Risk-informed Context-based HRA Method

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Risk-informed accident management & HRA

- How to apply different sciences to reflect interactions within a **Socio-Technical System (STS)**, to assess **Human Error Probability (HEP)?**
- HRA, related to PSA, needs to include at least two ***RI*** quantities:

1. ***Probability of occurrence*** or ***frequency*** is interpreted as *a complementary cumulative distribution function (ccdf)* of the sum of the STS states (after HFE):

   ∑unsafe STS states)/(∑all STS states)

   for ***Cognitive error probability (CEP):***

   (∑unknown STS states + ∑unrecognizable STS states)/(∑all STS states)

2. ***Hazard magnitude*** - *error-producing potential* of an unsafe STS state

Context-based accident management & HRA

by Performance Evaluation of Teamwork (PET) method

- Since a human action (HA) includes different mental & manual, individual & group processes, its ***performance-based*** feature should be interpreted as *context-based, situation-based* or *dynamic*
- The HA in PSA/HRA should be modeled qualitatively & quantitatively as *STS variability* and described mathematically with numbers/probabilities, figures & graphs.
- The most important **conceptual explanations** of the PET method & models are:
  1. Statistical **holographic-like** description of the HTOE system behavior (macro- & micro-),
  2. Reconciliation of **objective facts** & **subjective images**,
  3. Coexistence of classical, Bayesian & quantum probability on STS holistic & atomistic levels,
  4. Numerical (probabilistic) context evaluation as superposition of ***object-image-situation***,
  5. Controllable context-sensitive network reliability models.

Approaches for STS reliability modeling

- The **system approach** focuses on *the conditions, situations and context in which a person deliberately and conscientiously performs his/her actions to effectively manage the system and limit the consequences of the risk of its operation*.**“**
- The **holistic approach** means that human performance needs to be considered as a variability of a whole STS where HTOE interacts each other.
- **The use of structural/functional decomposition**, customary for PSA modeling, **in HRA does not work** because they break the most important & dynamic interactions in the system and cannot explain its holistic behavior.
- In IAEA NS-G-2.15 (2009) a **'symptom-based approach'** was recommended:

  "2.14. The approach in accident management should be based on directly measurable plant parameters or parameters derived from these by simple calculations.“

  - **STS Failure Event vs. Human Failure Event (HFE)**
  - **SIF (PSF) for a symptom (stimuli) vs. aggregated PSFs for a whole crew performance**

Symptom-based approach to statistical description of the STS context

- *The real-world decision-making processes need to be modeled in the context of the complex multi-agent and multi-level STS.*

How to analyze the STS performance and collect HRA data?

- **The basic idea** follows the ***Shannon theorem (1948)*** of the distinction between macro- & microscopic levels **to change the set of microscopic accessible states** *(quantum states)* **with equivalent subsets of macroscopic states** (*bit states*).
- The PET* symptom-based approach for STS context description was based on **countable items with operational relevance** (*symptoms are stimuli with meaning or front-line interaction results*) as **Goals**, **Transitions**, **Actions**, **Functions**, **Parameters**, **Events** & **Resources**.

* **"PET" abbreviation is a HRA technique for HEP multi-level scanning & computing .**

