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DIGITAL RISK ASSESSMENT AND PREDICTION IN TECHNOLOGY PROCESS STAGES OF ORE-STREAMS

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ABSTRACT

The goal of the work is to improve the quality of the management process by quantifying and predicting management and decision-making risks in multi-parameter systems, using ore streams as an example. The key to the ore management system in the paper is the control process. The control process appears to be a complex procedure involving measurement procedures, comparison of the measured value with the standard and decision-making. Under conditions of parametric uncertainty of control agents, control is accompanied by decision-making errors in the form of false and undetected rejects. In the true context, probable errors are defined as two types of risk: manufacturer's risk and client's risk. To quantify these risks, probabilistic and simulation models have been developed to investigate the impact of statistical characteristics of control agents and simulations on control outcomes. The validity and effectiveness of the modelling is tested with a computer experiment. The modelling approach developed is universal and can be used in a variety of scientific and technical practical applications. The authors have proposed a new multi-approach methodology for quantifying decision-making risks in a multi-parameter control system.

Keywords: *Management, Agent, Probability, Control, Credibility, Model, Norm, Error, Process, Risks, System.*

1. INTRODUCTION

In the Republic of Kazakhstan, one of the factors of innovative development of all sectors of the economy, regardless of ownership, is digitalization, which is reinforced by the Government program: "State program "Digital Kazakhstan"/Prescription of the Government of the Republic of Kazakhstan of 12 December 2017 No. 827". [1]. Digitalization has now undergone a new transformation and has taken the form of "digital transformation" [2,3]. The heart of "digitalization" is information technology, which appears to be a kind of "concentrated human knowledge" especially with the advent of the internet, becoming a "networked mind". Information technology plays a special role in decision-making processes, which encompass all stages of management processes. The implementation of new information technologies contributes to the development of the computer modelling approach, which faces new challenges in moving beyond the boundaries of "low-level modelling". High-level modelling is the modelling of vertically and horizontally integrated complex processes [4,5]. Low-level modelling is typical of the initial period of introduction of any new idea, new technique or management approach. This stage has been passed by all sectors when the period of computerization began: in the management area of computer-integrated manufacturing (CIM); in CAE system (computer-aided engineering system) design; in process control of CAPCS (Computer-Aided Process Control System); in publishing, etc. All of these systems are now called information systems (IS), which are also divided into different types according to their purpose. The recent buzzwords are: digitalization, 3D technology, artificial intelligence (AI). It is still premature to talk about AI, as all known AI solutions rely on software and hardware realities and on statistical principles of approximating empirical data by known algorithms created by the developer. From the way they write, "something is being done in neural technology".

During the initial introduction of CAE system (computer-aided engineering system), it was thought that the main problem in design was the preparation of shop drawings. When this problem was partially solved, it turned out that at this stage, apart from the additional expenses, no particular breakthroughs were found. The use of GIS, BIM and 3D technologies is now considered an innovative approach in the design of complex systems, including mining [2]. The 3D direction should be divided into modelling and functioning using robotics. What new things are proposed in 3D modelling, what new real-world results this technology will offer, is the question. For instance, in [6] it is quoted: "BIM technology can improve accuracy by 40%...". It is not clear what the author means when he uses the term "accuracy". There is no such metrological parameter in the standards how to quantify this "accuracy". Rather, there is error, uncertainty, reliability. And the question arises - what was the "accuracy" of design before the introduction of BIM, if it has been increased by 40%. What exactly was increased, what was measured? And further on: " due to BIM technology it is possible to achieve high optimization of work and improved accuracy". There is no such thing as low or high optimization. The optimal solution is a mathematical solution. It is the min or max points depending on what the problem is being solved for.

And although all of these "automatizations" start with the word "system" and this sounds so frequent and sometimes inappropriate that the essence and meaning of the concept itself is lost, becoming a common speech or textual phrase, just like "optimization", "bifurcation", "risk", "life cycle", etc. The systemic nature of modern design should, with a competent professional approach, take on a pre-eminent place. For example, E. Deming, when classifying the causes of poor quality in any field of human activity, divided them into two groups: "special, detectable by common sense, and systemic". At the same time, he noted that 94% of the causes of poor quality are systemic in nature and that by addressing only specific causes, the proportion of which is 6%, "it is fundamentally impossible to achieve a radical change in quality" [7].

