Study on Human Errors in DCS of a Nuclear Power Plant

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Abstract: More and more main control rooms in advanced nuclear power plants (NPP) use computer-based displays and controls, which are called digital control systems (DCS). DCS changes some technological aspects in a NPP control room, including information display systems, alarm systems, controllers and components and computer-based procedure systems. These changes on man-machine interface (MMI) alter the ways of operators acquiring information and controlling the system and thus give rise to new human error issue. In order to investigate the impact of the new MMI on human reliability, the researchers conducted a study in a reference plant with DCS. The practical operation data as well as the experimental data were acquired to study the causes, effects and recovery factors of the new human errors. The research makes an effort on providing a foundation for human error prevention in a DCS and human reliability analysis.

Keywords: digital control system; human error; human factor events; human reliability analysis

1. INTRODUCTION

Human factor is a major contributor to the safety of nuclear power plant (NPP). The operators conduct monitoring and control tasks in the main control room of a nuclear power plant. In a digital main control room, the man-machine interface differs greatly from that of a traditional one. Digital control system (DCS) changes some technological aspects in a NPP control room, including information display systems, alarm systems, controllers, components, computer-based procedure systems and computerized operator support systems. An analog-based conventional control room uses hard-wired displays, such as alarm tiles, indicators, lights, gauges and scales and hardwired controls, such as switches, buttons, knobs and handles. In emergency, operators walk around the panels to acquire information and manage the events on the panels by following paper procedures. In a DCS, information is displayed on video display units (VDU) and large display system (LDS) and controls are made by mouse and keyboard. The digitalization of main control room gives rise to many changes in terms of human factor. The human factor analysts would identify the human errors thus caused and try to understand the reasons and the mechanism of recovery. The final purpose is to propose a plan to reduce these errors to improve the safety of the nuclear power plant.

The empirical study on human errors should be based on the identification and categorization of external forms of human errors. The basic external form is the “task unit” of human behavior, for instance, “clicking a mouse” or “switching between screens” in a DCS. Higher level of “task unit” includes conducting a series of actions or a set of actions for the purpose of realizing the particular function of a system. For example, in case of post-accident management, operators fail to isolate the ruptured SG.

According to Rasmussan[1], human behavior is categorized into three types, the skill-based , rule-based and knowledge-based. The behavior of low consciousness involves low level task unit which is always skill-based and rule-based. Higher level of knowledge-based human behavior involves more complicated diagnosis process. Operators’ action is divided into two phases, “forming the intention” and “action execution”. The errors of intention are mistakes and those of action execution are slip and lapse. Slip is the failure of attention while lapse is the failure of memory[2].

In order to investigate the possible new errors and their mechanism in a DCS, the research group collected the human factor event reports on the spot and simultaneously did experiments. Researchers analyzed these reports and made a summary in the following sections.

2. ANALYSIS ON HUMAN FACTOR EVENTS

The research group collected human factor events by designing a record system for operators reporting their errors by themselves. These reports collected errors on the basis of “task unit”. More than 400 human factor event reports were collected in the reference nuclear power plant with a DCS control room for a time period of 18 months. The events analyzed in this paper are mainly featured by DCS man-machine interface covering errors of action execution, monitoring and poor design of man-machine interfaces.

2.1 Errors of action execution

New DCS man-machine interfaces change the cognition of operators and thus change the action execution mode. Errors of action execution are the major external form of human errors in connection with DCS ,e.g. the observable phenomenon reflected from within human cognition. These errors fall into four categories, those of time, action, target and sequence. 29 events were recorded in which 20 occurred in the routine operating period accounting for 69% of the total. The others occurred when operators were re-trained on full-size simulators.

The reports show that the majority of the errors occurs on manipulating the control objects. It mainly includes two types of errors, one is target error and another is action error. The former is the operators acting on wrong control objects and 15 events are related to this. Most of these cases are in the configuring of screen displays, e.g. secondary task in a DCS when operators opened a wrong picture. Some cases involve operators controlling on wrong objects within one picture. Action error means that operators omit a step in the procedure or act in a wrong sequence.

As for the tasks when errors happened, most errors (4 of 29) happened when operators conducted isolation and when operators reset the state of the equipments (4 of 29) on the operation displayed on computers.

As for the causes of these errors, the failure of operators’ attention and memory is a major contributor. Long-time work and poor design of man-machine interfaces might cause the operators lose their attention and memory. In one case, operators were not familiar with the picture and made VVP steam pressure waved up and down.

As for the consequences of the events, five of them were considered having impacts upon systems, including total loss of L3KIC, the stoppage of L8DVN, unexpected initiation of L3RIS002PO, L4RRA safety valve moved six times and L3RIS003VP not in automation position when it was started.