PET dynamic context-based HRA

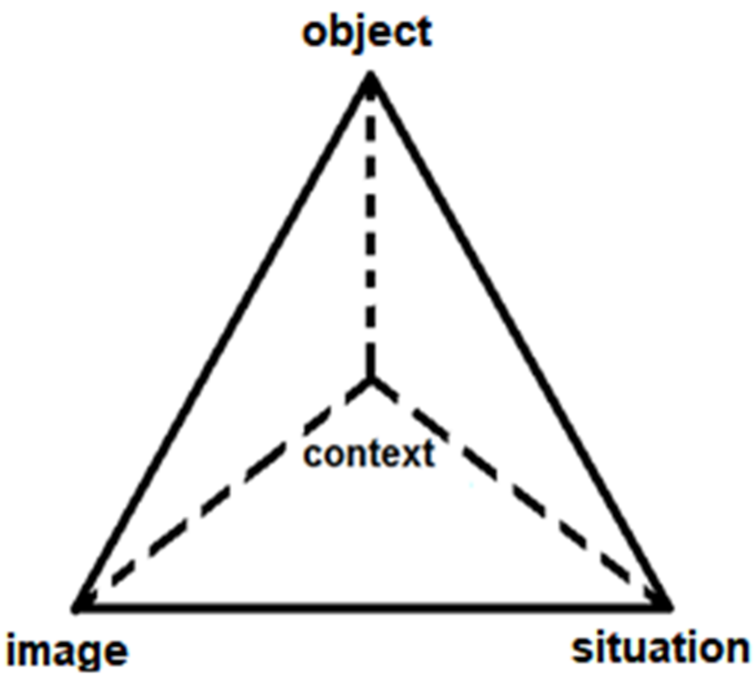
1. **Dynamic and quantifiable concept of context** - *"a common state of universe, mind and image of object in situation in their relation“*
2. **Context evaluation** is based on the **“performance shifts”** (symptoms' influence)**:**

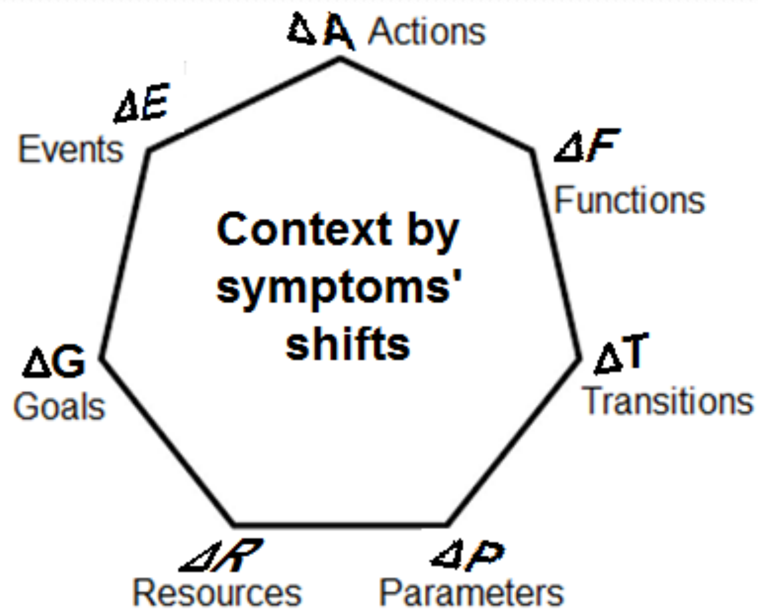
Similar to: **||Expectation - Drift| - Accumulated Danger|** *(Dekker, 2007)*

3. **Context-sensitive reliability models** of:
   - **Individual cognition** & **execution**
   - Teamwork - **mutual stepwise communication**, coordinated group thinking, **iterative cognition & execution**
   - Leadership and **group decision-making**
4. Models of individual or group behavior, emotion, volition, etc.

