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Incorporation TACOM and SPAR-H into the operating procedure of nuclear power plants

Xiaosong Zhao *, Rui Zhang, Shumeng Zhao, You Wu, Zhen He

Department of Industrial Engineering, Tianjin University, Tianjin 300072, China

A R T I C L E I N F O

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A B S T R A C T

The digital control system has improved the equipment reliability and the productivity of nuclear power plants (NPPs) greatly. However, the human error in main control room of digital control systems has become a major influence for the safety and economic efficiency. Based on the task complexity and human reliable analysis, this study analyzes the procedural tasks in the main control room. Standardized Plant Analysis Risk Human Reliability Analysis (SPAR-H) method lacks cognitive activity analysis and the results are not accurate due to the subjective assessment of performance shaping factors (PSFs). The TACOM (Task Complexity) quantification method is then introduced to SPAR-H method to gain precise results. Finally, the steam generator tube ruptures is analyzed using the improved method and comparison is made between the result and empirical data. The result shows that the improved method can effectively identify task complexity factor to achieve a more accurate prediction of the human error probability, and the improvement of the prediction is significant to the safe operation of nuclear power plant. Moreover, the improved method can distinguish the tasks that with similar difficulties which is very important for the task selection in time-urgent situation.

1. Introduction

As a kind of clear energy, the nuclear power has gain widely attention in today's increasingly serious environmental pollution. With the development of the nuclear power technology, the fourth-generation digital main control rooms have been established in many NPPs to improve the productivity and equipment reliability. The introduction of the digital control system has greatly changed the operating environment. Many studies have indicated that the human error probability (HEP) in digital main control room is the highest and the effects are seriously (Wang and Liu, 2013). About 70% of the accidents are related with human error in NPPs (Hollnagel, 1998). Well-designed procedure clearly shows that the objects, methods and steps can effectively reduce the operator's physiological and psychological loads, and avoid the human error caused by oblivion and omission. The procedures in main control room can effectively improve the human reliability and support the operator complete the tasks successfully in poor environment. However, the amount of the information contained in the procedures increases greatly, the operator's workload becomes more concentrated. Many studies reveal that the higher the degree of the equipment automation, the more complex the procedural tasks are. Then the operators are more likely to make an error (Zhang, 1993). So TACOM has been recognized to be the key factor that affects the operators (Wood, 1986; Campbell, 1988; Jacko and Ward, 1996; Gill and Hicks, 2006).

Recently, the complexity of emergency operating procedures (EOPs) in NPPs has attracted the attention of several researchers (Shin, 2001; Park et al., 2002; Park et al., 2001). Park and Jung (2007a; 2007b) developed TACOM measure that can quantify the complexity of emergency tasks stipulated in EOPs of NPPs. The first phase may be the classification of significant factors that affect the performance of emergency tasks stipulated in procedures (Park, 2009; Park and Jung, 2008). The TACOM scores have been found to have significant correlations with operation time across different EOPs. The TACOM scores are believed to characterize the level of task complexity (Park and Cho, 2010; Liu et al., 2012).

Related studies about task complexity have been widespread in many industries and social behavioral sciences. And, the influence of task complexity on human performance and behavior has been recognized by researchers in many fields. Zhang et al. (2009) proposed that the average operation time, subjective complexity rating and subjective workload could be predicted well from the

* Corresponding author.
E-mail address: zhaoxs_tju@tju.edu.cn (X. Zhao).

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operation complexity value. And the error rate could be partly explained by the operation complexity value. Xu et al. (2008) showed that high-complexity tasks and lack of sufficient training may lead to a higher error rate, and task complexity and training level can significantly influence the operation time. Ham et al. (2012) identified task complexity factors and applied the method to procedure-based tasks of NPPs as a case study. Zhang (2012) explored the impact of task complexity on people's mental models of Medline Plus. Some measurements of task complexity are given in references (Zaeh et al., 2009; Mattsson et al., 2011; Fast-Berglund et al., 2013; Podofillini et al., 2013; Park and Jung, 2015). The measurement method is verified in Volvo (Mattssona et al., 2012).

A series of human reliability analysis (HRA) method have been developed within these decades. Since 1990s, HRA had been developed, which mainly includes Cognitive Reliability and Error Analysis Method (CREAM), A Technique for Human Error Analysis (ATHEANA), the Standardized Plant Analysis Risk Human Reliability Analysis (SPAR-H) (Gertman et al., 2005). The earliest HRA method known to people was the reliability study of complex weapon system, carried out by Sandia national laboratory (SNL) Well-designed procedure. The research which was considered as the start of HRA had already evaluated the human error residing in the risk analysis of complex weapon system. In the 1st international conference on Human Reliability Analysis (1964) some inchoate methods were proposed, such as Technique for Human Error Rate Prediction (THERP). That conference was a significant symbol that implied HRA had been applied to quantification analysis of human error influence in complex system (Swain, 1990). The U.S. Nuclear Regulatory Commission (NRC), the U.S. Electric Power Research Institute, the Swiss Federal Nuclear Safety Inspectorate, Organization for Economic Cooperation and Development (OECD) Halden Reactor Project carried out an international evaluation study of HRA methods aiming to develop an empirically method based on understanding of the performance, strengths, and weaknesses of the 13 experiments (Lois et al., 2008; Bye et al., 2010). The assessments were drawn mainly from two aspects: 1) Whether the method has the capacity to identify PSFs and operational details of the performance of the required actions. 2) Whether it has the ability, if applied correctly, to use this information in the accurate evaluation of the HEPs.

