PHYSICAL METHODS FOR ANALYSIS AND TREATMENT OF RISKS IN A SYSTEM WITH PLANNED EVOLUTION

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By using nonlinear formalisms of physics and time-series, we proposed a model of quantitative analysis to describe the administration (analysis and treatment) of the risks appeared in the planned evolution of a system. For emphasizing the accumulation of non-treated risks, we used interconnected pulses, based on large time-scale patterns created by a slow-varying amplitude of vibrations. This leads to a similar and well-known feature within fractals theory for Koch curve. Based on usual accepted data for risks probability and impact, we developed a nonlinear model for estimating the level of risks and the efficiency of the risks treatment.

Keywords: risks analysis, interconnected pulses, fractals, nonlinear formalism

1. Introduction

Any activity takes place in presence of some risks, which must be taken into consideration (assumed). As a potential danger, a possible problem in reaching the proposed objectives, an „effect of uncertainty on objectives", the risks influence can be either negative or positive, but the deviation from the initial planned evolution of the considered system can generate some events with negative impact. Neglecting the risks can lead to the performance decreasing.

There are many criteria to classify the risks [1]. For example*, pure* risks are considered to lead to an undesired result -a damage- (explosion, storm, wrong technology); *speculative r*isks can determine either a loss or a gain (ex. entrepreneurial risks, too advanced technology risk, placebo effect in medicine). The first ones are considered *static*, and the second ones *dynamic.* A *fundamental* risk affects the entire world (a pandemic disease), but a *particular* one influences only individuals or a small part of the society (theft).

In industrial units, an analysis and integration of risks management for the increase of predictability for some technological processes is therefore necessary for a better performance and a longer life of the equipment, as a usual performing of good quality, with a predictable behaviour, by adequate methods and materials. This specific process, with adequate and flexible methods, is integrated in an

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efficiently structured system of the quality and environment management, health and security assessment, risks estimation and combative management [1].

Risks treatment is a continuous cyclical process, including some optional methods of tackling the situation generating the risk, their replacement in terms of the results, or even in some situations maintaining the current situation accepting the risk. Monitoring the situations, the feedback of the results as a new input, taking into account the interdependence of different risks are explicit specifications in the standard SR ISO 31000:2010.

These characteristics show a nonlinear evolution of the system, permitting as adequate some nonlinear formalisms and methods.

In the literature, some qualitative, semi-quantitative, quantitative or combination of them are reported. The most known are OCTAVE (Operationally Critical Threat, Asset and Vulnerability Evaluation) which is a semi-quantitative method; UCRA (University of California Risk Assessment), based on 9 steps, resulted by following the standard BS7799; VAR - a selection of methods of risks minimization and determination of the investments level, that are quantitative methods [2]. Nowadays, for an easier and efficient risks administration, rigorous models of risks identification, analysis and treatment are necessary. We proposed such models, based on some physical nonlinear and fractal methods, adapted to our analysis, taking into account other previous results [3, 4, 5].

2. Accumulation of non-treated risks

2.1. General considerations

The importance of risks problem is of maximum importance, by decreasing the involved costs connected with the negative events and leading to the increase of the predictability, preventing and monitor the systemic risks.

Risk analysis is necessary when in a process there are events that may be associated with certain consequences on the final result of the process. The usefulness of this anlysis is therefore connected with what is defined as the object of analysis of the system and its boundaries, the amplitude or importance, possibility to influence and involved costs. To be controlled it is necessary to initiate a program of optimization of the processes involved in the respective system, similar with the Deming cycle (Plan–Do- Check-Act) [2].

The decision of considering or neglecting the risks is of major importance, since the non-treated risks could accumulate in time and in interconnection each-other, as in a nonlinear process.

For describing the accumulation of non-treated risks in an industrial process, we used a physical model based on interconnected pulses and showed that it leads to a similar situation as in the well-known Koch curve [6]. Time-series aspects are well known in physics applications and in organizational aspects. Quite often, we can encounter phenomena with mathematical models based on pulse sequences, in applications as industrial management sequences of different human actions performed by individuals or collectivises. In our model, the events with important risks will be simulated by applied shocks on a material, generating some vibrations within its structure.