Context representation & modeling of STS variability by symptoms' deviations

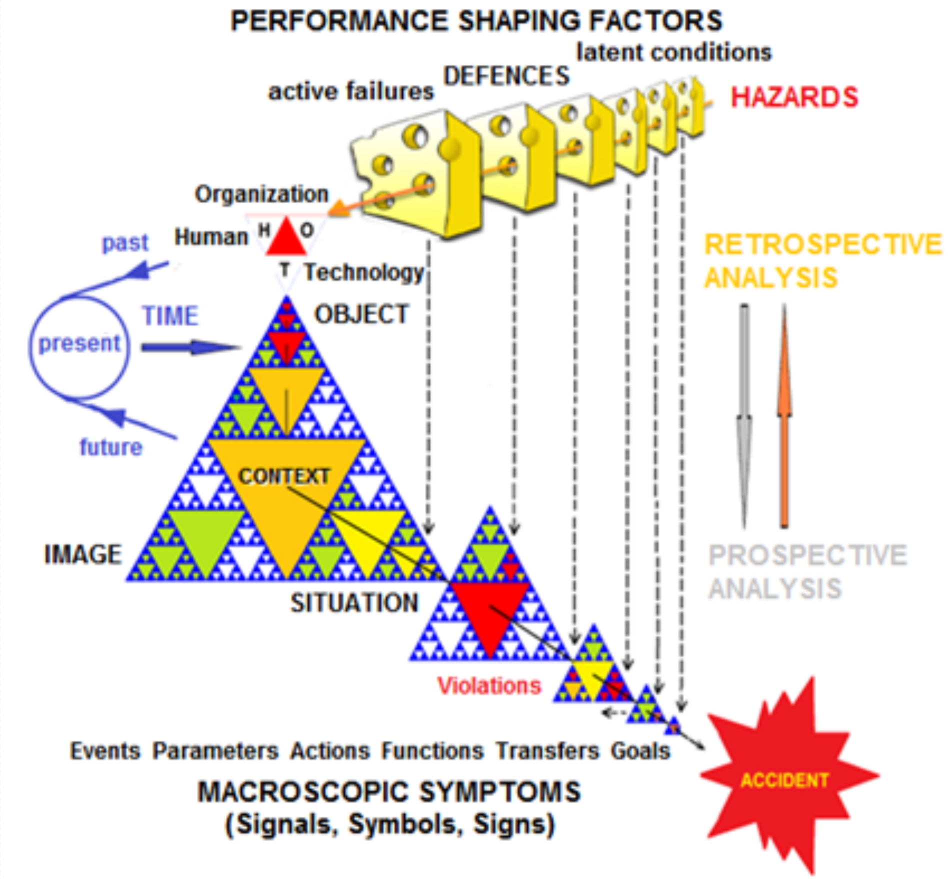
The lumped together qualitative & quantitative aggregated PSFs to context evaluation hampers HRA because it is difficult to bring different information "to a common denominator“

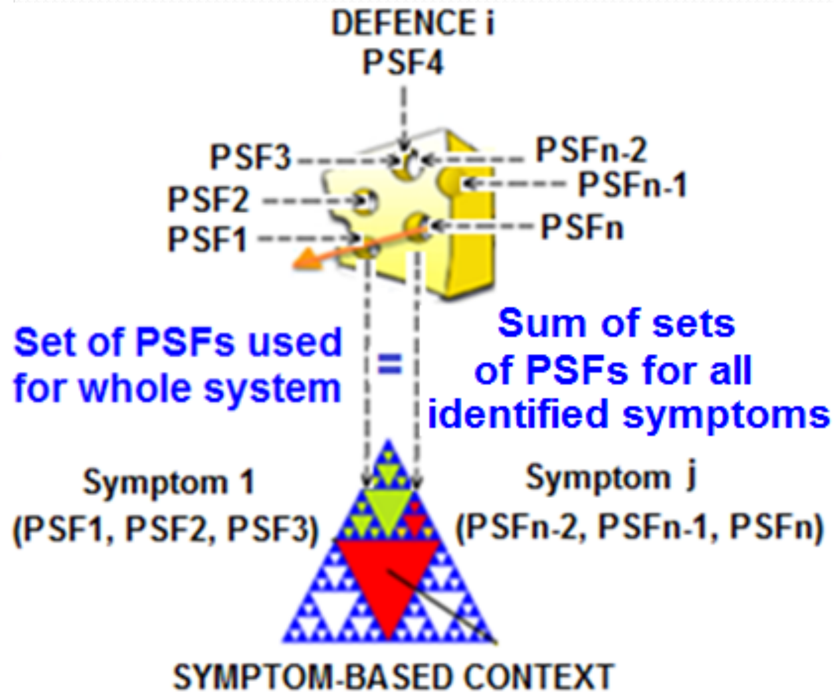




How to use context determined for mental models and a heuristic concept of **Symptoms** (Stimuli = *Alarms or Signals, Symbols, Signs*) to indicate “how context influences actions”.

