ON THE CHARACTERIZATION OF RISK

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This paper analyses the concept of Risk, proposes a general definition of Risk in mathematical terms,and derives some practicable ways to describe the risk adequately for use in risk assessments.

THE DEFINITION OF RISK

There is nothing new in the concept of Risk, though its quantitative assessment in connection with the use of new technologies is quite recent. Correspondingly, qualitative definitions abound and can be found in any dictionary. However, there is no accepted technical definition of Risk in the literature on the risk assessment of technologies (to be distinguished from its use in insurance). In fact, one can recognize in the literature a search for a technically adequate definition of the term. By "adequate" it is meant that the definition would be of a sufficiently general nature, and that it would be exact in the mathematical sense, so that quantitative practical description of the risk could be derived for any case of interest.

Qualitative definitions

Let us first examine two qualitative definitions of Risk in order to extract the conceptual elements of the term. A dictionary (9) defines *Risk* as *exposure to the chance of injury or loss*. A modern text on Risk, with a strong philosophical bias (7), gives the definition *Risk is the potential for realization of unwanted, negative consequences of an event*. The second definition differs from the first mainly by explicitly limiting the consideration to the results of an event, the limitation being necessary for risk analysis of specific systems or accidents.

From the definition it is seen that risk has three conceptual elements: *An event, Harmful consequences*, and *Probability*. The harmful consequence can be an immediate result of the event, but it can follow a development of the event, which can be described as a chain of events (Fig. 1). For example, a pipe-break in a water-cooled nuclear reactor can be followed by loss of coolant, damage to fuel elements, contamination of the coolant, escape of radioactivity, irradiation of people and contamination of buildings, and finally by impairment of the health of a few of these people, loss of property, and probably other damage as well. The event that initiated the accident can be unique, it could be an earthquake in our example, but the choice of the event whose risk we consider is arbitrary to a large extent. We may choose the initiating event, but also any of the

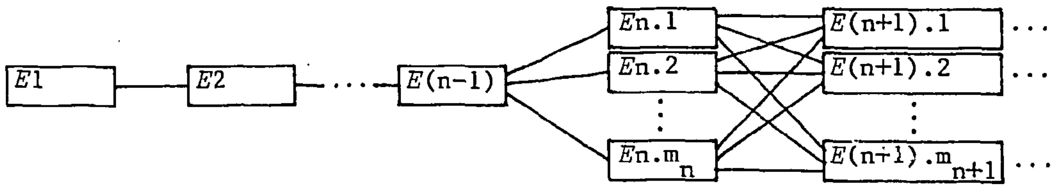

Figure 1. The development of event *E*1, a schematic representation.

following or even preceding events, like the loss of coolant or escape of radioactivity in our example, or the existence of a nuclear power plant. Similar arbitrariness exists in the choice of the conequence, which, in the example, could be the final results, but also the irradiation and contamination, the escape of radioactivity, or even the pipe-break. the last examples of a consequence shows that there is no inherent distinction between an event and a consequence. An event can be regarded as *the* event in one analysis, and as a consequence in another.

The probability of a consequence is combined of the conditional probability of the consequence given that the event has happened, and the probability of the event. However, limiting the definition of Risk to that of a specific event, it would be convenient to take the conditional probability as *the* probability, bearing in mind that it is conditional and depends on the event.

Technical definitions

In common usage, *Risk* is thought of as *the probability of an undesirable occurence* (4), and this definition is taken for granted in many discussions on the risks of technologies (e.g. 6). This definition is adequate for one-consequence events, but fails in the case of several-consequence events. Another common definition is that *Risk is the product of the frequency* (or probability per unit time) *of an event and the magnitude of its harm* (10). Like the former, this definition strictly applies only to one-consequence events, but it also involves the idea of proportionality (i.e. that changing the probability is equivalent to changing the magnitude by the same factor). The risk is given as the expectation of the consequence, and it can easily be generalized to events that can have many consequences of different magnitudes but of the same kind, by defining *Risk* as *the expectation of the consequence*. This can be expressed in many ways, like *the probability per unit time of the occurence of a unit cost burden* (8).

