.4, 0.3, 0.2 and 0.1, for $n=0$, 1, 2 and 3, respectively, and the question about how conservative $n=2$ really is can be raised.

Secondly, we need to clarify how conservatism relates to the strength of the knowledge on which the probabilities are based. A risk description is defined through the risk metrics but also the knowledge and strength of knowledge that support the probability judgements. If we replace n by 2, does the strength of knowledge increase or decrease?

Thirdly, we question the usefulness of conservatism in the practical decision making processes. Risk assessment is not only about verification in relation to acceptance criteria; equally important is its use to compare options with respect to risk. Clearly, for such a purpose, the conservatism could hamper the appropriate use of quantified risk assessments. We question what is really gained by

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conservatism – is not sensitivity analysis able to give the same input to the decision making?

The issue of conservatism in safety management has been discussed in many contexts, for example in the nuclear industry in the late 90s in US in relation to the use of traditional safety analysis methods based on deterministic requirements and safety margins (in line with the defence-in-depth principle and other cautious policies to meet the risk and uncertainties). Quantitative risk assessments are introduced to supplement these analysis methods and avoid "unnecessary conservatism". The key is to be properly risk-informed (see e.g. [2,11,15,21]). The present paper addresses the issue of conservatism in the way risk is assessed and how this risk information is presented to the decision makers, and we will argue that this type of conservatism is problematic and should be avoided.

We will discuss these topics in Section 3, following a formal risk assessment set-up for discussing these in Section 2. Our recommendations and conclusions are presented in Section 4.

2. A formal set-up

In quantified risk assessments (QRAs), a set of probability-based risk metrics are defined, such as the probability of specific events (for example, at least n number of fatalities or the impairment of some defined safety functions) or some expected values (for example PLL, the expected number of fatalities in a year). These metrics are computed on the basis of some models, typically event trees and fault trees, as well as more technical models based on physical representations of phenomena like fire and explosions.

Let y denote such a metric, and let x be a vector of parameters of the total model f used for computing y. Hence we can write

$$y = f(x).$$

To illustrate the set-up, a simple example will be used (based on [3]). See Fig. 1. The model is an event tree with initiating event "major gas leakage" and two branching events: B: ignition and C: explosion. Depending on these events the outcome is 2, 1 or 0 fatalities, as shown in the figure. Let p_1, p_2 and p_3 be (frequentist) probabilities of the events A, B and C, respectively, where it is understood that B is conditional on the occurrence of A, and C is conditional on the occurrence of A and B. Furthermore, let r denote the (frequentist) probability of two fatalities. Then the event tree model states that

$$r = p_1 \cdot p_2 \cdot p_3$$

In the risk assessments, estimates (denoted *) of the quantities are produced, leading to

$$r^* = p_1{}^* \cdot p_2{}^* \cdot p_3{}^*$$

An alternative way of expressing the risk is to start from Fig. 1 and the event tree model there, and use subjective (also referred to as judgemental or knowledge-based) probabilities P to express

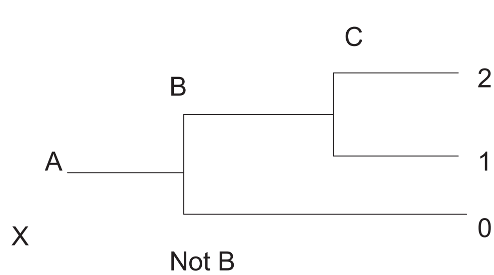

Fig. 1. Event tree example. A: major gas leakage, B: ignition, C: explosion and X: number of leakages (based on [3]).

the uncertainties related to the events A, B and C, to obtain

$$P(Y = 2) = P(A) \cdot P(B|A) \cdot P(C|A, B).$$

The underlying model giving this probability takes the form

$$I(Y = 2) = I(A) \cdot I(B) \cdot I(C),$$

where I is the indicator function which is 1 if the argument is true and 0 otherwise.

In the former frequentist case, y corresponds to r^*, and x to $p^* = (p_1{}^*, p_2{}^*, p_3{}^*)$, whereas in the alternative case y corresponds to $P(Y=2)$, and x to $(P(A), P(B|A), P(C|A,B))$. The function f is defined by $f(x) = x_1 \bullet x_2 \bullet x_3$ in both cases.

The metric with its model is based on a set of assumptions. Two examples in the case of Fig. 1 are:

a. The number of fatalities is 2 if the events A, B and C occur.
b. The number of leakages in the period considered is 1.

Let $z = (z_1, z_2, \ldots z_m)$ denote the vector of assumptions made. Then we can write

$$y = f(x|z),$$

where $f(x|z)$ denotes the function f given the assumptions z. In both cases we use the risk assessment to support decision making on comparing options and to make judgements about risk acceptability/tolerability.

Using this set-up, in the coming section we will discuss what conservatism in risk assessment means. For this purpose we will rewrite the set-up slightly.

Assume we can write z_i as a function of a parameter u_i, so that we can write $z_i = z_i(u_i)$. Consider the a) and b) examples above, and let us refer to them as z_1 and z_2, respectively. Then we may write a) as $z_1(u_1) = u_1 = 2$ and b) as $z_2(u_2) = u_2 = 1$, where u_1 expresses the number of fatalities if the events A, B and C occur and u_2 is the number of leakages in the period considered. We see that the risk metric y is an increasing function in each u_i, meaning that increased values of the assumption parameters lead to higher risk according to the metric used.

Introducing the vector $u = (u_1, u_2, \ldots u_m)$, we can also write y as a function of u, giving

$$y = y(u_0),$$

where u_0 is the vector of assumptions made in the concrete case; here $u_0 = (2,1)$.

3. What is conservatism in risk assessments? Discussion

From the set-up of Section 2 we are now ready to discuss what conservatism means in a risk context. The point of departure is the risk index y which can be written

$$y = y(u_0),$$

where u_0 is the vector of assumptions made.

So what does conservatism mean in this context? Three possible interpretations come quickly to mind:

I. $u_0 \geq u^*$, where u^* is the "best estimate" ("best judgement") vector of u ("best estimate interpretation") and $\geq$ relates to all components of the vector, i.e. $u_{0i} \geq u_i{}^*$
II. $u_0 \geq u_T$, where u_T is the vector of the "true" parameters of u ("true parameter comparison interpretation")
III. The analysts are confident that $u_0 \geq u_T$ ("true parameter comparison interpretation with confidence statement")