Risk-informed Context-based Human Reliability Assessment Method

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Abstract: The reliability of the risk-informed decision-making process could be modeled as digraph that represents the Rasmussen's step-ladder structure in its dynamics. This digraph connects the cognitive sub-processes by controllable context-sensitive edges and iterative links. The assumption that the edges represent only non-selective context-sensitive influence and have equal reliability (context probability) is made. It allows dynamic reliability calculations, simulations and numerical experiments as first approximation of context-sensitive cognition and communication reliability modeling. The context is described by symptoms based on performance monitoring and risk-informed analysis of system states.
The structure of the geometrical group reliability model digraph is used for modeling mutual communication during the group decision-making process. The differences between individual severity of contexts of two members of group determine mutual context communication probability for mutual interaction in the group communication process. Both digraph reliability models are designed and solved by the Analysis of Topological Reliability Digraph method and its codes.
The paper presents a risk-informed and context-based Performance Evaluation of Teamwork (PET) method. The macroscopic holistic context evaluation procedure of the PET method gives opportunity for correct definitions of emerging issues, challenges, and possible solutions in the field of HRA. In addition, the measuring the durations for recognition and disregard of symptoms, depending on various PSFs, by utilization of models on the microscopic atomistic level, and extended use of simulator data could improve the quality of HRA, accident analysis, PSA and risk-informed decision-making respectively.

Keywords: Probabilistic Context Quantification, Context-Sensitive Mental Models, Dynamic HRA Holographic-like Behaviour, Performance Evaluation of Teamwork.

1. INTRODUCTION

The human reliability analysis (HRA) determinates the human failure event (HFE) potential and evaluates its probability, usually and conditionally in two sequential stages – cognitive (decision-making) and executive (response). If the cognitive stage is performed by group, then the decision-making process becomes more complicated, since it involves mutual communication between group members and a leader who makes a choice.

Two context-sensitive models of mental processes are investigated – individual cognition and mutual communication. Their structures and parameters are identified and fitted based on the current state-of-the-art in probabilistic interpretation of context, mental processes and network reliability. The most important parts of the explanation of these models are: holographic-like behavior, reconciling of objective and subjective images, statistical description of a human-organization-technology (HOT) system, coexistence of classical, Bayesian and quantum probabilities, macroscopic context quantification as superposition of object-image-situation and network reliability.

The paper presents a risk-informed and context-based Performance Evaluation of Teamwork (PET) method. The macroscopic holistic context evaluation procedure of the PET method gives opportunity for correct definitions of emerging issues, challenges, and possible solutions in the field of HRA. In addition, the measuring the durations for recognition and disregard of symptoms, depending on various PSFs, by utilization of models on the microscopic atomistic level, and extended use of simulator data could improve the quality of HRA, accident analysis, PSA and risk-informed decision-making respectively.

2. THEORETICAL UNDERPINNING FOR HEURISTIC RELIABILITY MODELING OF MENTAL PROCESSES

The reliability models as a mathematical model do not completely reflect all of the properties of a real object. For the mental reliability models there are no exact analytical solution and the problem is too hard even for a Monte Carlo simulation. Consequently, the only possibility is to use a heuristic approach - procedure and models. The term "heuristic" is an extension of analytical methods in areas where such methods cannot be exactly proven and we are not sure that the method of solution is still correct. It means that sometimes it is necessary to omit some specified conditions, to make additional assumptions and to change the description of an analyzed phenomenon in order to allow the use of available theories and mathematical tools. To create adequate reliability models for cognition, communication and decision-making based on context of the HOT system, one has to combine the knowledge of probability, context, cognition, network reliability and psychology theories. Let us consider the relevant aspects and concepts of these theories and possible points of contact for their pragmatic adjustment.

2.1. Applicability of Probabilistic Approaches

2.1.1 Classical vs. Bayesian approach

There are two general ways to interpret probability which can be called "classical" and "Bayesian". "Classical" probability, which is also called *"objective"*, "physical" or "frequency", is associated with random natural systems. "Objective" probability explains, or is invoked to explain, the stable frequency when dealing with random experiment. "Bayesian" probability, also called "evidential" ("epistemic" or *"subjective"*), can be assigned to any statement whatever, even if no random process is involved, as a way to represent its subjective plausibility, or the degree to which the statement is supported by the available evidence.

The Bayesian approach enables us to use the new information about HOT system context. The changes of context factors in time could be taken into account and they can be interpreted as "prior" and "posterior" [1], which serves a basis for context dynamics description. The dynamic description of a context-sensitive mental process is based on "objective" and "subjective" images. That is why both "objective"[1] and "subjective" probabilities and the Bayesian approach are used.

