Reliability Evaluation of Slack Times in NPP HMS Processes

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Abstract

The paper presents capacities of Performance Evaluation of Teamwork method for simplified probabilistic treatment and quantification of operators' performance. Based on the archives of NPP full-scope simulator training the capacities of the method for the HMS slack times evaluation are presented. The archives contain scenarios of four accidents for 16 operator's crews of the Kozloduy NPP with WWER-1000. The slack times for different operators in one crew, in different crews and in different scenarios are evaluated.

1 Introduction

The human-machine system (HMS) behaviour is formed and influenced by the dynamic processes' interactions in hardware, software and liveware. The representations of the hardware and software performances are quantities that can be observed and measured. They can be explicitly determined and defined by matrices, which eigenvectors form a Hilbert space. On the other hand, the dynamic aspects of liveware are a product of perturbations in physical and mental processes. They are not easily observed and measured. The interaction of a human with complex system represents a combination of technological, organizational, psychological, physical and mental processes and the prediction of the HMS behaviour is too difficult. That is why the expert judgment is in considerable use to overcome the inaccuracies in mental and situational models. Another way to overcome the difficulties of predicting operator performance is to simulate all processes in parallel and to expose the operators to variations that can occur during various normal and accident scenarios.

2 Concepts and definitions

Since the nineteenth century, an important approach has been oriented toward the study of reaction/response time (RT) and considerable theoretical and experimental literature and methodology have developed in support of this approach. Donders (1968) assumed that by simplifying the mental task the experimenter could 'subtract' a mental process or controversially could make the mental task more complex by 'adding' a mental process to the overall set of mental operations. Finally, by subtracting the average RT for the simpler task from that of the more complex task, the experimenter could estimate the mental duration required to perform the deleted operation.

The duration of a path is the sum of the durations of all the processes on it.

The $d(a,b)$ denote the duration of the longest path from vertex a to vertex b. Suppose process y follows process x on a path.

Important concepts for the analysis of networks are "critical path" and "slack" whose definitions follow. Intuitively, the critical path is the longest path through the network and the slack refers to how much a process needs to be prolonged before it affects the start time of a process y, or the overall finishing time.

The slack from process x to process y is the longest amount of time by which x can be prolonged without delaying the onset of y: $s(xy')=d(o, y')-d(o, x')-d(x)-d(x'', y')$.

The total slack for process x is the longest amount of time by which x can be prolonged without delaying the response made at r: $s(xr)=d(o, r)-d(o, x')-d(x)-d(x'', r)$.

A critical path of a network on a trial is a path from the source to the sink whose duration is maximal over all other paths through the network. The duration of the critical path is the RT for that trial.

Given values *s(xr)*, *s(yr)* and *s(xy')*, we let *s(yx")= s(yr)-s(xr)+s(xy')*.

The coupled slack from *x* to *y* is: *k(xy)=s(xr)-s(xy')*. Coupled slack is important in the deterministic situation, when the process durations are real numbers rather than random variables. If the processes are prolonged by amounts which are not too small, then the combined effect on RT of prolonging two sequential processes *x* and *y* is the sum of the effects of prolonging them individually plus the coupled slack, *k(xy)*.

Suppose *x* and *y* are two *prolonging processes* in a directed, acyclic network. Suppose factor 1 affects process *x* and factor 2 affects process *y*. Let *D(z)* denote the duration process *z* when both factors are at their lowest level. In particular, the duration of *x* is *D(x)* and that of *y* is *D(y)* when both factors are at their lowest levels. Suppose when factor 1 is at level 2, the duration of process of *x* is *D(x)+U*, where *U* is a non-negative random variable. Factor 1 is said to *increment the duration* of *x*.

3 Time measuring of mental processes

Many research programms have been conducted by different organizations to provide information on the performance of nuclear power plant (NPP) main control room (MCR) operators when responding to emergency/abnormal/normal events in the plants and in the full-scope simulators. The initial impetus for these programms were the need for data to assess proposed design criteria for the choice of manual versus automatic action for accomplishing safety-related functions during design basis accidents. They also included studies of training simulator capabilities, of procedures and data for specifying and verifying simulator performance, and of methods and applications of task analysis.

