CONTRIBUTION TO CONSEQUENCES ANALYSIS USING FUZZY PROBABILITY

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Abstract: This article deals both with dependability and risk analysis from a complex point of view. Both these fields seem to be similar in many aspects, but unfortunately no congruence in sources of basic characteristics has been reached, yet. Statistical files are often very vague in terms of monitoring dependability measures or risk factors. There is a great need to use another point of view to describe these factors. One of those measures and fragments of risk or dependability are consequences both in terms of an event occurrence and failure occurrence. By using a new approach, better interconnection between these both fields and deeper applicability would be provided. A theory of fuzzy probability could be one of these new methods that could facilitate modelling of quantitative factors.

Key words: Risk, Dependability, Consequences, Management, Complex systems

1. INTRODUCTION

Dependability and risk are concepts that similarly as many other underwent a complex historical development and even today they are interpreted in many different ways and are used in various contexts. Analyses of these characteristics have also undergone a long development.

In connection with this paper, the dependability will be understood as a certain characteristics of studied objects (products, systems) that we endeavour to affect using the analysis, prognosis, calculations, modelling, testing and other tools. In a similar way we shall interpret a risk that is also a certain feature or characteristics of object that expresses its certain potential. We also strive to influence a risk using analysis, prognosis, calculations, and modelling, testing and other tools. First, we shall focus on dependability and its brief description and after that we shall aim at risk. The main attention will be paid to consequences which are related both with risk (in terms of an event occurrence) and dependability (in case of failure which is only more precise expression of an event). The consequences recognition, estimation, assessment, analysis and evaluation are more or less dependent onto a man decision. From historical point of view we do not have very often the possibility to verify and validate the human decisions very precisely. Unfortunately we need to have a tool for both better decision making and for respective validation of our decisions. The fuzzy theory seems to be very suitable for this purpose. It works both with uncertainty and vagueness. As the consequences determination is influenced both with vagueness and uncertainty mostly using language values this method suits to this very well. We would like to speak about that more detailed.

2. DEPENDABILITY AND RISK RELATIONSHIP

To describe dependability, we shall use a valid definition as given in the Terminology Standard (ČSN IEC 50 (191)). Here, dependability is defined as follows: *Dependability is collective term used to describe availability performance and its influencing* factors*: reliability performance, maintainability performance and maintenance support*. This definition implies a fact that a capability of the object of fulfilling required functions is not usually determined by characteristics of the object itself, but also by external factors, e.g. by a level of maintenance support needed.

The term dependability is used only for general description and characteristics defined in this way cannot be generally expressed by any numerical measure. Dependability of every product is understood as an integral part of the total sum of features that influence an ability to meet established and assumed needs of the user. In general, this ability is called a quality. Its individual sub-factors, e.g. availability, reliability and maintainability can be expressed numerically with the help of concrete factors.

The term risk has also undergone a long development. Meeting risk in accomplishing certain activities and studying objects and various effects, almost always it has negative emotions on us.

For the needs of various analyses, several terms have been adopted mainly from the English speaking countries. The best known is ***Risk and Hazard***. These terms have their own content, which is not usually used in purely autonomous form, but in connection with other circumstances (areas), to which it refers. For the needs of our study and this article it can be expressed as follows:

Let it exists a certain source of risk, either tangible (environment, object, human being) or intangible (activity). This source can have both positive, but as in our case also negative impact to its surroundings (other tangible or intangible elements). The existence of this impact is not always so important. The existence of such risk (i.e. negative impact) becomes important only when its impact or importance results from an interaction, which exists between an element (individual, group, technical object or activity) and a source (environment or activity).

In this moment it is necessary to realize that risk as such *does not exist*, *if there is no interaction between the source of risk and object (element) that has a certain relationship to this source*. It is necessary to take into account that interaction can also have various forms. It may be, for example, a ***voluntary***, ***involuntary***, ***random***, ***intentional,*** *etc.* interaction. The effect of these impacts can be attributed especially to an environment, in which the object occurs during its existence. Any such impacts shall be generally called ***area of risk***.

The important and integral part of all analyses will be precise, quality and sufficient identification of just this source of risk. Without this source we can hardly deal with a risk in a qualified way.

Contrary to dependability, which nearly in all cases applies to technical objects, a risk has such characteristics that it refers to a wide area of human activities and known disciplines.

This is only a brief introduction into a dependability and risk relationship. In further text we shall focus on analysis of dependability and risk resulting from the events – accidents and failures of technology. Contrary to an analysis of dependability, we can often meet only with a purely qualitative expression at the technical objects risk analysis. This is not because we would not want more, but simply because we are able to achieve nothing more concrete.