On large time-scale patterns created by the slow-varying amplitude of the generated vibrations, a medium-power shock applied at certain intervals, before a final fracture phenomenon, will generate specific damping vibrations inside the material. The subsequent shock, if applied before the annihilation of these damping vibrations, a certain degree of coherence of the effects could be achieved, for a maximum value of the amplitude, corresponding to the envelope of generated vibrations. In this case, the effect of a final shock-pulse generating the fracture is enhanced. Based on the analytical form that describes these phenomena, we developed an equivalent model to the fractal Koch curve [5].

2.2 Koch curve equivalent model

In industrial engineering applications, apparently non-interconnected aspects can be joined together in mathematical models suitable for optimizing organizational aspects and for improving human action for qualitative changes similar to fracture phenomena. Fractal aspects are less noticed in the case of human behaviour. However, at a deeper insight it can be observed that human actions can be decomposed in sets of similar actions with different parameters; these parameters exhibit variations at larger time scale (annual cycles) quite similar to those noticed at a lower time-scale (daily cycles), suitable for a fractal description.

In [5] it was shown how the fracture of materials is usually described in terms of three distinct nodes, determined by the direction of crack propagation and loading. These patterns were used in modelling fracture using fractals – namely never-ending patterns self-similar across different scales. In our model we use: (i) fractal aspects involved in perception of vibrations, and (ii) the interconnection of shock waves necessary for fracture phenomena.

Geometric fractals are well known (as Sierpinski carpet, Koch snowflake etc.)[6], using fixed geometric replacement rules, either stochastic or deterministic. A common feature consists in the existence of certain structures, which are substituted at the next iteration step. The technique of subdividing a shape into smaller copies of itself keeps its continuity at each iteration, as for Koch curve. It was shown that either the non-linear effect consisting in spatial effects - like in Koch curve generation, or in temporal effects - as the enhancement of high-amplitude pulses at the end of a certain sequence, can be explained through interlaced pulses.

In our model, Koch curve is linked with the formation of new scale patterns at each step, using oscillations and waveforms of continuous functions with continuous partial derivatives with respect to space-time coordinates. Yet within Koch curve can be noticed certain points where the first derivatives with respect to space coordinates are discontinuous.

Let us consider some virtual waves created within a line segment able to develop the specific Koch pattern during the next iteration. The existence of space points with discontinuity for first spatial derivative could be easily justified by the assumption of a certain threshold. Supposing that: (i) a dimensional change along each segment starts only when the local amplitude of this virtual wave exceeds a minimal value, and (ii) the material can undergo changes under the form of monotonically increasing or decreasing linear functions. We model the construction of the specific Koch pattern through the sequence a-b-c presented below.

A virtual stationary wave with maximum wavelength is generated along the segment with the boundary conditions corresponding to fixed endpoints. The amplitude of this virtual wave is supposed to be equal to the length of future segments to grow. For simplicity, let us consider this distance as unity. Using the intuitive assumption based on the form of wave's energy generating the transition, which is proportional to the squared amplitude of the wave, we can write:

a) The local amplitude *Ampl* (x) of the stationary wave:

$$Ampl(x) = \sin\frac{\pi x}{3} \tag{1}$$

b) Two breaking points (where the first spatial derivative exhibits discontinuity) will be generated at those space points where the local amplitude of the virtual wave will exceed a certain threshold *Th*:

$$Th^2 = 3/4 \tag{2}$$

so that:

$$\sqrt{1 - Th^2} = 1/2 \tag{3}$$

According to previous equation, the x coordinate for these points will equal 1/3 and 2/3 (the starting point of a linearly increasing segment and the ending point of a linearly decreasing segment, respectively).

c) The phase:

$$\phi_1 = \pi/3 \text{ and } \phi_2 = 2\pi/3 \text{ for } x = x_1 \text{ and } x = x_2 \tag{4}$$

is transferred to the angle generated by these segments with the direction of the initial segment. It results that a vortex at the distance h

$$h = \sqrt{3}/2 \tag{5}$$

from the initial segment is created. A new equilateral triangle with unity sides has been generated, the base being situated in the middle of the previous segment, split into three equal parts, as required by Koch curve.