As for the recovery of the errors, 13 of the 29 cases were recovered instantly and most of them (8cases) were recovered by operators themselves, two were recovered by other people or supervisors and three of them were recovered by alarms or annunciators. The other recovery facts could not be identified in reports.

The errors of action execution fall into two categories, error of omission (EOO) and error of commission (EOC)[3]. EOO comes from lapse, e.g. the failure of memory making operators forget the whole task or a part of the task. EOC has two sources, one is the mistake in forming the intention to execute the task, and another is that the task is not executed in a correct manner due to the distraction of attention. Analysis found that in the recorded human factor events most of them were EOCs. For five of the recorded human factor events, operators seemed to feel difficult to act on controllers andd gadgets. Interview and observation showed that operators were difficult to control or to feel the feedback on the computer. After digitalization, because of the diversified controlling objects displayed on computers combined with poor interface design, some simple skill-based actions, for example, pressing a button, might require high consciousness and cause serious consequences. In other words, the low consciousness task in traditional analog control room could possibly transfer into behaviour requiring high-consciousness.

2.2 Errors of Monitoring

While nuclear power plant becomes more and more automatic, the major routine task of operators in a DCS control room becomes monitoring on the screens. 18 human factor events in regard to monitoring were recorded in which 11 happened in main control room and 7 on the spot. The events could be classified into two categories. The first category was that when operators finished operations on the equipments, they failed to track the state of the equipments or the systems. Eight human events were involved, for example, failing to monitor the water-level gauge when conducting water make-up; not efficiently monitoring the plant state in nitrogen purging and when adjusting L4RRI B flow rate and L4RRI020VN was turned off and not replaced to a normal state, etc.. The second was that operators failed to detect the abnormal conditions when equipment or system went wrong. There were ten such kind of human factor events. For example, operators didn't detect abnormalities after taking over from the preceding shift.

As for the causes of the errors, time pressure may be the main cause. It seems that the operators were prone to lose monitoring on the state of equipments or system at shift handover. The second reason is related to work plan. Eight of the recorded human factor events were in the period of overhaul when operators were involved in a lot of work. So the critical parameters were not efficiently monitored. The third reason may be related to poor design of DCS man-machine interface.

As for the recovery, alarms, annunciators, the third person or other organization barriers are strong recovery factors. In monitoring process, no self-recovery event was recorded.

All monitoring errors are EOOs. Operators paid no attention on or omitted information due to the failure of memory or attention.

2.3 Errors in relation to man-machine interface

Operators do their routine work (computer-based monitoring and control) on man-machine interface in a DCS. The man-machine interface has great impacts upon the human performance and reliability which needs a careful consideration in human reliability analysis.

The recorded events show that all the problems on man-machine interface are because of poor design of pictures and control gadgets, such as the relationship between control system components not very clear, the inappropriate controller positions, improper unlock and interlock, poor matching of controllers with system response and poor design of input fields and formats etc..

Nearly all the simple tasks on computer screens are skill-based. The computer screen is mono-dimensioned and has a narrow display scope. The information that activates the action of operators is easy to be ambiguous to cause slips and lapses. They both involve errors in performing well-practiced actions with low consciousness.

Though in the reference plant there were many human errors possibly having some kind of relationship with the design of the man-machine interface, the operators detected and recovered from most of the errors by themselves. There existed a strong self recovery factor.

3. Conclusion and summary

From the collected data we could find that the computer-based behavior in a DCS changed the way of acquiring information and control input. This change makes a different allocation of attention and memory resources of the operators from that in a traditional analog control room[4-7]. Therefore it may produce new human errors or human errors may appear in new forms. DCS makes the following changes.

Firstly, DCS may change the operators' cognitive workload. In DCS, operators' cognitive workload differs greatly form that in a traditional control room. This difference comes from the physical changes of the man-machine interface[8-12]. An analog-based conventional MCR uses hard-wired displays and controls while in a DCS operators sitting before a set of computers monitoring and controlling. This changes how operators percept, process and feed back the information and thus changes operators' cognitive workload.

DCS changes how people percept the information. In a conventional analog control room, the control panels with a multi-dimensioned physical structure display information directly. This directly-displayed information seems to be more compatible with the indications of the actual state of the plant. In DCS, most of the information is hidden behind the screens and operators need to make some efforts on secondary task to get these information. More cognitive load is needed.