3. POSSIBLE APPROACH IN ANALYSING

Both risk or dependability analysis can be carried out in various stages of technical life of the object studied. Some partial steps of analysis can be very similar in certain aspects. However, to achieve the basic data for quality analysis need not always be so easy.

For dependability analysis we use various partial indicators that ultimately interpret a required characteristic in a numerical form. To express these indicators, it is possible to use a relatively wide scope of mathematical procedures or expressions. It is an expression of events resulting in various effects such as failure, recovery, achieving of limit state, performance degradation, etc. To be able to describe or model these events, various tools of dependability can be used. They are mostly based on a theory of probability**.** We shall not deal with their description. Individual indicators can be achieved using tools applied in dependability in all stages of technical life of the object.

The same approach applies for a risk analysis, since occurrence of some event is always that what links risk and dependability. However, for a risk it refers to events that in accordance with an interaction have an unwanted and dangerous development for us. To better understand when individual events can occur, it is possible to analyze risks in a similar way as in analysis of dependability. In single groups (stages) it is possible to apply a great amount of deterministic or stochastic methods that are the most suitable for analysis in a given period. It refers to:

- *Inherent dependability (risk)* – is dependability (risk) „embedded" into an object during its design and production. It does not involve worsening effects of operational conditions, environment, maintenance techniques, human factor, etc.;

- *Operational dependability (risk)* - is a dependability (risk) with considering the effects of operational and other conditions;
- *Estimated (predicted) dependability (risk)* - is dependability (risk), which is a result of calculations, analysis and prognosis of dependability (risk) of the projected object. Thus, it is the result of used estimation methods, input data on dependability (risk) of elements, used calculation model of the system dependability (risk), knowledge and abilities of an analyst who carries out an estimation, etc.

Up to now we talked about the events connected with the function and operation of technical object, it is advisable to rather narrow our view. In our study, first, we shall focus on an analysis of failures and their effects. In order to explain our procedure and to unambiguously outline the way of perceiving events, we shall apply several types of scales that seem to be suitable for our goal. These scales enable attaching a word meaning to events that occur. By the events we shall understand occurrence of the failure. But for many procedures, both immediate and consequent, attachment of these verbal meanings is not always sufficient. Sometimes, we would like to work with the numerical values that we would obtain from qualified data. In accordance with the above-mentioned scales, the seriousness of event (failure) effects can be divided into several groups. These are the groups that deal with a severity of event (failure) effects and its intensity (frequency, rate) of occurrence. Table 1 shows one of possible classification of severity of effects (e.g. **Mil-Std 1309, SAE ARP 5580-FMEA, IEC 608 12**).

Tab. 1: Failure severity levels

Category	*Consequence to Personnel*
Catastrophic	***Single or multiple death(s)***
Critical	***Multiple serious injuries or severe occupational illness***
Marginal	***A single severe injury or occupational illness; and or multiple minor injuries or minor occupational illnesses***
Minor	***At most a single minor injury or minor occupational illness***

According to intensity (frequency or probability) of event (failure) occurrence that has some meaning for our analysis, several groups can be distinguished. An example of their possible classification is shown in Table 2.

Tab. 2: Evaluation of probability

Probability	*Definition*
Frequent	***Likely to be continually experienced***
Probable	***Likely to occur often***
Occasional	***Likely to occur several times***
Remote	***Likely to occur some time***
Improbable	***Unlikely, but may exceptionally occur***
Incredible	***Extremely unlikely given the assumptions recorded about the system. It can be assumed that the event will not occur.***

With respect to the fact that individual scales are described in words only, it is very important who makes the analysis of a given event. As there exist a number of classes in a group (meaning „distance" between individual expressions), it is very important how an evaluator solves the problem in question. Let us assume that an experienced specialist who will not influence it by his subjective feelings will do this analysis. However, it is obvious that a subjective influence of a human being cannot be fully excluded. Then it is possible to say that it is a certain form of an expert (subjective) analysis, which is in a great extent dependent on knowledge, maturity and sometimes perhaps on the mood of an expert. Let us suppose that a level of subjectivity is on acceptable level.

From the results achieved by adding the word meaning to the effect it is possible to consequently create a certain form of matrix figure of acceptability or dismissal of failure occurrence characterized by a given effect and frequency of occurrence. On the basis of ratio of individual elements related to the event studied, we can decide if a given solution is acceptable for this event (failure). Whether the event is acceptable for us or not can be simply identified from a graphical-matrix representation as shown in Table 3.