2.1.2 Quantum models for mental processes

2.1.2.1 Holographic images and information entropies

Lashley [2] proposed that interference patterns among wave fronts in brain electrical activity could serve as the substrate of perception and memory as well. Pribram [3] told a story of how he "immediately realized that axons entering the synaptic domain from different directions would set up interference patterns." Leith and Upatnicks [4] "describe how recording of interference patterns on film tremendously enhanced storage and processing capability. Images could readily be recovered from the store by appropriate procedures that had been described by Dennis Gabor [5]. Gabor called his mathematical formulation a hologram". According to him, a "holon" is quanta of information in quantum holography, the basis of Magnetic Resonance Imaging, Positron Emission Tomography (PET[2]) scans and other image processing procedures. Pribram [6] provides detailed reviews of

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[1]Sometimes the word "objective" could be applied to probability, which means "physical", but it also refers to "evidential" probabilities that are fixed by rational constraints (logical and epistemic probabilities).

[2]The popular use of the "PET" abbreviation is for Positron Emission Tomography that is a nuclear medicine functional imaging technique for scanning and computing. In this article, the "PET" is used basically for the Performance Evaluation of Teamwork models as a HRA method for "holographic scanning and computing" of the human performance.

experimental results that support the assumption that holography as a useful metaphor for understanding the brain/mind relation with regard to perception and memory: "Most holograms, and I believe neural holograms are of this type, result when wave-forms initiated by a source reach their destination by two or more routes so that patterns of interfering wave fronts become established."

Holographic images and information entropies provide some valuable ideas of how to develop appropriate mental models and use them in dynamic decision-making process.

2.1.2.2 Bayesian and quantum probabilistic models for cognition

Bayesian probability is the most suitable probabilistic framework for describing cognitive processes, but the human cognition interference violates the fundamental laws of classical and Bayesian probability theory, e.g.:

- conjunction fallacy - *Probability (A and B)>Probability (A)*,
- disjunction fallacy - *Probability (A)>Probability (A or B),Probability (B)>Probability (A or B)*,
- commutativity in conjunction - *Probability (A and B)≠Probability (B and A)*,
- law of total probability - *Probability (A) = Probability (A and X) +Probability (A and not X)*,
- averaging effects, unpacking effects, and order effects on inference.

There are experimental data in cognition that cannot be modeled by means of any classical or Bayesian theory, and the theoretical physicists know, that "data showing deviations from set theoretic rules" are an indication that a quantum model exists [7].

Consequently, mental models should be holographic-like "surface processing structure" and an analogy of quantum entropy should be used more fully on the quantum level of information, where "deep processing" (borrowed from Noam Chomsky by Pribram) is needed [3]. In the PET method, it was also proposed to use two levels of context description and quantification of cognitive process – macro level (bit entropy) and micro level (quantum entropy) but only first of them is used for now [7].

The context-cognition interaction is performed by information processing and exchange of "units" of information (bits). A macroscopic information entropy parameter (context) has to connect and integrate sub-processes of cognition. Statistical mechanics demonstrates that energy entropy is governed by probability, and for the information entropy a macroscopic parameter is *context probability* (*CP*) or *'contexture'*. The term 'contexture'[3] is coined by analogy with 'temperature' as a potential to exchange information vs. heat, to show the similarity between information entropy and energy entropy as a distribution of information vs. energy.

2.2. Retrospection of Human Performance Context Quantification

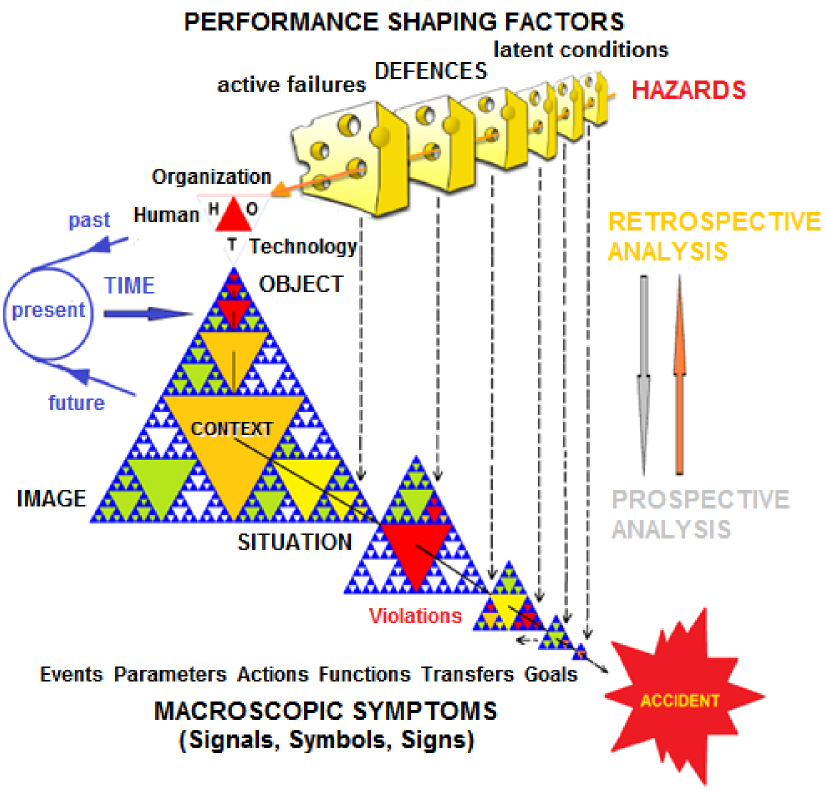
The PSFs, influential or context factors of the "all generations" HRA methods, include quantitative and qualitative factors together for context determination by multiplication of factors based on fuzzy expert judgment. Application of such lumped together qualitative and quantitative factors to HRA, on one hand, increases the useful information about HA analysis, but on the other hand, hampers its use for quantification because it is quite difficult to bring different kinds of information "to a common denominator" for HRA or accident analysis. It is necessary to distinguish them based on their nature, propensity for quantifying and the clear idea of how to use context determined in mental models.