Any IS, as we know from the textbooks, consists of technical support, mathematical support, software, information, organizational and methodological support, etc. All of the above are just the system support or the supporting part. The design of the system itself starts with the functional part. Digitalisation is necessary, but humans think in analogue form, and many tasks are solved many times faster than any computer system. Hybrid technology is now being developed where not only technologically, but in an ideological sense, linguistic approaches, such as fuzzy sets theory and ChIPs based on this are used [8].

In ore-stream engineering, as in many other fields, one of the key and complex tasks is risk assessment and management: "producer" risk and "consumer" risk [9]. In design, the " manufacturer" risk may be the "project contractor's risk" and the "consumer" risk may be the "project client's risk". Quantifying risks is a highly complex problem. Among the main factors that create this problem are multiparametricity, multicriteria and determinism. In 1986, James Lighthill, president of the International Union of Pure and Applied Mathematics, made the following sensational declaration: he apologised on behalf of his colleagues in the International Union for the fact that *"for three centuries, the educated public has been misled by an apology for determinism based on Newton's system, whereas it can be considered proven, at least since 1960, that this determinism is an erroneous position"*.

If we focus on the life cycle (LC) stages of an ore-stream as a design object, there are many spontaneous occurrences, explicitly or implicitly, initiated by the upper management level, which limits the ability to model and predict the consequences of such probabilistic cases. The randomness factor in this practice often nullifies the design results and, this must be accepted as a pattern. The entire design methodology is based on statistical data presented in tabular form, in graphical form in the form of nomograms, in analytical form, where calculated mathematical expressions are built in the form of regression models on empirical data. However, almost nowhere are statistical estimates or error corridors given in calculation formulas or graphs. In the real situation, design errors accumulate 'historically' from the first stage in the lifecycle of a project. The next and one of the very serious methodological system errors is the existing approach of calculation of design parameters - "from the average" of the previous stage or calculation act to the next one. In this case, the design error of the previous stage is retained and multiplied in the next stages, increasing the so-called "uncertainty", which has additive properties of accumulation [10,11,12].

Accumulation of uncertainty "from the previous to the next" was investigated in Ust-Kamenogorsk building-road institute in work [13] in 1983, where the way of formation of a final error of control of the concrete diagnostic indicator of the diesel engine, beginning from the factory design documentation to procedure of measurement of diagnostic parameter of serviceability of the engine in operational conditions was studied. This approach was subsequently implemented in the food industry and consolidated in 2015 by the standard [14], which is a precautionary model for product safety and quality management based on the principles of HACCP (Hazard Analysis and Critical Control Point). This system ensures control at absolutely all stages of the technological process, i.e. the product life cycle, at any point in the product life cycle where a risk situation is likely to occur. An absolute merit of the HACCP system is its ability not only to identify risks, but also to predict them. HACCP is based on: hazard analysis, risk assessment and identification of critical control points in each phase of the process. This approach is logical and promises to be effective in most sectors of the economy.

Of particular importance in projects and decision-making processes is the so-called regulatory framework. There are no methods for formally justifying the norms objectively, and with a high degree of certainty it can be argued that they cannot exist in principle. All norms are developed on the basis of statistical data or expert assessments. In current design practice, normative values are considered to be deterministic values, but these values cannot in principle be deterministic in nature, which also increases the uncertainty (entropy) of the design results. I. Prigozhin and I. Stengers also write in their book [15] - "Determinism, which for many years seemed synonymous with scientific cognition, has now been reduced to a property valid only in a limited range of situations".

In the end-to-end digitalization of computationally linked streams, the rounding error inherent in digital machines, which becomes perceptible in "long" sequential calculations in single-precision mode, cannot be ignored.

From the analysis of this material and the arguments discussed but not included in the paper, it is hypothesized that the source of systemic unpredictable things that arise is some mechanism that is integral to the evolution of the system. It follows "that existing properties and classical definitions of the system over-simplify the nature of the processes taking place". The factor of uncertainty consequently generates risks. In the early 2000s, the views of academics were published discussing the major issues of the coming twenty-first century. The discussion highlighted two issues, one of which was " learning to manage risk". Numerous studies in various vital spheres confirm that risk management is one of the most important technologies of our civilization ensuring human progress, which makes the problem of risk assessment, forecasting and management in these spheres one of the most complex and urgent tasks.

Risk conditions are those in which the distribution laws of the parameters and results under investigation are known. Risk in a management system usually occurs during the control and subsequent decision-making process of the control results [16]. Control is a technology containing a set of objects and procedures, where each of them is independent of the others and can be regarded as an agent of a complex system [17]. In real conditions, these agents have a random nature, which in the process of control and decision-making leads to control errors that can be interpreted as risks, and risk management should be called - robust control.