It is evidently easy to farther generalize the definition of Risk to a linear (weighted) combination of the expectations of consequences of different kinds, but there remain two major objections even to this definition. The first is an almost universal feeling that the idea of proportionality, on which any linear expectation definition is based, is unacceptable (e.g. 5,7,10). For very frequent and relatively minor events, which occur several times every year, the expectation of the consequence, preferably accompanied by a measure of its variability like the standard deviation, is quite satisfactory. This can apply to small industrial accidents, side-effects of medical treatments and the like, from societal (but not the personal) point of view. In connection to the nuclear industry it applies to small leaks and routine releases of radioactivity. However, risk assessment of modern technologies is often concerned with major accidents, and there , 1000 deaths with a probability of 1:1000 per year would not seem equivalent, to most people, to one death every year.

The second objection is that there are no accepted ways to compare harms, injuries or damages of different kinds, like deaths and illnesses, or ruin of property and ruin of archeological sites. The last objection would hold against any attempt to characterize the risk by one number, even a non-linear function of the consequences and probabilities. It can be hoped that one day such a function would be agreed upon (5), but attempts to establish one resulted in differing and contradicting results (3,7).

For these reasons Okrent (3) defined *Risk* as *probability and consequence*, meaning that the whole probability distribution function is needed to characterize the risk. Indeed, notwithstanding any formal definition, modern risk assessments presented their risk estimates as probability, or frequency distribution functions of the magnitude of the consequence (2,10), as was originaly suggested by Farmer (1). This definition is still unsatisfactory. A few variables (e.g. deaths and illnesses), however useful, would not characterize the risk completely. Two types of risk emerge to be relevant, individual or personal risk and societal or national risk (2), and the relationship between them is not clear. An even more general definition is needed.

It is proposed here to define *the Risk of an event* as *the probability space on the space of possible harmful consequences* (to which the no-harm event has been added). The terms of this definition is taken from mathematical probability theory, appart from the term *harmful consequence* which replaces the term *event* in probability. The definition, though abstract and not directly usable for the description of risk, puts at our disposal the conceptual and manipulational mechanisms of probability theory.

THE REPRESENTATION OF RISK

One outcome of the definition as a probability space is the possibility to define random variables in it, that is numerial functions on the space of consequences. The joint probability distribution, or density function (in the generalized function sense) induced by the space on a set of any harm-measuring functions, shall be called *a representation* of the Risk. The above-mentioned risk assessments (2,10) presented estimates of some representations of the risk they assessed.

In choosing a representation of the risk of an event, there are two levels of freedom or arbitrariness. The first is in choosing the space, that is in deciding what events should be regarded as the conequences. The second is in choosing the representation or representations, that is deciding on relevant and practical variables that would characterize the consequences. In the example of nuclear reactor accidents, one can choose the consequence space of radiation-doses and contamination, or the space of health effects and property loss. In each space one can choose first the receptor of the risk to be considered, and than the parameters that describe the consequence from the viewpoint of that receptor. Two such viewpoints are the individual and the societal, which lead to individual and societal representations, but there can be many other intermediate, viewpoints. The risk to a local community or to an industrial company, for example, would lead to corresponding communal and company representations. However, since any individual is also a citizen of his country, a member of his community and so on, a representation from one viewpoint would not suffice for proper evaluation of the risk.

Calculating the probability distribution of a set of parameters, it should be remembered that in any one possible outcome of the event, many different consequences happen together. In the example of a nuclear reactor accident, a certain number of people would have immediate radiation illnesses, others would develop late cancers, et cetera (in health-effects space from societal viewpoint); or a certain person would receive different radiation-doses to each of his organs (in radiation-dose space from the individual viewpoint). For this reason the joint probability distribution is needed for representation of the risk. For proper evaluation of the risk in risk assessments, this statistical interdependence of the parameters of a representation should be described at least by the correlation between the parameters.

The choice of meaningful representations and their description should be one of the main concerns of risk assessments.

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