Dynamic holistic & atomistic symptom-based context evaluation





Theoretical Underpinning for Heuristic Reliability Modelling of Mental Processes

- The term "heuristic" is an extension of analytical methods in areas where such methods cannot be exactly proven (the correctness of method is questionable!).
- It means that is necessary to omit some specified conditions, to make additional assumptions and to change the description of an analysed 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 the STS context (HTOE), one has to combine the knowledge of probability, context, cognition, network reliability and psychology theories.

Applicability of probabilistic approaches
Classical vs. Bayesian approach

As you know, there are two general ways to interpret probability:

- **"Classical" probability** - called ***"objective"***, "physical" /stable *"frequency"*
- **"Bayesian" probability** - called "evidential" ("epistemic" or ***"subjective"***), as a way to represent its **subjective plausibility**, or the degree supported by available evidence.
- The Bayesian approach enables us to use the new information about the STS context.
- The changes of the number of recognised symptoms in time could be interpreted as "prior" and "posterior", but it serves also as a basis for a HA context dynamics.
- The dynamic description of a context-sensitive mental process is based on the deviations between "objective" facts and "subjective" images/implementations.
- Both "objective" and "subjective" probabilities and the Bayesian approach are used.

Applicability of Probabilistic Approaches

Quantum models for mental processes

- Holographic images & information entropy provide some valuable ideas of how to develop appropriate mental models & use them in dynamic decision-making process.
- There are experimental data in cognition that cannot be modelled by means of any classical or Bayesian 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.
- If **"data showing deviations from set theoretic rules"** then it is an indication that a quantum model exists.
- Consequently, mental models should have **holographic-like "surface processing structure"** (**macro level - bit s**) & an analogy of **quanta** should be used more fully on the **quantum (micro) level** of information, where **"deep processing"** is needed.

Psychometric Test Elements
Uncovering mental processes

- Routinely, psychometricians seek to develop a mathematical theory of *systems with partial order of the process & sub-processes* & not with *holographic-like behaviour.*

The major issues about uncovering mental processes are the following:

- Psychological measurements "*do not identify processes with additivity*";
- All factors not only influence process but also vary with time;
- *Factors influencing* not only durations but also *outputs of processes* are unexplored;
- *The expectation of a sum of random variables is equal to the sum of the expectations;*
- The *discrete aspect of the processing* postulates is definitely of psychological interest;
- The *systems with feedback/iteration 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 mental models** is the *implausible requirement* that a process cannot start before all its immediate predecessors have finished.

Principles & assumptions for hybrid modeling

Aspects & principles of cognition control

Additional empirical and experimental assumptions have been made about:

- Seriality/parallelity, concurrentness/sequentality of human performance;
- Factor and time dependence in cognitive process and sub-processes (functions);

Four principles of cognitive control could be formulated:

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

Principles & assumptions for hybrid modeling

Assumptions for PET hybrid mental modelling

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

1. The processes are independent and they occur sequentially in time;
2. The configuration of a process changes simultaneously, i.e. the control over the transients between processes is parallel (“holistic approach”).

- *Assumption B:* Control of individual cognition or decision making is based on selective influence (context-free) and non-selective (contextual) factors’ interference.
- *Assumption C:* Time dependences between cognition and context

1. The selective influence of context factors on cognition can be ignored for the average case (individual and conditional) & for group thinking and performance;
2. The duration of symptom recognition could be measured;
3. The duration of transition between connected processes is much longer than the duration of any sub-process.