The term robustness is derived from robust and literally means robust, rough. When applied to algorithms for statistical data processing, "robust statistical procedures must be able to "withstand" errors that in one way or another can get into the raw data or distort the assumptions of the probability-statistical models used" [7]. The term "robust" became popular in the 1970s and was originally used to refer to the "robustness" of the results of statistical analyses of data, with no consideration of measurement procedures. Later on, the scope of the concept of "robustness" has expanded considerably and many works have appeared, e.g. in control theory, as "robust control". In a canonical sense, the main task in control system design is to find a synthesis model for such a design that keeps the design conditions, performance and criteria of the system within acceptable limits, despite the presence of uncertainties in the design environment, and to be insensitive to some changes in parameters. Consequently, the formulation of the robust control problem is related to the requirement to preserve the performance of the system in the presence of uncertainties in its model implementation. And robustness is the preservation of system functionality under all kinds of influences, both destabilizing and disruptive. In automatic systems, for example, one of the key requirements for system robustness is stability. In socio-economic systems, the range of robustness criteria is very broad and often depends on the researcher and his or her point of view. In the design of complex multi-parameter systems, to which the design of a motorway should be referred, robustness can have the meaning of quality or optimality of design risks. Broadly speaking, robustness in design is a derivative of the uncertainty of the design agents.

In order to quantify the risks in the form of probabilities R_{fr} - false rejects and R_{ur} - undetected rejects, analytical expressions have been proposed in the literature. These probabilities depend on a number of statistical parameters and factors: the magnitude of the random error of measurement (uncertainty) and its distribution law, the statistical characteristics of the controlled parameter and its distribution law, the statistical laws of the norms and their position on the controlled parameter field. Norms are either "bottom", "top" or bilateral (tolerance) restrictions. In known studies, normal laws of distribution of the controlled parameter and the measurement error are generally assumed. Norms are also considered to be deterministic quantities. However, recently there have been papers suggesting that norms should be considered as random variables with appropriate distribution laws [16]. The results of the machine simulation gave an overall picture in the form of graphical illustrations of the effect of diagnostic error at given tolerances on the diagnostic parameter on the probabilities of undetected and false failures, as well as the reliability of the control. A number of analytical expressions have been proposed to quantify customer and consumer risks. Thus, a model of the customer risk dependence (PZAK) with a normal law distribution of errors and a uniform law distribution of the control parameter has the following form:

$PZAK=-298+478\ V+3.9\ S_{avg}\ -188\ V^2-2.4\ V\ S_{avg}-0.012\ (S_{avg})^2$

A model of the producer risk relationship (PIZ) with a normal law distribution of V and S is as follows:

$PIZ=-203+333\ V+2.28\ S_{avg}\ -133\ V^2-2.7\ V\ S_{avg}-0.017\ (S_{avg})^2$

For the purpose of computer modelling, software tools were developed and computer experiments were carried out. Computer experiments have shown that risk and control quality do not depend on a single modelling agent, but are largely determined by a systemic composition of the statistical properties of the model parameters. The total number of such combinations (compositions) is 729 variants. Each variant has its own practical application, which opens up great perspectives in modelling the situations considered.

Control is only one of the four management functions: organization, planning, motivation, control. Due to the high demand for quality assessments, not only of individual operations and procedures, but also of the system as a whole, there is a scientific and practical task of developing methods and techniques for quality assessment both by differentiated indicators of business processes and by an integrated criterion. In these tasks, the problem of fuzzy modeling data emerges. The application of computer technology makes it possible to obtain and use adequate results in the specified conditions of uncertainty with the involvement of new sections of mathematics.

One of the effective and promising formal tools in modern tasks of modelling management processes under uncertainty is fuzzy logic, which is based on the theory of fuzzy sets, where functions, arguments and variables take a linguistic qualitative form. It then seems possible to use understandable qualitative indicators, e.g.: "good", "bad", "young", "old", "expensive", etc. Compared to traditional classical methods of quantitative modelling, this technique significantly speeds up the result with acceptable accuracy.

Fuzzy methodology uses its own rules, conditions, formulations, concepts, conclusions. For the procedure of transformation (phasification - fz) of fuzzy values into a quantitative form, special "membership functions" with a typical analytical description are used. The results of using fuzzy controllers in the real-world control systems, have shown significant performance advantages over clear approaches and controllers. Control accuracy is improved by suppressing random noise.

