UNCERTAINTY OF PROBABILITY COMPONENT OF ACCIDENTAL RISK

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ABSTRACT

Concept of accidental risk is intended to be an objective measure for assessing the risk of accidents in the technosphere. Metric of risk should combine estimation both probability (possibility) of the accident and the damage it caused. For various reasons, any parameter of risk has uncertainty. The problem of uncertainty quantifying arose very early in the study of accidental risk. Often used in practice dotted (scalar) estimation of probabilistic component of risk metric are in most cases inadequate since embody great internal uncertainty

In order to provide maximum objectivity by the hazards of various kinds evaluating in the area of technological safety was proposed and received wide use such a measure as a risk. Despite the wide diversity of opinions of experts concerning the determination of the term "risk", apparently, most of them would agree with the interpretation of risk as "a combination of event probability and its consequences".

Thus, from a mathematical point of view, the accidental risk of any emergency events (or objects, or technologies) can be specified by a vector quantity having two components: PCR and DCR:

- PCR (a component of risk associated with the possibility of an accident) – a quantity, that is quantified the magnitude of subjective probability (possibility) to implement accident. For quantitative estimates the PCR can be axiomatically defined as the quantitative value having the dimension year^{-1}, taking any value in the range 0 ... 1;
- DCR (risk component characterizing damage from an accident) – a quantity, which express the total negative consequences of the accident in terms of money.

Quantitative assessment of the emergency danger in the methodology of risk associated with both performing calculations on mathematical models, and using the methods of expert estimations. Due to various circumstances, which will be discussed below, are obtained result – the value of risk – has uncertainty, which must also be quantified.

The problem of uncertainty existence and uncertainty quantification is inherent in any parameter accidental risk, it is a key problem of risk-methodology on the whole. This problem was first recognized and placed on the agenda at an early stage of technical risk research, when group of prof. Norman Rasmussen prepared report "WASH-1400" on safety of commercial nuclear reactors (US NRC, 1975), and, a little later – when US NRC (special committees of National academy of sciences) published his first report (US National Research Council, 1983). However, twenty five years after these events the same committee stated (US National Research Council, 2009), that the problem of analysis and quantification of uncertainty in risk-methodology is still far from being resolved.

In a quantitative sense, the uncertainty presence means, that instead of the scalar (dotted) values the model parameters of dangerous accidents should be characterized by interval (the range of values), which is a segment of the real number axis. Finally, the result of calculation of risk – risk-metric – will also be an interval. In the quantitative assessment of uncertainty theory by the parameters of accidental risk uncertainty quantification, several alternative approaches have been developed, that were designed:

a) for the expression of uncertainty parameter;

b) establishing rules, that allow to express the uncertainty of the result of model calculations through the uncertainty of its parameters.

These approaches include:

- probabilistic, that consists in postulating of belonging the parameter value to a particular type of probability distributions;
- "fuzzy" (based on the use of fuzzy sets), according to which the membership function of the parameter is specified on the basis of expert judgment;
- synthetic, using the formalism of Demster-Shafer, allowing to combine probabilistic and expert intervals;
- interval, or boundaries method" of Scott Ferson.

The most popular of these approaches is probabilistic interpretation of uncertainty. Meanwhile, the use of classical frequency interpretation of probability regarding the expression of uncertainty in parameter requires special consideration.

As it is known, the scientific method requires that the subject of study has a set of stable, repeatability and intersubjective properties which allow, in particular, to identify it.

On the other hand, the dialectic of scientific research consist in:

- the analysis and differentiation of primary and secondary properties (parameters) of the object, which is the subject of study;
- the synthesis – designing a model of the object, including all its basic properties.

Furthermore, there are two types of description and prediction of the behavior of macroscopic objects (in the area of classical physics):

1. deterministic;
2. probabilistic.

First type implements in simple models that take into account only a limited number of core (generic) object properties. Deterministic models predict scalar values of the model parameters.

The second ones consider all the existing factors, but not as part of the Laplace determinism, but fundamentally differently, predicting the probability of parameter value in a given interval.

Well known, that in the theory of accidental risk widely used methods of reliability theory, in particular, to predict the probability of failure of elements of technical systems with the potential accident. Let's consider the applicability of probabilistic description to quantify uncertainty for example PCR – predicting the probability of failure of the technical element.

Generally accepted that the operational characteristics of any product, technical elements are determined by the aggregation of:

1. a few determinants of deterministic type;
2. set of substantially weaker factors of random type.

This applies both to the properties of the element, and exposure of external impacts on it.

In other words, each item has a set of:

1. "generic" characteristics, which in fact allow to combine these objects in the group (in other words, to identify them);
2. individual properties.

In turn, the individual characteristics of the element can be divided into two classes:

1. properties, which don't affect performance quality. These parameters do not take into account in the model;
2. characteristics, giving the variability of "generic" qualities in a relatively small range.