Tab. 3: Hazard evaluation

	Severity			
Frequency	Minor	Marginal	Critical	Catastrophic
Frequent				
Probable				
Occasional				
Remote				
Improbable				
Incredible				

	Zone of non acceptable hazard.
	Zone of acceptable hazard.

From the above-mentioned steps is evident how to follow individual events-failures on the technical object. However, it is very important for us and it is again common both for the risk analysis and for dependability analysis to adequately determine severity of effects of individual failures. The above-mentioned scale shown in Table 1 it is evident that severity can be classified in a certain manner. Using known mathematical tools, it is not such a problem for the occurrence rate (shown in Table 2). Question at issue ensues when in a case of a severity of effects we want to be sure by our decision and when we expect that our surety will have a sound basis.

Another thing, which is to be considered, is a need to take certain steps of intended analyses, during which it is necessary to work with numeric value. But how to quantify such a vague characteristics? Some sectors will express this characteristic simply by money. In technical practice it is not so simple. One of the possibilities how to address this issue is to use a theory of fuzzy probability which the authors seem very suitable for a given purpose.

4. ANALYSIS OF SEVERITY OF EFFECTS WITH USING A THEORY OF FUZZY PROBABILITY

Let us assume that any technical object in any instant of time can occur in any operational state (operational condition – state "0", failure state – state "2" or partially failure state – functionality is limited, but not lost – state "1"). A transfer between these states is subject to stochastic laws. As suitable means to depict transfers between individual operational states is use a theory of Markov processes. However, we shall not deal with a description of transfers between individual operational states. A greater attention will be paid to mathematical modelling of effects related to a transfer between individual states.

As transfers between states are connected with a number of effects, it is very important to deal with them in more detail. The most important and from the respect of the function of the object also the most critical is a transfer from an operational state into a failure state. This transfer can result in the worst effects. However, it will depend what is the mechanism of a transfer. If a transfer is caused by a scheduled downtime of the object because of the preventive maintenance, it is unpleasant matter, but better than if, for example, a transfer caused by an unexpected failure with devastating results.

To evaluate severity of effects of failures of technical objects, we decided to use fuzzy set theory**.** Since this theory uses vague terms that already appear in classification of severity of failure effects, then a decision on acceptability of failure and determination on the importance of the object on which the failure appeared. Simultaneously, it is possible using this theory to assign numerical value to the studied circumstance and thus we consider it suitable. Through this theory it is also possible to include **severities of failure effects *D*** of single objects into a fuzzy set**.** Here, we shall assume that single fuzzy sub-sets consist of **coefficients of failure effect severity.** Based on the seriousness of these effects it will be later determined to what level are the given groups indispensable. To classify the **failure effect criticality i**n relation to the inherent availability of technical object we have selected the following three criteria of influence on:

- Function - $\mathbf{D_1}$,
- Safety - $\mathbf{D_2}$,
- Recovery-related costs - $\mathbf{D_3}$.

For every of these criteria we created an ascending scale of coefficients to enable to assess a seriousness of possible effects of failure related to the individual criteria. The severity scale is determined by a set **I** with four elements $I \in \{1;2;3;4\}$, while a value of coefficient of individual effect of failure in relation to selected criteria is denoted D_i, where $i \in <1,2,3>$. The principle is that with an increasing value of coefficient increases also a severity of effect. These values serve as the basis to express a severity of failure effect ***D***. The resulting coefficient ***D*** is at the same time a coefficient of seriousness of a given object and a relation expresses it:

$$\mathbf{D = D_1 \cdot D_2 \cdot D_3;\ D_{min} = 1, D_{max} = 64} \tag{1}$$

To construct a fuzzy sub-set, a "fuzzification of values" is used. Actual observed values of physical values are bounded and are expressed by means of real numbers. Therefore as a universum of fuzzy numbers that represent vague concepts related with a classification of failure effects, a suitable closed interval for every of them will be sufficient. We will reach single classes of failure effects (seriousness) by dividing the resulting coefficient ***D*** into suitable sub-intervals (see above). For practical use and graphical representation a trapezoidal fuzzy number is suitable, see Fig. 1, where **μ** expresses a function of applicability and **x** obtained fuzzy number.