DCS also changes the way how operators process the information. The information is processed in human brain by working memory, the allocation of attention and the extraction from the long-term memory. In a conventional control room, the majority of the input of the phonological loop is visual information, such as the light of annunciators, the form of the control knobs and the position of the gauges etc. and the auditory information (alarms or sounds). The visual information is processed on visuospatial scratchpad of working memory and decoded into phonological repetition and stored[6]. In DCS, the semantic representation of symbols, texts and charts is directly processed by phonological loop. In addition, the efficiency of working memory heavily depends on its capacity. In a conventional control room, the panels and controllers possess a multi-dimensional form with a certain physical construction. Through training operators easily form distinctive chunks when processing information. But the semantic representation on computers appears to be more ambiguous. This may give rise to different stability of working memory and thus produce influence on the cognitive workload.

DCS also changes the way human allocates the resource of attention. In a conventional control room, the entire information stimulus is at a fixed position on panels. The information is visually salient. Furthermore, data-driven information could be more easily detected and operators could access them more conveniently. In DCS, the attention seems to be model driven while in a conventional one it seems to be a combination of model-driven and data-driven data.

Secondly, DCS may change the role of individual crew member. DCS changes the behavior of a single operator and therefore the role of an operator in a crew. In a traditional control room, a sole operator is just one part of a crew cognition. When accident happens, all the crew members are sitting before the panels and share the information timely. They discuss, negotiate, exchange information and make judgment. In DCS, RO1 and RO2 are respectively a complete cognition unit. The independent work of each operator causes new risks. One risk is that the errors of the operator are not easily detected by other people and thus produce impacts upon the crew reliability. Another risk is that the operator may sink into following the procedure when accident happens and may lose situation awareness. In the reference plant, experiments on full-size simulator show that RO1 & RO2 have low situation awareness and this is supplemented by another crew member US (unit supervisor). The situation awareness of the crew heavily depends on the communication between crew members.

The third significant change may take place in the course of following procedures. In a traditional control room, operators use paper procedures while in DCS operators use computer-based procedure. The way of following procedures are different, including how to get the necessary information, the way of supervising and the monitoring of system feedback. Nevertheless, the ways by which the procedures are presented make the execution of procedures different. Furthermore, the paper procedure is convenient for operators to track what have been done and predict what will happen. In DCS, if you want to realize these, you need to do many secondary management tasks. Therefore it will possibly increase the opportunities of errors.

From the collected reports and observations upon simulator training we know that DCS makes difference. It changes the cognitive workload of operators and the role of each member in a control room. It also changes the way of following procedures and may possibly produce new errors. Further research is still needed on the above-mentioned issues and thus to improve the human reliability in a DCS.

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References

[1] J. Rasmussen. *“Information processing and human-machine interaction: An approach to cognitive engineering”*. North Holland , 1986,New York.
[2] J. Rasmussan. *“Skills, rules and knowledge: signals, signs and symbols, and other distinctions in human performance models”*, IEEE transactions on systems, Man & Cybernetics, 13,pp.257-266, (1983)
[3] A.D. Swain, Guttmann H E. *“Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Application”* . NUREG/CR-1278, Sandia National Laboratories, Washington, DC.,(1983).
[4] J. Rasmussen, & K.J. Vicente. *“Coping with human errors through system design: Implications for ecological interface design”*. International Journal of Man-machine Studies,31,pp.517-534,(1989).
[5]P.M.Sanderson. *“Cognitive work analysis. In J.M.Carroll(Ed.) HCI models, theories, and frameworks: Toward a multi-disciplinary science”* (pp.225-264). San Francisco: Morgan Kaufmann.
[6] A. D.Baddeley, & Hitch, G. J. “*Working memory”*. The psychology of learning and motivation (Vol. VIII, pp. 47–89)”. New York: Academic Press. (1974).
[7] J.A. Spurgin. *“Human Reliability Assessment”*, CRC Press, Taylor & Francis Group, Boca Raton, FL 33487-2742 (2010).
[8] N.J.Cooke. “*Varieties of knowledge elicitation techniques”*. International Journal of Human-computer Studies,41,pp.151-173,(1994).
[9] K.A.Ericsson & H.A. Simon. *“Protocol analysis: Verbal reports as data”*. Cambridge, MA: MIT Press (1985).
[10]E.Hollnagel,& D.D.Woods. *“Cognitive systems engineering: New wine in new bottles. International Journal of Man-machine Studies”*,18, pp.583-600,(1983).
[11] J.Rasmussen, & K.J.Vicente, *“Coping with human errors through system design: Implications for ecological interface design”*. International Journal of Man-machine Studies,31,pp.517-534,(1989).
[12]P.M.Sanderson. “*Cognitive work analysis”*. *In J.M.Carroll(Ed.) HCI models, theories, and frameworks: Toward a multi-disciplinary science (pp.225-264).* San Francisco: Morgan Kaufmann (2003).