Thus, any "generic" parameter of group of similar objects is not a scalar quantity, but has "internal uncertainty" and most adequately could be described by the interval value. In addition, since most of the parameters on the reliability of products are determined during the measurement , always accompanied by measurement uncertainty of types A and B, (JCGM 100:2008), to the internal uncertainty is added measurement uncertainty. As a result, the experimental data of the parameter value will always be an interval, which is usually called confidence interval. However, as it would be shown further, not always probabilistic interpretation of uncertainty interval is adequate.

A complete set of fixed type products forms parent population, and factory tests some of their number give a sample statistics, which characterized by sample mean, variance and other statistical parameters. The sample statistics are subject to Bernoulli theorem, according to which by infinite number of tests the sample mean tends to the expectation value, and the variance tends to zero.

However, generally speaking, parent population of products of the same type made by different plants even immediately after their production, would have different parameters of the probability distribution (probability theory developed by well-known methods of testing statistical hypotheses about the equality of means and variances). Moreover the Bernoulli's theorem is not executed for mixed samples.

Consider, for example, steel storage tanks for oil products. If tanks of horizontal type are manufactured in the factory on standard conditions, tonnage vessels with vertical walls are fabricated outdoors, "on-site" by the sheet assembly using manual welding. In the circumstances, their operational qualities significantly differ immediately after the manufacture.

After the start of the technical operation the differences (load modes, climatic conditions, maintenance, etc.) will only increase this initial spread of propeties, including those, which determine their reliability. It is not surprising that published in different reference bases information parameter of reliability about (e.g., failure rate) often are very different, the difference reaches a few orders of magnitude.

Study a typical method for obtaining scalar estimates of reliability parameter of equipment (for example, the frequency of failure of the tank with oil products, year^{-1}), published in the databases (like OGP publications, EIREDA, OREDA, AMINAL, MHIDAS, Technica Det Norske Veritas , etc.). The principle is to collect statistics on failures (often differentiated: on failures on demand, while working for the calendar time of use) for the greater of number possible equipments for greater period of time. Quotient of the number of accidents by number of tanks-year is treated as a result. For example, to assess the frequency of failures tanks of petroleum products in the report (OGP publications, 2010) the following information was used:

1. 122 cases in the world for the period 1965 – 1989 according to a report from Technica 1990. Atmospheric Storage Tank Study, Confidential Report for Oil & Petrochemical Industries Technical and Safety Committee, Singapore, Project No. C1998;

2. 69 such accidents for the period 1981 – 1996 of the report LASTFIRE 1997. Large Atmospheric Storage Tank Fires – A Joint Oil Industry Project to Review the Fire Related Risks of Large Open-Top Floating Roof Storage Tanks;

3. 107 similar emergency events in the period 1951 – 1995 according to the American Petroleum Institute API 1998. Interim Study – Prevention and Suppression of Fires in Large Aboveground Atmospheric Storage Tanks, American Petroleum Institute Publication 2021A.

As a result, numerical estimates presented in such databases should be treated with great caution, because the sum total of the world's operating tanks so varied in quality that could hardly be considered as the parent population. No wonder, that annual statistics of such accidents is extremely variable both in temporal and spatial (geographical) dimension. Thus, although the evaluation and presented a point value, it contains a large latent uncertainty.

In the analysis of accidental risk, as opposed to factory test products, that conducted to determine their reliability, they have to deal with the elements, which typically belong to different parent population. This occurs because they are often produced in different plants, have different and individual history loads and maintaining. Therefore the concept of the mean and variance, as some stable and objective values for arbitrary aggregate of their, is completely meaningless.

Of course, you can always select any number of these elements, calculated for any of the parameter mean and sample variance. But these calculated values from other similar combination of elements likely to be a radical distinguish. Consequently, in this case such essential requirements of the scientific method as the stability and repeatability investigated properties are not met.

Opinions expressed in many (not all) cases, when performing an uncertainty quantification of accidental risk parameters make unsuitable probabilistic approaches and the use of related concepts dispersion. In those cases, when the situation is stable in a statistical sense (e.g., meteorological conditions at a particular site), a probabilistic description is quite adequate

The same objection could be made against the use of fuzzy numbers (fuzzy set) to quantify the uncertainty, because it assumes the existence of a stable membership functions.

CONCLUSIONS

The most universal method to quantify the uncertainty of the risk parameters is interval method. Analysis performed in this article showed that the probabilistic method is not suitable in most cases, because the elements of real technical systems do not meet the basic requirement of their belonging to the same parent population. Therefore, such concepts as mean, variance in this case does not make sense.

It is required further development of interval mathematics methods, which allow obtaining less informative, but more reasonable quantitative estimates of uncertainty

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