Petkov and Furuta [9] have proposed a heuristic concept of Context Factors and Conditions (CFCs) as just quantitative factors to indicate "how context influences actions". They also consider the CFC as a symptom that can be reflected, traced and changed during the scenario progression in time. Petkov and Groudev [10] proposed an indirect similarity between material ("transition temperature shifts") and mental processes ("transition contexture shifts" or "human performance shifts") to measure dynamic deviations of symptoms. The "shifts" are understood as the differences between objective (real) and

[3] The term context is kept for the regular use.

subjective (imaginable) past and future of interaction of the HOT system. Petkov [1, 8] used Bayesian approach for CFCs "shifts" specification, retrospective and prospective HRA - see Figure 1.

Figure 1: Dynamic holistic symptom-based context qualification and quantification [8].



The basic idea and some prerequisites for context quantification of human performance based on "images" have been clarified in [11]. The concept "image" is the imprint of the consciousness and sub-consciousness of the "transition contexture shifts" that affect the person's physical, physiological, psychological and psychosocial ability to make sense, perceive the object (HOT system) and perform action in its context. Matching the object in situation is an approximation that could be identified and described as an "image" [11] or as a "signature" [12]. The term "context probability" was applied as a measure for "probability and severity distribution" of error-forcing context. But this general definition of context is not so practical to be a measure. The practical definition of context is: *a probabilistic (statistical) measure of the degree of the system state randomness defined by the number of accessible states taking place in the system's ensemble*.

The qualitative and quantitative definitions of error, violation, context, symptom and their violated image of symptom (VIS) are presented in [8, 13]. In the PET method, the VIS is considered as a strategic decision and introduces of "inevitable 'resident pathogens' within the system," resulting in a resonant increase in severity of error-forcing context, i.e. the *CP* and HFE probability. Taking into account the relativity of time when the strategic decision was made, seconds or years ago, we can conclude that the difference of the PET VIS, in comparison to the Reason's violation definition, is that it may be in apparent or latent conditions, but these conditions must lead to a sharp/resonant increase in the severity of error-forcing context, i.e. *CP(t)* [13].

Symptom recognition and dynamics of cognitive context are iterative and recursive functions. In order to calculate *CP(t)*, the durations of recognition for any symptom (as CFC) and cognitive disregard durations of CFCs and VISs are needed. At the next step of iteration of cognitive process, we may use the new duration of symptom recognition based on previous calculation.

2.3. Elements of the Mathematical Psychological Theory

2.3.1 Uncovering mental processes

Routinely, mathematical psychologists and psychometricians seek to develop a mathematical theory of *systems with partial order of the process and sub-processes* and not with *holographic-like behavior*. They describe them by means of directed graphs, PERT (Program Evaluation and Review Technique) or CPM (Critical Path Method) networks.

The major conclusions about uncovering mental processes are the following:

- "Although we view the test for additivity as one important strategy in an overall systematic approach to uncovering psychological processes, *we do not identify processes with additivity*" [14]. The use of time (by additive factor method), for measuring the influence of different factors on mental processes makes the investigation difficult [10]. All the factors not only influence mental process but also vary with time (*context-recognition recursion*). Therefore, we have to analyze a function, whose arguments are also functions of time (recursion). Indeed, if certain relative time is represented as a function of factors, the rate of mental process can be measured by this time but transformation is not always unique. That is why the notions "direct" and "indirect" influence are introduced and they require additional specifications. For example, the concept "coupled slack" [15] is very vivid and original, but it is better to use the easiest perceived parameters as "speed" [16] or "duration" terms for mental processes [17]. Other important conclusions about uncovering mental processes are the following:
- *Factors that influence* not only durations but also *outputs of processes* have not been investigated. [15].
- *Expectancy and consequence of context factors: The expectation* (the mean) *of a sum of random variables* (in this case, serial processing times) *is equal to the sum of the expectations, which is true for any set of random variables whether or not they are independent* [54]. This makes possible the use of dependent factors for context quantifications provided that we employ the mean (not median) [1].
- The *discrete aspect of the processing* postulates is definitely of psychological interest.
- The *feedbacks systems are not presently included and networks, which permit the temporal overlap of sequentially arranged processes,* are also not covered.
- The major objection to *networks* as models for human information processing is the *implausible requirement* that a process cannot start before all its immediate predecessors have finished [18]. To override this requirement, we have suggested the use of the ATRD method that makes possible managing the configuration of mental process at once.