Fuzzy sets theory dates back to 1965 when Professor Lotfi Zadeh of UC Berkeley published the seminal paper "Fuzzy Sets" in the journal

"Information and Control". [8]. The adjective "fuzzy", which has the meaning of fuzzy, hazy, is introduced into the name of the new theory in order to distance itself from the traditional clear mathematics and Aristotelian logic, which operate with clear concepts: "belonging - not belonging", "true - false".

The membership function is a function that allows you to calculate the degree to which an arbitrary element of a universal set belongs to a fuzzy set.

A linguistic variable is a variable whose values can be words or phrases from a natural or artificial language.

A term is any element of a term set. In fuzzy set theory, a term is formalized by a fuzzy set with a membership function.

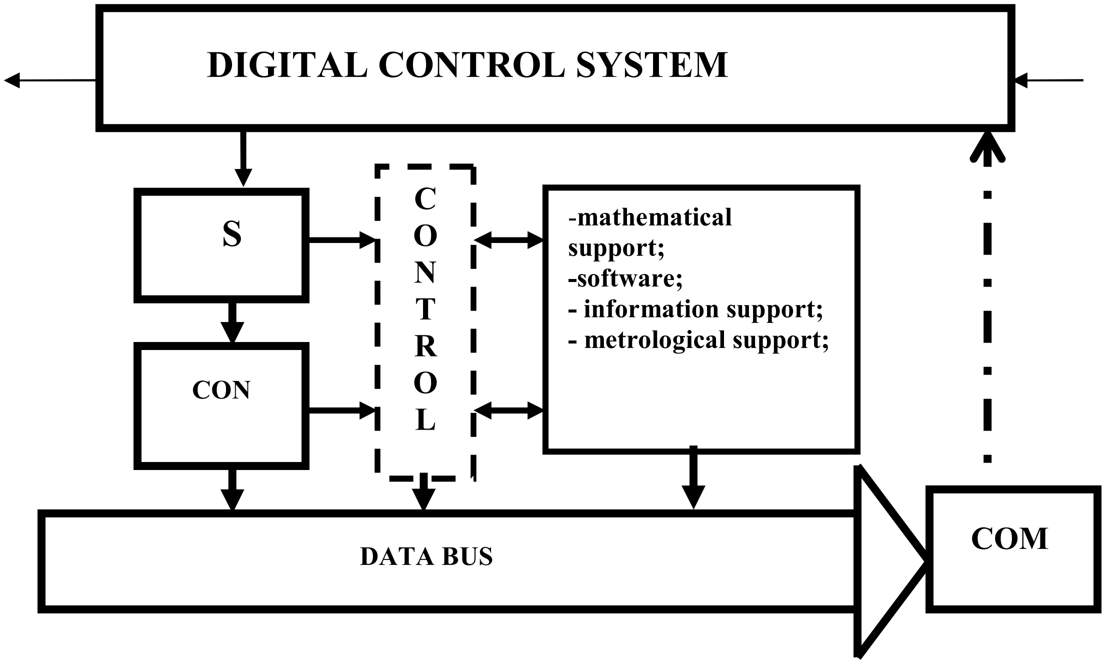
The first stage in the development of a robust model of systematic organizational and technical support for ore-stream is to justify the linguistic variables and develop an integral criterion for quantitative assessment of ore-stream quality. As a result of expert analysis, the following linguistic variables of the automated ore-stream management system were identified and justified as informationally and economically significant: amount of funding, quality of personnel, under the sensor S there will be ore with different constitution over the whole spectrum of possible values. Over a period of time, which is determined by the technology and "artificial intelligence" of the system, the characteristics monitored must be statistically significant and correct information. The monitoring period for which random fluctuations in the "technological background" are to be eliminated or reduced is determined automatically. Statistical estimates such as mean values, uncertainty parameters, statistical distribution laws, and predictive estimates are determined during processing by the information-analytical complex in the knowledge base of the system. In the formal interpretation, the quality of the digital ore-stream control system is represented as a mathematical convolution, weighted by the level of technological and economic importance of the collateral agents.

qualification of personnel, quality of products, quality of raw materials used. The result in the form of integral weighted convolution was a quantitative criterion of the quality of the control system.