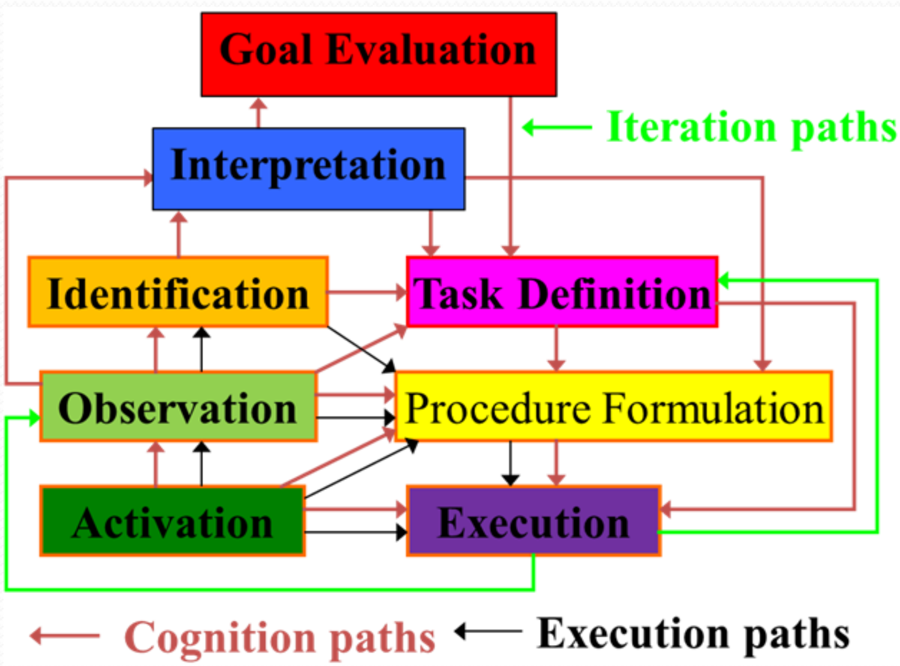
Context-sensitive Probabilistic Control & Reliability Evaluation of Decision-making

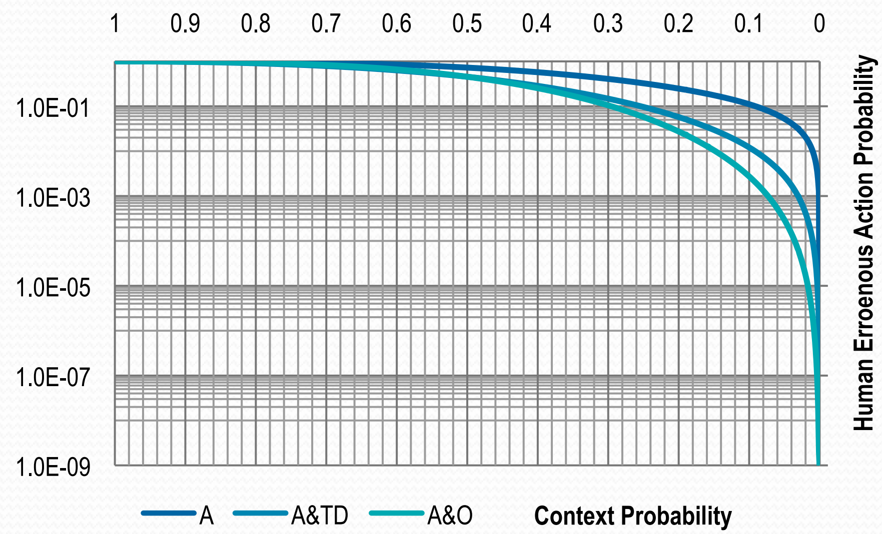
- Only individual cognition and group communication control based on **macroscopic context-sensitive probabilistic description** (based on bit entropy) is presented.
- **Context-sensitive reliability models (structures & parameters)** for evaluation of individual cognition & communication on the decision-making phase are proposed.
- An explicit decision-making process framework leaves aside the important implicit framework for cognition control based on selective influence (and quantum entropy).