2.3.2 Principles and assumptions for hybrid modeling of cognition

2.3.2.1 Analyzing aspects and principles of cognition control

Proposing "Simple Model of Cognition" Hollnagel [19] states: "We must be able to understand why human cognition was configured or functioned in a particular way given the particular conditions… Instead, the actual ordering or organization of cognitive functions in a situation, i.e., the control, is seen as determined by the context and conditions… the theory would try to understand and explain how cognition was controlled under the given circumstances."

To investigate cognition control by context, time and other factors, additional empirical and experiment-based assumptions have been made about:

a. Seriality/parallelity, concurrentness/sequentality of human performance;
b. Factors' dependence in cognitive process and sub-processes (functions);
c. Time dependence in cognitive process and functions.

Four principles of cognitive control could be formulated [20]:

1. *Goal instantiation and orientation*: Cognitive control depends on current, instantiated goals whose contents specify outcomes to be achieved by one's own action;
2. *Juxtaposition*: Cognitive activity results from juxtaposition (or synchronous activation) of mental state contents and available information;
3. *Minimum deliberation*: Cognitive control by instantiated goals involves minimum deliberation or planning, at least for routine activities; and
4. *Minimum control*: Fluency is achieved by minimizing the amount of explicit information involved in the cognitive control of activity.

2.3.2.2 *Assumption A:* Sequential and iterative process of cognition

Rasmussen made the following assumption in support of his Step-Ladder Model (SLM): “Rational, casual reasoning connects the ‘states of knowledge’ in the basic sequence.”

Hollnagel [21] justifiably criticizes this assumption: “Changes in the environment are, in terms of the SLM, described as changes in the input to decision making, but not directly have any effect on how the steps are ordered; their assumed “natural ordering” is maintained from one cycle to the next. The bypasses are variations of or deviations from the prototypical sequence; they may skip one or more steps but the underlying step-by-step progression is immutable”. It should be noted, that the focus of Hollnagel’s criticism is not entirely correct [22]. Even in [19] Hollnagel leaves the sequentiality in the influence of context. However, as was emphasized in [22], the cognition is not sequential for context influence and the context controls configuration and speed of cognitive process.

The cognitive process most probably is sequential in time because “Minimum control” principle. It is not sequential for any factor’s influence, context control configuration and speed of the cognitive process. That is why in the PET method a different approach was proposed by calculation of contexture: generation of context combinations and their quantification in certain limitations on symptoms. The limitations on variation of symptoms are determined on the basis of the relative deviation of the subjective human notion (mentality, mental model of situation) from the existing objective notion of a given real situation. They are observed simultaneously, not consecutively (one factor after another) [8], but recursively [23].

Following the logic of separation of decision-making from response phase of human action and possibility to repeat some cognitive functions, the final element of decision sequence “execution” could be “execution of iteration” and not always “execution of action”, e.g. "a circle of iteration." Cognition is based on context but its symptoms are recognized or based on the cognition. Consequently, the reasonable assumption about cognition is:

Assumption A: Cognitive/decision-making process is ordered/sequential and iterative process in time, and recursive in the context.

The occurrence of iterative mental processes in time is sequential. Within one iterative step it is a serial process. However, in the next iterative step, this sub-process can be absent, sequential, parallel or concurrent. “Rather, we believe that processes should be studied in terms of their relationships, whether they function in series or simultaneously (i.e., in parallel) or in some other *hybrid fashion*, one significant aspect being the implications borne by these relationships for reaction/response time as affected by pertinent experimental factors” [14]. It is supposed that the human cannot fix these different iterative steps and perceives them as a “whole” that “is not reducible to the sum of its parts”.

From the *Assumption A*, it follows that feedbacks in cognitive process are accomplished indirectly – by external link between sequential iterations.

It also follows from the above assumption that “temporal overlap of sequentially arranged processes” should not take place because sub-processes and transients are sequential in time. However, without distinguishing between the iterative steps, one cannot distinguish between (or *control*) their respective times, i.e. *the time of processes and transitions between them should be simultaneous*.

To reach an agreement between these contradictory statements, we make the following additional assumptions:

A1. The processes are independent and they occur sequentially in time;

A2. The configuration of a process changes simultaneously, i.e. the control over the transients between processes is parallel (“holistic approach”).

2.3.2.3 *Assumption B:* Dependence of context factors and conditions

The iteration and recursion allows for configuration management of the cognitive process in order to have an effect on how the steps are ordered. In other words, the control option is to have active cognitive functions/sub-processes (selective influence) and non-selective control by contexture. If we change probability of connection between sub-processes by non-selective and selective influences, then the structure configuration could be changed even in one iterative step.

