EVALUATING SITUATION AWARENESS IN THE CONTROL ROOM: THE DEVELOPMENT AND INITIAL TESTING OF THE PROCESS AWARENESS AND SITUATION UNDERSTANDING (PASU) MEASURE

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ABSTRACT

What should we ask the control room crew about when evaluating situation awareness? Currently available freeze probe techniques concentrate on trends of process parameters. Analysis of control room work shows that there are far more involved in control room crews' Situation Awareness (SA). The Process Awareness and Situation Understanding (PASU) measure has been developed from an analysis of control room work and includes probing the crew about the status of safety functions and main plant systems such as coolant supply, ordinary and emergency power supply, main reactor parameters, and main plant parameters. Results from a nuclear control room evaluation showed that the crew's overview of safety functions developed differently across scenario phases compared to the crew's overview of main process parameters. SA in the nuclear control room seems to be a multifaceted phenomenon and valid measurement needs to cover its aspects. Initial empirical testing showed that PASU was sensitive to scenario phases and related to other performance indicators. PASU, or measures based on similar principles, can be a valid and useful probe based technique for use in the evaluation of control room design and control room work. The measure will fill a gap in the research literature and will serve as an example of SA measurement with utility for control room evaluation.

Key Words: Situation awareness, freeze probe technique, control room assessment, validation

1 INTRODUCTION

The measurement and analysis of Situation Awareness (SA) is a key topic of the design and evaluation of human-machine systems [1]. Guides and standards recommend evaluation of SA for control rooms, e.g. [2] and [3]. Valid and useful SA measures are therefore important basis for decisions regarding design alternatives, acceptability of design solutions, and evaluation of personnel competence.

Unfortunately, few SA measures with a proven track for control room evaluation are available [4]. One option for SA assessment is freeze on-line probe techniques. This technique typically includes freezing a simulated task, asking the operators a set of questions which they respond to and comparing their response to the actual system status. Advantages of freeze probe techniques are direct and objective assessment [1]. But what should we ask the nuclear control room crew about? Query techniques in the nuclear domain, e.g. [5, 6], have been limited to the evaluation of dynamic trends of process parameters and have been based on research from the aviation industry [7]. We do not know the validity of these approaches for assessing control room work.

This paper describes a new measure – PASU – that is currently being developed by the Halden Reactor Project (HRP) to assess SA in the nuclear control room [8]. The project has developed a first version from analysis of control room work and performed initial empirical testing of the measure. This paper reports work in progress.

2 SITUATION AWARENESS IN THE CONTROL ROOM

To gain overview of situation awareness of control room work the project analyzed operating procedures and discussed with experienced operators and training instructors. Two Boiling Water Reactors (BWRs) served as cases for analysis of control room work.

As a starting point the analysis focused mainly on disturbance and accident situations. The case BWRs had "first check" procedures for the reactor and turbine side that the control room crew shall apply in case of disturbances or events. The procedures guide the control room crew in getting an overview of plant and safety status to provide a basis for their strategic decisions, for example what procedures to apply to the situation.

The reactor side procedures concentrated on the status of the systems belonging to the main safety functions of reactivity, the integrity of the primary system and the containment. Regarding plant parameters the procedure concentrated on the reactor power, reactor level, reactor vessel pressure, and containment pressure. The procedure also included checking actuated safety signals and coolant systems being in operation. The analysis of the turbine side procedure pointed to similar aspects of turbine side functions, turbine side systems and parameters. The Supervisor would apply a procedure for checking overall safety status, checking the status of main parameters related to plant safety, applying a so called symptom based procedure if any of the symptoms were fulfilled.

From these analyses and discussions with experienced operators and subject matter experts the project outlined a general overview of SA elements and the role of SA in control room work. Figure I below illustrates main SA elements and SA as basis for the control room crew's strategic decisions.