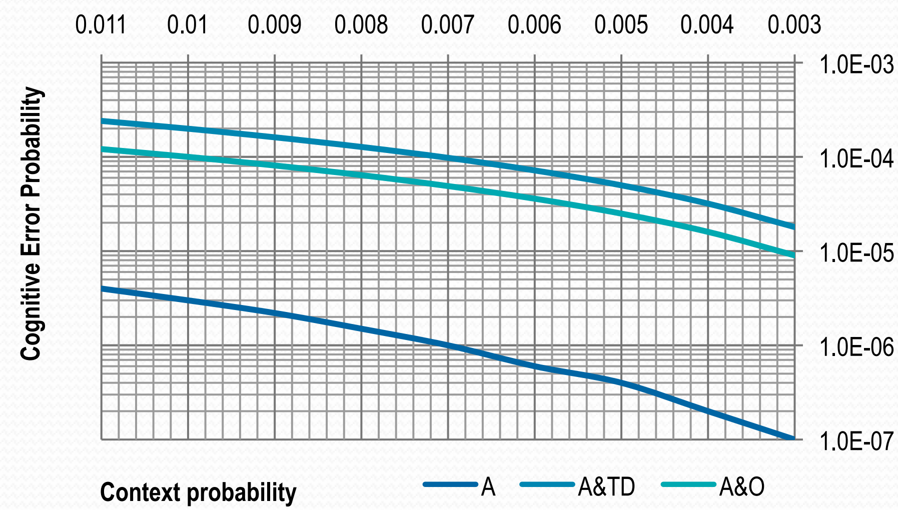
Empirical Fitting of Generative Data Context-sensitive Reliability Models

- 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 Rasmussen's Step-Ladder Model (SLM) cannot be directly applied as a reliability model due to the fact, that time and probability parameters are qualitatively assessed.
- If the model is modified by some simplifications based on assumptions above then these qualitative features can be assessed quantitatively and applied.
- All graph models of reliability can be reduced to Source - Terminal (ST) reliability.
- As a result of these simplifications is obtained a digraph reliability model of cognition.
- This model reflects all experimentally proven edges of the cognitive process with non-selective context influence and two possible iterative steps (Ujita et al., 1990).
- The **green edges** show the possible iterations, **black edges -** the *Execution digraph reliability model* as a subset of the *Cognition digraph reliability model* (**red edges**).