Risks in this integrated business process system appear at the control and decision-making stage in the form of probable control errors, which are interpreted as probable risks R_{fr} and R_{ur}. It is important to note that the values of probable risks R_{fr} and R_{ur} at the control stage do not assess the quality of control by the end result in the closed loop recovery of the system's operating functions, because control is information on the basis of which, if necessary, a regulatory action is taken on the control object to restore its target functions. In reality, the feedback loop also has limited accuracy in restoring the functions of the current system, and the magnitude of the control action is a random function of many factors and arguments.

2. MAIN PART.

A structural and functional model of ore-stream can be represented in Figure 1. The aggregate state of the ore is highly dependent on numerous natural and technological factors. In working phase at a particular moment of time



S- SENSOR; CON – CONVERTER; COM-COMPUTER

Figure 1: Structural And Functional Model For Digital Ore-Stream Quality Management

Ore-stream quality assessment is a multi-parameter, multi-agent system problem. The functional quality of the ore-stream, as Figure 1 shows, is determined by the hardware, mathematics, software, etc. A key problem in digital control of complex multi-parameter systems is the development of a criterion for quantifying the quality of the control system, and especially the quality of control and decision-making. This problem is substantially and sometimes inexplicably complicated in the context of statistical uncertainty of control agents, fuzzy data and fuzzy regulatory framework. Given that the problem to be solved is multi-parameter and the process to be modelled consists of different in nature objects that are systematically related to each other, it seems appropriate to consider the structural model in the form of an agent-based model. Agent-based modelling explores the influence of system agents on the behavior of the whole system, which is called "bottom to top" modelling. Considering control as a content - process of a multi-agent system, the following agents can be distinguished in it: external agents (design environment); agent - design object; agent - apparatus; agent - norm; agent - decision algorithm; agent - means and method of regulation. All of these agents are considered to be of statistical nature. The agent-regulation is not considered in this paper, as it is a separate task.

In order to further develop mathematical models for estimating and predicting probable control errors, some conditional parameter S_i is chosen. The density function of the distribution of this parameter is $f(S)$. The following tolerances will be the limit design standards: S_l - the lower limit (norm) and S_h - the higher limit and their statistical characteristics in the form of distribution laws $\Theta(S_l)$ and $\Theta(S_h)$. The distribution density function of the random error of a measuring instrument is $\varphi(y)$. It follows from the formulated task that the uncertainty parameters of the agent model under study are the standard deviations (SD): σ_s - SD of the controlled parameter; σ_φ - SD of the measurement error; σ_Θ - SD of the norms.

In parametric control, the following four probable events are generally possible:

- the true value of the parameter S_i is within the permissible normative limits $S_l < S_i < S_h$ and the measured value S_{im} is within the tolerance limit $S_l < S_i < S_h$;
- the true value of the parameter S_i is out of tolerance ($S_i < S_l$ or $S_i > S_h$) and the measured value is out of tolerance ($S_{im} < S_l$ or $S_{im} > S_h$);
- the true value of the parameter S_i is within the tolerance zone ($S_l < S_i < S_h$) and the

measured value Sim exceeds the higher limit or falls outside the lower limit ($S_{im} < S_l$ or $S_{im} > S_h$). In this outcome, there is a case where the true value of the controlled parameter is in the tolerance zone - "pass", but the "apparatus" erroneously detects it outside the limit - "fail". This is called a " false reject " and the probability of its occurrence is called the probability of false rejection P_{fr};

- the true value of the parameter S_i is out of range ($S_i < S_l$ or $S_i > S_h$) and the measured Sim value is within tolerance ($S_l < S_{im} < S_h$). This is called undetected reject and the probability of its occurrence is the probability of undetected reject P_{ur}.

Figure 2 presents a graphical model of the formation of control errors (risks) under random tolerances.

In this case, any deviation from the "normal" is called a "reject".

The above group of events is called the complete group of incompatible events in probability theory. The first two cases of this group are error-free outcomes, and they are not considered.

The latter two events are errors (risks), which are made possible by the fact that every measurement is accompanied to a greater or lesser extent, but necessarily by a random error of measurement, and consequently by erroneous conclusions and decision-making. The subject of the study is the last two events. In order to quantify these probable errors, mathematical models are proposed to estimate the probabilities of both events as a function of the statistical characteristics and laws of interest. In this case we consider a composition in which the law of the distribution of the limit value S_h in is approximated by a normal law and the controlled parameter S by a Weibull law. Such a composition is reasoned by the fact that the value of the limit depends on many factors, which, according to the limit theorem, provides the basis for the choice of this hypothesis. Weibull's law, as research has shown, is not only one of the common among the known laws, but also the most acceptable one for modelling purposes.