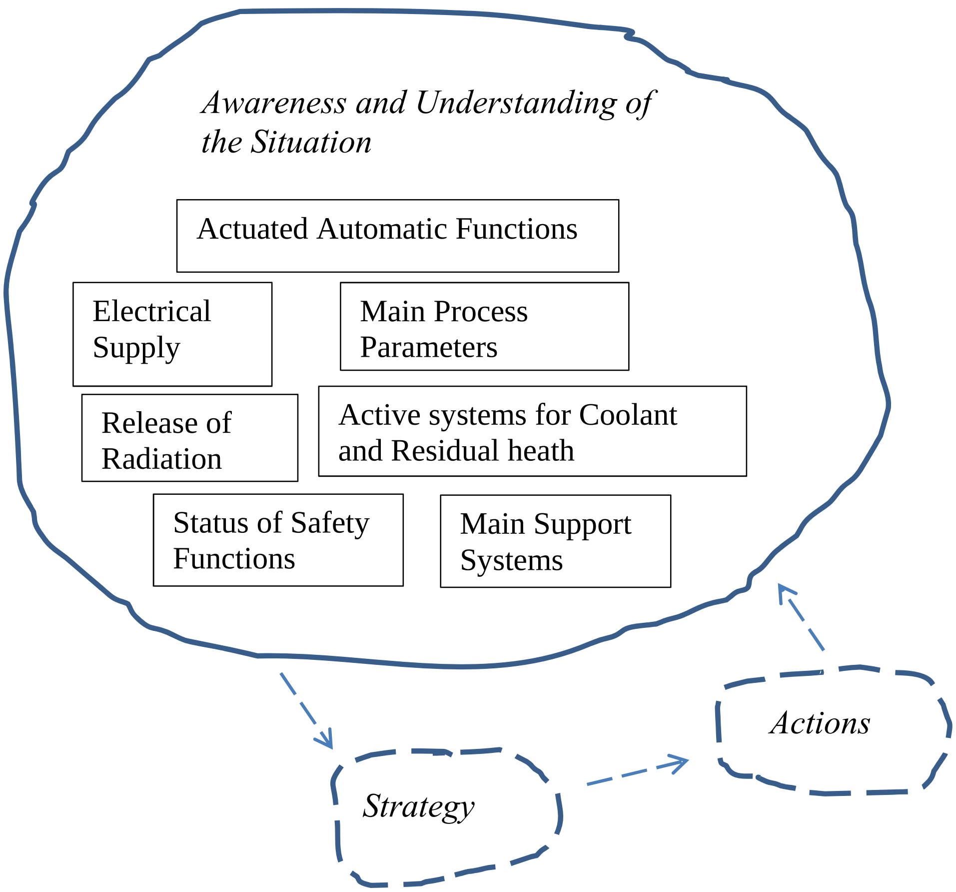

Figure 1. Elements of SA in the control room.

3 THE PROCESS AWARENESS AND SITUATION UNDERSTANDING (PASU) MEASURE

The current version of the PASU measures consisted of a set of probes that could generically be applied to any disturbance or event for the case plants. The current version could be applied to all three control room positions of the case plants, but some parts of the measure were more relevant for the reactor side and some parts were more relevant for the turbine side. The current version prioritized reactor safety and a majority of probe items applied to the reactor side of the plant. Table I provides a brief description of current version's fourteen sub-scores. Each sub-score were based on several probes.

Table I. PASU sub-scores (SA elements)

PASU sub-score	*Description*
Main parameter status	The operator's answers queries about the current values of nine main plant parameters The answers are compared to bounds of upper and lower values defined by Subject Matter Expert (SME). The score results from number of hits.
Main parameter trend	Queries on trends (increasing, decreasing, stable) of nine main plant parameters compared to the actual trend.
Main parameter priority	Queries on nine main plant parameters compared to expert defined priority.
Reactor parameter status	Queries about current status of reactor level, reactor pressure and reactor effect. The answers are compared to bounds of upper and lower values defined by the SME. The score results from number of hits.
Reactor parameter trend	Queries on trends (increasing, decreasing, stable) of reactor level, reactor pressure and reactor effect compared to the actual trend.
Reactor parameter priority	Queries on reactor level, reactor pressure and reactor effect compared to expert defined priority.
Reactor level regulation	The operator selects one out of four status categories for the main feed water and each of four auxiliary feed water trains. The answer is compared to SME defined correct answer based on simulator status.
Residual heat transfer	The operator selects from a list the active sub-systems (four) for the residual heat transfer.
Coolant supply	The operator selects from a list the active systems and/or sub-systems (eight) for the residual heat transfer.
Power supply	The operator answers if offsite power and/or house turbine are available or not. The score is based on number of hits.
Emergency power supply	The operator answers if each of four diesel generator backed up bus bars are available or not. The item includes status of sub bus bars.
Actuated functions	The operator answers what functions have been actuated (a list of all functions). The score is based on hits.
Safety function status	The operator answer of the status of each of six main safety functions is ok or not. If not Ok, the operator can specify deviation of the relevant system, sub-system and/or component, and provide a comment.
Emergency operation symptoms	The operator answers if the criteria for entering each of seven EOPs is or has been fulfilled.