Symptoms interference influences all “control edges” of various processes (holistic approach) and other factors, which influence the sub-processes, could be included in this "holistic approximation" of decision-making process. Consequently, the reasonable assumption about factors' dependences on mental processes is the following:

Assumption B: Control of individual cognition or decision making is based on selective influence ("context-free") and non-selective (contextual) interference of different factors.

2.3.2.4 *Assumption C:* Time dependences between cognition and context

The assumption is that interference between context factors is accomplished by "modulating context control edges". They depend on context and have holographic-like behavior (all edges of cognitive process have equal contexture). Therefore, the selective influence on sub-processes of cognition/decision-making in the model is considered to be independent and quasi-constant, having a stochastic nature (presented as nodes). The modeling by PET and solving by ATRD methods stick to the following rule of induction [24]: *If a conclusion/assumption/hypothesis proves that the model is incorrect, it can be modified or even substituted by another one on obtaining new facts. If the equal probabilities of the cognitive sub-processes coupling are not realistic assumption, then the selective influence could compensate for local asymmetry.*

Another useful induction rule is: "No empirical observations should be a priory rejected." An assumption will be made below that the edges with selective influence can be ignored in most of the cases (average individuals and conditions). It relies on empirical data showing that the duration of transitions between sub-processes is much longer than the duration of all sub-processes, and on the empirically proven fact that the probability for the sub-processes to succeed is much higher [25]. The contextual edges are called: “modulating context control edges” or “context axons”. The cognitive systems belong to "systems based entirely on holographical behavior."

The independence of sub-processes is determined by:

1) the availability of given independent factors that selectively influence given sub-processes;
2) the definition of mental process.

There are two building elements of a hybrid process model – a node and an edge. The first, node, is context independent ("context-free") and allows for modeling independent sub-processes. The second, edge, is context dependent ("context axon"), with equal dependence of all edges of a given type of configuration. It determines the type of interaction between the sub-processes.

Rasmussen [26] suggested three types of human behavior: *skill-based*, *rule-based* and *knowledge-based*. They can be also referred to as *automatic*, *algorithmic* or *analytic*. According to him, symptom (signal, sign or symbol) recognition falls into different types depending on the degree of information organization. Duration for recognition of a specific symptom can be evaluated based on empirical investigation and measurement. If the duration of symptom recognition is not determined by empirical research, the duration of symptom recognition could be based on expert judgment about the type of the recognized symptom. In [25] it is pointed out that: “There is an observed tendency that the operator’s cognitive process level becomes deeper as time proceeds based on reconfirmation, e.g. it is skill-base for about 1 minute, rule-based for about 5 minutes, and knowledge-based behavior about 30 minutes after an incidents occurrence.” Consequently, the reasonable assumptions about time dependences between cognition and context are the following:

Assumption C:

C1. The selective influence of context factors on cognition can be ignored for the average case (individual and conditional);

C2. The duration of symptom recognition could be based on expert judgment about the type of the recognized symptom (as initial approximation);

C3. The durations for recognition of skill-based, rule-based and knowledge-based symptoms would be suggested in correlation 1:5:30;

C4. The duration of transition between connected processes is much longer than the duration of any sub-process. This reflects the widely recognized fact in psychology that the responses to a global structure are faster than the responses to the local one [27].

3. DYNAMIC CONTEXT-BASED DECISION-MAKING EVALUATION

3.1. Context-sensitive Control of Rasmussen's Step-ladder Model

The successful application of this model for analysis of the cognitive process reliability is possible, if it is used not only as a “procedural prototype”, but as a “contextual control model” as well [22]. However, we do not have to isolate the characteristics of the cognitive process (such as function, task, step, and operation…), but regard them as a “holistic” interaction, since “they have meaning only in relation to one another” [28].

Hollnagel [21] points out, that in SLM the cognition “control was not explicitly described” and that “all this makes the control problem more difficult to solve”. That is why, we will try to propose context-sensitive reliability models (context-sensitive structure and parameters) for evaluation of individual cognition and mutual communication on the decision-making phase of human performance. Only cognition control based on macroscopic context probabilistic description (as based on bit entropy) is presented. This is an explicit decision-making process framework that leaves aside for now the other important implicit framework for cognition control, which is based on selective influence (and quantum entropy).