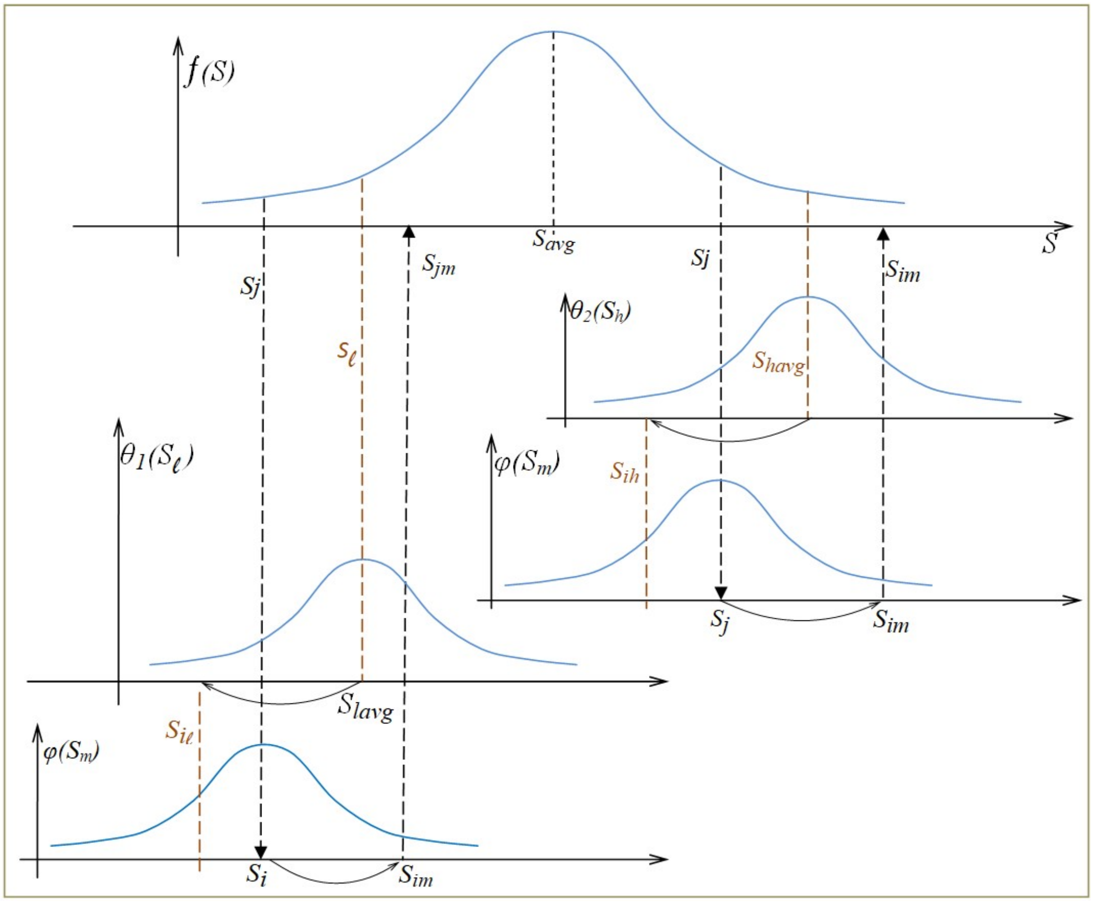


Figure 2: Graphical Model Of Control Error Generation For Random Tolerances

Weibull's law is a three-parameter law. Many known laws, including the normal law, can be regarded in some approximation as special cases of this law. The density function of the Weibull law is as follows:

$$f(S,\alpha,\beta,\gamma)=\frac{\beta}{\alpha}(S-\gamma)^{\beta-1}e^{-\frac{(S-\gamma)^{\beta}}{\alpha}},\quad S\geq\gamma, \quad (1)$$

where: α - scale parameter;
β - shape parameter;
γ - location parameter.

With shape parameter β= 0.5 an exponential law is modelled, with β= 2.5 a Rayleigh law is approximated and with β = 3.25 the Weibull distribution shape is close to a normal law, which is quite often used in research practice. However, another advantage of Weibull's law is that, unlike the normal law, which has an analytical form of an integral law of distribution, it has the following form:

$$F(S)=1-e^{-\frac{(S-\gamma)^{\beta}}{\alpha}} \qquad (2)$$

$$N_{ur}=\sum_{i=1}^{k}N\int_{Li}^{Hi}\theta(S_h)dS_h\sum_{j=0}^{m}\left[\exp\left(-\frac{S_j^{\beta}}{\alpha}\right)-\exp\left(-\frac{S_j^{\beta}+1}{\alpha}\right)\right]$$
$$\times\frac{1}{\sqrt{2\pi}}\int_{-3}^{\frac{S_j-S_{hj}}{\sigma_{\varphi}}}e^{-\frac{z^2}{2}}dz \qquad (4)$$

Then, the probabilities P_{fr} *and* P_{ur} will be found from the following expressions

For simplicity in mathematics, let us first consider the case of the one-limit parameter constraint "top".