All PASU sub-scores were based on proportion correct answers and ranged from 0 to 1. The calculation compared the operators answer to a correct answer defined by a subject matters expert. The subject matter expert (SME) utilized the simulator status (trends, logs, parameters, etc.) when determining the correct answers.

4 INITIAL EMPIRICAL EVALUATION OF PASU

4.1 Method

PASU was applied in two empirical studies and the analysis presented in this paper focused on indications of validity and utility of the measure. Study 1 applied a PASU version with sub-scores as described in Table I above with the exception of Main parameter status, Main parameter trend and Main parameter priority. Study 2 applied a PASU version with sub-scores as described in Table I.

Study 1 [9] investigated control room interfaces in the Halden Human Machine Laboratory. PASU was collected as an "add-on" to the original study, and was applied at the end of two accident scenarios (scenario A and B). The experiment utilized a set of human performance measures including SCORE expert observer based performance assessment [10, 11] and operator self-assessments. Three crews each consisting of a supervisor, reactor operator and turbine operator participated in the study. The study 1 allowed for investigating the differences in PASU sub scores between the two scenarios compared to the differences in SCORE and self-assessment between the two scenarios.

Study 2 was a control room evaluation related to a periodic safety review of a Swedish boiling water reactor. The PASU was chosen among the available candidates in the literature as the operator based SA measure for the evaluation. Five crews consisting of a supervisor, reactor operator and turbine operator participated in the study. The study utilized four scenarios that were organized according to three scenario phases representing different working conditions for the crew. Thereby, the study 2 allowed for investigation of PASU's sensitivity to these working conditions. Generally phase 1 involved production problems and plant process deviations, phase 2 involved a safety event, and phase 3 contained aggravating safety event and control of the plant.

4.2 Results Study 1

The crews generally performed better in scenario A than in scenario B. The mean SCORE performance for the crews (n= 3) for scenario A and scenario B was 5.49 and 4.60 respectively (close to statistically significant difference, $t(2) = 3.46$, $p = .07$). The mean operator self-rating of situation awareness (n= 9) for scenario A and scenario B was 4.67 and 4.00 respectively (statistically significant, $t(8) = 2.31$, $p = .05$). The mean operator rating of mental demand was very similar for scenario A and scenario B, 4.11 and 4.00 respectively.

To investigate the correspondence between PASU and overall performance the analysis investigated if PASU sub-scores were higher in scenario A than in scenario B and hence corresponding with the general performance differences of the two scenarios. The analysis of the eleven PASU sub-scores identified significant differences between scenario A and scenario B for four sub-dimensions: Coolant supply , $F(1, 8) = 5.26$, $p = .05$; Emergency power, $F(1,8) = 5.77$, $p = 0.04$; Actuated functions, $F(1,8) = 8.89$, $p = .02$; and Safety function status, $F(1,8) = 6.00$, $p = .04$. Figure 2 below shows the actual differences for the four sub-scores and their directions across the two scenarios.