The procedure could be repeated for next iterations, and begins with a straight line (step *n=1*) divided into three equal segments. In the next step *n=2* the middle segment is replaced by the two sides of an equilateral triangle of the same length as the segment removed. (Fig.1)

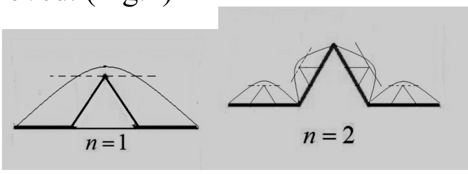

Fig. 1 - Fractal Koch curve construct

In the step *n=3* the procedure is repeated by taking each of the resulting segments, dividing them into three equal parts and replacing each of the middle segments by two sides of an equilateral triangle. The Koch snowflake can be obtained by using three copies of the Koch curve placed around the three sides of the initial equilateral triangle and facing outwards. Its boundary can be constructed by the Lindenmayer system [6].

2.3. Further study of the risks' dynamics

Further study of the dynamics of risk involvement in a process by using oscillations (vibrations) can also be based on the general assumption that many times non-linear equations of evolution generate oscillations between certain numbers of specific values for large time intervals. An example is the logistic map.

Thus, the analysis can be extended in time domain to a sequence of different pulses generating consonant oscillations [5], when for two successive sounds the ratio between their time periods can be expressed as a ratio between two integers *m/n.* This is in fact the condition for *n* oscillations of the subsequent pulse to be situated within *m* oscillations of the preceding pulse. Consequently, we can suppose that the temporal pattern of a preceding pulse is multiplied within the memory of the material, so as an extended virtual time interval results and the consonance will be achieved. This means that the frequencies of preceding and subsequent pulse should represent significant terms of the Fourier transform applied on an extended virtual time interval. According to consonance/dissonance theory, a lower value for this interval implies lower integer m*, n* and a higher degree of consonance. As a result, virtually extended time-intervals of the same pattern appear and the consonance for a subsequent pulse is realized according to the coincidence with a significant term of the Fourier transform.

This result shows the *accumulation* in time of similar phenomena in consonance, i.e. the vibrations modelling the risk factors accumulated on an interval in an industrial unit, the fracture of the material being assimilated with the weak or even catastrophic result of the industrial process. Therefore, for a serious analysis the risks have to be taken into account and removed.

3. Estimating the level of risks

The criteria used for risks evaluation can be connected with their occurrence, cause, amplitude or gravity, the possibility of influence and the involved costs.

By using Ishikawa diagram 4M (machinery, materials, manpower, methods) [7] for risks estimation we exemplify here the Cause-Effect diagram for metal spraying process applied for reconditioning of parts:

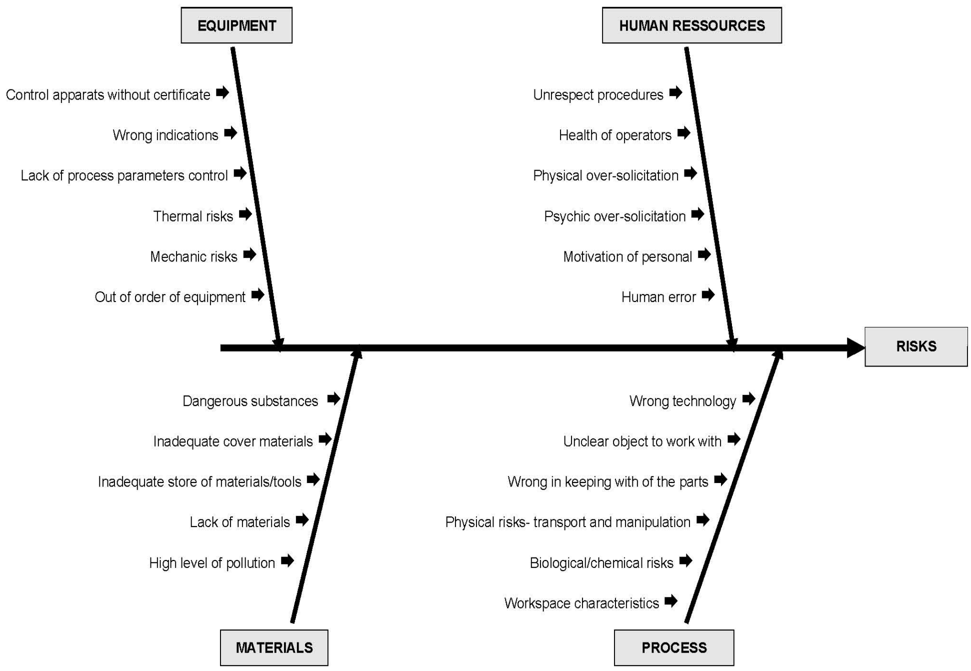

Fig.2 The Cause-Effect diagram

The mathematical model of multi-scale interconnected pulses resembling fractals could improve some studies through significant consequences. The previously mentioned fracture effect is a *nonlinear* phenomenon since it cannot be explained as a superposition of individual effects of each pulse. Nonlinear phenomena generated by a sequence of external pulses applied upon a damping system can be extended to other processes involving enhanced transitions by repetitive factors.

The basis of the analysis and administration of risks *are risks evaluation criteria and risk assesment principles*. A qualitative appreciation of the **risks level** could be obtained considering a certain probability that a weakness of the system appears and investigating the gravity of this weakness action within the system. Consequently, the model of the system behaviour under some risky operations proposes a risk graduate characterisation in terms of the *Probability P* of a risk to produce in a time *Interval* from 1 to 5 years, with the risks *Qualificative* as in the following table:

Table 1

Clasification of risks

Probability *P*	0.1	0.3	0.5	0.7	0.9
Interval	5 years	3-5 years	1-3 years	1 year	<1 year
Qualificative	Seldom	Small probability	Possible	Very probable	Almost sure

In addition, the possible *Impact I* of a risk, with values from 1 to 100 for grading the possible consequences of the risk (unsignificant, minor, moderate, major, critical) is used. Therefore, the **risks level** could be calculated as a product of pairs of values of the above amounts *P and I*, and could be used as a **qualitative factor** for the risks study and treatment [2]. Nowadays, more and more rigorous approaches are needed, as for example the so-called risk „matrix", a 2D table based on probability and impact values, for comparing risks and elaborating risk scenarios. Sometime a risk matrix contains indications of acceptability, being used to assign risk levels (measured on a logarithmic scale) to each of the combinations of consequence and frequency of occurrence of events. However, risk matrix is not quite a mathematical tool [2].

Taking into account that the risk influence on systems is similar with a physical nonlinear process, we tried to find out an adequate mathematical description, for improving a **quantitative** feature of risks management. In our 3D model, we use the values for probability *P* and impact *I* as *input X* and *Y* data, respectively, for elaborating a graphic 3D dependence of the *output* Z of the risks factors' effectiveness (scored from 1 to 100) on the system. This surface graph is the result of a fitting method performed with the TableCurve3D software, by considering the appropriate analytical form of the predicted evolution of the system. Based on this current equation, the qualitative appreciation performed by previous mentioned methods will take a **predictive** and **quantitative** character [7], the program providing the goodness of fit criteria, coefficient standard errors and confidence limits for the fitted parameters function extrema, the fitting method, an analysis of variance and data table statistics. It shows how much precision is preserved in the current equation when the successively fewer digits of precision is used in the coefficients, the *Z* value of each data point, the predicted *Z* value, the residual and % residual, and the prediction limits.