To solve the problem numerically, we divide the interval of variation of the limit from S_{sm}- 3σ_s to S_{sm} + 3σ_s into K sections, where S_{sm} is the sample mean of the norm, σ_s is the sample standard deviation of the norm. Let's find interval probabilities P_1, P_2,...P_j,...P_k and probable number of controlled objects randomly falling in each interval P_1N, P_2N,....P_jN.... P_kN at a sample size of N.

Omitting the known intermediate transformations used in numerical integration, we give the final expression for the total number of false rejects from the sample N.

$$N_{fr}=\sum_{i=1}^{k}N\int_{Li}^{Hi}\theta(S_h)dS_h\sum_{j=0}^{m}\left[\exp\left(-\frac{S_j^{\beta}}{\alpha}\right)-\exp\left(-\frac{S_j^{\beta}+1}{\alpha}\right)\right]$$
$$\times\frac{1}{\sqrt{2\pi}}\int_{\frac{S_{hi}-S_j}{\sigma_{\varphi}}}^{+3}e^{-\frac{z^2}{2}}dz \qquad (3)$$

In the case of a missed reject, the number of N_{ur} will be

$$P_{fr}=N_{fr}/N;\quad P_{ur}=N_{ur}/N. \qquad (5)$$

A software application was developed to implement the computer experiment. The results of the computer modelling in 2D and 3D graphical form are shown in Figures 3 to 6. Figure 3 shows a flat model of the dependence of the probability of a false reject (P_{fr}) as a function of the uncertainty ratio $\sigma_{\varphi}/\sigma_s$

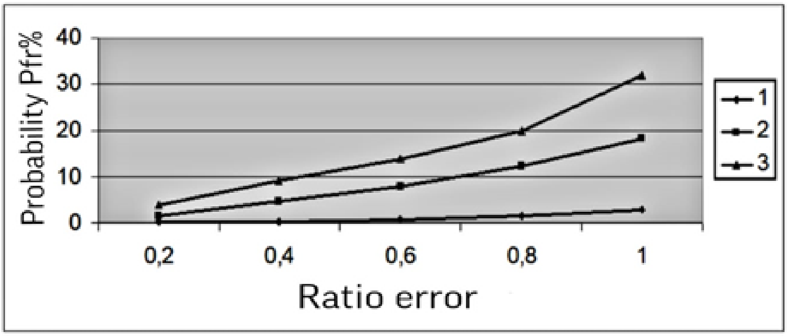


Figure 3: Dependence Of False Reject Probability (P_{fr}) As A Function Of Uncertainty Ratio $\Sigma_{\varphi}/\Sigma_s$

The upper curve is plotted for a norm in deviation from the mean value of the monitored parameter within $S_{avg}\pm\sigma_s$, the average curve for a norm within $S_{avg}\pm2\sigma_s$ and the lower curve for a norm within $S_{avg}\pm3\sigma_s$.

As Figure 3 shows, risks are a system composition of the ratio of measurement uncertainties to the uncertainty of the norm. When uncertainties are equal or close to equal, the control error "false reject" can be as high as 30%. The economic assessment of the loss, in this case of the manufacturer (probability - risk of false rejects P_{fr}), is assessed specifically depending on the actual task at hand.

Flat graphical model forms do not provide an overall spatial 3D picture of the interactions and dependencies of the modelling agents and the result. 3D models are built for this purpose. Such a model is shown in Figure 4 for the previous example.