3.2. Empirical Fitting of Context-sensitive Reliability Models

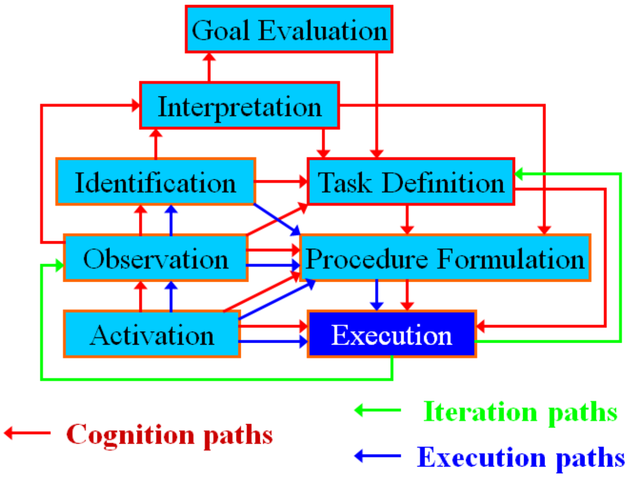
The aim of the empirical fitting is to identify and present a reliability model (structure and parameters) for evaluation of individual cognition, mutual communication and decision-making phase of human performance and to give explicit idea of its control. The reliability modeling of cognition follows the theoretical underpinning, assumptions and framework presented in previous paragraphs. The macroscopic or bit context quantification, configurations of the model of individual cognition and mutual communication model of group decision-making are described and implemented as three barriers for optimum cognition and decision-making control.

3.2.1 Structure of the step-ladder reliability model of cognition

The SLM cannot be directly applied as a reliability model due to the fact, that time and probability parameters are qualitatively assessed. However, if the model is modified by some simplifications (based on assumptions in 2.4.2) then these qualitative characteristics can be applied.

As mentioned above, all graph models of reliability can be reduced to ST reliability. In such reliability models "directed edges not in any path from S to T have been deleted" [29]. As a result of these simplifications we obtain the PET digraph reliability model of cognition – Figure 2. In it, green lines indicate the models of possible iterations. This model reflects all experimentally proven edges of the cognitive process with non-selective context influence and two possible iterative configurations (for two iterative steps). The green edges show from where the possible new iteration will start. The Execution digraph reliability model used in [30] is also presented in blue as a digraph and a subset.

Figure 2: Step-ladder digraph reliability model of cognitive process



The distribution of concurrent edges in the decision-making process can generate various hypotheses about the organization of the whole cognition process with different iterative steps, for example:

A. **One-step model "Activation-Execution"**, including all nodes and concurrent edges from Activation (A) to Execution (E) inclusive;
B. **Two-step model "A-E & Iteration Task Definition-Execution"**, including all nodes and concurrent edges of the model A (without E) plus absolutely reliable iteration link between Task Definition (TD) and concurrent edges between TD and E inclusive;
C. **Two-step model "A-E & Iteration Observation-Execution"**, including all nodes and concurrent edges of model A plus absolutely reliable iteration link between E and Observation (O) and all concurrent edges between O and E inclusive;
D. **Three-step model "A-E & Iteration Observation-Execution"**, 3-step A-(I)-TD-(I)-O-E or A-(I)-O-(I)-TD-E models, including all nodes and concurrent edges of model B plus absolutely reliable iteration links between O and E and all concurrent edges between O and E inclusive.

3.2.2 Structure of the reliability model of mutual communication in group

The structure of the geometrical Group Reliability Model (GRM) digraph, proposed by Furuta and Kondo [22], is used for modeling of mutual communication during group decision-making process. The differences between individual contextures of two group members determine mutual context communication probability or communication contexture for mutual interaction into group communication process: $CCP_{kj}(t)=CP_j(t)-CP_k(t), k\neq j$.

3.2.3 Context-sensitive parameters of reliability models

As the reliability model of cognition uses only non-selective influence, it is based only on the context in which symptoms interact. The context is assessed by the PET context quantification procedure as a *context probability (CP)*. For simplicity's sake we assume that the processes in "context axons" (contextures) begin simultaneously and their probabilities of the cognitive sub-processes coupling are equal. The PET *context quantification procedure* consists in counting the identical bit states [13].

4. ADVANCED PRACTICE BY PET METHOD

4.1. Interpretation of Findings and Drawbacks

The PET technique is an engineering HRA method for "holographic scanning and computing" of context, individual and group probabilities of HOT system performance. The primary goal of the PET approach is to model explicitly the HOT interactions and minimize the use of expert judgment in procedures, so that to decrease the uncertainty of evaluated probabilities.

The developed PET reliability models of individual cognition and mutual communication in group decision-making are based on the PET macroscopic context quantification procedure by HOT symptoms and take into account only their non-selective (contextual) influence. The error-forcing context probability (contexture) is the potential for erroneous human performance. The dynamic contexture could determine the most appropriate and safe moment for a HOT mission step implementation. Consequently, the reliability models of individual cognition and group communication could evaluate HFE probabilities for the confident time period before, during and after a planned HOT mission. In order to obtain these probabilities for a certain action, it could be assessed as an average of plausible implementation interval with its upper and lower limits (macro-uncertainty).

The models and procedures of the PET HRA method provide sequential and dynamic defense-in-depth barriers for monitoring and avoiding erroneous teamwork performance by reducing:

- probability of the error-forcing context – *CP(t)*, where for the most severe context – CP=1,
- individual cognitive error probability,
- crew error probability.