Based on empirical results and simulator archive time data are accumulated:

Available time, defined as the operator's available time for situation diagnosis, decision-making and performing an action (only for situations where time is a limiting factor). These times could be specified on the base of expert judgment as well.

Duration for each stage of action, specified by real measurement in control room/deck, simulator data, by expert judgment or by operator interviews.

The "slack time" is defined as the temporal difference between the deadline or available time and the run time. More formally, the slack time for a process is defined as *(d−t)−s*, where *d* is the process deadline, *t* is the run time since the task start, and *s* is the remaining performance time or "slack time". How to evaluate the "slack time" is important question of safety, operation and training analyses.

We assumed that the mental (cognitive, communication and decision-making) processes are partial-ordered, sequential and iterative. The occurrence and combination 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 or be concurrent.

Therefore, if we indicate by s_{a1}, $s_{a1÷a2}$, s_{a2}, $s_{a2÷a3}$…, $s_{aN-1÷aN}$, s_{aN}, the N sequential process in N-1 sequential transitions of iterative steps of a give mental process S_a. By t_{a1}, $t_{a1÷a2}$, t_{a2}, $t_{a2÷a3}$, …, $t_{aN-1÷aN}$, t_{aN} we indicate their respective timings and $t_{a1}+t_{a1÷a2}+t_{a2}+t_{a2÷a3}+\ldots+t_{aN-1÷aN}+t_{aN}=T_{ai}+T_{ai-1÷ai}=T_a$. By analogy, by s_{b1}, $s_{b1÷b2}$, s_{b2}, $s_{b2÷b3}$…, $s_{bM-1÷bM}$, s_{bM}, we indicate the M sequential iterative steps of a mental process S_b, that follows S_a, and by t_{b1}, $t_{b1÷b2}$, t_{b2}, $t_{b2÷b3}$, …, $t_{bM-1÷bM}$, t_{bM} their respective timings and $t_{b1}+t_{b1÷b2}+t_{b2}+t_{b2÷b3}+\ldots+t_{bM-1÷bM}+t_{bM}=T_{bj}+T_{bj-1÷bj}=T_b$. For these two processes one could see that certain their parts could be sequential, parallel or coincident.

"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 RT as affected by pertinent experimental factors" (Townsend, 1984). It is supposed that the human cannot fix these different iterative steps and perceives them as "whole" that "is not reducible to the sum of its parts".

4 Performance Evaluation of Teamwork method

The paper presents capacities of Performance Evaluation of Teamwork (PET) method for simplified probabilistic treatment and quantification of operators' performance. It includes macroscopic "second-by second" context models of cognition, communication and execution processes and reliability models of group decision-making, individual cognition and execution (Petkov, 2002).

It is inferred, by the PET method, that the decision making for different actions in different context will be taken at different times and durations. By computation of basic statistics (mean times and their standard deviations) the most appropriate distribution could be fitted for different stages of human action.

The linear time extraction schemes for human action decision-making for operation of fault-tolerant system and in post-accident scenario are presented on Figures 1 and 2]. Where the beginning times and durations of timeline are as follows: $_{0}$=Initiator; t_{PF}=Procedure Formulation; $(t_I–t_0)$=Control Delay; t_E=Execution; $(t_A–t_0)$=Perception Delay; $(t_E–t_B)$=Execution delay; t_A=Activation; t_B=Beginning limit; t_O=Observation; $(t_C–t_B)$=Minimal Execution Duration; t_{Id}=Identification; t_C=Commissioning limit; t_{In}=Interpretation; $(t_L–t_C)$=Equipment & processes' delays; t_{GE}=Goal Evaluation; t_L=System limit; t_{TD}=Task Definition.