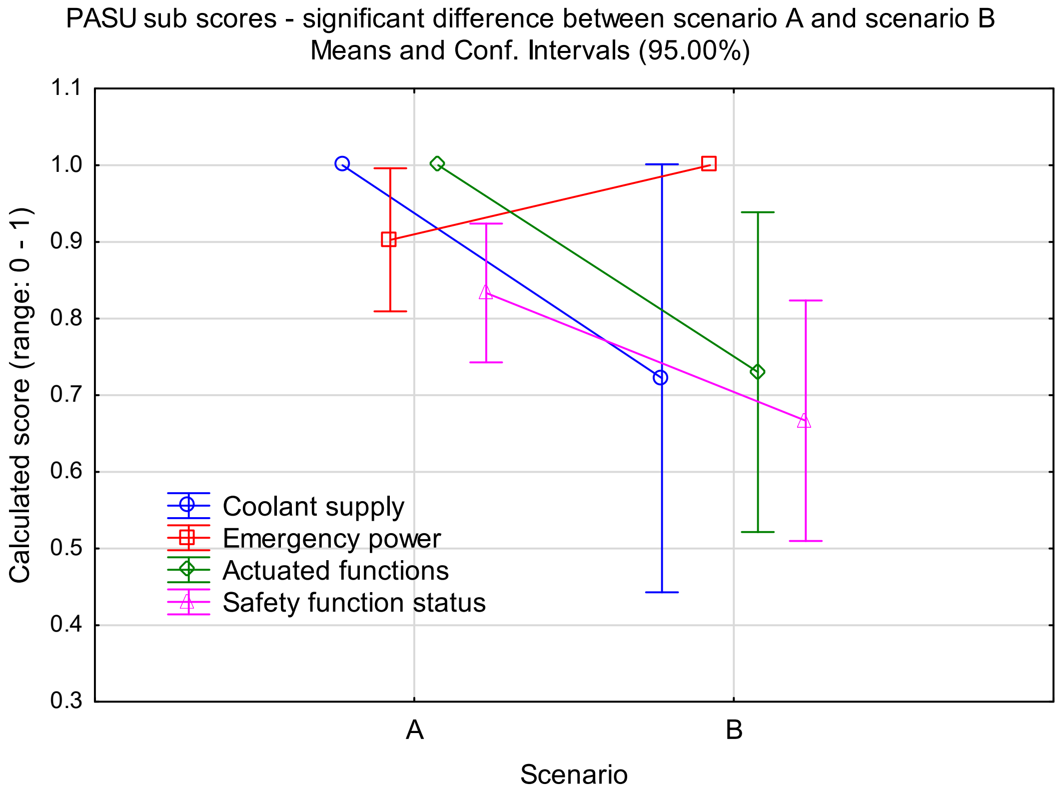

Figure 2. PASU sub scores significantly different between scenario A and scenario B.

Three of the four significant sub scores were in the direction assumed to support PASU correspondence with overall performance and self-assessment of situation awareness. The fourth sub-score, Emergency power was in the opposite direction. However the figure 2 shows that the mean difference between scenario A and scenario B was smaller for the Emergency power than for the other three sub-scores suggesting that relatively lower weight can be attached to the sub-scores in the non-supporting direction. In summary, these initial results provided some support for PASU measuring elements corresponding with other performance indicators, and thereby providing initial results for criterion related validity for PASU.

4.3 Results Study 2

The four scenarios applied in the evaluation contained three phases of different characteristics regarding the team's work. The evaluation included a short scenario break for operator data collection after each phase including the application of PASU. Although the scenario structures varied slightly between the scenarios the general progression of the three phases were as follows.

1. Production problems and plant process deviations
2. Safety event involving actuation of safety functions
3. Aggravating safety event and control of plant

An investigation of sensitivity resulted in statistically significant effect of scenario phase on ten out of fourteen PASU sub-scores. For example, the effect of phase on Main parameter status was $F(2, 24) = 3.96$, $p = .003$, and the effect of phase on Safety function status was $F(2, 24) = 20.13$, $p < .001$. Figure 3 shows the mean PASU sub-scores and their 95% confidence intervals.