The conclusion about SPAR-H method indicated that it is easy to apply to the HEP. The PSFs considered in SPAR-H method is comprehensive. The traceability of the quantification is good due to the unambiguous relationship between PSFs and HEPs. Some improvements also need to be done to gain a more accurate prediction (Liao et al., 2014). The assessment of PSFs in SPAR-H is subjective. The identification of the relevant PSFs seemed to be guided by the analysts' knowledge and understand which may lead to the omission of important drive PSFs (Forester et al., 2012). In the international HRA empirical study described above, the SPAR-H method overlooked important performance shaping factor TACOM in three human errors. It is also worth noting that the multipliers of some PSFs are too high or too small which may lead to conservative or optimistic human error probabilities.

Based on the analysis above, in this paper, we incorporate TACOM and SPAR-H to analyze the procedural tasks and predict the HEP in the main control room. A model based method will be constructed for the procedural tasks in NPPs main control room, which including the task types confirming, multiplier of the PSFs except task complexity identifying, quantification by the TACOM measure and the quantification of human error. At the same time the steam generator tube ruptures in main control room is analyzed using the improved method. At last the comparisons are analyzed between the result and empirical data.

2. Methodology

The main steps for the application of TACOM measure in SPAR-H method are confirming the task types, identifying the multiplier of the PSFs except task complexity, task complexity quantification using the TACOM measure and quantifying the human error probability, which are shown in Fig. 1.

2.1. The four steps are

2.1.1. Task type confirming

In SPAR-H method, there are two kinds of task types: diagnosis task and action task. Multiplier of PSFs identifying is based on the assignment of task types, diagnosis or action. In performing tasks, operators may only need to perform action tasks.

Diagnosis tasks typically rely on knowledge and experience to understand the existing condition. Operators have to expend mental energy to observe and interpret what information is present, determine what the information meanings, think of possible causes and decide what to do about it. The greater the amount of observing, interpreting, thinking and deciding the operator performs, the more significant the amount of diagnosis activity that is taking place. Action tasks mainly include operating equipment, starting pumps, conducting calibration or testing, carrying out actions in response to alarms and performing other activities during the course of following plant procedures or work orders.

2.1.2. Multiplier of PSFs identifying

Based on the task types, important PSFs and the multipliers are identified. The multipliers of the same PSFs in different task types may be different, which is shown in Table 1 (Barati and Setayeshi, 2012). The task complexity need not to be assessed now, its multiplier will be calculated by TACOM measure next.

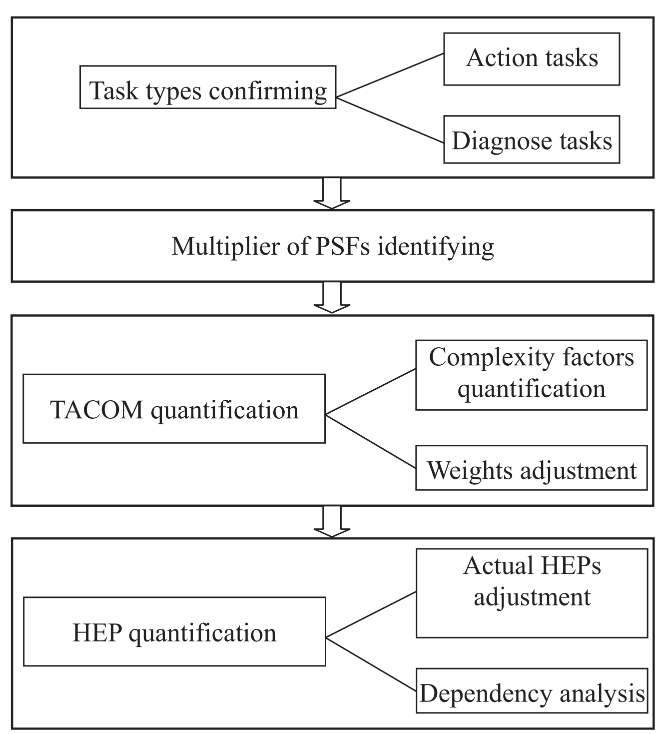

Fig. 1. The main steps in the method.