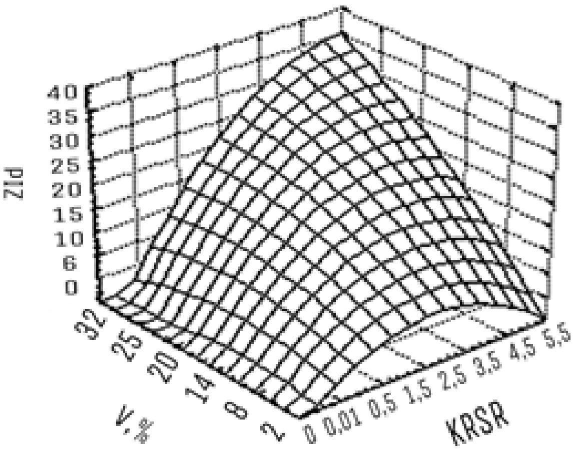


Figure 4: Risk Level Of The Producer (PIZ Manufacturer)

Figure 5 shows a flat model of the probability of undetected rejects (P_{ur}) as a function of the uncertainty ratioσ_φ/σ_s, which is the risk of the end-user (customer).

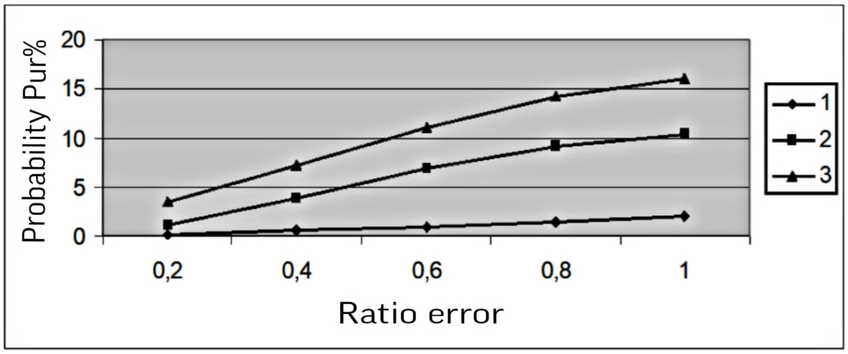


Figure 5: Dependence Of Undetected Reject Probability (Pur) As A Function Of Uncertainty Ratio Σφ/Σs

Also here, the upper curve is plotted for a norm in deviation from the mean value of the monitored parameter within $S_{avg}\pm\sigma_s$, the average curve for a norm within $S_{avg}\pm2\sigma_s$ and the lower curve for a norm within $S_{avg}\pm3\sigma_s$.

Figure 6 shows a 3D model of the end-user (customer) risk.

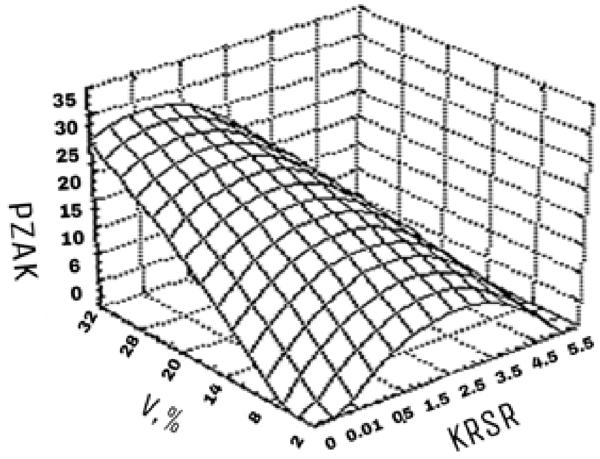


Figure 6: Consumer Risk Level (PZAK)

Visualizing the results in the 3D interpretation (Figure 6) can indeed be useful and reveals effects that are not visible in the 2D plot. For example, Figure 6 reveals all the non-linearity of the problem and reveals a region of maximum, which is a synergy of many parameters and is not detectable in 2D constructions.

3. CONCLUSIONS AND IMPLICATIONS

As can be seen from the results of the machine experiments shown in Figures 3,4,5,6, the probability of a false reject P_{fr} (manufacturer's risk) is the most influential. When the measurement error σ_φ is commensurate with the value of σ_s the risk can exceed 30%. As can be seen from the diagrams, the influence of the uncertainty of the norms is higher than that of the uncertainty, which leads to a considerable variation of the control results. This implies that the choice of norms must be prioritized on a project-specific basis for reasons of operational efficiency.

The results, presented in 3D form, show a picture of latent parametric synergies, as can be seen in the figure, where the zone of minimum risk is visualized, which raises the new challenge of developing a program to highlight this zone analytically.

In order to create a metrologically and economically optimal ore-stream quality management system, an end-to-end numerical model is needed that implements a trajectory of the calculated results of the facility life cycle with an integrated regulatory interface between all stages of the life cycle.

The results obtained can be used as mathematical and methodological support for automated design systems of complex multiparameter multi-agent stochastic-programmable systems.

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