Rasmussen's Step-Ladder Model Digraph





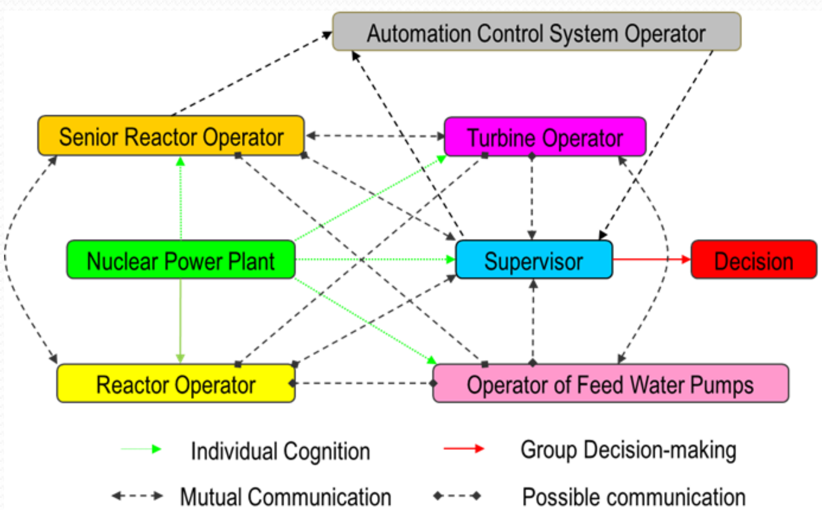


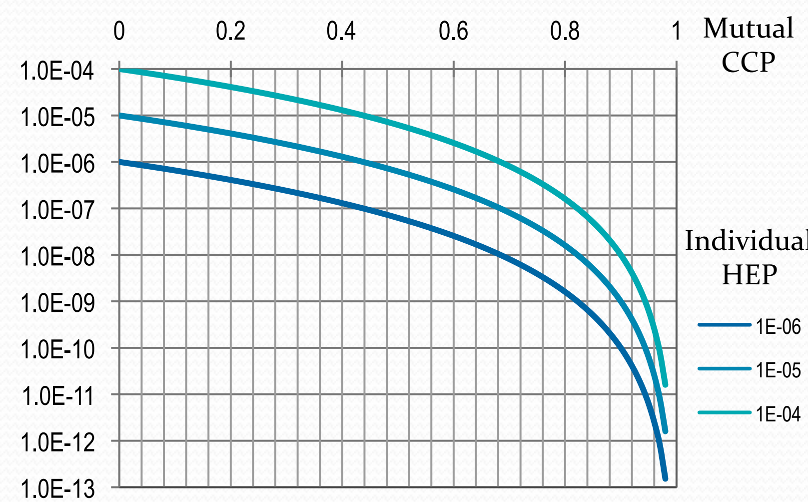
Structure of the group reliability model of communication & decision-making

- The structure of the Group Reliability Model (GRM) digraph, proposed by Furuta & Kondo (1992), is used for modelling of mutual communication during group decision-making process.
- The differences between individual ***Context Probability (CP_i)*** of two group members determine the *Communication Context Probability (CCP_{kj})* for mutual interaction into group communication process:

$$CCP_{kj}(t)=CP_j(t)-CP_k(t),\ k\,\boxed{?}\,j$$

Crew Communication Model (VVER-1000)





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 evaluated by the PET context quantification procedure as a *CP(t)*.
- It consists in counting (in chronological order) the identical bit states.
- For simplicity's sake we assume that the processes in “context axons” (CP) begin simultaneously and their probabilities of the cognitive sub-processes coupling are equal.

Advantages & Drawbacks of the PET Method

Advantages:

- The PET HRA method provides sequential & dynamic barriers for defence-in-depth, for monitoring and avoiding erroneous teamwork performance by reducing:
  1. **probability of the error-forcing context – *CP(t)***
  2. **individual HEP(t)**
  3. **crew HEP(t)**
- Determination the most appropriate and safe moment for implementation.
- Evaluation of the HEPs for the confident time period before, during & after a STS mission.

Drawbacks & **Missing, Undeveloped Models**:

1. The hazard magnitude of all unsafe states is allowed to be the same, (equivalent);
2. The subjective separation of the STS states because human does not respond to each STS state because of ant doubt, intuition, fear or laziness;
3. *systematic measurement of symptom recognition durations* based on FSS or real data;
4. *selective influence* ("context-free") in sub-processes of cognition;
5. an appropriate leadership model (with cognition, volition & emotion) .

Advanced Practice by PET Method

Risk-informed HRA

- HFEs are unexpected unsafe acts (with assessed frequency & judged hazard magnitude) leading to unwanted outcomes in STS.
- Evaluation of *HEP(t)* gives risk-informed holistic potential for erroneous actions.
- The HFE probability has been changing in time before, during and after any symptom.
- Both frequency & hazard magnitude of the STS context should be dynamic variables.
- 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.
- This "prevailing" context could exist only for some short time interval, if at all.
- Implicit, static & pseudo-holistic determination of context based on an anchor HFE probability & fuzzy PSFs values judged by expert, makes HRA methods superficial & insensitive to the STS behavior (structures, interactions, context and processes).
- The main reason for the HRA insensitiveness is the lack of models & data for a holographic-like behavior of the STS interactions in multifactorial context.

Conclusions

- The presented heuristic models of individual cognition & mutual communication of decision-making process are based on probabilistic approaches & network reliability as an attempt to overcome the conceptual limitations in context interpretation, psychometric test models and uncovering mental processes by deliberate and intuitional assumptions and empirical observations.
- The goal was to propose controllable reliability models with structure & parameters for individual cognition & mutual communication processes in group performance.
- By using the macroscopic context quantification and digraph reliability models with context-sensitive edges and holographic-like behaviour for non-selective influence on cognition and communication processes, the PET method scans and computes approximately cognition, recovery, communication and execution error probabilities.
- The PET method as a tool for a simplified understanding, monitoring and scanning of the STS performance and could be used as a generative HRA data model.

THANK YOU FOR YOUR ATTENTION!