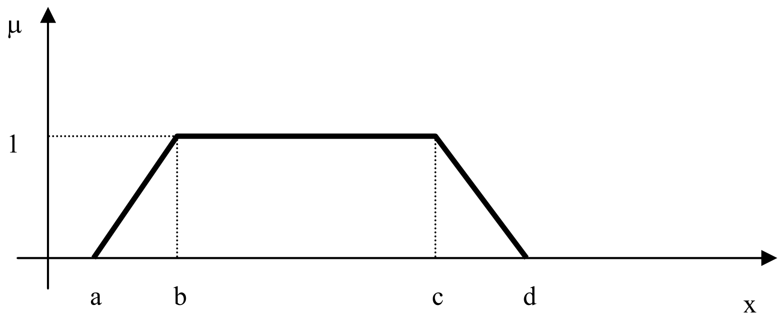

Fig. 1: *Example of trapezoidal fuzzy number*

To establish a concrete value of function of applicability for fuzzified value of selected quantity, it is sufficient to identify in which interval this value usually occurs. This interval is then a core of fuzzy number sought and we denote it as < b,c >. For our case, this core is always expressed by marginal values of single severity of failure effects (see above). Further, we determine what values the quantity does not acquire for certain. We assume a set of these values in the form $(-\infty;a) \cup (d;\infty)$, while $a<b\leq c<d$. Then an interval <a;d> is a support-set „**A**“ of a fuzzy number sought.

We shall express a function of applicability of fuzzy number sought into a set „**A**“ as follows:

$$\mu_A(x) = max\left(min\left(\frac{x-a}{b-a}, \frac{x-d}{c-d}, 1 \right), 0 \right). \tag{2}$$

This expression, incl. trapezoidal shape of fuzzy number can be used for all classified severities of failure effects (see below). For the needs of technical application and based on the above mentioned scale relating to individual criteria, we divide severity of failure effects in accordance with the above-mentioned Table 1 into the following groups:

Minor	state **„0“**	fuzzy set < 1;4 >;
Marginal	state **„1“**	fuzzy set < 6;16 >;
Critical	state **„1“**	fuzzy set < 18;36 >;
Catastrophic	state **„2“**	fuzzy set < 48;64 >.

An example of fuzzy set with division of seriousness of effects is shown in Fig 2.

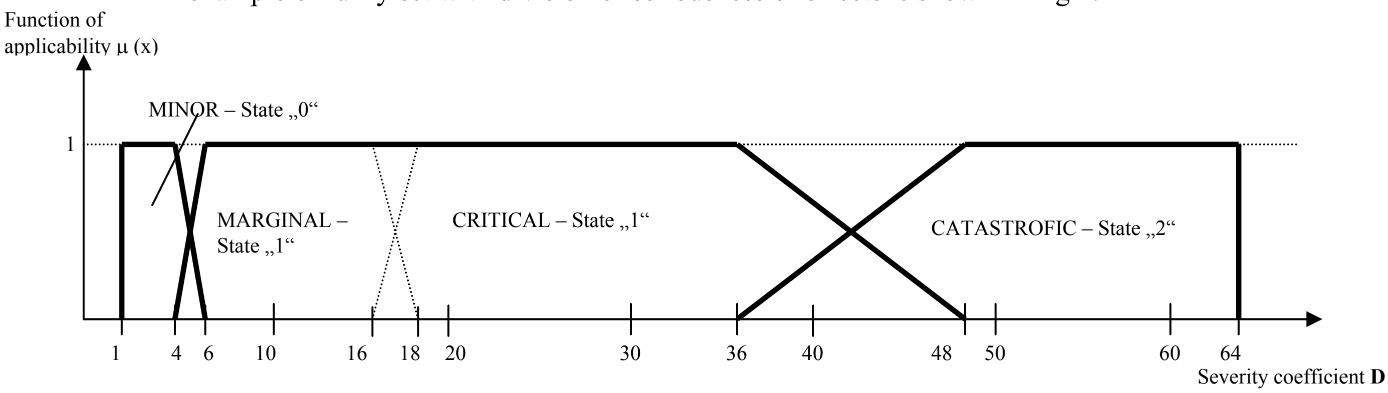

Fig. 2: *Mathematical graphical model of applicability of individual severities of failure effects into the fuzzy sets*

5. CONCLUSION

With the use of the above-mentioned procedure enabling analysing severity of failure effects of technical objects, it is possible to review any technical applications. Its use is especially suitable for those objects, the failure of which has a serious impact on the whole, society, environment, etc. These are primarily strategically and technically important objects such as, for example, power facilities, chemical and petrochemical installations, etc. This method can be also applied for military applications.

The results show not only how serious the effects of failures of given object (elements) are, but also a rate of importance of a given object (element). In addition, it can result in a mathematical model, which allows show how and in what way individual objects can transfer between its functional states. For users, these results are important primarily because they indicate beforehand weaknesses that must be paid attention to already in the design phase or that should be more focused on in the operation proper (preventive review) or preventive maintenance measures.

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