Therefore, any Z value on the graph has a set of input values and can be associated with a specific and concrete state of the system and with a proposed scenario of events and methods. In Fig. 3, we evidenced three probability intervals (small, medium, maximum) for the risk, by using a polynomial equation:

$$z = a + bx + cx^2 + dx^3 + ex^4 + fx^5 + gy + hy^2 + iy^3 + jy^4 + ky^5 \quad (6)$$

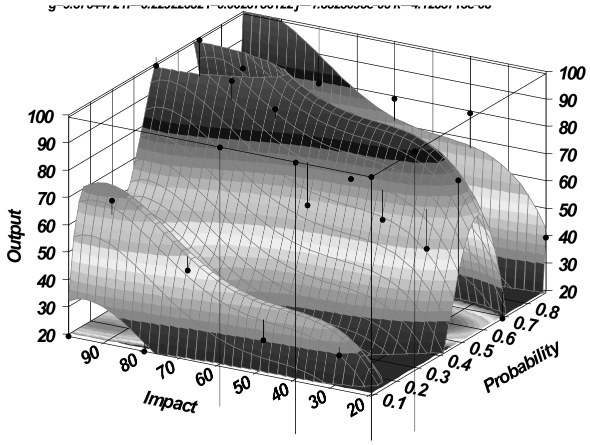

Fig. 3 - Different levels of risks (polynomial/rational equation).

A possible stable (steady state) output can be obtained (Fig.4), by applying, a specific nonlinear form for the risks influence that demonstrates the possibility to control the risks influence, by adequate methods. The graph in Fig.4 is obtained with the Levenberg-Marquardt algorithm [8] and is associated with the nonlinear equation:

$$z = a + LOGISTICX(b, c, d) * LOGISTICY(1, e, f) \quad (7)$$

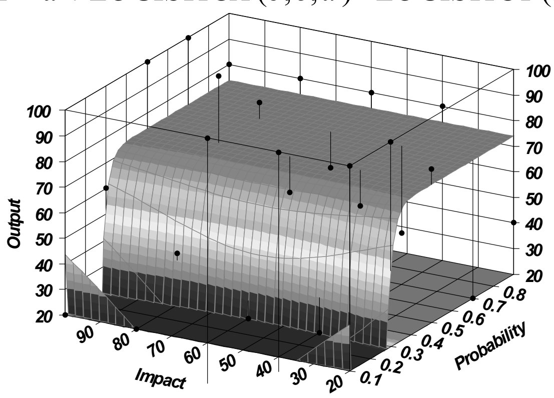

Fig. 4 - Steady state output in terms of probability and impact of the risks.

Logistic analysis was largely used for studying long economic cycles. A long-term sustainable steady-state industrial economy would necessarily be characterized by a quantitative dynamical analysis of all factors. In [10] a nonlinear dynamic analysis based on optical signals is presented, in terms of the logistic map consequences in bifurcation and chaos in a system evolution.

We extracted from the numeric summary the parameters values (that can denote the measures included in the concrete management program), the standard error and confidence limit (Table 2).

Table 2

Numeric summary

Parameter	Value	Standard Error	Confidence Limit
a	73.93724956	6.7333563	85.57646475
b	-970.042925	724760.647	1.25184e+06
c	0.195124452	1.01378693	1.947546826
d	0.023910351	4.407059807	7.641911711
e	57.53648947	28.86332717	107.4293603
f	21.73559047	21.86836637	59.53703907

The chosen equation reflets the nonlinear background of the risks influence and gives the possibility to predict the output for some planned measures to be used for efficiently treating the risks, to select the most appropriate methods of risks minimization on the basis of industrial standards in concrete situations of the enterprise. In terms of the desired result, on can choose the desired output and the most appropriate analytical form of the current equation; every point of the graph can be associated with accepting, tolerate, transfer or externalize the risk.