5 Implementation

Based on the archives of NPP full-scope simulator (FSS) training the capacities of the PET method for the HMS "slack times" evaluation are presented. The archives and slack times results contain scenarios of three accidents for 16 operator's crews of the Kozloduy NPP with WWER-1000:

- Steam Generator Tube Rupture (SGTR);
- Steam Line Break into Containment (SLBC);
- Loss of Feed Water (LFW).

For each scenario a certain Performance Shaping Factor (PSF) was varied. Accordingly to the scenario, they were lack of alarm system (ALAR), workload (WKLD) and unfamiliarity with human-machine interface (UFHMI).

The "slack times" for different operators in one crew, in different crews and in different scenarios are evaluated.

6 Conclusion

The reliability evaluations of slack times by the PET method are made about the adequacy of the crew performance by whether plant variables are kept within specified bounds and whether certain actions are taken in due time, in the correct sequence, and manner. So the plant variable data are examined, examples are reactor temperature, and pressure, also discrete data like opening of pressure relief valves, etc. Also, of importance is whether the operators took the correct actions, like tripping the reactor, and obeying the correct sequence of actions according to the procedures.

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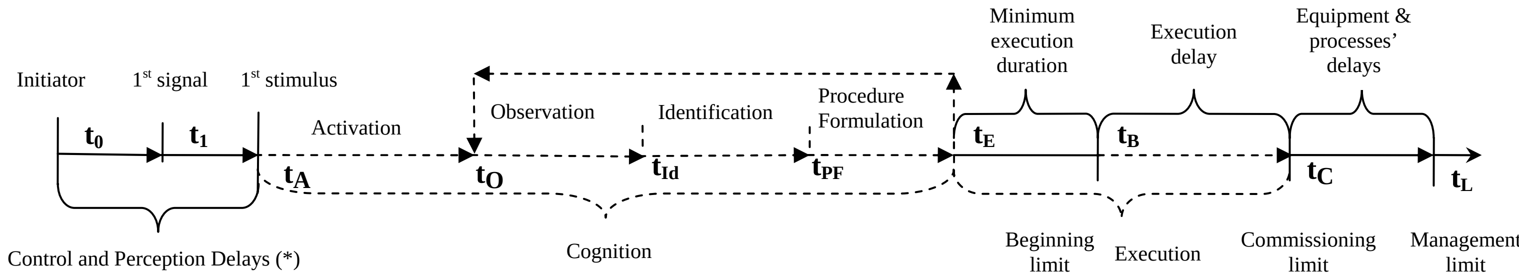

Figure 1: Linear Time Extraction Scheme of Human Action Decision-making Process for Operation of Fault-Tolerant System

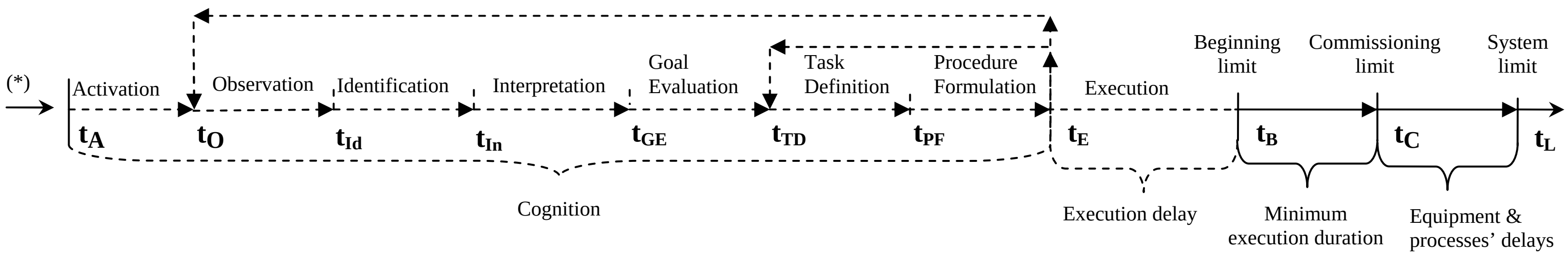

Figure 2: Linear Time Extraction Scheme of Human Action Decision-making Process in Post-Accident Scenario