According to the outlined modeling framework of the PET method for decision-making of human performance, there are three important aspects which are not developed in the current PET models and should be added:

- skill-, rule-, knowledge-based model used for initial expert judgment of symptom recognition durations could be avoided by systematic measurement of these times based on full-scope simulator or real data-mining;
- selective influence ("context-free") in cognition (sub-processes) and in communication (individual features of crew members) is not modeled in the PET models, so some additional psychometric models of these mental processes should be developed;
- PET method uses an absolutely reliable decision-maker due to the lack of an appropriate leadership model, which should take into account not only cognition, but also volition and emotion.

4.2. Risk-informed HRA by PET Method

HFEs are unexpected events (with assessed frequency) in HOT system leading to unwanted outcomes (with assessed severity). Their probabilities evaluate risk-informed holistic and dynamic potential for erroneous actions. The HFE probability has been changing in time before, during and after any HFE, and severity of STS context should be dynamic variable of this error-producing potential. In nuclear accident conditions this dynamic and holistic measure could be defined as CP.

Previous HRA methods try to predict a HFE probability in the "prevailing" context that means in a statistical average context of an average crew performance. However, this "prevailing" context exists only for some short time interval during the accident. A static value (anchor) of HFE probability based on a judged average context of crew for identified task is calculated. The HFE probability is adjusted by multiplication of guessed values of PSFs taking into account the variability of all system components. Fuzzy logic of each HRA technique, tabulated and justified by its database is used to introduce PSFs into the HFE probability variation. Usually, a cited database is 'know-how' of the HRA method. It is verified and validated by the owner and concerned national regulator. But the structures and parameters of models and obtained data are not accessible for other users in order to check them and to repeat data-mining. The benchmarking of the HRA methods is based on results for similar identified tasks, but not on models and experimental data.

Implicit, static and pseudo-holistic determination of context based on an anchor HFE probability and fuzzy PSFs values judged by expert, makes HRA methods superficial and insensitive to the STS models (structures and parameters), HFE symptoms and causes, and human performance processes.

The main reason for the HRA insensitiveness is the lack of models and data for a holographic-like behavior of the human interactions in a complex situation and multifactorial context. These models are substituted with expert judgments and multiplication of concurrent PSFs considered for specific task. This subjective way of HFE probability evaluation does not allow a systematic and multi-layered study of HOT system performance and risk-informed HRA. Practical PET applications for retrospective and prospective HRA and accident analyses are shown in [31]. The PET screening, holistic & atomistic quantification approach and integration in PSA for risk-informed applications are presented in [32].

5. CONCLUSION

The presented individual cognition and mutual communication models of decision-making process are based on probabilistic approaches and network reliability theory as an attempt to overcome the conceptual limitations in context interpretation and understanding of psychometric models of mental processes by deliberate and intuitional assumptions and empirical observations. The goal was to propose controllable reliability models with structure and parameters for individual cognition and mutual communication processes in group performance.

By using the macroscopic context quantification and SLM structure with context-sensitive edges that have a holographic-like behavior for non-selective influence on cognition and communication processes, the PET method gives a macro-approximation of the correct description of the given mental processes. A practical approach was presented for relative embodiment of an implicate order of context-cognition recursion in an explicate structure for risk-informed decision-making.

References

[1] Petkov, G., Bayes' Approach to Specification of HCR Correlation Coefficients, *Proceedings of 1999 ASME-PVP Conference*, (Boston, USA, August 1-5,1999), ASME-PVP, Vol. 285, pp.3-10.
[2] Lashley, K.S., *The problem of cerebral organization in vision*. In Biological Symposia, VII: Visual Mechanisms pp 301-322 JaquesCattel Press, 1942, Lancaster.
[3] Globus, G., Pribram, K., Vitiello, G., Brain and Being: At the boundary between science, philosophy, language and arts, *Advances in Consciousness Research*, 58, 2004, xii, 350 pp.
[4] Leith, E.N. and Upatnicks, J., Photography by Laser. *Scientific American* 212: 24-35, 1965.
[5] Gabor, D., Theory of communication, *Journal of the Institute of Electrical Engineers*, 93, 429-441 (1946).
[6] Pribram, K., *Brain and perception: Holonomy and Structure in Figural Processing*, Hillsdale, N. J.: Lawrence Erlbaum Associates, 1991.
[7] Hampton, J. A., Overextension of conjunctive concepts: Evidence for a unitary model for concept typicality and class inclusion. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 14, 12–32, 1988.
[8] Petkov, G., Symptom-based context quantification for dynamic accident analysis, *Safety Science* (2018), https://doi.org/10.1016/j.ssci.2018.02.027.
[9] Petkov, G., Furuta, K., Application of PN-Based Method for Identification and Classification of Human Actions in NPP TLRS, *Proceedings of PSAM4* (New York, USA, 13-17 September 1998), Springer London Ltd., Vol.2, pp.1136-1141, 1998.