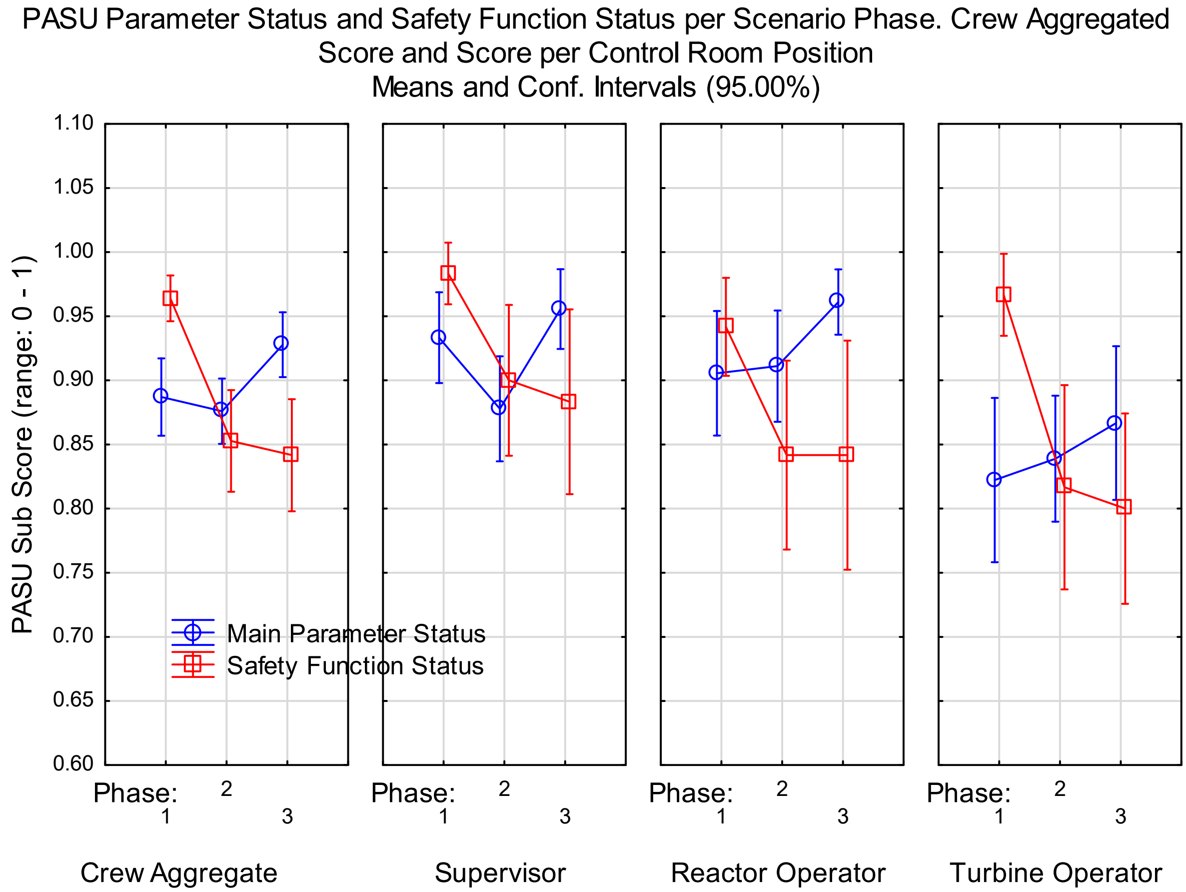

Figure 3. PASU Main parameter status and safety function status across three scenario phases. Crew aggregate and results for each control room position.

The ten out of fourteen significant effects of scenario period suggested that the PASU was sensitive to important variation in the control room crews work situation and type of tasks. Interestingly, the effects of scenario phase were different for the operators' overview of main parameter status and the overview of safety function status. The quite similar patterns across the three phases for all three control room positions, even if different levels of scores, suggested reliable measurement.

Looking at the crew aggregated results presented in the left part of figure 3, we see that the crew's overview of main parameters was at a similar level in phase 1 and phase 2, and was highest in phase 3. On the contrary, the crew's overview of safety function status was highest in phase 1 and slightly decreased from phase 2 to phase 3. One interpretation of the results was that the operators generally maintain a global overview during the scenarios (represented by the overview of main parameters). In the last phase of the scenarios the crew has identified the events and has chosen a plant control strategy, the situation has calmed down and the operators have an increased overview of the main process parameters. During phase 2 and phase 3 the scenarios contained a number of system failure and the operators are not fully aware of these failures and their implications for the safety function statuses. Due to the redundancy of safety systems, failures do not necessarily impact process parameters in a given scenario phase, but rather represent a latent problem that can manifest itself when a safety function is called for. This latter element of SA is thereby not captured by the overview of process parameters.

The implication for the PASU measure is that the measure captured the different development of sub-elements of situation awareness across different working conditions. This is a very promising result for establishing validity and utility for control room evaluation. It is crucial to identify what elements of SA are adequate and what elements need improvement - and in what situations.

The general implication is that evaluation of situation awareness based on overview of process parameters only seems to be too limited. The crew's overview of safety function status followed a different pattern than overview of main parameters. Consequently, valid inferences about SA in the control room need to be based on valid measurement of the important elements of SA.

5 CONCLUSIONS

The analysis of control room work as well as the initial empirical results support that situation awareness in the nuclear control room is a multifaceted phenomenon. Important elements of SA in the control room include overview and understanding of the status of safety functions and main plant systems such as coolant supply, ordinary and emergency power supply, main reactor parameters, global plant parameters. Previous approaches evaluating the status of process parameters capture only one part of situation awareness in the control room. Instead of relying on definitions and techniques from other domains the measurement of analysis of SA in the nuclear domain should be based on the analysis of control room work.

The PASU SA measure is under development at the Halden Reactor Project. The measure is based on analysis of control room work and preliminary results supports that the PASU can be a valid and useful probe based technique for use in the evaluation of control room design and control room work. The measure will fill a gap in the research literature and will serve as an example of SA measurement with utility for control room evaluation.

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