For the first two options no measure is needed; a preventive plan could be adopted instead, operative only if the risk appears [7, 9]. The last ones mean to partly manage or send the risk treatment with another unit or parts of the same. In all cases, a *residual* risk, defined as the risk level remained after the implementation of the risks management program, must be accepted. It can be appreciated by using the residual graph (Fig. 5) of the difference between observed and predicted value of output in terms of input values in equation (7):

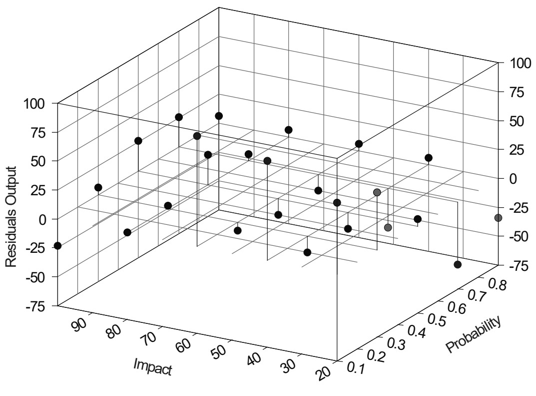

Fig.5 - Residual graph of risks predicted influence.

4. Conclusions

In context of the digitalization of the operations in all domain, the increase of predictability is necessary and can be realized by consideration of a project of quality improving for nonconformity reduction, based on dynamic models of system behaviour for the social responsibility, for analysing the ecologic impact of the processes, and for possible risks treatment. Many times, it is necessary more than a description to specify the consequences of some risky events, and their plausibility in different situations, that can be better determined by modelling the ensemble of events results or by extracting results from the disponible data, in terms of tangible impacts. Nowadays, the best results are considered those of a *quantitative analysis* of the risks [1]. Adequate computer models [4, 9] are coming to help in a more accurate and rapid picture of real systems. The paper presents some proposals for modelling the non-treated risks accumulation and for estimating the risks level and the effect of their treatment. Large-scale consequences in human action within industrial units can be obtained.

For accounting for the accumulation of non-treated risks, we present a dynamical model for Koch curve growth based on virtual stationary waves and a threshold level within a certain material. Starting from an acoustical analogy, we used specific consonant phenomena, similar with the interconnection of shock waves (actually the risks in the evolution of the analysed system), necessary for fracture phenomena. Therefore, as we assumed, this model showed that the accumulation and growth of the non- treated risks has a scientific basis and have to be taken into account.

Since real systems– any of them- are in a continuous and nonlinear evolution, our study used a nonlinear mathematical treatment, usually connected with physical phenomena [10].

The dynamics of non-treated risks accumulation starts from the assertion that many times nonlinear equations of evolution generate oscillations between certain numbers of specific values for large time intervals. An example is the logistic map [11]. We connect this assumption with the generally nonlinear behaviour of the real systems, for developing a nonlinear model of risks estimation and of their treatment effect, based on the *Probability P* of risks to produce on a time period and on the *Impact I* of risks. By using this model, one can develop a *planned evolution* of the system, in terms of the desired results. A possible steady-state (stable behaviour) can be reached**.** The chosen equation leads to the prediction of the output for the most appropriate methods of risks minimization in concrete situations. In terms of the desired result, on can choose the desired output and the most appropriate analytical form of the current equation; every point of the graph can be associated with accepting, tolerate, transfer or externalize the risk. The paper also discussed the residual risk, present in all cases and accepted as such.

Having a scientific basis, these models show the necessity and the most appropriate way to apply the management of risks in industrial organizations, in order to obtain good results and to assure a secure environment for the employees [9]. Similar ideas are found in the literature [12, 13, 14] for accounting the new perspective in a scientific treatment of the industrial units problems [15, 16, 17], in connection and analogy with other domains [18, 19, 20, 21] based on nonlinear formalisms. As we stated, risks analysis and treatment having as a basis the flexibility and adequation principles, being applied to each organization, either to a specific activity or to the whole unit [22]. Moreover, integrated risk management can act with positive results in a large area of domains, such as technology advances, infrastructure and transport [23], capacity improvements and behaviour, business, market, fiscal rules and outcomes analysis, social evolution, health, climate stability and variability [24].

As an application of the management definition: "Using what you have to get what you need" [1], the risk management – "Being smart about taking chances" [1] -has to be currently applied in our enterprises as a usual tool for facing the dynamics of the world market.

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