[10] Petkov, G., Groudev, P., Correlation between Human and Material Shocks In Symptom-Based Emergency Procedures, *Proceedings of 1999 ASME-PVP Conference* (Boston, MA, USA, August 1-5, 1999), ASME-PVP, Vol.392, pp.25-35, 1999.
[11] Petkov G., Networked Risk Images in Human Action Context, *CT99 Conference*, (San Francisco, CA, USA, August 11-14, 1999) http://www.cogtech.org/CT99.
[12] Wisse, P.E., *Metapattern: context and time in information models*, Addison-Wesley, Boston, 2001.
[13] G. Petkov, Enhancing the Plant's Capability for Design Extension Conditions Based on Time-Dependent Context Evaluation of Human Performance in ATWS Events, *ASME J. Nucl. Eng. Radiat. Sci.*, NERS-16-1133, DOI: 10.1115/1.4039000, 2018.
[14] Townsend, J., Uncovering Mental Processes with Factorial Experiments, *Journal of Mathematical Psychology*, 28, 363-400, 1984.
[15] Townsend, J., Schweickert, R., Toward the Trichotomy Method of Reaction Times: Laying the Foundation of Stochastic Mental Networks, *Journal of Mathematical Psychology*, 33, 309-327, 1989.
[16] Donders, F., Die Schnelligkeit Psychischer Processe, *Archiv fur Anatomie and Physiologie*, 657-681. (In W.G. Koster Ed. Attention and Performance II (pp.176-315), Amsterdam: Elsevier/North-Holland.), 1868.
[17] Petkov, G., Stefanov, E., Reliability Evaluation of Slack Times in NPP HMS Processes, *Proceedings of 6th International Conference 'Mathematical Methods in Reliability' – MMR'2009*, Moscow, Russia, June 22-27, 2009, p.531-534.
[18] Schweickert, R., Townsend, J., A Trichotomy: Interactions of Factors Prolonging Sequential and Concurrent Mental Processes in Stochastic Discrete Mental (PERT) Networks, *Journal of Mathematical Psychology*, 33, 328-347, 1989.
[19] Hollnagel, E., *"Cognitive Reliability and Error Analysis Method (CREAM*)", Elsevier, 1998, Oxford.
[20] Carlson, R., Experienced Cognition, Taylor & Francis, 346p., 1997.
[21] Hollnagel, E., *Human Reliability Analysis: Context and Control*, Elsevier Science Ltd., London, 1993.
[22] Petkov, G. Identification and Fitting of Human Cognition Model, *Proceedings of the ASME-PVP Conference* (Seattle, USA, July 23-27, 2000), ASME-PVP, Vol.400, pp.35-48.
[23] Petkov, G., Kostov, E., Filipov, K., Stefanova, A., Atanasova, B., Andreeva, M., Groudev, P., Dynamic context evaluation of human actions in severe accident analysis and management, *ESREL'2015*, Zurich, September 7-10, 2015.
[24] Petkov, G., 2002. Reliability and Risk Analysis by the ATRD Method, *Journal of Reliability Engineering Association of Japan*, REAJ, Vol.24, No.2, 2002.3, pp.155-164.
[25] Ujita, H., Fukuda, M., Kubota, R., Hayashi, M., Plant Operator Performance Evaluation Based on Cognitive Process Analysis Experiment. *Proceedings Topical Meeting on Advances in Human Factors Research on Man/Computer Interactions: Nuclear and Beyond*, Nashville, TN, 1990.
[26] Rasmussen, J., 1983. Skills, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models, *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. SMC-13, NO.3, May/June 1983, pp.257-266.
[27] Latimer, C., Stevens, C., Some remarks on wholes, parts and their perception. *Psycoloquy* 8 (13), http://www.cogsci.soton.ac.uk/cgi/psyc/newpsy?08.13, 1997.
[28] Nickols, F., The difficult process of identifying processes why it isn't as easy as everyone makes it sound, *Knowledge and Process Manage*, 5, 1: John Wiley& Son's, 1998.
[29] Satyanarayana, A., Prabhakar, A., New Topological Formula for Rapid Algorithm for Reliability Analysis of Complex Networks, *IEEE Transactions on Reliability*. 2:82 (1978).
[30] Petkov, G., Mondeshky, I. and Milev, D., HRA Corroborative Studies Based on Dynamic Context Description, *3rd International Symposium on Systems & Human Sci*ence*: SSR 2006*, EC-JRC, Vienna, Austria, 6-8 March 2006.
[31] Petkov, G., Team performance comparison in core-melt units of Fukushima Daiichi NPS based on dynamic context quantification of accident, *PSAM Topical Conference 2017*, Munich, Germany, June 7-9, 2017, GRS.
[32] Petkov, G., Symptom-based approach for dynamic HRA and accident management, *ESREL'2018*, Trondheim, Norway, June 17-21, 2018.